MUSCLE-STRENGTHENING EXERCISE AND PUBLIC HEALTH ASSESSMENT AND MONITORING

A Thesis submitted by

Jane Shakespear-Druery, BSpEx (Hons)

For the award of

Doctor of Philosophy

2022

ABSTRACT

Participation in muscle-strengthening exercise (MSE), e.g., using weight machines, free weights, or bodyweight, improves health and independently reduces the risks associated with many non-communicable diseases. While MSE is included in national/global physical activity guidelines, participation in MSE is low. Moreover, methods assessing MSE participation vary considerably leading to a potential misunderstanding of the relationship between MSE and health. Therefore, this thesis by publication aims to (i) review the assessment of MSE within public health surveillance (Study 1), (ii) examine relationships between MSE and health (Study 2 and 3), and (iii) describe the development, reliability/validity testing (Study 4) of a new survey instrument to assess multiple MSE participation components and influencing factors (Study 5). Study 1 comprised a systematic review of MSE surveillance studies (k=156). Secondary data analyses explored the relationship between adult MSE participation and five chronic health conditions (Study 2, N = 16,301); and hypertension (Study 3, N = 10,519). Study 4 describes the development of the Muscle-Strengthening Exercise Questionnaire (MSEQ) and its test-retest reliability (n = 85) and concurrent validity (n = 54). Factors influencing adult MSE participation (N = 435) were analysed in Study 5. Study 1 identified the under-representation of key MSE guideline components and highlighted the need for standardisation. Studies 2 and 3 showed, compared to doing none, adults who reported any MSE (~19%) had a reduced prevalence of having a chronic condition. Study 4 showed 'acceptable' reliability and validity of five key MSE components. Study 5 identified five behavioural factors that significantly influenced the odds of meeting the MSE guidelines. Overall, the data presented in this thesis increases the body of knowledge regarding the relationship between MSE and health. Moreover, this PhD has developed a new valid and reliable questionnaire to assess population-level MSE participation. Current findings could aid campaigns targeting populations most at risk of chronic disease and increase MSE uptake and adherence at the population level.

CERTIFICATION OF THESIS

I Jane Shakespear-Druery declare that the PhD Thesis entitled Muscle-Strengthening Exercise and Public Health Assessment and Monitoring is not more than 100,000 words in length including quotes and exclusive of tables, figures, appendices, bibliography, references, and footnotes.

This Thesis is the work of Jane Shakespear-Druery except where otherwise acknowledged, with the majority of the contribution to the papers presented as a Thesis by Publication undertaken by the Student. The work is original and has not previously been submitted for any other award, except where acknowledged.

Date:

Endorsed by:

Associate Professor Jason A. Bennie
Principal Supervisor

Professor Katrien De Cocker
Associate Supervisor

Professor Stuart J.H. Biddle
Associate Supervisor

Student and supervisors' signatures of endorsement are held at the University.

STATEMENT OF CONTRIBUTION

The following detail is the agreed share of contribution for candidate and co-authors in the presented publications in this thesis. All journal CiteScore values, Scientific Journal Rank indicators (SJR) and Source-Normalised Impact per Paper (SNIP) are based on 2021 Scopus Source Details and Journal Quartile rankings are retrieved from SciMago Journal rankings, and Journal Impact Factor (IF) values as reported by Clarivate Analytics (2022) are correct as at 28 July 2022:

Paper 1:

Shakespear-Druery, J., De Cocker, K., Biddle, S. J. H., Gavilán-Carrera, B., Segura-Jiménez, V., & Bennie J. A. (2021). Assessment of Muscle-Strengthening Exercise in Public Health Surveillance for Adults: A Systematic Review. *Preventive Medicine, 148,*106566. https://doi.org/10.1016/j.ypmed.2021.106566

(Q1 Journal; CiteScore: 6.3; SJR: 1.406; SNIP: 1.619; Impact Factor: 4.637)

Jane Shakespear-Druery contributed 80% to the planning, development, analysis, drafting and revising the final submission of this paper. Collectively Katrien De Cocker, Stuart J.H. Biddle, Blanca Gavilán-Carrera, Victor Segura-Jiménez, and Jason A. Bennie contributed the remainder.

Paper 2:

Shakespear-Druery, J., De Cocker, K., Biddle, S. J. H., & Bennie J. A. (2022). Associations between Muscle-Strengthening Exercise and Prevalent Chronic Health Conditions in 16,301 Adults: Do Session Duration and Weekly Volume Matter? *Journal of Science and Medicine in Sport, 25*(5), 407-418. https://doi.org/10.1016/j.jsams.2022.01.001

(Q1 Journal; CiteScore: 6.9; SJR: 1.496; SNIP: 1.780; Impact Factor: 4.597)

Jane Shakespear-Druery contributed 80% to the planning, development, analysis, drafting and revising the final submission of this paper. Collectively Katrien De Cocker, Stuart J.H. Biddle, and Jason A. Bennie contributed the remainder.

Paper 3:
Shakespear-Druery, J., De Cocker, K., Biddle, S. J. H., & Bennie J. A. (2022). Associations between Duration and Volume of Muscle-Strengthening Exercise and Clinically Assessed Hypertension among 10,519 UK Adults: A Cross-Sectional Study. *Journal of Hypertension, 40*(5), 947-955. https://doi.org/10.1097/HJH.0000000000003098

(Q1 Journal; CiteScore: 6.9; SJR: 1.107; SNIP: 1.543; Impact Factor: 4.776)

Jane Shakespear-Druery contributed 80% to the planning, development, analysis, drafting and revising the final submission of this paper. Collectively Katrien De Cocker, Stuart J.H. Biddle, and Jason A. Bennie contributed the remainder.

Paper 4:
Shakespear-Druery, J., De Cocker, K., Biddle, S. J. H., & Bennie J. A. (2022). Muscle-Strengthening Exercise Questionnaire (MSEQ): An Assessment of Concurrent Validity and Test-Retest Reliability. *BMJ Open Sport & Exercise Medicine, 8*(e001225), 1-10. https://doi.org/10.1136/bmjsem-2021-001225

(Q1 Journal; CiteScore: 4.6; SJR: 0.847; SNIP: 1.294; Impact Factor: N/A)

Jane Shakespear-Druery contributed 80% to the planning, development, analysis, drafting and revising the final submission of this paper. Collectively Katrien De Cocker, Stuart J.H. Biddle, and Jason A. Bennie contributed the remainder.

Paper 5:
Shakespear-Druery, J., De Cocker, K., Biddle, S. J. H., & Bennie J. A. (manuscript under review). Associations between behavioural correlates and muscle-strengthening exercise guideline adherence in adults: A cross-sectional study. *International Journal of Sport and Exercise Psychology.*

(Q2 Journal; CiteScore: 6.2; SJR: 0.892; SNIP: 1.874; Impact Factor: 4.048)

Jane Shakespear-Druery contributed 80% to the planning, development, analysis, drafting and revising the final submission of this paper. Collectively Katrien De Cocker, Stuart J.H. Biddle, and Jason A. Bennie contributed the remainder.

ACKNOWLEDGEMENTS

Without the support and guidance from the following people, this program of research would not have been possible. It is to them that I owe my deepest gratitude and respect.

- Associate Professor Jason Bennie (Principal Supervisor), thank you for your knowledge and support in all things strength-related and for allowing me the opportunity to increase the footprint of muscle-strengthening exercise on the global stage. Your feedback has made me a better writer and I thank you for that. May you continue to lift the big rocks.
- Professor Katrien De Cocker (Associate Supervisor), thank you for being my PhD 'mother' and imparting your knowledge and guidance, especially in all things HSE-related.
- Professor Stuart Biddle (Associate Supervisor), thank you for imparting your infinite wisdom and your consistent guidance throughout my PhD journey. Despite bends in the road the gears always shifted in the right direction.

I remember being asked at my confirmation of candidature presentation what it was like to have three PhD supervisors. My response now is the same as it was then, each of you has brought your own unique talents, perspectives, and knowledge to the table and for that I will be forever grateful.

- Associate Professor Tracy Kolbe-Alexander, for your unwavering support and remaining a constant reminder of the fact that this was not just an academic degree, but also an emotional degree.
- Associate Professor Lainie Cameron, for your unwavering support through my doctoral journey. Thank you for being such a fan.
- Dr Tricia Kelly and Ms Rowena McGregor, for your Endnote technical support and guidance throughout this research.

- Thank you to the participants and health professionals who dedicated their time to completing the interviews related to the Health Survey for England 2012 and 2016.
- Thank you also goes to the participants who volunteered their valuable time to complete the initial Muscle-Strengthening Exercise Questionnaire, and the subsequent questionnaires related to the reliability and validity testing phases.
- My fellow candidates Dr George Thomas and Dr Jonathan Cagas, thank you for your support during these past three years.
- My mother Laurel Shakespear, thank you for unconditional love and support in all that I do. Along with your willingness and the excitement that you expressed when reading these works.
- My husband and three children, thank you for allowing me the luxury of following my passion for research.

This research has been supported by an Australian Government Research Training Program Scholarship and a University of Southern Queensland Research Training Program Stipend Scholarship.

TABLE OF CONTENTS

Deleted:
Deleted:
Deleted:
Deleted:
Deleted:

Deleted:
Deleted:
Deleted:
Deleted:
Deleted:
Deleted:

LIST OF TABLES

ABBREVIATIONS

ACSM	American College of Sports Medicine
ADLs	Activities of daily living
AOR	Adjusted odds ratio
APR	Adjusted prevalence ratios
BMD	Bone mineral density
BMI	Body mass index
BP	Blood pressure
BRFSS	Behavioral Risk Factor Surveillance System
CATI	Computer assisted telephone interview
CDC	Centers for Disease Control and Prevention
CHAMPS	Community Health Activities Model Program for Seniors
CI	Confidence interval
CVD	Cardiovascular disease
DBP	Diastolic blood pressure
FITT	Frequency, intensity, time, type
GoPA	Global observatory of physical activity
GPAQ	Global Physical Activity Questionnaire
HbA_{1c}	Glycosylated haemoglobin
HOMA-IR	Homeostatic model assessment of insulin resistance
HSE	Health Survey for England
ICC	Intraclass correlation coefficients
IPAC	International Physical Activity Questionnaire
κ	Kappa coefficients
NHANES	National Health and Nutrition Examination Survey
mmHg	Millimetres of mercury
MSE	Muscle-strengthening exercise
MSEQ	Muscle-Strengthening Exercise Questionnaire
MVPA	Moderate-to-vigorous physical activity
NCDs	Non-communicable diseases

PA	Physical activity
PR	Prevalence ratio
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analyses
RCTs	Randomised controlled trials
rho; ρ	Spearman’s rank correlation coefficients
RPE	Rating of perceived exertion
SB	Sedentary behaviour
SBP	Systolic blood pressure
SPSS	Statistical package for the social sciences
VIF	Variance inflation factor
VO_{2max}	Maximal oxygen uptake
WHO	World Health Organisation

CHAPTER 1: INTRODUCTION

1.1 Overview of the Chapter

The objective of this chapter is to first define physical activity and establish the context in which this research is being conducted. Next, muscle-strengthening exercise is defined alongside an explanation for the inclusion of muscle-strengthening exercise within physical activity guidelines, and presenting the health benefits associated with participation in muscle-strengthening exercise. Additionally, this chapter will explain the common methods used to assess muscle-strengthening exercise in public health surveillance, describe the prevalence and correlates of participation at the population level, and outline gaps in the current research evidence concerning muscle-strengthening exercise among adults. Throughout this chapter, the aim is to provide a literature overview that informs the research objectives of this *PhD Thesis by Publication.*

1.2 Physical Activity and Health

Physical activity is defined as "*any bodily movement produced by skeletal muscles that results in energy expenditure*" (Caspersen, Powell, & Christenson, 1985) (p. 126). Physical activity is evident across multiple domains, namely occupational, transport, household, and leisure-time (Caspersen et al., 1985). While it has been argued that undertaking physical activity within each of the four domains influences participant health, the benefits of undertaking physical activity during ones' *leisure-time* are considered more likely to be health-enhancing (Appelqvist-Schmidlechner et al., 2020; Holtermann, Hansen, Burr, Søgaard, & Sjøgaard, 2012; White et al., 2017), whereas others, for example occupational physical activity, may not - due to possible risks associated with the repetitive nature of the activities undertaken (Holtermann et al., 2012). Leisure-time physical activity is defined as being "*performed at one's discretion when one is not working, transporting to a different* *location and not doing household chores*" (Physical Activity Guidelines Advisory Committee, 2018) (p. c-2). As this research applies a public health lens, along with the literature supporting a stronger positive correlation with health, the focus for this PhD research is within the domain of *leisure-time* physical activity.

Furthermore, exercise is classified as a sub-component of physical activity, however not all physical activity is classified as exercise (U.S. Department of Health and Human Services, 2018). To be recognised as exercise, the activity must be one that: (i) has been planned; (ii) contains structure; (iii) is considered ongoing or repetitive; and (iv) is undertaken with the specific goal to improve the health or fitness of the participant (U.S. Department of Health and Human Services, 2018). Moreover, two key exercise modes are included in national and international physical activity guidelines. They are: (i) aerobic physical activity (including walking, jogging, and running) which is primarily undertaken to improve an individual's cardiorespiratory fitness, and (ii) muscle-strengthening exercise, which has multiple outcome goals such as improved strength (World Health Organization, 2020b).

1.3 Defining Muscle-Strengthening Exercise

Muscle-strengthening exercise (MSE) is a type of exercise modality that, if done regularly, can increase the strength, power, endurance, and mass of skeletal muscle (U.S. Department of Health and Human Services, 2018). Types of MSE commonly include the use of weight machines and performing bodyweight exercises. Common terms associated with MSE include strength training, resistance training, muscle-strengthening activity, weight training, and weightlifting (Bennie, Shakespear-Druery, & De Cocker, 2020; World Health Organization, 2020b). Specifically, strength is the ability to lift weight, for example, the amount of weight/resistance that can be overpowered (Physical Activity Guidelines Advisory Committee, 2018). Endurance is the ability to lift weight for a period of time, such as, how many times/how long the weight/resistance can be overpowered (Physical Activity Guidelines Advisory Committee, 2018). MSE is commonly considered within contexts such as: time (e.g., the duration or how long an exercise is undertaken by a participant); duration (e.g., the length of time in which an activity or exercise is performed); and frequency, represented by the number of times (how often) an exercise or activity is performed, and is usually expressed in bouts per week (World Health Organization, 2010).

The current American College of Sports Medicine (ACSM) position stand includes guidance around the specificity of individual MSE prescription (Garber et al., 2011). While there are eight specific MSE components included within the position stand, they are regularly referred to using the acronym known as the 'FITT' principle (Garber et al., 2011). This reflects the Frequency (how often each of the major muscle groups should be exercised), Intensity (which can range from very light through to very hard), Time (which refers to the duration of the exercise, albeit the construct of time has yet to be effectively quantified concerning MSE) and Type (which refers to the mode of exercise, such as body-weight exercise) which are modified to deliver an exercise prescription that meets the individual's specific training goals (Garber et al., 2011).

1.4 Muscle-strengthening Exercise and Guidelines for Physical Activity

Since their inception in the early 1970s public health recommendations regarding physical activity and exercise produced by governments and leading health agencies have centred on person-specific goals and exercise prescription components that can be tailored to meet the fitness goals, and improve the health, of the individual such as increasing cardiorespiratory fitness (Oja & Titze, 2011). A shift in the focus, from individual fitness to one of a public health orientation, was seen in 1995 when scientific evidence-based physical activity guidelines for health were released jointly by the Centers for Disease Control and Prevention (CDC) and the American College of Sports Medicine (ACSM) following research by Pate et al. (1995). Since this, these guidelines are updated periodically as new evidence is produced supporting the dose-response relationship between physical activity and health-related outcomes. Initially, the recommendations centred on aerobic physical activity, and it was not until 2008 that MSE was included within the guidelines (U.S. Department of Health and Human Services, 2008).

While the *Global Recommendations on Physical Activity for Health* (World Health Organization, 2010), included exercise guidelines for all adults, the recommendations for MSE were to target "*all the major muscle groups… on at least two days a week*". This version of the guidelines did not stipulate a time (or duration) recommended to undertake MSE each day, nor the level of intensity of MSE. Moreover, some national guidelines include suggestions regarding the types of exercises, such as lifting weights, using resistance bands, or doing body-weight exercises such as push-ups (Department of Health and Social Care, Llwodraeth Cymru Welsh Government, Department of Health Northern Ireland, & Scottish Government, 2019; U.S. Department of Health and Human Services, 2018). Most recently, the WHO released an update to its original 2010 guidelines. The 2020 'Guidelines on Physical Activity and Sedentary Behaviour' expanded the 2010 guidelines to include an additional construct stating that adults (18–64 years), including individuals with a disability or with one or more chronic conditions, should undertake MSE "*at moderate or greater intensity*" (Bull et al., 2020). The recommendations regarding the frequency of participation, and targeted muscle groups, remained unchanged i.e., "*completed on two or more days a week*" and targeting "*all the major muscle groups*" (Bull et al., 2020). Moreover, for adults aged 65 years and older (with or without disability/chronic conditions), the guidelines included recommendations for weekly physical activity (on three or more days) inclusive of MSE at "*moderate or greater intensity*" (Bull et al., 2020).

1.5 Muscle-Strengthening Exercise and Health

Health research is typically undertaken using data from clinical and epidemiological studies. Clinical research includes the use of systematic reviews and meta-analyses of randomised controlled trials, usually characterised as short-duration intervention studies using smaller homogenous sample sizes, to investigate individual health outcomes. While, epidemiological studies use data obtained from population-representative and large prospective cohort studies to assess health risks at the population level.

The evidence from epidemiological and clinical studies continues to grow in support of undertaking MSE to reduce the risks of all-cause and disease-specific mortality, and morbidity associated with chronic disease (Nascimento et al., 2021; Saeidifard et al., 2019; Steele et al., 2017; World Health Organization, 2020b). Regular participation in levels of 'health enhancing' MSE is key, and often recommended as a suitable adjunct therapy (Cormie et al., 2018) and/or non-pharmacological treatment (Ambrose & Golightly, 2015; Whelton et al., 2018; Zhang et al., 2008), in the management and prevention of chronic conditions and non-communicable disease (NCD). An overview of the current evidence in each context (clinical, epidemiological) will now be discussed.

1.5.1 Clinical Evidence

Clinical exercise studies of MSE typically include methodologies consisting of short session durations (~ 1-2 hours), conducted on 2-7 days/week, for intervention periods lasting from 6-52 weeks (Gordon et al., 2018). The interventions can be supervised or unsupervised (or both), conducted in a clinical/laboratory setting or in the home, typically containing sample sizes of <40 individual participants from clinical or non-clinical populations (Ashton et al., 2018).

Cardiometabolic health: A recent meta-analysis of clinical exercise studies by Ashton et al., (2018) identified positive health outcomes for participants who undertook MSE. Specifically, these related to cardiovascular health risk factors such as systolic and diastolic blood pressure (SBP and DBP), maximal oxygen uptake (VO_{2max}), artery dilation under increased blood flow (flow-mediated dilation), fasted insulin levels, homeostatic model assessment of insulin resistance (HOMA-IR), and fasted glucose levels (Ashton et al., 2018). Improvement rates varied depending upon the length of time that the respective MSE intervention programs were conducted (e.g., mean SBP and DBP reduced ~5 mmHg, mean HOMA-IR reduction ~1.22 mg/dL), age of the sample studied, and if the participants were from clinical or non-clinical populations (Ashton et al., 2018). Furthermore, in an earlier meta-analysis of randomised controlled trials by Strasser, Siebert, and Schobersberger (2010), glycosylated haemoglobin (HbA_{1c}) reduced significantly (pooled weighted mean difference of 0.48% [range -1.18% to 0.00%]) among 219 adults who undertook MSE (compared to 206 adult controls), noting the effect was comparable with pharmacological interventions. Moreover, a dose-response relationship between higher volumes of MSE and reductions in blood pressure (SBP and DBP) compared to lower volumes of MSE was observed. Additionally, a meta-analysis of randomised control trials (RCTs) containing patients with type 2 diabetes mellitus found that absolute HbA_{1c} levels decreased by 0.57% amongst those undertaking MSE, compared to controls (Umpierre et al., 2011). However, this mode-specific analysis contained only 330 participants (182 intervention vs 148 control) across a total of four studies.

Musculoskeletal health: Emerging evidence indicates that MSE may have a role in increasing bone mineral density (BMD) among postmenopausal women undertaking this exercise modality 3 days per week, however, there is currently substantial heterogeneity among limited studies (Martyn-St James & Carroll, 2009). Another study identified stronger associations between increased BMD and programs that were inclusive of MSE and high-impact exercises among premenopausal women (Martyn-St James & Carroll, 2010). A meta-analysis of male participants investigated the dose-response relationship between the number of sets/repetitions per week (low = <5, medium = 5-9, high = ≥10) of MSE and muscle strength (Ralston, Kilgore, Wyatt, & Baker, 2017). They found that participants (mean age 23.4 years) who undertook high weekly volumes of MSE had greater strength gains (regardless of type e.g., multi-joint/isolated [effect size range 0.18-0.23, p = <0.05]; or measurement i.e., one-repetition maximum [effect size 0.14, p = 0.06]), compared to those completing low volumes (Ralston et al., 2017). In a similar meta-analysis with younger and older males and females, Schoenfeld, Ogborn, and Krieger (2017) identified a positive relationship with each additional set of MSE and muscle mass (hypertrophy) (mean effect size 0.013 [p = 0.008]). Importantly, among individuals with compromised exercise capacity, this study suggests that even lower weekly volumes of MSE may induce a positive physiological response (Schoenfeld et al., 2017).

Sarcopenia, which is often defined by reduced muscle mass combined with impaired muscle performance (Rizzoli et al., 2013), is not unique to geriatric populations (Santilli, Bernetti, Mangone, & Paoloni, 2014). Chronic conditions and comorbidities including cachexia (due to conditions such as cancer, congestive cardiomyopathy, and end-stage renal disease) are prevalent across the lifespan and can lead to sarcopenia (Santilli et al., 2014). Treatments for sarcopenia include the recommendation for undertaking MSE (Rizzoli et al., 2013; Waters, Baumgartner, Garry, & Vellas, 2010) to counter the effects of lost physical functioning (Prado et al., 2018). Moreover, individual quality of life is influenced by many environmental factors (Rizzoli et al., 2013). While undertaking MSE in older age has also been associated with a reduction in frailty and improvements in ADLs (C. K. Liu & Fielding, 2011), these factors are also associated with an improvement in quality of life.

Functional health: A review of 121 randomised control trials by C. J. Liu and Latham (2009) concluded that physical function in older adults could improve with undertaking regular MSE 2-3 times per week. In reviewing specific clinical representations of this study (C. J. Liu & Latham, 2009) Mangione, Miller, and Naughton (2010) established clear links to the benefits of undertaking MSE among older adults, where the specific goal was to improve activities of daily living (ADLs) and maintain independence. Moreover, the narrative review by McLeod, Stokes, and Phillips (2019) highlights the importance of MSE in the management and reduction of morbidity associated with mobility disability, diabetes, cardiovascular disease, and cancer among older adults. Most recently, a systematic review and meta-analysis by Pinheiro et al. (2020) found that undertaking MSE alone or in conjunction with other exercise (e.g., endurance), may positively influence bone health, thereby reducing the risk of osteoporosis among adults aged >65 years. While a dose-response relationship was not established, their findings indicated that higher bouts of MSE, combined with other exercise, were likely to provide greater benefits. However, a systematic review investigating the relationship between quality of life and ADLs, and interventions including MSE (n = 15) among frail older adults, found mixed results (Campbell et al., 2021). With positive effects only observed within the studies that also measured physical outcomes improvements, such as walking speed and balance.

Mental Health: A meta-analysis by Gordon et al. (2018) reviewed the benefits of MSE and depression identifying that depressive symptoms were reduced significantly after pooling data from 33 randomised control trials. The symptom reductions appeared regardless of the individual characteristics of the participants, or program parameters such as, intervention/session duration, frequency of sessions, intensity, or level of supervision (Gordon et al., 2018). Similarly, in a meta-analysis and meta-regression, Gordon, McDowell, Lyons, and Herring (2017) found that symptoms of anxiety were significantly reduced among participants undertaking moderate to vigorous MSE. This finding was also regardless of individual or program parameters (Gordon et al., 2017). However, greater positive effects of MSE participation were observed amongst healthy participants compared to those reporting a mental or physical disorder (Gordon et al., 2017). Moreover, the reduction in symptoms of anxiety was similar for MSE alone compared to those for moderate-to-vigorous aerobic physical activity (MVPA) (Gordon et al., 2017).

1.5.2 Epidemiological Evidence

Epidemiological evidence represents findings from systematic reviews and meta-analyses of prospective observation/national cohort and cross-sectional studies conducted to investigate the risk or prevalence of the targeted exposure or disease at the population level. These studies are important as they provide a mechanism to translate findings from clinical studies and apply them within the context of the broader population. Growing evidence from epidemiological research has shown the independent benefits of MSE participation.

For mortality-related outcomes, a meta-analysis, including 11 longitudinal studies by Saeidifard et al. (2019), identified an association between MSE and a reduced risk of all-cause mortality. Noting that when participants performed any MSE, there was a reduction in the hazard ratio of 21%, compared to no MSE. Interestingly, they found that performing MSE following the MSE recommendation of at least two times per week did not provide an additional protective factor compared with undertaking MSE >0 to two sessions per week (Saeidifard et al., 2019), thereby indicating that performing some MSE may be better than not undertaking any.

More recently the meta-analysis by Momma, Kawakami, Honda, and Sawada (2022) found a 15% reduced risk of all-cause mortality amongst participants who did MSE compared to those doing none. This study was also one of the first to also assess the dose-response relationship between

MSE and health. The authors observed a 'J' shaped curve with the lowest incident of all-cause mortality (~17%) at a duration of 40 minutes/week of MSE with benefits evident up to 140 minutes/week (Momma et al., 2022). In additional analysis they observed a 40% reduced risk among participants undertaking both MSE and MVPA (≥150 minutes/week) compared to doing none. Furthermore, the authors analysed the relationship between MSE participation and the risk of cardiovascular disease (CVD), total cancer, diabetes, and lung cancer. Overall the relative risk of these conditions were 0.83, 0.88, 0.83, and 0.90 respectively among those undertaking MSE compared to doing none (Momma et al., 2022). Moreover, a dose-response relationship with MSE was observed for CVD (lowest risk ~18% for 60 minutes/week, with benefits evident up to ~130 minutes/week); total cancer (lowest risk ~9% for 30 minutes/week, with benefits evident up to ~130 minutes/week); and a ~2% reduced risk of diabetes among participants undertaking up to 60 minutes/week of MSE. The combined associations (MSE + MVPA) were also assessed for CVD and total cancer, with ~46% and ~28% reduced risk observed respectively. While this study has increased the understanding of the relationship between MSE participation and health, the authors acknowledged that the findings were based on a limited number of studies, from data obtained mostly via self-report, predominantly using U.S. participants, and were overall assessed as low-to-very low in quality. Therefore the findings should be used with caution.

For diabetes, among a prospective study of ~99,000 U.S. female nurses who self-reported their MSE behaviours at baseline, there was a reduced risk of developing type 2 diabetes, compared with those who reported no MSE (Grnøtved et al., 2014). While any duration of MSE was found to reduce the risk of diabetes, the lowest risk observed within this population was amongst those reporting >150 minutes of MSE per week (pooled relative risk = 0.69 [95% CI 0.50-0.94]) irrespective of MVPA or other conditioning activities (Grnøtved et al., 2014). Similarly, in a study of ~32,000 U.S. males from the Health Professionals Follow-up Study, a dose-response relationship between participants reporting ≥150 minutes/week of MSE, and a reduced risk of type 2 diabetes (relative risk = 0.71 [95%CI 0.49-1.00] *p* trend 0.009) was observed independent of MVPA (Grnøtved, Rimm, Willett, Andersen, & Hu, 2012). While these studies contain data from non- representative populations (i.e., mostly well-educated white participants) these data collectively suggests that MSE participation could be a suitable alternative to other exercise modes (e.g., aerobic/conditioning) in the prevention of type 2 diabetes (Grnøtved et al., 2014; Grnøtved et al., 2012).

A recent meta-analysis of prospective observational studies by Isath et al. (2022) found similar associations among ~158,000 participants, observing a 29% reduced risk of diabetes for participants undertaking MSE compared with those reporting no MSE. The risk of diabetes was also observed to be lower among participants undertaking high levels of MSE (>150 minutes/week or >22 sessions). This study also assessed the relationship between MSE participation and all-cause mortality (*N* = 177,940), with an overall risk reduction of 17% observed, compared to those doing no MSE. However, the strongest associations were among those reporting low rates of MSE (<60 minutes/week or 1-7 sessions).

For cardiovascular disease, Shiroma et al. (2016) found a 17% reduced risk of cardiovascular disease in those reporting time spent in MSE compared to those reporting none, among a sample of ~35,000 women from the Women's Health Study (hazard ratio 0.83, 95% CI 0.72-0.96). After adjusting for other activities (including time spent in lower-intensity activities and MVPA) the largest reduction in the risk for cardiovascular disease was seen amongst women reporting 60 to <120 minutes/week of MSE (hazard ratio 0.74 [95% CI 0.57–0.96]). However, limitations of this study included the non-reporting of times per week (frequency), intensity, and type (mode) of MSE.

In a more recent systematic review and meta-analysis (k=10) by Shailendra, Baldock, Li, Bennie, and Boyle (2022) the authors found an ~18% reduced risk of CVD among adults who reported MSE participation compared to those reporting none. Moreover, in dose-response analysis they observed a 'U' shaped association between the duration of MSE, with the highest 'benefit' observed amongst those reporting a maximum of 60 minutes/week of MSE. Their analyses extended to include the associations between reporting MVPA alone and the two modes combined (MSE + MVPA), with an overall reduced risk for CVD of ~29% and ~46% observed respectively. This study also included analyses relating to MSE participation and the associated risk of all-cause mortality and cancer. The authors founds reductions of ~18%, ~25% and ~40% for all-cause mortality, and ~16%, ~0% and ~28% for cancer respectively, for MSE alone, MVPA only, and the two modes combined (MSE + MVPA). However, similar to previous studies of MSE participation, these data were obtained using questions with unknown reliability or validity, at a single point in time, through self-report (Shailendra et al., 2022). A further limitation to this study was small number of included studies, with most (~80%) contained data from U.S. participants.

For mental health, there is currently a lack of prospective cohort studies assessing the benefits of MSE on this health outcome. However, a recent cross-sectional study, containing a representative sample of German adults (aged ≥18 years), showed that participants reporting any participation in MSE (regardless of the frequency i.e., 1 to ≥5 times/week) had a lower prevalence of increased depressive symptoms (APR range: 0.46-0.94) compared to those who reported undertaking no MSE, independent of participation in MVPA (Bennie, Teychenne, & Tittlbach, 2020). In a further study of this sample, Bennie and Tittlbach (2020) found the prevalence of reporting 'poor' (range 0.77-0.83) or 'very poor' (range 0.60-0.69) sleep quality was reduced among participants who reported participation MSE, compared to those reporting no MSE. Addition analysis, including adjustments made for MVPA, showed similar results. While this study did not directly assess depressive symptoms, adjustments were made for the severity of depressive symptoms in their analyses (fully adjusted model). Moreover, it has been suggested that ‘poor’ sleep quality may be related to disordered mental health (Grandner, 2017; João, Jesus, Carmo, & Pinto, 2018). However, the results from these data have limitations, due to (i) the cross-sectional nature of the sample, therefore limiting causality, and (ii) the use of self-reported data for each outcome/exposure variable, which may result in responder bias (Bennie, Teychenne, et al., 2020; Bennie & Tittlbach, 2020). Therefore, the results are to be viewed with caution, with further research conducted using large population-representative samples from other countries.

For cancer, the review by Mazzilli, Matthews, Salerno, and Moore (2019) identified a significantly lower independent risk of colon cancer and an indicative lower risk of kidney cancer within ~215,000 U.S. adults aged 50-71 years who undertook MSE compared to no MSE. They observed a lower risk of colon cancer in men (hazard ratio=0.91; 95% CI, 0.84-0.98) when compared to women (hazard ratio=1.00; 95% CI, 0.93-1.08) who undertook MSE compared to those who did not (Mazzilli et al., 2019). They did not observe a dose-response relationship with undertaking higher levels (2-10+ hours per week) of MSE when compared to undertaking low levels (5 mins to 1.5 hours per week) of MSE (Mazzilli et al., 2019), indicating that even at low levels undertaking MSE may provide a reduced risk of colon cancer.

1.6 Muscle-Strengthening Exercise Surveillance

Public health surveillance, according to the WHO Chairman in 1968, “*implies the systematic collection and use of epidemiological information for the planning, implementation and assessment of control of communicable disease*” (World Health Assembly, 1968). The concept was expanded to include non-communicable diseases, such as dysregulated mental health, cardiovascular disease, and cancer (World Health Assembly, 1968). Whilst physical activity has been assessed in representative samples at the population level for decades since, with the 1975 U.S. Health Interview Survey among the first to ask respondents about participation in regular exercise (National Center for Health Statistics, 1977), the focus of physical activity surveillance has exclusively focussed on assessing population levels of MVPA (Branscum & Fairchild, 2019; Troiano, Stamatakis, & Bull, 2020). Moreover, MSE was included within the third National Health and Nutrition Examination Survey (population-representative sample of U.S. adults) in 1996, with the inclusion of a simple yes/no and frequency-based question regarding MSE i.e., lifting weights (Crespo, Keteyian, Heath, & Sempos, 1996; National Center for Health Statistics, 1994). Since this time the number of surveillance instruments assessing MSE participation has grown significantly with the largest increase seen in 1999, followed by 2003 and 2011 (Shakespear-Druery et al., 2021). However currently, most of the instruments still focus only on the frequency (days per week) of participation (Bennie, Shakespear-Druery, et al., 2020; Shakespear-Druery et al., 2021).

1.6.1 Muscle-Strengthening Exercise Assessment

MSE is exclusively assessed in large population samples through self-reported questionnaires (Pedišić & Bauman, 2014). While it is acknowledged that data obtained via methods of self-report can increase bias risks, such as when participants may respond in terms of the answers they think are more socially desirable (Cohen, Manion, & Morrison, 2017), or under/over report activities/conditions (Duffy, Smith, Terhanian, & Bremer, 2005), there are currently no other forms of assessment used for MSE. This is in contrast to MVPA where the use of accelerometry is commonplace, because presently accelerometers are not able to assess MSE (Strain, Milton, Dall, Standage, & Mutrie, 2019). Alternate assessment tools for large-population surveillance, such as through the use of personal physical activity tracking devices or mobile phone applications, are restricted due to current technology limitations (Strain, Wijndaele, & Brage, 2019). Moreover, the use and availability of such technologies may be restricted in low-income countries. Regardless, researchers of wearable technologies have raised caution regarding the use of such devices to track physical activity at the population level (Brodie et al., 2018). Citing 'hidden' biases such as the over/under estimating of activity levels due to use of algorithms which have been based on perceived wearer characteristics including sex, ethnicity, and level of obesity. There also remains much debate regarding the suitability of data from wearable technologies when tracking physical activity for health surveillance purposes. Areas of concern include (i) data representativeness, (ii) variability in wearing position and device used, (iii) interpersonal and intrapersonal diurnal wearing patterns, and (iv) manufacturer changes to tracking algorithms, all of which need satisfactory resolution (Strain, Wijndaele, Pearce, & Brage, 2022).

1.6.2 Muscle-Strengthening Exercise Prevalence

Globally, reported MSE prevalence rates, based on data from large-population studies, vary from 10.4% (Bennie, Pedišić, van Uffelen, Charity, et al., 2016) to 18.6% in Australian (Bennie, Pedišić, van Uffelen, Gale, et al., 2016); 17.2% in Finnish (Bennie et al., 2017); 27.4% in Scottish (Strain, Fitzsimons, Kelly, & Mutrie, 2016); 6.1% to 26.5% (depending on the types of MSE included) in U.K. (Sandercock, Moran, & Cohen, 2022) and 30.2% in U.S. (Bennie et al., 2018) adult populations meeting MSE recommendations (≥2 times/week).

Moreover, in the first European multi-country (*N* = 28) study on MSE prevalence, Bennie, De Cocker, Smith, and Wiesner (2020) found large variations between respondents from Northern Europe (range 34.1%-51.6%) compared to those from South-Eastern Europe (range 0.7%-7.4%), who met the MSE guidelines of ≥2 times/week. Overall they found that only 17.3% of respondents met the frequency guideline (≥2 times/week) while just over double (36.1%) reported sufficient MVPA (Bennie, De Cocker, et al., 2020). Interestingly, the MSE prevalence rates for Finland reported in this study (34.1%) were almost double those reported by Bennie et al. (2017) using data captured during comparatively the same research year. This is most likely due to differences in the way that MSE was assessed within each of the surveillance instruments. This is a key strength of the European study, as the same methodology was applied across all 28 countries, and therefore allows for direct comparability of data between each of the countries.

When prevalence rates for MSE are compared to the prevalence estimates of those meeting the MVPA guideline i.e., at least 150 minutes of moderate-intensity aerobic physical activity, or at least 75 minutes of vigorous-intensity aerobic physical activity, or an equivalent combination of both per week (World Health Organization, 2010) the disparity becomes evident, with MVPA rates ranging from between ~31% to ~64% (Bennie, De Cocker, et al., 2020; Bennie et al., 2018; Bennie et al., 2017; Bennie, Pedišić, van Uffelen, Gale, et al., 2016; Strain, Fitzsimons, Foster, et al., 2016). Moreover, when comparing rates of non-participation between the two modalities (MSE and MVPA) the difference is even more concerning with nearly double reporting no MSE (57.2%) compared to only 32.2% reporting no MVPA (Bennie, Shakespear-Druery, et al., 2020).

Moreover, some studies include rates of MSE participation (from asking a simple yes/no question), as well as reporting prevalence rates (meeting the recommended guideline of ≥2 times/week), with participation rates seen higher than those assessed against the MSE recommendation (Bennie et al., 2018; Humphries, Stanton, Scanlan, & Duncan, 2018; Stamatakis et al., 2018). Prevalence rates have been reported to be lower for people targeting the recommended major muscle groups (Loustalot, Carlson, Kruger, Buchner, & Fulton, 2013) than for participants who do not target the major muscle groups (e.g., they may only perform upper body or lower body MSE). In a U.S. study, prevalence levels for participation in MSE on two or more days per week have been estimated at 31.7%, with rates dropping to only 6.0% with the inclusion of the seven major muscle group recommendations (Loustalot et al., 2013). However, is important to note that the sample size of this study (*N* = 4,271) was much lower in comparison to the U.S. study (*N* = 397,423) by Bennie et al. (2018). A recent cross-sectional study of U.K. adults (*N* = 253,423), using data from the *Active Lives Survey,* investigated if prevalence rates of MSE (≥2 times/week) varied depending on the types of MSE included (Sandercock et al., 2022). Overall, this study found that prevalence rates varied considerably for both males (7.9%, 16%, 28%) and females (4.3%, 9%, 25%), with the lowest rates observed using 'Guideline' MSE (which included: weight training, circuit training, bodyweight exercise, yoga, and weightlifting), compared to 'Evidence' MSE ('Guideline' MSE plus running, football, free weights, tennis, and gymnastics), and the MSE included within the Health Survey for England 'HSE' classifications (a list of 34 activities inclusive of activities such as water-skiing, ten-pin bowling, golf, and aerobics) respectively (Sandercock et al., 2022). This results of this study adds further argument to the need for consistency in the way MSE is assessed at the population level.

1.6.3 Muscle-Strengthening Exercise Correlates

Decades of research have been conducted into the correlates of physical activity (including personal attributes such as age and sex), however most of this research has focussed on MVPA participation within middle-to-high income countries (Bauman et al., 2012).

Many factors may influence people's participation in MSE including demographic, intrapersonal, interpersonal, and environmental (Rhodes, Lubans, Karunamuni, Kennedy, & Plotnikoff, 2017). For demographic factors, a review by Rhodes et al. (2017) identified MSE participation having a positive association with (i) higher education; (ii) positive perception of personal health and quality of life; and (iii) normal body mass index. Studies have also identified negative associations for MSE with (i) being female; (ii) being older; and (iii) receiving lower income

(Bennie, De Cocker, Teychenne, Brown, & Biddle, 2019; Freeston et al., 2017; Humphries et al., 2018). In a recent systematic review, Rhodes et al. (2017) identified factors classified as intrapersonal (links between affective judgements and self-efficacy) with undertaking MSE. However, the evidence appeared to be mixed when undertaking MSE for perceived health benefits (Rhodes et al., 2017). For interpersonal factors, a strong link was identified with program leadership, however, marital status appeared to be unrelated, compared to being unmarried (Rhodes et al., 2017), although a previous study of 6,035 adults from Israel did observed higher odds of MSE participation among those who were non-married, compared to married respondents (Zach & Lissitsa, 2016).

Furthermore, in a recent meta-synthesis (k=20) of barriers and facilitators to MSE participation, among females aged 15-78 years, Vasudevan and Ford (2022) found that gender-based stigmas, discouragement and negative comments regarding MSE were common barriers. Facilitators to MSE participation included social support, affirming statements and companionship, while respondents were also motivated by weight-loss goals (Vasudevan & Ford, 2022). However, juggling work-life balance, lack of accessibility, poor knowledge, and lack of supervised MSE, and boredom were associated with poor adherence. While this study highlighted some consistent themes related to MSE participation the sample size of the included studies was small (ranging from 3 to 49 participants), and included specific populations (e.g., previously trained bodybuilders, ballet dancers, college athletes, elite athletes, and individuals with disabilities [spinal cord injury, Parkinson’s, Multiple Sclerosis]) therefore the generalisability of their findings may be limited in application at the population level.

1.7 Limitations and Current Gaps in Research

This chapter has highlighted many limitations currently faced within MSE research, some influenced by the relative ‘infancy’ of MSE research, compared to the tenure of aerobic physical activity. First, is the large variation in the types of individual exercises that are included and classified as MSE, including the debate of which exercises are considered to be ‘health-enhancing’. Second, is the ongoing variability between the components or constructs included in national and international MSE guidelines (frequency, and/or intensity, and/or muscle groups). Third, is that clinical exercise studies of MSE are mostly conducted using small samples, while epidemiological research exploring the relationship between MSE and health (including areas such as mental health) are under-researched.

The most significant limitations are evident within the population level surveillance of MSE. First, is the variety of participation questions included with surveillance instruments (yes/no, frequency, or more intuitive). Second, and directly influenced by the surveillance instrument employed, is the use of crude thresholds or cut-points for classifying the prevalence of MSE participation (Bennie, Teychenne, De Cocker, & Biddle, 2019; Dankel, Loenneke, & Loprinzi, 2016; Saeidifard et al., 2019). This not only limits the comparability of MSE prevalence within different populations and between countries, is also limits our understanding of the relationship between MSE and health at the population level (Bull et al., 2020). Furthermore, only a limited number of surveillance instruments measure MSE participation constructs aligned with their respective national or international MSE guidelines. The next limitation is that population level surveillance of MSE is reliant solely on data obtained through self-reported means, as there are currently no device based measurement tools available. Moreover, there is considerable debate regarding this topic and therefore it would appear that researchers are a long way off from finding a suitable solution or alternative. Last, while the sociodemographic correlates of MSE are well researched, other factors such as behavioural factors are not.

By focusing on endeavours aimed to achieve a more unified approach in the way MSE is recommended within physical activity guidelines, and assessed at the population level will be beneficial. This will result in a greater transparency and comparability of MSE data, in efforts to identify population subgroups most at risk of disordered health through non-participation. Additionally, increasing our knowledge regarding the optimal dose of MSE for maintaining general health, along with efforts to reduce the risks associated with chronic conditions and non-communicable diseases.

1.8 Aims and Objectives of the Research

This PhD thesis by publication comprises five separate studies. Study 1 is a systematic literature review of existing literature on the surveillance systems used to assess MSE within large adult populations; Study 2 and Study 3 examine the relationships between MSE, including the role of duration/volume/intensity, and chronic conditions, using an existing large population sample; Study 4 describes the development of a new survey instrument that assesses MSE participation constructs beyond frequency (i.e., duration, intensity, type, muscle groups) and test its validity and reliability, and Study 5 provides an insight into the key barriers/facilitators of MSE.

CHAPTER 2: PAPER 1 – Assessment of muscle-strengthening exercise in public health surveillance for adults: A systematic review

This systematic literature review has been peer-reviewed and was accepted for publication in *Preventive Medicine* on 16 April 2021. It was published online on 26 April 2021 and appears in the literature at the time of writing as:

Shakespear-Druery, J., De Cocker, K., Biddle, S. J. H., Gavilán-Carrera, B., Segura-Jiménez, V., & Bennie, J. (2021). Assessment of muscle-strengthening exercise in public health surveillance for adults: A systematic review. *Preventive Medicine, 148,* 106566. https://doi.org/10.1016/j.ypmed.2021.106566.

The format may differ from the accepted pre-copyedited version. It has been reformatted to remain consistent with the rest of the thesis.

2.0 Abstract

There is strong scientific evidence that muscle-strengthening exercise (i.e. use of weight machines, push-ups, situps) is independently associated with a reduced risk of multiple chronic diseases (e.g., diabetes, hypertension, cardiovascular disease). However, prevalence rates for meeting the muscle-strengthening exercise guideline (≥2 times/week) are significantly lower (~20%) than those reported to meet the aerobic physical activity guideline (e.g., walking, jogging, cycling) (~50%). It is therefore important to understand public health surveillance approaches to assess muscle-strengthening exercise. The aim of this review was to describe muscle-strengthening exercise assessment in public health surveillance. Informed by the PRISMA guidelines, an extensive keyword search was undertaken across 7 electronic data bases. We identified 86,672 possible articles and following screening (n = 1140 in full-text) against specific inclusion criteria (adults aged ≥18 years, English, studies containing <1000 participants), extracted data from 156 manuscripts. Fifty-eight different survey systems were identified across 17 countries. Muscle-strengthening exercise frequency (85.3%), duration (23.7%) and intensity (1.3%) were recorded. Muscle-strengthening exercise questions varied significantly, with some (11.5%) requiring a singular 'yes' vs 'no' response, while others (7.7%) sought specific details (e.g., muscle groups targeted). Assessments of duration and intensity were inconsistent. Very few studies measured the validity (0.6%) and reliability (1.3%) of muscle-strengthening exercise questions. Discrepancy exists within the current assessment systems/surveys used to assess muscle-strengthening exercise in public health surveillance. This is likely to impede efforts to identify at risk groups and trends within physical activity surveillance, and to accurately assess associations between muscle-strengthening exercise and health-related outcomes.

Keywords: assessment, measurement, muscle-strengthening exercise, public health surveillance

2.1 Introduction

Regular participation in physical activity is key in the prevention and management of non-communicable diseases (NCDs: diabetes, hypertension, cardiovascular disease, etc.) (World Health Organization, 2014). Physical activity guidelines describe various types, frequencies and quantities of physical activity or exercise that all individuals can undertake for health benefits (Bull et al., 2020). Public health-focused recommendations for physical activity were initially established in the U.S. in 1995 (Pate et al., 1995), with these recommendations centred on aerobic physical activity (e.g., *adults should accumulate 30 minutes or more of moderate-intensity physical activity on most, preferably all, days of the week*) (Pate et al., 1995). Over the past decade, muscle-strengthening exercise (MSE) was also included within the U.S. guidelines (U.S. Department of Health and Human Services, 2008). The new 2020 World Health Organization's (WHO) '*Guidelines on physical activity and sedentary behaviour*' state that for "*additional health benefits*" adults (18–64 years) should engage in muscle-strengthening exercise "*at moderate or greater intensity"* including "*all the major muscle groups*" and should be completed *"on two or more days a week*" (Bull et al., 2020). While the new 2020 WHO guidelines have expanded on the 2010 guidelines by including recommendations regarding muscle-strengthening exercise intensity, there is no recommendation made for time (duration) (Bull et al., 2020; World Health Organization, 2010).

While most of the research on the health benefits of physical activity has focussed on aerobic moderate-to-vigorous intensity physical activity (MVPA: brisk walking, jogging, cycling) (Handy & Blaha, 2017), the evidence from epidemiological and controlled experimental studies is growing in support of undertaking muscle-strengthening exercise to reduce the risks and morbidity associated with chronic disease within adult populations (Steele et al., 2017). In brief, evidence from systematic reviews links the independent benefits of undertaking muscle-strengthening exercise with a reduced risk of mortality (Saeidifard et al., 2019), enhanced cardiometabolic health (Ashton et al., 2018), and lower levels of depression and anxiety (Gordon et al., 2018). In spite of this evidence, compared to the public health promotion of aerobic MVPA, the promotion of muscle-strengthening exercise has largely been forgotten (Strain, Fitzsimons, Kelly, & Mutrie, 2016). Moreover, muscle-strengthening guidelines are often overlooked in physical activity surveillance (Milton et al., 2018).

In comparison to the decades of research on the assessment of aerobic MVPA (Branscum & Fairchild, 2019), research on the assessment of muscle-strengthening exercise is limited (Bennie, Shakespear-Druery, & De Cocker, 2020). Currently, muscle-strengthening exercise is assessed in public health surveillance exclusively through self-reported questionnaires (Strain, Milton, Dall, Standage, & Mutrie, 2019). Prevalence rates are typically measured against the guideline of ≥2 times/week (Bennie et al., 2020). Globally, reported muscle-strengthening exercise prevalence rates, based on data from large population studies, range from about 10% to 30% (Bennie, Lee, et al., 2018; Bennie et al., 2017; Bennie, Pedišić, van Uffelen, Charity, et al., 2016; Bennie, Pedišić, van Uffelen, Gale, et al., 2016; Strain et al., 2016). The inconsistencies in the way muscle-strengthening exercise is assessed across countries are likely to explain this discrepancy in prevalence rates. The use of accurate assessments (Brownson, Jones, Pratt, Blanton, & Heath, 2000) of muscle-strengthening exercise, is essential for establishing health effects, tracking trends, and assessing the effectiveness of interventions (Milton et al., 2018; Strain et al., 2016). Therefore, applying a standardised approach to the collection and analysis of data concerning population-level physical activity engagement is essential (Brownson et al., 2000). However, since there has been no systematic review of the systems/surveys used to assess muscle-strengthening exercise in public health surveillance, little is known about the description of the items contained within the surveys, or the reliability and validity of surveys used.

The aim of this study, therefore, is to conduct the first systematic review of muscle-strengthening exercise surveillance systems/surveys used within large adult-population-based studies. Specifically, this review will:

(i) Describe the types and frequency of surveillance systems/surveys used within public health surveillance of muscle-strengthening exercise;

(ii) Report on the reliability and validity of the identified systems/surveys.

2.2 Methods

Study inclusion and exclusion criteria

Studies were included if meeting the following inclusion criteria:

(i) The aim of the study was to measure muscle-strengthening exercise, in the context of leisure-time physical activity;

(ii) The system/survey under study was a self-reported questionnaire, either self-administered or administered by a researcher in the form of an interview (face to face, computer-assisted telephone interview (CATI), online, telephone);

(iii) The questionnaire measured muscle-strengthening activities/ exercise;

(iv) A study was accepted as a full-text original article in a peer-reviewed journal until 19 June 2019;

(v) The article was published in English;

(vi) The sample population was predominantly adults aged 18 years and over;

(vii) The sample population was ≥1000 free-living participants. This threshold was set to encompass studies that included population-representative samples.

Studies were excluded if meeting the following exclusion criteria:

(viii) All studies with a clinical population;

(ix) Abstracts only, those reporting statistics only or muscle-strengthening activities/exercise not reported separately from e. g., aerobic/stretching exercise;

(x) Occupational, household, transport-related physical activity or aerobic physical activity;

(xi) Accelerometer measures or measures of physical strength.

Search strategy

Informed by the PRISMA guidelines (Moher, Liberati, Tetzlaff, Altman, & the PRISMA Group, 2009) an extensive keyword search was undertaken across 7 electronic databases between 18-19 June 2019: (i) Cumulative Index to Nursing and Allied Health Literature (CINAHL); (ii) EBSCOhost academic search ultimate; (iii) PsychInfo; (iv) Scopus; (v) SportDiscus; (vi) Web of science; and (vii) Proquest (for grey literature, theses, and dissertations). All data were imported into Endnote (Daigneault, Jacob, & Ouimet, 2014). Appendix A has a description of the final search terms. Additionally, an ancestry search was completed on the reference lists of all the included articles, with this data also imported into Endnote (Clarivate, Camelot UK Bidco Limited, Philadelphia, PA, USA) (Daigneault et al., 2014).

Study selection

A review of the title and abstract was conducted by the principal author (JSD). Full-text articles were independently screened by the principal author (JSD) and co-authors (BGC, VSJ) against the specific inclusion/exclusion criteria, with any disagreement discussed and resolved with the last co-author (JAB). An ancestry search (a visual screening of each reference list from all the included articles to identify any additional articles for inclusion, this process has also been described as snowballing within the literature) (Greenhalgh & Peacock, 2005) was conducted (JSD) resulting in 6 additional articles, following an agreement with co-authors (JAB, KDC) (see Figure 1).

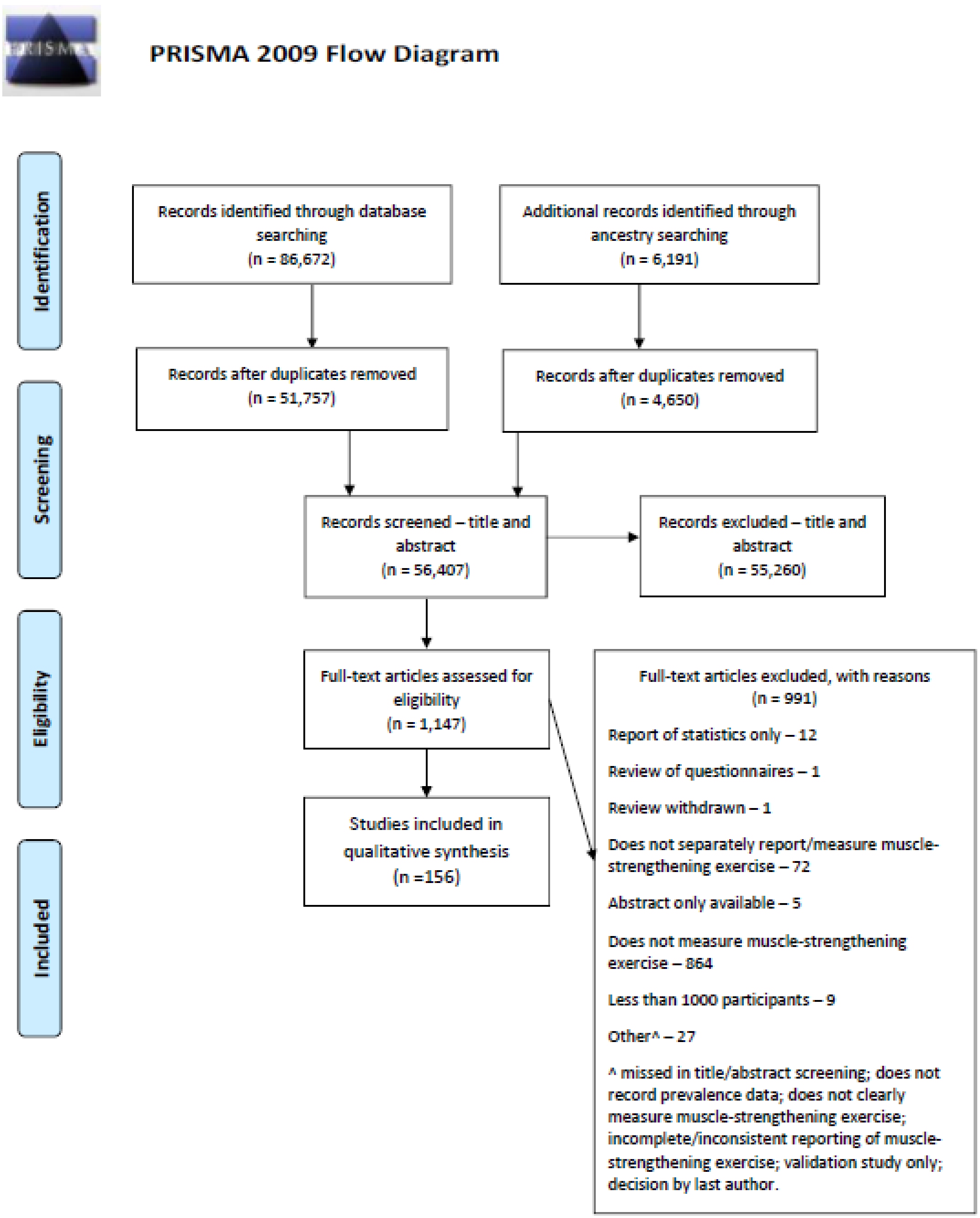


Figure 1.

Data extraction

For each included article data extraction was undertaken by the main investigator (JSD), and included: author/year; study design and sample characteristics; muscle-strengthening exercise questions (including key exercise prescription components); assessed participation and prevalence rates; and reliability and validity measures (a summary of each article is included in Online Supplementary Table 1).

Risk of bias

Given the focus on adult large population health surveillance (n= ≥1000) and descriptive nature of the data extraction, (e.g., assessing types/frequency of the surveillance systems/surveys used, wording of items), risk of bias assessment was not deemed to be necessary.

Approach for narrative synthesis of the data

The following data were extracted for each of the included articles: Country, Continent, Author, Year, Study design and sample characteristics (age, sex, data year (start), participant numbers), Surveillance system, Measurement tool, Question/s, Yes/No only response required, Number of questions, Timeframe assessed, Reported percentage meeting muscle-strengthening exercise guideline, Reported percentage of participation in muscle-strengthening exercise, Frequency measure (yes/no), Intensity Measure (yes/no), Type (terminology), Time measure (yes/no), Correlates, Included correlates (yes/no), Reliability, Reliability discussed (yes/no), Validity, Validity discussed (yes/no), Notes (see Online Supplementary Table 1). Due to the diverse way in which muscle-strengthening exercise was assessed, and the age/age groups of participants, across the included articles, a meta-analysis was not able to be performed.

2.3 Results

Search results and study selection

We identified 86,672 possible articles and following removal of duplicates (n = 34,915) the title and abstract of 51,757 articles were reviewed. Of these, 1,140 articles were then reviewed in full. Seven articles from ancestry searches (n = 6,191) were reviewed in full. A total of 156 articles were included in our analysis (see Figure 1).

Study characteristics

The 156 included articles analysed data collected from years 1969-2015. Data collection from U.S. participants was identified in 65.4% of the included articles. The other studies were conducted in Australia (8.3%), Korea (5.1%), Canada (4.5%), United Kingdom (4.5%), Japan (4.5%), Brazil (1.3%) and one each in Finland, Guatemala, Ireland, Israel, Italy, Libya, Pakistan, South Korea, Sweden and Taiwan. Participant sample size ranged from 1,051 (Harada, Shibata, Ishii, Liao, & Oka, 2014) to 497,967 (Mu, Cohen, & Mukamal, 2014, 2015). Most articles included participants aged 18 years and older (for example: ≥18 years, 26.9%; >20 years, 9.0%; >65 years, 9.0%; and 20-85 years, 4.5%) with some articles only providing mean age data (5.8%). Most (95.5%) included both male and female data (149 articles), the remaining data was reflected as single sex i.e. female (2.6%) or male (1.9%).

Systems/surveys including the assessment of muscle-strengthening exercise

A total of 58 different systems/surveys (see Table 1) were identified across 17 countries. The U.S.-based National Health and Nutrition Examination Survey (25.0%), National Health Interview Survey (15.4%) and Behavioral Risk Factor Surveillance System (10.3%) are the most commonly reported items.

Table 1: Surveillance system/survey (n=58) identified per country.

Country	Surveillance system/survey used	Reference
Australia	Active Australia survey	(Brown et al., 2013)
	Australian Diabetes, Obesity and Lifestyle study	(Minges et al., 2013)
	Central Queensland Social Survey	(Dalbo et al., 2015) (Humphries, Duncan, & Mummery, 2008) (Humphries, Stanton, Scanlan, & Duncan, 2018)
	Concord Health and Aging in Men Project	(Hsu et al., 2018)
	Exercise, Recreation and Sport Survey	(Bennie, Pedišić, van Uffelen, Charity, et al., 2016) (Merom, Cosgrove, Venugopal, & Bauman, 2012) (Eime et al., 2015) (Mealing, Bowles, Merom, & Bauman, 2011)
	National Nutrition and Physical Activity Survey	(Bennie, Pedišić, van Uffelen, Gale, et al., 2016) (Freeston et al., 2017)
	New South Wales Fall Prevention telephone survey	(Merom, Pye, et al., 2012)
Brazil	Surveillance System of Risk Factors and Protection for Chronic Noncommunicable Diseases	(de Lima, Lima, & do Carmo Luiz, 2017)
	Brazilian Living Standards Measurement Survey	(Monteiro et al., 2003)

Table 1: Surveillance system/survey (n=58) identified per country.

Country	Surveillance system/survey used	Reference
Canada	Canadian Community Health Survey	(Garriguet & Colley, 2014)
	Canadian Longitudinal Study on Aging	(Copeland, Good, & Dogra, 2019) (Dogra et al., 2018)
	General Social Survey	(Panten, Stone, & Baker, 2017)
	National College Health Assessment	(Scarapicchia, Sabiston, & Faulkner, 2015)
	National Population Health Survey	(Da Costa, Lowensteyn, & Dritsa, 2003) (Perks, 2017)
Finland	Finnish Regional Health and Well-being Study	(Bennie et al., 2017)
Guatemala	Nutritional supplementation trial	(Gregory, Ramirez-Zea, Martorell, & Stein, 2007)
Ireland	North/South Ireland Food Consumption Survey	(Livingstone et al., 2001)
Israel	Social Survey	(Zach & Lissitsa, 2016)
Italy	Longevity check-up 7+	(Landi et al., 2018)
Japan	Not disclosed	(Harada et al., 2014) (Harada, Shibata, Oka, & Nakamura, 2015)
	COMMUNIty-wide CAmpaign To promote Exercise study	(Kamada et al., 2018) (Kamada et al., 2013) (Masamitsu et al., 2015)
	Japan Epidemiology Collaboration on Occupational Health Study	(Kuwahara et al., 2015)

Table 1: Surveillance system/survey (n=58) identified per country.

Country	Surveillance system/survey used	Reference
	SSF National Sports-Life Survey	(Harada, Oka, Ota, Shibata, & Nakamura, 2008)
Korea	Korea National Health and Nutrition Examination Survey	(Bennie, Ding, et al., 2018) (Hong, Kim, & Lee, 2013) (Kim, Lee, Kye, Chung, & Kim, 2015) (E. Y. Lee, Carson, Jeon, Spence, & Tremblay, 2019) (J. Lee, Kim, & Jeon, 2016) (Oh, Son, et al., 2017) (Oh, Kim, Lee, Jung, & Lee, 2017) (Yeom, Jung, & Choi, 2011)
Libya	General Student Health Survey	(El Ansari, Khalil, Crone, & Stock, 2014)
Pakistan	7 Day recall	(Ahmad et al., 2015)
South Korea	Korean Survey on Citizens' Sports Participation	(Curtin, Lee, Yun, & Spence, 2018)
Sweden	PEAK-25 Cohort - Self-administered questionnaire	(Callréus, McGuigan, Ringsberg, & Åkesson, 2012)
Taiwan	Taiwanese version of the International Physical Activity Questionnaire-long version (IPAQ-LV)	(Lin, Park, Hsueh, Sun, & Liao, 2018)
United Kingdom	British Regional Heart Study	(Aggio et al., 2018)
	General Student Health Survey	(El Ansari et al., 2011)

Table 1: Surveillance system/survey (n=58) identified per country.

Country	Surveillance system/survey used	Reference
	Health Survey for England	(Stamatakis & Chaudhury, 2008) (Stamatakis et al., 2018)
	MRC National Survey of Health and Development	(Kuh & Cooper, 1992)
	Scottish Health Survey	(Strain et al., 2016) (Strain, 2018) (Stamatakis et al., 2018)
United States	Aerobics Center Longitudinal Study	(Bakker et al., 2017) (Bowles, 2005) (Sandler et al., 2014)
	American Time Use Survey	(Dunton, Berrigan, Ballard-Barbash, Graubard, & Atienza, 2009)
	Behavioral Risk Factor Surveillance System	(Bennie, De Cocker, Teychenne, Brown, & Biddle, 2019) (Bennie, Lee, et al., 2018) (Bennie, Teychenne, De Cocker, & Biddle, 2019) (Churilla et al., 2018) (Desmond, Jackson, & Hunter, 2015) (Dipietro, Williamson, Caspersen, & Eaker, 1993) (Ford et al., 2003) (Kamil-Rosenberg, Greaney, Hochman, & Garber, 2019) (Mu et al., 2014) (Mu et al., 2015)

Table 1: Surveillance system/survey (n=58) identified per country.

Country	Surveillance system/survey used	Reference
		(Pabayo, Fuller, Lee, Horino, & Kawachi, 2018) (Scarola, 2016) (Sciamanna et al., 2017) (Vezina, Der Ananian, Greenberg, & Kurka, 2014) (Keadle, McKinnon, Graubard, & Troiano, 2016) (Ham, Macera, Jones, Ainsworth, & Turczyn, 2004)
	Cardiovascular Health Study	(Monin et al., 2015)
	College Student Health Survey	(Vankim, Ehlinger, Lust, Story, & Laska, 2010)
	Education and Research Towards Health Study	(Redwood et al., 2009)
	Go for the Gold" employee wellness program	(Byrne et al., 2016)
	Health Information National Trends Survey	(Robertson, Song, Taylor, Durand, & Basen-Engquist, 2018)
	Health Professionals Follow-up Study	(Mekary et al., 2015)
	Health risk survey	(Nelson, Lust, Story, & Ehlinger, 2008)
	HealthStyles Survey	(Kruger, Blanck, & Gillespie, 2006) (Loustalot, Carlson, Kruger, Buchner, & Fulton, 2013)
	Millennium Cohort Study	(de la Motte et al., 2019)

Table 1: Surveillance system/survey (n=58) identified per country.

Country	Surveillance system/survey used	Reference
	Modified CHAMPS questionnaire	(Zizzi et al., 2006)
	National College Health Assessment	(Wald, Muennig, O'Connell, & Garber, 2014)
	National Health and Nutrition Examination Survey	(Alnojeidi, Johnson, Richardson, & Churilla, 2017) (Bertera, 2003) (Buckner, Loenneke, & Loprinzi, 2017) (Cangin, 2017) (Cangin, Harris, Binkley, Schwartzbaum, & Focht, 2018) (Cheng et al., 2007) (Churilla, Johnson, Magyari, & Crouter, 2012) (Churilla, Magyari, Ford, Fitzhugh, & Johnson, 2012) (Crespo, Keteyian, Heath, & Sempos, 1996) (Czwornog & Austin, 2015) (Dankel, Loenneke, & Loprinzi, 2015) (Dankel, Loenneke, & Loprinzi, 2016a) (Dankel, Loenneke, & Loprinzi, 2016b) (Dankel, Loenneke, & Loprinzi, 2016c) (Dankel, Loenneke, & Loprinzi, 2017b) (Dankel, Loenneke, & Loprinzi, 2017a) (Daumit

Table 1: Surveillance system/survey (n=58) identified per country.

Country	Surveillance system/survey used	Reference
		et al., 2005) (Edwards & Loprinzi, 2016) (Edwards & Loprinzi, 2018) (Evenson, Wen, & Herring, 2016) (Fan, Ham, Muppidi, & Mokdad, 2009) (Galuska, Earle, & Fulton, 2002) (Keadle et al., 2016) (Gao & Zhu, 2011) (Jensen-Otsu & Austin, 2015) (Kruger, Yore, & Kohl, 2007) (Kurka et al., 2015) (Loenneke & Loprinzi, 2018) (Loprinzi, 2016a) (Loprinzi, 2016b) (Loprinzi & Loenneke, 2015) (Loprinzi & Loenneke, 2018) (Loprinzi, Addoh, & Mann, 2017) (Loprinzi, Addoh, Wong Sarver, Espinoza, & Mann, 2017) (Loprinzi, Loenneke, & Abe, 2015) (Loprinzi, Loenneke, & Blackburn, 2015) (Magyari & Churilla, 2012) (Spees, Scott, & Taylor, 2012) (Zhao et al., 2014)
	National Health Interview Survey	(Adams & Schoenborn, 2006) (Blackwell & Clarke,

Table 1: Surveillance system/survey (n=58) identified per country.

Country	Surveillance system/survey used	Reference
		2016) (Carlson, Fulton, Schoenborn, & Loustalot, 2010) (Chevan, 2008) (Kraschnewski et al., 2014) (Kraschnewski et al., 2016) (Kruger, Carlson, & Kohl III, 2006) (Kruger, Carlson, & Buchner, 2007) (Kruger et al., 2009) (Murphy et al., 2017) (Schoenborn & Adams, 2010) (Schoenborn, Adams, Barnes, Vickerie, & Schiller, 2004) (Schoenborn, Adams, & Peregoy, 2013) (Schoenborn & Stommel, 2011) (Sciamanna et al., 2014) (Siahpush et al., 2019) (Swan, Friis, & Turner, 2008) (Tarasenko, Chen, & Schoenberg, 2017) (Tarasenko, Linder, & Miller, 2018) (Wu et al., 2016) (Xu, Dahlhamer, Zammitti, Wheaton, & Croft, 2018) (Yusuf et al., 1996) (Keadle et al., 2016) (Ham et al., 2004)

Table 1: Surveillance system/survey (n=58) identified per country.

Country	Surveillance system/survey used	Reference
	National Physical Activity Survey	(Ham et al., 2004)
	National Physical Activity and Weight Loss Survey	(Ciccolo, Gabriel, Macera, & Ainsworth, 2010) (Kruger, Yore, Ainsworth, & Macera, 2008)
	New York City Neighborhood and Mental Health in the Elderly Study II	(Mooney et al., 2018) (Mooney et al., 2015)
	New York County Health Census	(Eaton, Nafziger, Strogatz, & Pearson, 1994)
	Nurses' Health Study	(Grnøtved et al., 2014)
	Nurses' Health Study II	(Grnøtved et al., 2014)
	Structured questionnaire	(Tucker & Silvester, 1996)
	VITamins And Lifestyle study	(Littman, Kristal, & White, 2005)
	Women's Health Study	(Kamada, Shiroma, Buring, Miyachi, & Lee, 2017) (Shiroma et al., 2016)

Table 1: Surveillance system/survey (n=58) identified per country

Variation of questions for frequency, duration and intensity

Assessments of frequency (85.3%), intensity (1.3%) and duration (23.7%) were recorded across the 58 systems/surveys.

Frequency

For frequency, some asked one simple 'did you do/do you do' style question, eliciting a dichotomous 'yes' vs 'no' response (11.5%) for undertaking muscle-strengthening exercise. Additionally, half (50.6%) asked multiple questions (e.g., *did you do any physical activities specifically designed to strengthen your muscles*, and *how many times did you do these activities designed to strengthen your muscles*). Within these, 7.7% were asking for more detailed responses (e.g., *inclusion of muscle group(s)* (Loustalot et al., 2013); *location of muscle-strengthening activities performed* (Loustalot et al., 2013); *what is your main reason for engaging in* (Monteiro et al., 2003); and asked to *specify seasonal variations* (Callréus et al., 2012)) (see Table 2 for an example, also see Online Supplementary Table 2 for a full list of the questions identified within the included articles). However, some of the included articles did not describe the muscle-strengthening exercise assessment methods (7.1%), with the remaining 30.8% asking: 'how many times; how much time spent; how often; or type' styled questions. Most (67.9%) of the systems/surveys asked participants to reflect on their 'past' muscle-strengthening exercise behaviours, however the time period of these varied considerably with: *past 30* days (16.8%); *previous month* (11.2%); *weekly* (11.2%); and *past week* (8.9%) the most frequently identified. Other muscle-strengthening exercise behaviour periods included: c*urrent activity*; *periodically; regular engagement;* and *usual behaviour*, however these appeared less frequently.

Table 2: Example of depth and richness of data sought within the included studies.

Simple 'yes/no' questions
1. 'In the last week, did you do any gym-based resistance training'? (Humphries et al., 2008). 1. Participants reported whether they performed 'any physical activity designed to strengthen muscles such as weight-lifting, push-ups or sit-ups, over the past 30 days' (Cangin et al., 2018).
Complex closed questions used in a single system/survey

- “Do you currently perform any strength based training to build or maintain muscle? This could include activities such as training at home or the gym using barbells, dumbbells, hand weights or weight machines.”
- “How many days each week do you perform strength based training activities?”
- “When you perform the activities to build or maintain muscle, how many different exercises do you perform?”
- “On average how many repetitions do you perform in each set?” and
- “Thinking about the weight that you lift during your muscle strengthening sessions, we would like you to categorise the intensity of this weight on a scale of 1–10, where 1 means that it is no effort at all, 5 is moderate effort and 10 is the weight you can only lift once” (Humphries et al., 2018).

Table 2: Example of depth and richness of data sought within the included studies.

Duration

Within the 37 articles (23.7%) that reported an assessment of duration, there were differences in the way responses (minutes/hours) were ascertained from participants. Questions included for example: “*the average exercise duration (minutes) for each session of muscle-strengthening physical activity using either free weights or weight training machines over the past 3 months”* (Bakker et al., 2017); “*the average duration of each session: 1 to 15 minutes, 16 to 30 minutes, 31 to 60 minutes, or more than one* hour” (Garriguet & Colley, 2014); *“how many hours a week?” with six response options (<1, 1–2, 3–4, 5–6, 7–8, and ≥9 hr)* (Zizzi et al., 2006); and *“when you took part in this activity, for how many minutes or hours did you usually keep at it?”* (Scarola, 2016).

Intensity

While two articles (1.3%) included the reporting of muscle-strengthening exercise intensity, how each was assessed differed. Harada et al. (2015) applied a perceived intensity of *light, moderate, or high*, and excluded data from participants who indicated light intensity as they were regarded as non-performers of muscle-strengthening exercise at this level of effort. In Humphries et al. (2018) respondents were asked to *categorise the intensity of this weight on a scale of 1–10, where 1 means that it is no effort at all, 5 is moderate effort and 10 is the weight you can only lift once.* The applied scale was reportedly based upon ACSM guidelines for resistance training.

Modalities of included muscle-strengthening exercise

While most surveillance systems/surveys provide respondents with examples of muscle-strengthening exercises, there is inconsistency in the terms used to describe muscle-strengthening exercise. Within the included articles we identified 44 different modalities (terms/terminology) used as examples to identify muscle-strengthening exercise. The 5 most frequent modalities identified were: push-ups (12.5%); sit-ups (12.5%); lifting weights (11.2%); calisthenics (8.4%); and weight lifting (8.7%). However less common terms/exercise modalities including 'keep fit' (Stamatakis & Chaudhury, 2008), 'neuromuscular training' (Bennie et al., 2017), 'military exercise', 'power team', and 'prime movers' (Bennie, Pedišić, van Uffelen, Charity, et al., 2016).

Participation and prevalence rate of muscle-strengthening exercise

Rates of participation ('yes' or 'no') in muscle-strengthening exercise (>0 times/week) were reported within over half of the studies (55.8%) with rates varying from as low as 1.1% (Aggio et al., 2018) to 76.9% (Cheng et al., 2007). Prevalence rates, assessed against the muscle-strengthening exercise guideline (≥2 times/week), were reported in 78 (50.0%) of the articles and varied from 3.2% (Blackwell & Clarke,

2016) to 69.9% (de la Motte et al., 2019). Twenty articles (12.8%) reported rates of participation (‘yes’ or ‘no’) and prevalence (≥2 times/week) (Bakker et al., 2017; Bennie, Lee, et al., 2018; Bennie, Pedišić, van Uffelen, Charity, et al., 2016; Byrne et al., 2016; Chevan, 2008; Churilla, Johnson, et al., 2012; Dankel et al., 2016b; Evenson et al., 2016; Galuska et al., 2002; Grnøtved et al., 2014; Harada et al., 2008; Hong et al., 2013; Humphries et al., 2018; Kurka et al., 2015; Merom, Pye, et al., 2012; Schoenborn et al., 2013; Stamatakis et al., 2018; Strain, 2018; Strain et al., 2016; Wald et al., 2014).

Validity and reliability of self-reported measures of muscle-strengthening exercise

Most articles (69.9%) did not report on the validity of the survey, with only one (0.6%) independently assessing internal validity (Monteiro et al., 2003). The remaining 29.5% referenced previous research that had cited validity. Of the 46 articles citing validity, two U.S. surveillance systems/surveys were the most frequent. They are the National Health and Nutrition Examination Survey (NHANES, 32.6%) and the Behavioral Risk Factor Surveillance System (BRFSS, 13.0%). For NHANES, the study by Loprinzi, Loenneke, and Abe (2015) was referenced 53.3% of the time for the convergent validity of the muscle-strengthening exercise questions. For the BRFSS, two studies were referenced, first Loprinzi, Loenneke, and Abe (2015) (50.0% of the time), and second Yore et al. (2007) (concurrent validity) was identified once (16.7%). In Yore et al. (2007), it was reported moderate validity inferences (κ = 0.40–0.52), for the strengthening measure, when comparing a physical activity log against the survey questions.

For reliability, 80.1% were unreported, with two articles (1.3%) independently assessing reliability (Callréus et al., 2012; Kamada et al., 2013), the remaining 18.6% (29 articles) referenced previous research. The results for Kamada et al. (2018) assessment of test-retest reliability was reported as moderate and acceptable ($\rho = 0.75$) for muscle-strengthening exercise, whereas Callréus et al. (2012) found no significant difference (p value range 0.13–1.0) when conducting the Sign Test on the responses to the two administrations of their questionnaire. Of the 29 articles that cited reliability, the BRFSS was the most frequently identified surveillance system/survey, with the study by Yore et al. (2007) referenced 66.7% of the time for test-retest reliability. Yore et al. (2007) reported excellent test-retest reliability ($\kappa = 0.85$-0.92) for the muscle-strengthening exercise measure when comparing the results of the first administration of the survey against the second and third survey administrations.

2.4 Discussion

To our knowledge, this systematic review provides the first synthesis of muscle-strengthening exercise participation assessment systems/surveys used in public health surveillance. The key findings were that there is large heterogeneity in the measures used and that the validity and reliability of muscle-strengthening exercise questions are rarely assessed.

This review has identified that globally there is a multitude of different surveillance systems/surveys, used between and within countries. This finding is similar to that by Milton et al. (2018) in their recent review of the Global Observatory of Physical Activity (GoPA) ‘country cards’ where they observed 42 different surveillance systems/surveys within 44 countries. However, their analysis included systems/surveys that measured aerobic MVPA ($n = 34$) alone, with only 4 systems/surveys (Health Survey for England; Scottish Health Survey; Health Survey for Northern Ireland; and the BRFSS) that sought specific muscle-strengthening exercise data (Milton et al., 2018).

While many aspects of the surveillance systems/surveys, identified within our review, may be similar, individual nuances are most likely to limit the ability to formally compare results across studies. A key future research question is concerning the time period being assessed (e.g., past or current activity) and, when the results are compared against recommended muscle-strengthening exercise guideline, are they comparable periods or is average data being used (e.g., past 7 days or past year)? A further potential point of consideration needs to consider whether the questionnaire seeks to explore the participant's ability to recall activities or whether the systems/surveys seeks information that is typical of the respondents' usual exercising behaviours. Consistency in the period under review will aid researchers in understanding actual participant behaviour and assist comparability of muscle-strengthening exercise data across surveillance systems/surveys and various populations/countries.

Another finding was the inconsistency in the terminologies used within muscle-strengthening exercise surveillance systems/surveys. This may influence the accuracy of participation, especially from responders who have limited physical activity literacy. Furthermore, our review showed that the examples of muscle-strengthening exercise modalities within the questionnaires were highly varied, with 44 different terms identified. This difference in the number and/or type of modalities could lead to inconsistency in participant responses, with some not providing a positive response if, for example, they know the exercise by a different name (Ham et al., 2004). Participant responses may therefore be influenced by their level of physical activity literacy and other factors, including cultural influences, such as language, cultural norms, and ethnicity (Ainsworth, Cahalin, Buman, & Ross, 2015; Tudor-Locke et al., 2003). In the review by Ham et al. (2004) they discuss the influence that differing examples, used to describe muscle-strengthening exercise, may have on reported prevalence rates between individual surveillance systems/surveys. Therefore, the ability to accurately compare prevalence rates between different populations may also be hindered.

Our review shows the clear need for further research is needed to understand the impact that cultural influences may have on muscle-strengthening exercise participation, building on the earlier work in this area on aerobic physical activity by Tudor-Locke et al. (2003). Additionally, we suggest that existing global surveillance tools, such as the Global Physical Activity Questionnaire (GPAQ) (World Health Organization, 2020) could be expanded to include the assessment of muscle-strengthening exercise (i.e. including visual examples of muscle-strengthening exercise within their show cards), along with the WHO providing examples of muscle-strengthening exercise within their physical activity guidelines (Bull et al., 2020). Furthermore, the categorisation of muscle-strengthening exercises specifically undertaken to improve or maintain muscle strength requires further research. The paper by Strain et al. (2016) highlights the inclusion of activities such as horse riding and lawn bowls as muscle-strengthening activities. However, it remains unclear as to what extent that these activities may influence health-related outcomes or the global efforts to reduce NCD’s.

The current physical activity guidelines do not include recommendations regarding muscle-strengthening exercise duration, therefore, it is not surprising that less than one-quarter of articles within our review included an assessment of duration. The present study also showed that, regardless of the way that muscle-strengthening exercise duration is assessed, there needs to be a unified approach in measuring the actual time spent exercising. For example, a respondent may indicate that they undertake 30 minutes of muscle-strengthening exercise, however, what is not known is how much of that time is actually spent lifting/lowering/pushing/pulling. A portion of the time indicated may be allocated to setting up their weights/machine and or taking rest periods between each exercise group/set (which is a recommended component of muscle-strengthening exercise) (Garber et al., 2011). Further research is needed to identify the most feasible and practical approach to assess actual muscle-strengthening exercise duration and apply this approach within large population surveillance.

Our paper highlights a distinct gap in obtaining responder exercise intensity data, with only two surveillance systems/surveys including this. While there is limited research on the influence that muscle-strengthening exercise intensity may have on reducing the risks associated with chronic disease (McGuigan, Newton, & Kraemer, 2006), it is still considered an important component to track within public health surveillance (Siahpush et al., 2019). However, equally, it is acknowledged that the accurate assessment of muscle-strengthening exercise intensity will present a challenge for public health surveillance. Clinical measures of intensity (e.g., the use of weights equipment based accelerometers/linear transducers) do not currently appear to be financially or physically viable on such large scale studies.

A further key finding was that there is a clear lack of reference to both the validity and reliability of the systems/surveys used to measure muscle-strengthening exercises within large population surveillance. Within our review, two articles (Loprinzi, Loenneke, & Abe, 2015; Yore et al., 2007) were the most commonly cited within the surveillance systems/surveys, when reporting on the methods used to assess muscle-strengthening exercise. However, the comparison between even these two is difficult as only Yore et al. (2007) has assessed both aerobic MVPA and muscle-strengthening exercise questions. For concurrent validity of aerobic MVPA, Yore et al. (2007) reported poor to fair validity - using accelerometry (κ = 0.17-0.22), and moderate validity - using physical activity logs (κ = 0.40-0.51) for the recommended activity when comparing against the survey questions. Similar validity was found for muscle-strengthening exercise (κ = 0.40-0.52) (Yore et al., 2007) using physical activity logs. For test-retest reliability, Yore et al. (2007) reported substantial reliability (κ = 0.67-0.84) for the recommended aerobic MVPA measure when comparing the results of the first administration of the survey against the second and third survey administrations. However, the results for reliability were significantly stronger for muscle-strengthening exercise (κ = 0.85-0.92) (Yore et al., 2007). While the use of physical activity logs to validate muscle-strengthening exercise behaviour may be a possible option, given the high participant burden (Ainsworth et al., 2015), its use in public health surveillance research may be limited. It might be possible that other forms of validity, such as face validity, may provide better approaches to establishing the psychometric properties of muscle-strengthening exercise questionnaires.

Additionally, while it is acknowledged that obtaining data through self-reported methods can increase the risk of bias (e.g., where respondents may answer in terms of what they think is socially desirable) (Cohen, Manion, & Morrison, 2017), there are currently no alternate forms of assessment for muscle-strengthening exercise participation. This is in contrast to aerobic MVPA (were the use of accelerometers is common). Limited research has been conducted, and only within clinical/laboratory settings, on the use of devices such as wrist (Conger et al., 2016) or hip (Butte, Ekelund, & Westerterp, 2012) worn accelerometers to accurately identify muscle-strengthening exercise performance. Alternate assessment tools for large population surveillance, such as through the use of personal physical activity tracking devices or mobile phone applications, are currently restricted due to technology limitations (Strain, Wijndaele, & Brage, 2019).

Recommendations for future research

Our results clearly show that a consistent approach is required to accurately analyse and compare data between surveillance systems/surveys globally. Further research is needed to identify the most feasible and practical approach to assess muscle-strengthening exercise intensity within large population surveillance. Researchers will then understand the importance of obtaining/tracking this data or, be comfortable that on a large population scale that obtaining this information is as a greater cost to participants (e.g., responder fatigue) than the benefit that the data currently provides. Based on our review, we conclude that no single surveillance system/survey contains the optimum set of questions to assess and report on muscle-strengthening exercise behaviour and, that a combination of several existing surveillance approaches is necessary to create a new comprehensive questionnaire. Most systems/surveys do not obtain data for each recommended component (e.g., frequency, intensity, time, type, repetitions, sets) (Garber et al., 2011) of muscle-strengthening exercise and the research gap regarding the importance of these individual components remains. This is an opportunity for future research to build upon. While research into the independent benefits of undertaking muscle-strengthening exercise (against health-related conditions/outcomes, and in comparison to global physical activity recommendations) is ongoing, one approach to bridge the surveillance gap may be to review and update the current global surveillance tools, such as the GPAQ or the International Physical Activity Questionnaire (IPAQ) to include component measures for muscle-strengthening exercise. Importantly, the reviewed system/survey should incorporate specificity regarding the: frequency (specific days muscle-strengthening exercise is completed); intensity (using a perceived rating scale); time (actual time spent completing muscle-strengthening exercises) type (name or description of the exercise/muscle groups used); and the number of, exercises, sets and repetitions for each exercise. The reviewed system/survey would optimally be also tested for validity and reliability.

Additionally, more research into the testing of the reliability and validity of future surveys is needed. While it is acknowledged that varying the questions contained within national population surveillance questionnaires may pose additional burden on both researchers (comparability) and responders (fatigue), we believe that it is equally if not more important to obtain additional muscle-strengthening exercise behaviour information to better understand the relationship with health, and guide future health promotion messages. We recommend the minimum should include some basic 'program' parameters i.e. frequency (days per usual week), intensity (scaled from very light to very hard), type (specific exercise mode) and, time (duration per session) (Garber et al., 2011), with a further/future expansion of the questions to include an understanding about the muscle groups used.

A key strength of this study is that it is the first systematic review of muscle-strengthening exercise surveillance systems/surveys used in large population-based studies with an adult population. Due to the volume of articles obtained during the 'identification' phase, the eligible study sample size was reviewed. Following an agreement with the co-authors, the inclusion/exclusion criteria were refined to include only those studies with ≥1000 participants, as studies containing less than this number may not be considered 'surveillance' studies. Therefore, there is a risk that some data were lost and not included in this review. There is also a risk that data was lost due to the exclusion of unpublished works and those not published in the English language.

2.5 Conclusion

This review shows that there is large heterogeneity within the systems/surveys currently used to assess muscle-strengthening exercise in public health surveillance. This may impede efforts to identify at risk groups, trends and accurately assess improvements in health within large populations. Despite the growing evidence of the health benefits of undertaking muscle-strengthening exercise (Steele et al., 2017) prevalence rates (≥2 times/week) are globally low. Prevalence and participation rates may be influenced by the surveillance system/survey question structure, and the physical activity literacy of respondents. Greater emphasis and consistency is required in the communication of muscle-strengthening exercise recommendations globally. With the accurate assessment and comparability of physical activity behaviour data required to effectively track health trends and identify population subgroups most at risk of low participation levels.

Conflict of interest statement

The authors declare that they have no competing interests.

Authors' contributions

JSD, KDC, SJHB, and JAB conceptualised the study and developed the research plan. JSD conducted the search strategy and data extraction. JSD, BGC, and VSJ conducted the study selection. JSD drafted the initial manuscript. JAB, KDC, and SJHB provided guidance on the study and critically reviewed the manuscript. All authors read and approved the final version of the manuscript, and agree with the order of presentation of the authors.

Acknowledgements

This research has been supported by an Australian Government Research Training Program Scholarship and a University of Southern Queensland Research Training Program Stipend Scholarship. The authors wish to also thank Dr Tricia Kelly for her support and guidance in the search strategy phase of this review.

2.6 References

Adams, P. F., & Schoenborn, C. A. (2006) Health behaviors of adults: United States, 2002-04. In*: Vol. 10. Vital and Health Statistics*.

Aggio, D., Papacosta, O., Lennon, L. T., Ash, S., Whincup, P. H., Wannamethee, S. G., & Jefferis, B. J. (2018). Tracking of sport and exercise types from midlife to old age: a 20-year cohort study of British men. *European Review of Aging and Physical Activity, 15*, 9. doi:10.1186/s11556-018-0205-y

Ahmad, W., Taggart, F., Shafique, M. S., Muzafar, Y., Abidi, S., Ghani, N., . . . Ghaffar, N. (2015). Diet, exercise and mental-wellbeing of healthcare professionals (doctors, dentists and nurses) in Pakistan. *Peerj, 3*, 13. doi:10.7717/peerj.1250

Ainsworth, B., Cahalin, L., Buman, M., & Ross, R. (2015). The current state of physical activity assessment tools. *Progress in Cardiovascular Diseases, 57*(4), 387-395. doi:10.1016/j.pcad.2014.10.005

Alnojeidi, A. H., Johnson, T. M., Richardson, M. R., & Churilla, J. R. (2017). Associations between low back pain and muscle-strengthening activity in US adults. *Spine, 42*(16), 1220-1225. doi:10.1097/brs.0000000000002063

Ashton, R. E., Tew, G. A., Aning, J. J., Gilbert, S. E., Lewis, L., & Saxton, J. M. (2018). Effects of short-term, medium-term and long-term resistance exercise training on cardiometabolic health outcomes in adults: Systematic review with meta-analysis. *British Journal of Sports Medicine*, 1-9. doi:10.1136/bjsports-2017-098970

Bakker, E. A., Lee, D. C., Sui, X. M., Artero, E. G., Ruiz, J. R., Eijsvogels, T. M. H., . . . Blair, S. N. (2017). Association of resistance exercise, independent of and combined with aerobic exercise, with the incidence of metabolic syndrome. *Mayo Clinic Proceedings, 92*(8), 1214-1222. doi:10.1016/j.mayocp.2017.02.018

Bennie, J. A., De Cocker, K., Teychenne, M. J., Brown, W. J., & Biddle, S. J. H. (2019). The epidemiology of aerobic physical activity and muscle-strengthening activity guideline adherence among 383,928 U.S. adults. *International Journal of Behavioral Nutrition and Physical Activity, 16*(1), 1-11. doi:10.1186/s12966-019-0797-2

Bennie, J. A., Ding, D., Khan, A., Stamatakis, E., Biddle, S. J. H., & Kim, J. (2018). Run, lift, or both? Associations between concurrent aerobic–muscle strengthening exercise with adverse cardiometabolic biomarkers among Korean adults. *European Journal of Preventive Cardiology*, 1-11. doi:10.1177/2047487318817899

Bennie, J. A., Lee, D.-c., Khan, A., Wiesner, G. H., Bauman, A. E., Stamatakis, E., & Biddle, S. J. H. (2018). Muscle-strengthening exercise among 397,423 U.S. adults: Prevalence, correlates, and associations with health conditions. *American Journal of Preventive Medicine, 55*(6), 864-874. doi:10.1016/j.amepre.2018.07.022

Bennie, J. A., Pedišić, Ž., Suni, J. H., Tokola, K., Husu, P., Biddle, S. J. H., & Vasankari, T. (2017). Self-reported health-enhancing physical activity recommendation adherence among 64,380 Finnish adults. *Scandinavian Journal of Medicine & Science in Sports, 27*(12), 1842-1853. doi:10.1111/sms.12863

Bennie, J. A., Pedišić, Ž., van Uffelen, J. G. Z., Charity, M. J., Harvey, J. T., Banting, L. K., . . . Eime, R. M. (2016). Pumping iron in Australia: Prevalence, trends and sociodemographic correlates of muscle strengthening activity participation from a national sample of 195,926 adults. *PLoS ONE, 11*(4), 1-15. doi:10.1371/journal.pone.0153225

Bennie, J. A., Pedišić, Ž., van Uffelen, J. G. Z., Gale, J., Banting, L. K., Vergeer, I., . . . Biddle, S. J. H. (2016). The descriptive epidemiology of total physical activity, muscle-strengthening exercises and sedentary behaviour among Australian adults--Results from the national nutrition and physical activity survey. *BMC Public Health, 16*(1), 1-13. doi:10.1186/s12889-016-2736-3

Bennie, J. A., Shakespear-Druery, J., & De Cocker, K. (2020). Muscle-strengthening exercise epidemiology: A new frontier in chronic disease prevention. *Sports Medicine - Open, 6*(1), 1-8. doi:10.1186/s40798-020-00271-w

Bennie, J. A., Teychenne, M. J., De Cocker, K., & Biddle, S. J. H. (2019). Associations between aerobic and muscle-strengthening exercise with depressive symptom severity among 17,839 U.S. adults. *Preventive Medicine, 121*, 121-127. doi:10.1016/j.ypmed.2019.02.022

Bertera, E. M. (2003). Physical activity and social network contacts in community dwelling older adults. *Activities, Adaptation and Aging, 27*(3-4), 113-127. doi:10.1300/J016v27n03_08

Blackwell, D. L., & Clarke, T. C. (2016) Occupational differences among employed adults who met 2008 federal guidelines for both aerobic and muscle-strengthening activities: United States, 2008–2014. In*: Vol. 2016. National health statistics reports*.

Bowles, H. R. (2005). *Incidence of activity limitations and its association with physical activity, fitness, and other lifestyle factors.* (3181933 Ph.D.), University of South Carolina, Available from _PROQUEST Dissertations & Theses A&I database.

Branscum, P., & Fairchild, G. (2019). Differences in determinants of aerobic and muscle strengthening physical activity among college students: a reasoned action approach. *Journal of Sports Sciences, 37*(1), 90-99. doi:10.1080/02640414.2018.1483179

Brown, W. J., Burton, N. W., Sahlqvist, S., Heesch, K. C., McCarthy, K. B., Ng, N., & van Uffelen, J. G. Z. (2013). Physical activity in three regional communities in Queensland. *Australian Journal of Rural Health, 21*(2), 112-120. doi:10.1111/ajr.12015

Brownson, R. C., Jones, D. A., Pratt, M., Blanton, C., & Heath, G. W. (2000). Measuring physical activity with the behavioral risk factor surveillance system. *Medicine & Science in Sports & Exercise, 32*(11), 1913-1918. doi:10.1097/00005768-200011000-00015

Buckner, S. L., Loenneke, J. P., & Loprinzi, P. D. (2017). Single and combined associations of accelerometer-assessed physical activity and muscle-strengthening activities on plasma homocysteine in a national sample. *Clinical Physiology and Functional Imaging, 37*(6), 669-674. doi:10.1111/cpf.12356

Bull, F. C., Al-Ansari, S. S., Biddle, S., Borodulin, K., Buman, M. P., Cardon, G., . . . Willumsen, J. F. (2020). World Health Organization 2020 guidelines on physical activity and sedentary behaviour. *British Journal of Sports Medicine, 54*(24), 1451. doi:10.1136/bjsports-2020-102955

Butte, N. F., Ekelund, U., & Westerterp, K. R. (2012). Assessing physical activity using wearable monitors: Measures of physical activity. *Medicine & Science in Sports & Exercise, 44*(Suppl. 1), S5-S12. doi:10.1249/MSS.0b013e3182399c0e

Byrne, D. W., Rolando, L. A., Aliyu, M. H., McGown, P. W., Connor, L. R., Awalt, B. M., . . . Yarbrough, M. I. (2016). Modifiable healthy lifestyle behaviors: 10-year health outcomes from a health promotion program. *American Journal of Preventive Medicine, 51*(6), 1027-1037. doi:10.1016/j.amepre.2016.09.012

Callréus, M., McGuigan, F., Ringsberg, K., & Åkesson, K. (2012). Self-reported recreational exercise combining regularity and impact is necessary to maximize bone mineral density in young adult women. *Osteoporosis International, 23*(10), 2517-2526. doi:10.1007/s00198-011-1886-5

Cangin, C. (2017). *Association of depression with anaerobic muscle strengthening activity, moderate intensity physical activity, long term lipophilic statin usage, and selected comorbidity: NHANES (national health and nutrition examination survey) 1999-2012.* (P.h.D.), The Ohio State University, Available from EBSCOhost psyh database.

Cangin, C., Harris, R., Binkley, P., Schwartzbaum, J., & Focht, B. (2018). Anaerobic muscle strengthening physical activity and depression severity among USA adults. *Preventive Medicine Reports, 10*, 299-303. doi:10.1016/j.pmedr.2018.03.005

Carlson, S. A., Fulton, J. E., Schoenborn, C. A., & Loustalot, F. (2010). Trend and prevalence estimates based on the 2008 physical activity guidelines for Americans. *American Journal of Preventive Medicine, 39*(4), 305-313. doi:10.1016/j.amepre.2010.06.006

Cheng, Y. J., Gregg, E. W., De Rekeneire, N., Williams, D. E., Imperatore, G., Caspersen, C. J., & Kahn, H. S. (2007). Muscle-strengthening activity and its association with insulin sensitivity. *Diabetes Care, 30*(9), 2264-2270. doi:10.2337/dc07-0372

Chevan, J. (2008). Demographic determinants of participation in strength training activities among U.S. Adults. *Journal of Strength and Conditioning Research, 22*(2), 553-558. doi:10.1519/JSC.0b013e3181636bee.

Churilla, J. R., Johnson, T. M., Magyari, P. M., & Crouter, S. E. (2012). Descriptive analysis of resistance exercise and metabolic syndrome. *Diabetes and Metabolic Syndrome: Clinical Research and Reviews, 6*(1), 42-47. doi:10.1016/j.dsx.2012.05.004

Churilla, J. R., Johnson, T. M., Richardson, M. R., Williams, B. D., Rariden, B. S., & Boltz, A. J. (2018). Mode of physical activity participation by body mass index: 2015 behavioural risk factor surveillance system. *Research in Sports Medicine, 26*(2), 147-157. doi:10.1080/15438627.2018.1431531

Churilla, J. R., Magyari, P. M., Ford, E. S., Fitzhugh, E. C., & Johnson, T. M. (2012). Muscular strengthening activity patterns and metabolic health risk among US adults*. *Journal of Diabetes, 4*(1), 77-84. doi:10.1111/j.1753-0407.2011.00172.x

Ciccolo, J. T., Gabriel, K. K. P., Macera, C., & Ainsworth, B. E. (2010). Association between self-reported resistance training and self-rated health in a national sample of U.S. men and women. *Journal of Physical Activity and Health, 7*(3), 289-298. doi:10.1123/jpah.7.3.289

Cohen, L., Manion, L., & Morrison, K. (2017). *Research methods in education* (8th ed.). London, United Kingdom: Routledge.

Conger, S. A., Jun, G. U. O., Fulkerson, S. M., Pedigo, L., Hao, C., & Bassett Jr, D. R. (2016). Objective Assessment of Strength Training Exercises using a Wrist-Worn Accelerometer. *Medicine & Science in Sports & Exercise, 48*(9), 1847-1855. doi:10.1249/MSS.0000000000000949

Copeland, J. L., Good, J., & Dogra, S. (2019). Strength training is associated with better functional fitness and perceived healthy aging among physically active older adults: A cross-sectional analysis of the Canadian longitudinal study on aging. *Aging Clinical and Experimental Research, 31*, 1257-1263. doi:10.1007/s40520-018-1079-6

Crespo, C. J., Keteyian, S. J., Heath, G. W., & Sempos, C. T. (1996). Leisure-time physical activity among US adults - Results from the third national health and nutrition examination survey. *Archives of Internal Medicine, 156*(1), 93-98. doi:10.1001/archinte.156.1.93

Curtin, K. D., Lee, E. Y., Yun, L., & Spence, J. C. (2018). Context matters: Examining perceived health and fitness outcomes of physical activity participation among South Korean adults and youth. *International Journal of Behavioral Medicine, 25*(5), 548-557. doi:10.1007/s12529-018-9743-y

Czwornog, J. L., & Austin, G. L. (2015). Association of proton pump inhibitor (PPI) use with energy intake, physical activity, and weight gain. *Nutrients, 7*(10), 8592-8601. doi:10.3390/nu7105416

Da Costa, D., Lowensteyn, I., & Dritsa, M. (2003). Leisure-time physical activity patterns and relationship to generalized distress among Canadians with arthritis or rheumatism. *Journal of Rheumatology, 30*(11), 2476-2484.

Daigneault, P.-M., Jacob, S., & Ouimet, M. (2014). Using systematic review methods within a Ph.D. dissertation in political science: Challenges and lessons learned from practice. *International Journal of Social Research Methodology, 17*(3), 267-283. doi:10.1080/13645579.2012.730704

Dalbo, V. J., Czerepusko, J. B., Tucker, P. S., Kingsley, M. I., Moon, J. R., Young, K., & Scanlan, A. T. (2015). Not sending the message: A low prevalence of strength-based exercise participation in rural and regional Central Queensland. *Australian Journal of Rural Health, 23*(5), 295-301. doi:10.1111/ajr.12207

Dankel, S. J., Loenneke, J. P., & Loprinzi, P. D. (2015). Participation in muscle-strengthening activities as an alternative method for the prevention of multimorbidity. *Preventive Medicine, 81*, 54-57. doi:10.1016/j.ypmed.2015.08.002

Dankel, S. J., Loenneke, J. P., & Loprinzi, P. D. (2016a). Determining the importance of meeting muscle-strengthening activity guidelines: Is the behavior or the outcome of the behavior (strength) a more important determinant of all-cause mortality? *Mayo Clinic Proceedings, 91*(2), 166-174. doi:10.1016/j.mayocp.2015.10.017

Dankel, S. J., Loenneke, J. P., & Loprinzi, P. D. (2016b). Dose-dependent association between muscle-strengthening activities and all-cause mortality: Prospective cohort study among a national sample of adults in the USA. *Archives of Cardiovascular Diseases, 109*(11), 626-633. doi:10.1016/j.acvd.2016.04.005

Dankel, S. J., Loenneke, J. P., & Loprinzi, P. D. (2016c). The individual, joint, and additive interaction associations of aerobic-based physical activity and muscle strengthening activities on metabolic syndrome. *International Journal of Behavioral Medicine, 23*(6), 707-713. doi:10.1007/s12529-016-9570-y

Dankel, S. J., Loenneke, J. P., & Loprinzi, P. D. (2017a). Cancer-specific mortality relative to engagement in muscle-strengthening activities and lower extremity strength. *Journal of Physical Activity and Health, 15*(2), 144-149. doi:10.1123/jpah.2016-0204

Dankel, S. J., Loenneke, J. P., & Loprinzi, P. D. (2017b). Combined associations of muscle-strengthening activities and accelerometer-assessed physical activity on multimorbidity: Findings from

NHANES. *American Journal of Health Promotion, 31*(4), 274-277. doi:10.4278/ajhp.150520-QUAN-894

Daumit, G. L., Goldberg, R. W., Anthony, C., Dickerson, F., Brown, C. H., Kreyenbuhl, J., . . . Dixon, L. B. (2005). Physical activity patterns in adults with severe mental illness. *Journal of Nervous and Mental Disease, 193*(10), 641-646. doi:10.1097/01.nmd.0000180737.85895.60

de la Motte, S. J., Welsh, M. M., Castle, V., Burnett, D., Gackstetter, G. D., Littman, A. J., . . . Hooper, T. I. (2019). Comparing self-reported physical activity and sedentary time to objective fitness measures in a military cohort. *Journal of Science and Medicine in Sport, 22*(1), 59-64. doi:10.1016/j.jsams.2018.05.023

de Lima, D. F., Lima, L. A., & do Carmo Luiz, O. (2017). Daily physical activity of Brazilian carriers of arterial hypertension: A transversal analysis. *Colombia Medica, 48*(2), 82-87.

Desmond, R., Jackson, B. E., & Hunter, G. (2015). Utilization of 2013 BRFSS physical activity data for state cancer control plan objectives: Alabama data. *Southern Medical Journal, 108*(5), 290-297. doi:10.14423/SMJ.0000000000000282

Dipietro, L., Williamson, D. F., Caspersen, C. J., & Eaker, E. (1993). The descriptive epidemiology of selected physical activities and body-weight among adults trying to lose weight - The behavioral risk factor surveillance system survey, 1989. *International Journal of Obesity, 17*(2), 69-76.

Dogra, S., Good, J., Buman, M. P., Gardiner, P. A., Copeland, J. L., & Stickland, M. K. (2018). Physical activity and sedentary time are related to clinically relevant health outcomes among adults with obstructive lung disease. *BMC Pulmonary Medicine, 18*, 13. doi:10.1186/s12890-018-0659-8

Dunton, G. F., Berrigan, D., Ballard-Barbash, R., Graubard, B. I., & Atienza, A. A. (2009). Environmental Influences on exercise intensity and duration in a US time use study. *Medicine & Science in*

Sports & Exercise, 41(9), 1698-1705. doi:10.1249/MSS.0b013e3181a06c9b

Eaton, C. B., Nafziger, A. N., Strogatz, D. S., & Pearson, T. A. (1994). Self-reported physical-activity in a rural county - A New-York county health census. *American Journal of Public Health, 84*(1), 29-32. doi:10.2105/ajph.84.1.29

Edwards, M. K., & Loprinzi, P. D. (2016). The association between muscle strengthening activities and atherogenic index of plasma. *Preventive Medicine, 91*, 318-321. doi:10.1016/j.ypmed.2016.09.013

Edwards, M. K., & Loprinzi, P. D. (2018). Adequate muscular strength may help to reduce risk of residual-specific mortality: Findings from the national health and nutrition examination survey. *Journal of Physical Activity and Health, 15*(5), 369-373. doi:10.1123/jpah.2016-0385

Eime, R. M., Harvey, J. T., Charity, M. J., Casey, M. M., van Uffelen, J. G. Z., & Payne, W. R. (2015). The contribution of sport participation to overall health enhancing physical activity levels in Australia: A population-based study. *BMC Public Health, 15*, 12. doi:10.1186/s12889-015-2156-9

El Ansari, W., Khalil, K., Crone, D., & Stock, C. (2014). Physical activity and gender differences: Correlates of compliance with recommended levels of five forms of physical activity among students at nine universities in Libya. *Central European Journal of Public Health, 22*(2), 98-105. doi:10.21101/cejph.a4011

El Ansari, W., Stock, C., John, J., Deeny, P., Phillips, C., Snelgrove, S., . . . Mabhala, A. (2011). Health promoting behaviours and lifestyle characteristics of students at seven universities in the UK. *Central European Journal of Public Health, 19*(4), 197-204. doi:10.21101/cejph.a3684

Evenson, K. R., Wen, F., & Herring, A. H. (2016). Associations of accelerometry-assessed and self-reported physical activity and sedentary behavior with all-cause and cardiovascular mortality among US adults. *American Journal of Epidemiology, 184*(9), 621-632. doi:10.1093/aje/kww070

Fan, A. Z., Ham, S. A., Muppidi, S. R., & Mokdad, A. H. (2009). Validation of reported physical activity for cholesterol control using two different physical activity instruments. *Vascular Health and Risk Management, 5*, 649-661.

Ford, E. S., Heath, G. W., Mannino, D. M., Redd, S. C., Ford, E. S., Heath, G. W., . . . Redd, S. C. (2003). Leisure-time physical activity patterns among US adults with asthma. *CHEST, 124*(2), 432-437. doi:10.1378/chest.124.2.432

Freeston, J., Gale, J., Mavros, Y., Bennie, J. A., Pedisic, Z., Bauman, A. E., & Stamatakis, E. (2017). Associations between multiple indicators of socio-economic status and muscle-strengthening activity participation in a nationally representative population sample of Australian adults. *Preventive Medicine*, 44-48. doi:10.1016/j.ypmed.2017.06.020

Galuska, D. A., Earle, D., & Fulton, J. E. (2002). The epidemiology of U.S. adults who regularly engage in resistance training. *Research Quarterly for Exercise and Sport, 73*(3), 330. doi:10.1080/02701367.2002.10609027

Gao, Y., & Zhu, W. M. (2011). Identifying group-sensitive physical activities: A differential item functioning analysis of NHANES data. *Medicine & Science in Sports & Exercise, 43*(5), 922-929. doi:10.1249/MSS.0b013e3181fdcc25

Garber, C. E., Blissmer, B., Deschenes, M. R., Franklin, B. A., Lamonte, M. J., Lee, I. M., . . . Swain, D. P. (2011). Quantity and Quality of Exercise for Developing and Maintaining Cardiorespiratory, Musculoskeletal, and Neuromotor Fitness in Apparently Healthy Adults: Guidance for Prescribing Exercise. *Medicine & Science in Sports & Exercise, 43*(7), 1334-1359. doi:10.1249/MSS.0b013e318213fefb

Garriguet, D., & Colley, R. C. (2014). A comparison of self-reported leisuretime physical activity and measured moderate-to-vigorous physical activity in adolescents and adults. *Statistics Canada, 25*(7), 3-11.

Gordon, B. R., McDowell, C. P., Hallgren, M., Meyer, J. D., Lyons, M., & Herring, M. P. (2018). Association of efficacy of resistance exercise training with depressive symptoms: Meta-analysis and meta-regression analysis of randomized clinical trials. *JAMA Psychiatry, 75*(6), 566-576. doi:10.1001/jamapsychiatry.2018.0572

Greenhalgh, T., & Peacock, R. (2005). Effectiveness and efficiency of search methods in systematic reviews of complex evidence: Audit of primary sources. *BMJ, 331*(7524), 1064-1065. doi:10.1136/bmj.38636.593461.68

Gregory, C. O., Ramirez-Zea, M., Martorell, R., & Stein, A. D. (2007). Activities contributing to energy expenditure among Guatemalan adults. *International Journal of Behavioral Nutrition and Physical Activity, 4*, 8. doi:10.1186/1479-5868-4-48

Grnøtved, A., Pan, A., Mekary, R. A., Stampfer, M., Willett, W. C., Manson, J. E., & Hu, F. B. (2014). Muscle-strengthening and conditioning activities and risk of type 2 diabetes: A prospective study in two cohorts of US women. *PLoS Medicine, 11*(1), 15. doi:10.1371/journal.pmed.1001587

Ham, S. A., Macera, C. A., Jones, D. A., Ainsworth, B. E., & Turczyn, K. M. (2004). Considerations for physical activity research: Variations on a theme. *Journal of Physical Activity and Health, 1*(2), 98-113. doi:10.1123/jpah.1.2.98

Handy, C. E., & Blaha, M. J. (2017). Strong implications but weak evidence for strength training. *Journal of the American Heart Association, 6*(11), 1-4. doi:10.1161/JAHA.117.007761

Harada, K., Oka, K., Ota, A., Shibata, A., & Nakamura, Y. (2008). Prevalence and correlates of strength training among Japanese adults: Analysis of SSF national sports-life survey 2006.

International Journal of Sport and Health Science, 6, 66-71. doi:10.5432/ijshs.6.66

Harada, K., Shibata, A., Ishii, K., Liao, Y., & Oka, K. (2014). Perceived and objectively measured access to strength-training facilities and strength-training behavior. *Annals of Behavioral Medicine, 48*(1), 120-124. doi:10.1007/s12160-013-9572-9

Harada, K., Shibata, A., Oka, K., & Nakamura, Y. (2015). Association of muscle-strengthening activity with knee and low back pain, falls, and health-related quality of life among Japanese older adults: A cross-sectional survey. *Journal of Aging and Physical Activity, 23*(1), 1-8. doi:10.1123/JAPA.2013-0038

Hong, H., Kim, E. K., & Lee, J. S. (2013). Effects of calcium intake, milk and dairy product intake, and blood vitamin D level on osteoporosis risk in Korean adults: Analysis of the 2008 and 2009 Korea national health and nutrition examination survey. *Nutrition Research and Practice, 7*(5), 409-417. doi:10.4162/nrp.2013.7.5.409

Hsu, B., Merom, D., Blyth, F. M., Naganathan, V., Hirani, V., Le Couteur, D. G., . . . Cumming, R. G. (2018). Total physical activity, exercise intensity, and walking speed as predictors of all-cause and cause-specific mortality over 7 years in older men: The Concord health and aging in men project. *Journal of the American Medical Directors Association, 19*(3), 216-222. doi:10.1016/j.jamda.2017.08.018

Humphries, B., Duncan, M. J., & Mummery, W. K. (2008). Prevalence and correlates of resistance training in a regional Australian population. *British Journal of Sports Medicine, 44*(9), 653-656. doi:10.1136/bjsm.2008.048975

Humphries, B., Stanton, R., Scanlan, A., & Duncan, M. J. (2018). The prevalence and performance of resistance exercise training activities in an Australian population in relation to health authority guidelines. *Journal of Science and Medicine in Sport, 21*(6), 616-620. doi:10.1016/j.jsams.2017.09.018

Jensen-Otsu, E., & Austin, G. L. (2015). Antidepressant use is associated with increased energy intake and similar levels of physical activity. *Nutrients, 7*(11), 9662-9671. doi:10.3390/nu7115489

Kamada, M., Kitayuguchi, J., Abe, T., Taguri, M., Inoue, S., Ishikawa, Y., . . . Kawachi, I. (2018). Community-wide intervention and population-level physical activity: A 5-year cluster randomized trial. *International Journal of Epidemiology, 47*(2), 642-653. doi:10.1093/ije/dyx248

Kamada, M., Kitayuguchi, J., Inoue, S., Ishikawa, Y., Nishiuchi, H., Okada, S., . . . Shiwaku, K. (2013). A community-wide campaign to promote physical activity in middle-aged and elderly people: A cluster randomized controlled trial. *International Journal of Behavioral Nutrition and Physical Activity, 10*(44), 1-16. doi:10.1186/1479-5868-10-44

Kamada, M., Shiroma, E. J., Buring, J. E., Miyachi, M., & Lee, I. M. (2017). Strength training and all-cause, cardiovascular disease, and cancer mortality in older women: A cohort study. *Journal of the American Heart Association, 6*(11), 1-9. doi:10.1161/JAHA.117.007677

Kamil-Rosenberg, S., Greaney, M. L., Hochman, T., & Garber, C. E. (2019). How do physical activity and health vary among younger, middle-aged, and older adults with and without disability? *Journal of Aging and Physical Activity, 27*(2), 234-241. doi:10.1123/japa.2017-0215

Keadle, S. K., McKinnon, R., Graubard, B. I., & Troiano, R. P. (2016). Prevalence and trends in physical activity among older adults in the United States: A comparison across three national surveys. *Preventive Medicine, 89*, 37-43. doi:10.1016/j.ypmed.2016.05.009

Kim, J., Lee, Y., Kye, S., Chung, Y.-S., & Kim, K.-M. (2015). Association between healthy diet and exercise and greater muscle mass in older adults. *Journal of the American Geriatrics Society, 63*(5), 886-892. doi:10.1111/jgs.13386

Kraschnewski, J. L., Sciamanna, C. N., Ciccolo, J. T., Rovniak, L. S., Lehman, E. B., Candotti, C., & Ballentine, N. H. (2014). Is exercise used as medicine? Association of meeting strength training guidelines and functional limitations among older US adults. *Preventive Medicine, 66*, 1-5. doi:10.1016/j.ypmed.2014.05.012

Kraschnewski, J. L., Sciamanna, C. N., Poger, J. M., Rovniak, L. S., Lehman, E. B., Cooper, A. B., . . . Ciccolo, J. T. (2016). Is strength training associated with mortality benefits? A 15 year cohort study of US older adults. *Preventive Medicine, 87*, 121-127. doi:10.1016/j.ypmed.2016.02.038

Kruger, J., Blanck, H. M., & Gillespie, C. (2006). Dietary and physical activity behaviors among adults successful at weight loss maintenance. *International Journal of Behavioral Nutrition and Physical Activity, 3* doi:10.1186/1479-5868-3-17

Kruger, J., Carlson, S., & Kohl III, H. (2006). Trends in strength training--United States, 1998-2004. *Journal of the American Medical Association, 296*(12), 1459-1460. doi:10.1001/jama.296.12.1459

Kruger, J., Carlson, S. A., & Buchner, D. (2007). How active are older Americans? *Preventing Chronic Disease, 4*(3).

Kruger, J., Ham, S. A., Prohaska, T. R., Kruger, J., Ham, S. A., & Prohaska, T. R. (2009). Behavioral risk factors associated with overweight and obesity among older adults: The 2005 national health interview survey. *Preventing Chronic Disease, 6*(1), 1-17.

Kruger, J., Yore, M. M., Ainsworth, B. E., & Macera, C. A. (2008). Physical activity patterns associated with weight-control status: Differences by race and sex. *Journal of Physical Activity and Health, 5*(3), 456-468. doi:10.1123/jpah.5.3.456

Kruger, J., Yore, M. M., & Kohl, H. W. (2007). Leisure-time physical activity patterns by weight control status: 1999-2002 NHANES. *Medicine & Science in Sports & Exercise, 39*(5), 788-795. doi:10.1249/mss.0b013e3180333efc

Kuh, D. J., & Cooper, C. (1992). Physical activity at 36 years: Patterns and childhood predictors in a longitudinal study. *Journal of Epidemiology and Community Health, 46*(2), 114-119. doi:10.1136/jech.46.2.114

Kurka, J. M., Vezina, J., Brown, D. D., Schumacher, J., Cullen, R. W., & Laurson, K. R. (2015). Combined increases in muscle- strengthening activity frequency and protein intake reveal graded relationship with fat-free mass percentage in U.S. adults, NHANES (1999-2004). *Journal of Frailty & Aging, 4*(1), 26-33. doi:10.14283/jfa.2015.37

Kuwahara, K., Honda, T., Nakagawa, T., Yamamoto, S., Nanri, A., Kurotani, K., . . . Mizoue, T. (2015). Strength training and risk of type 2 diabetes in a Japanese working population: A cohort study. *Journal of Diabetes Investigation, 6*(6), 655-661. doi:10.1111/jdi.12347

Landi, F., Calvani, R., Picca, A., Tosato, M., Martone, A. M., D'Angelo, E., . . . Marzetti, E. (2018). Impact of habitual physical activity and type of exercise on physical performance across ages in community-living people. *PLoS ONE, 13*(1), 1-12. doi:10.1371/journal.pone.0191820

Lee, E. Y., Carson, V., Jeon, J. Y., Spence, J. C., & Tremblay, M. S. (2019). Levels and correlates of 24-hour movement behaviors among South Koreans: Results from the Korea national health and nutrition examination surveys, 2014 and 2015. *Journal of Sport and Health Science, 8*, 376-385. doi:10.1016/j.jshs.2018.11.007

Lee, J., Kim, Y., & Jeon, J. Y. (2016). Association between physical activity and the prevalence of metabolic syndrome: from the Korean national health and nutrition examination survey, 1999-2012. *SpringerPlus, 5*, 1-12. doi:10.1186/s40064-016-3514-5

Lin, C. Y., Park, J. H., Hsueh, M. C., Sun, W. J., & Liao, Y. (2018). Prevalence of total physical activity, muscle-strengthening activities, and excessive tv viewing among older adults; and their association with sociodemographic factors. *International Journal of*

Environmental Research and Public Health, 15(11), 9. doi:10.3390/ijerph15112499

Littman, A. J., Kristal, A. R., & White, E. (2005). Effects of physical activity intensity, frequency, and activity type on 10-y weight change in middle-aged men and women. *International Journal of Obesity, 29*(5), 524-533. doi:10.1038/sj.ijo.0802886

Livingstone, M. B. E., Robson, P. J., McCarthy, S., Kiely, M., Harrington, K., Browne, P., . . . Rennie, K. L. (2001). Physical activity patterns in a nationally representative sample of adults in Ireland. *Public Health Nutrition, 4*(5A), 1107-1116. doi:10.1079/phn2001192

Loenneke, J. P., & Loprinzi, P. D. (2018). Statin use may reduce lower extremity peak force via reduced engagement in muscle-strengthening activities. *Clinical Physiology and Functional Imaging, 38*(1), 151-154. doi:10.1111/cpf.12375

Loprinzi, P. D. (2016a). Epidemiological investigation of muscle-strengthening activities and cognitive function among older adults. *Chronic Illness, 12*(2), 157-162. doi:10.1177/1742395316641998

Loprinzi, P. D. (2016b). Muscle strengthening activities and mortality with considerations by hearing sensitivity. *International Journal of Audiology, 55*(5), 320-322. doi:10.3109/14992027.2016.1140233

Loprinzi, P. D., Addoh, O., & Mann, J. R. (2017). Association between muscle strengthening physical activities and mortality among American adults with mobility limitations. *Preventive Medicine, 99*, 207-210. doi:10.1016/j.ypmed.2017.02.013

Loprinzi, P. D., Addoh, O., Wong Sarver, N., Espinoza, I., & Mann, J. R. (2017). Cross-sectional association of exercise, strengthening activities, and cardiorespiratory fitness on generalized anxiety, panic and depressive symptoms. *Postgraduate Medicine, 129*(7), 676-685. doi:10.1080/00325481.2017.1336054

Loprinzi, P. D., & Loenneke, J. P. (2015). Engagement in muscular strengthening activities is associated with better sleep. *Preventive Medicine Reports, 2*, 927-929. doi:10.1016/j.pmedr.2015.10.013

Loprinzi, P. D., & Loenneke, J. P. (2018). Leukocyte telomere length and mortality among US adults: Effect modification by physical activity behaviour. *Journal of Sports Sciences, 36*(2), 213-219. doi:10.1080/02640414.2017.1293280

Loprinzi, P. D., Loenneke, J. P., & Abe, T. (2015). The association between muscle strengthening activities and red blood cell distribution width among a national sample of U.S. adults. *Preventive Medicine, 73*, 130-132. doi:10.1016/j.ypmed.2015.01.011

Loprinzi, P. D., Loenneke, J. P., & Blackburn, E. H. (2015). Movement-based behaviors and leukocyte telomere length among US adults. *Medicine & Science in Sports & Exercise, 47*(11), 2347-2352. doi:10.1249/MSS.0000000000000695

Loustalot, F., Carlson, S., Kruger, J., Buchner, D., & Fulton, J. (2013). Muscle-strengthening activities and participation among adults in the United States. *Research Quarterly for Exercise and Sport, 84*(1), 30-38. doi:10.1080/02701367.2013.762289

Magyari, P. M., & Churilla, J. R. (2012). Association between lifting weights and metabolic syndrome among US adults: 1999-2004 national health and nutrition examination survey. *Journal of Strength and Conditioning Research, 26*(11), 3113-3117. doi:10.1519/JSC.0b013e3182472f95

Masamitsu, K., Jun, K., Takafumi, A., Masataka, T., Shigeru, I., Yoshiki, I., . . . Motohiko, M. (2015). Community-wide promotion of physical activity in middle-aged and older Japanese: A 3-year evaluation of a cluster randomized trial. *International Journal of Behavioral Nutrition and Physical Activity, 12*, 1-13. doi:10.1186/s12966-015-0242-0

McGuigan, M. R., Newton, R. U., & Kraemer, W. J. (2006). Resistance training for better health in older adults. *International Journal of Sport and Health Science, 4*, 19-28.

Mealing, N. M., Bowles, H. R., Merom, D., & Bauman, A. (2011). Impact of scoring algorithm on physical activity prevalence estimates in

Australian adults. *Journal of Science and Medicine in Sport, 14*(1), 27-32. doi:10.1016/j.jsams.2010.05.003

Mekary, R. A., Grontved, A., Despres, J. P., De Moura, L. P., Asgarzadeh, M., Willett, W. C., . . . Hu, F. B. (2015). Weight training, aerobic physical activities, and long-term waist circumference change in men. *Obesity, 23*(2), 461-467. doi:10.1002/oby.20949

Merom, D., Cosgrove, C., Venugopal, K., & Bauman, A. (2012). How diverse was the leisure time physical activity of older Australians over the past decade? *Journal of Science and Medicine in Sport, 15*(3), 213-219. doi:10.1016/j.jsams.2011.10.009

Merom, D., Pye, V., Macniven, R., van der Ploeg, H., Milat, A., Sherrington, C., . . . Bauman, A. (2012). Prevalence and correlates of participation in fall prevention exercise/physical activity by older adults. *Preventive Medicine, 55*(6), 613-617. doi:10.1016/j.ypmed.2012.10.001

Milton, K., Varela, A. R., Strain, T., Cavill, N., Foster, C., & Mutrie, N. (2018). A review of global surveillance on the muscle strengthening and balance elements of physical activity recommendations. *Journal of Frailty, Sarcopenia and Falls, 3*(2), 114-124. doi:10.22540/JFSF-03-114

Minges, K. E., Magliano, D. J., Owen, N., Daly, R. M., Salmon, J., Shaw, J. E., . . . Dunstan, D. W. (2013). Associations of strength training with impaired glucose metabolism: The AusDiab study. *Medicine & Science in Sports & Exercise, 45*(2), 299-303. doi:10.1249/MSS.0b013e31826e6cd1

Moher, D., Liberati, A., Tetzlaff, J., Altman, D. G., & the PRISMA Group. (2009). Preferred reporting items for systematic reviews and meta-analyses: The PRISMA statement. *Annals of Internal Medicine, 151*(4), 264-269. doi:10.7326/0003-4819-151-4-200908180-00135

Monin, J. K., Levy, B., Chen, B. B., Fried, T., Stahl, S. T., Schulz, R., . . . Kershaw, T. (2015). Husbands' and wives' physical activity and depressive symptoms: Longitudinal findings from the cardiovascular health study. *Annals of Behavioral Medicine, 49*(5), 704-714. doi:10.1007/s12160-015-9705-4

Monteiro, C. A., Conde, W. L., Matsudo, S. M., Matsudo, V. R., Bonseñor, I. M., & Lotufo, P. A. (2003). A descriptive epidemiology of leisure-time physical activity in Brazil, 1996-1997. *Pan American Journal of Public Health, 14*(4), 246-254. doi:10.1590/S1020-49892003000900005

Mooney, S. J., Joshi, S., Cerdá, M., Kennedy, G. J., Beard, J. R., & Rundle, A. G. (2018). Longitudinal patterns of physical activity among older adults: A latent transition analysis. *American Journal of Epidemiology, 187*(7), 1549-1558. doi:10.1093/aje/kwy027

Mooney, S. J., Joshi, S., Cerdá, M., Quinn, J. W., Beard, J. R., Kennedy, G. J., . . . Rundle, A. G. (2015). Patterns of physical activity among older adults in New York City: A latent class approach. *American Journal of Preventive Medicine, 49*(3), e13-e22. doi:10.1016/j.amepre.2015.02.015

Mu, L., Cohen, A. J., & Mukamal, K. J. (2014). Resistance and aerobic exercise among adults with diabetes in the U.S. *Diabetes Care, 37*(8), e175-e176. doi:10.2337/dc14-0619

Mu, L., Cohen, A. J., & Mukamal, K. J. (2015). Prevalence and predictors of resistance and aerobic exercise among hypertensive adults in the United States. *Journal of Human Hypertension, 29*(6), 394-395. doi:10.1038/jhh.2014.104

Murphy, L. B., Hootman, J. M., Boring, M. A., Carlson, S. A., Qin, J., Barbour, K. E., . . . Helmick, C. G. (2017). Leisure time physical activity among U.S. adults with arthritis, 2008-2015. *American Journal of Preventive Medicine, 53*(3), 345-354. doi:10.1016/j.amepre.2017.03.017

Nelson, M. C., Lust, K., Story, M., & Ehlinger, E. (2008). Credit card debt, stress and key health risk behaviors among college students. *American Journal of Health Promotion, 22*(6), 400-407. doi:10.4278/ajhp.22.6.400

Oh, S. H., Kim, D.-K., Lee, S.-U., Jung, S. H., & Lee, S. Y. (2017). Association between exercise type and quality of life in a community-dwelling older people: A cross-sectional study. *PLoS ONE, 12*(12), 1-11. doi:10.1371/journal.pone.0188335

Oh, S. H., Son, S. H., Kang, S. H., Kim, D. K., Seo, K. M., & Lee, S. Y. (2017). Relationship between types of exercise and quality of life in a Korean metabolic syndrome population: A cross-sectional study. *Metabolic Syndrome and Related Disorders, 15*(4), 199-205. doi:10.1089/met.2016.0151

Pabayo, R., Fuller, D., Lee, E. Y., Horino, M., & Kawachi, I. (2018). State-level income inequality and meeting physical activity guidelines; Differential associations among US men and women. *Journal of Public Health, 40*(2), 229-236. doi:10.1093/pubmed/fdx082

Panten, J., Stone, R. C., & Baker, J. (2017). Balance is key: Exploring the impact of daily self-reported physical activity and sedentary behaviours on the subjective health status of older adults. *Preventive Medicine, 101*, 109-116. doi:10.1016/j.ypmed.2017.05.020

Pate, R. R., Macera, C. A., Pratt, M., Heath, G. W., Blair, S. N., Bouchard, C., . . . Wilmore, J. H. (1995). Physical activity and public health: A recommendation from the centers for disease control and prevention and the American college of sports medicine. *The Journal of the American Medical Association, 273*(5), 402-407. doi:10.1001/jama.1995.03520290054029

Perks, T. A. (2017). Investigating the physical activity behaviors of Canadian adults over time: Multilevel sex and age group trajectories across 2 decades. *Journal of Physical Activity and Health, 14*(12), 933-942. doi:10.1123/jpah.2017-0130

Redwood, D., Schumacher, M. C., Lanier, A. P., Ferucci, E. D., Asay, E., Heizer, L. J., . . . Slattery, M. L. (2009). Physical activity patterns of American Indian and Alaskan native people living in Alaska and the

Southwestern United States. *American Journal of Health Promotion, 23*(6), 388-395. doi:10.4278/ajhp.071211130

Robertson, M. C., Song, J., Taylor, W. C., Durand, C. P., & Basen-Engquist, K. M. (2018). Urban-rural differences in aerobic physical activity, muscle strengthening exercise, and screen-time sedentary behavior. *Journal of Rural Health, 34*(4), 401-410. doi:10.1111/jrh.12295

Saeidifard, F., Medina-Inojosa, J. R., West, C. P., Olson, T. P., Somers, V. K., Bonikowske, A. R., . . . Lopez-Jimenez, F. (2019). The association of resistance training with mortality: A systematic review and meta-analysis. *European Journal of Preventive Cardiology, 26*(15), 1647-1665. doi:10.1177/2047487319850718

Sandler, R. D., Sui, X., Church, T. S., Fritz, S. L., Beattie, P. F., & Blair, S. N. (2014). Are flexibility and muscle-strengthening activities associated with a higher risk of developing low back pain? *Journal of Science and Medicine in Sport, 17*(4), 361-365. doi:10.1016/j.jsams.2013.07.016

Scarapicchia, T. M. F., Sabiston, C. M., & Faulkner, G. (2015). Exploring the prevalence and correlates of meeting health behaviour guidelines among university students. *Canadian Journal of Public Health, 106*(3), E109-E114. doi:10.17269/cjph.106.4784

Scarola, G. T. (2016). *Muscle strengthening activities and its association with self-rated health among diabetic persons in North Carolina: An examination of 2013 BRFSS data.* (10118012 M.S.), The University of North Carolina at Charlotte, Available from _PROQUEST Dissertations & Theses A&I database.

Schoenborn, C. A., & Adams, P. F. (2010) Health behaviors of adults: United states, 2005-2007. In*: Vol. 10. Vital and Health Statistics* (pp. 1-132).

Schoenborn, C. A., Adams, P. F., Barnes, P. M., Vickerie, J. L., & Schiller, J. S. (2004) Health behaviors of adults: United States, 1999-2001. In*: Vol. 10. Vital and Health Statistics*.

Schoenborn, C. A., Adams, P. F., & Peregoy, J. A. (2013) Health behaviors of adults: United States, 2008-2010. In*. Vital and Health Statistics*.

Schoenborn, C. A., & Stommel, M. (2011). Adherence to the 2008 adult physical activity guidelines and mortality risk. *American Journal of Preventive Medicine, 40*(5), 514-521. doi:10.1016/j.amepre.2010.12.029

Sciamanna, C. N., Kraschnewski, J., Ciccolo, J., Rovniakl, L. S., Candotti, C., & Ballentine, N. (2014). Is exercise used as medicine? Association of functional limitations with meeting strength training guidelines among older US adults. *Journal of General Internal Medicine, 29*, S132-S132. doi:10.1016/j.ypmed.2014.05.012.

Sciamanna, C. N., Smyth, J. M., Doerksen, S. E., Richard, B. R., Kraschnewski, J. L., Mowen, A. J., . . . Yang, C. W. (2017). Physical activity mode and mental distress in adulthood. *American Journal of Preventive Medicine, 52*(1), 85-93. doi:10.1016/j.amepre.2016.09.014

Shiroma, E. J., Cook, N. R., Manson, J. E., Moorthy, M., Buring, J. E., Rimm, E. B., & Lee, I. M. (2016). Strength training and the risk of type 2 diabetes and cardiovascular disease. *Medicine & Science in Sports & Exercise, 49*(1), 40-46. doi:10.1249/MSS.0000000000001063

Siahpush, M., Farazi, P. A., Wang, H. M., Robbins, R. E., Singh, G. K., & Su, D. J. (2019). Muscle-strengthening physical activity is associated with cancer mortality: Results from the 1998-2011 national health interview surveys, national death index record linkage. *Cancer Causes & Control, 30*(6), 663-670. doi:10.1007/s10552-019-01169-z

Spees, C. K., Scott, J. M., & Taylor, C. A. (2012). Differences in amounts and types of physical activity by obesity status in US adults. *American Journal of Health Behavior, 36*(1), 56-65. doi:10.5993/ajhb.36.1.6

Stamatakis, E., & Chaudhury, M. (2008). Temporal trends in adults' sports participation patterns in England between 1997 and 2006: The health survey for England. *British Journal of Sports Medicine, 42*(11), 601-608. doi:10.1136/bjsm.2008.048082

Stamatakis, E., Lee, I.-M., Bennie, J., Freeston, J., Hamer, M., O'Donovan, G., . . . Mavros, Y. (2018). Does strength-promoting exercise confer unique health benefits? A pooled analysis of data on 11 population cohorts with all-cause, cancer, and cardiovascular mortality endpoints. *American Journal of Epidemiology, 187*(5), 1102-1112. doi:10.1093/aje/kwx345

Steele, J., Fisher, J., Skivington, M., Dunn, C., Arnold, J., Tew, G., . . . Winett, R. (2017). A higher effort-based paradigm in physical activity and exercise for public health: Making the case for a greater emphasis on resistance training. *BMC Public Health, 17*, 8. doi:10.1186/s12889-017-4209-8

Strain, T. (2018). *Analysis of scottish health survey data to inform scottish physical activity and sedentary behaviour policy and surveillance.* (13873505 Ph.D.), The University of Edinburgh (United Kingdom), Available from _PROQUEST Dissertations & Theses A&I database.

Strain, T., Fitzsimons, C., Kelly, P., & Mutrie, N. (2016). The forgotten guidelines: Cross-sectional analysis of participation in muscle strengthening and balance & co-ordination activities by adults and older adults in Scotland. *BMC Public Health, 16*, 1108. doi:10.1186/s12889-016-3774-6

Strain, T., Milton, K., Dall, P., Standage, M., & Mutrie, N. (2019). How are we measuring physical activity and sedentary behaviour in the four home nations of the UK? A narrative review of current surveillance measures and future directions. *British Journal of Sports Medicine*, 1-9. doi:10.1136/bjsports-2018-100355

Strain, T., Wijndaele, K., & Brage, S. (2019). Physical activity surveillance through smartphone apps and wearable trackers: Examining the UK potential for nationally representative sampling. *Jmir Mhealth and Uhealth, 7*(1), 1-13. doi:10.2196/11898

Swan, J. H., Friis, R., & Turner, K. (2008). Getting tougher for the fourth quarter: Boomers and physical activity. *Journal of Aging and Physical Activity, 16*(3), 261-279. doi:10.1123/japa.16.3.261

Tarasenko, Y., Chen, C., & Schoenberg, N. (2017). Self-reported physical activity levels of older cancer survivors: Results from the 2014 national health interview survey. *Journal of the American Geriatrics Society, 65*(2), e39-e44. doi:10.1111/jgs.14589

Tarasenko, Y., Linder, D. F., & Miller, E. A. (2018). Muscle-strengthening and aerobic activities and mortality among 3+year cancer survivors in the US. *Cancer Causes & Control, 29*(4-5), 475-484. doi:10.1007/s10552-018-1017-0

Tucker, L. A., & Silvester, L. J. (1996). Strength training and hypercholesterolemia: An epidemiologic study of 8499 employed men. *American Journal of Health Promotion, 11*(1), 35-41. doi:10.4278/0890-1171-11.1.35

Tudor-Locke, C., Henderson, K. A., Wilcox, S., Cooper, R. S., Durstine, J. L., & Ainsworth, B. E. (2003). In their own voices: Definitions and interpretations of physical activity. *Women's Health Issues, 13*(5), 194-199. doi:10.1016/S1049-3867(03)00038-0

U.S. Department of Health and Human Services. (2008). *2008 physical activity guidelines for Americans*. Washington, DC.

Vankim, N. A., Ehlinger, E., Lust, K., Story, M., & Laska, M. N. (2010). Understanding young adult physical activity, alcohol and tobacco use in community colleges and 4-year post-secondary institutions: A cross-sectional analysis of epidemiological surveillance data. *BMC Public Health, 10*(208), 1-9. doi:10.1186/1471-2458-10-208

Vezina, J. W., Der Ananian, C. A., Greenberg, E., & Kurka, J. (2014). Sociodemographic correlates of meeting US department of health and human services muscle strengthening recommendations in middle-aged and older adults. *Preventing Chronic Disease, 11*(E162), 1-10. doi:10.5888/pcd11.140007

Wald, A., Muennig, P. A., O'Connell, K. A., & Garber, C. E. (2014). Associations between healthy lifestyle behaviors and academic performance in U.S. Undergraduates: A secondary analysis of the American college health association's national college health assessment ii. *American Journal of Health Promotion, 28*(5), 298-305. doi:10.4278/ajhp.120518-QUAN-265

World Health Organization. (2010). *Global recommendations on physical activity for health*. Geneva, Switzerland: WHO Press.

World Health Organization. (2014). *Global status report on noncommunicable diseases 2014*. Retrieved from Geneva, Switzerland:

World Health Organization. (2020). *Global Physical Activity Questionnaire (GPAQ)*. Geneva, Switzerland: World Health Organization.

Wu, Y. L., Yang, L. L., Shen, X. L., Zhai, L., Fan, C. X., & Zhang, D. F. (2016). Effect of leisure-time aerobic exercise and muscle strength activity on sleep duration: Results from the 2012 national health interview survey. *Journal of Public Health, 24*(2), 117-124. doi:10.1007/s10389-015-0705-4

Xu, F., Dahlhamer, J. M., Zammitti, E. P., Wheaton, A. G., & Croft, J. B. (2018). Health-risk behaviors and chronic conditions among adults with inflammatory bowel disease - United States, 2015 and 2016. *Morbidity and Mortality Weekly Report, 67*(6), 190-195. doi:10.15585/mmwr.mm6706a4

Yeom, H. A., Jung, D., & Choi, M. (2011). Adherence to physical activity among older adults using a geographic information system: Korean national health and nutrition examinations survey IV. *Asian Nursing Research, 5*(2), 118-127. doi:10.1016/S1976-1317(11)60020-0

Yore, M. M., Ham, S. A., Ainsworth, B. E., Kruger, J., Reis, J. P., Kohl, H. W., III, & Macera, C. A. (2007). Reliability and validity of the instrument used in BRFSS to assess physical activity. *Medicine &*

Science in Sports & Exercise, 39(8), 1267-1274. doi:10.1249/mss.0b013e3180618bbe

Yusuf, H. R., Croft, J. B., Giles, W. H., Anda, R. F., Casper, M. L., Caspersen, C. J., & Jones, D. A. (1996). Leisure-time physical activity among older adults - United States, 1990. *Archives of Internal Medicine, 156*(12), 1321-1326. doi:10.1001/archinte.1996.00440110093012

Zach, S., & Lissitsa, S. (2016). Internet use and leisure time physical activity of adults - A nationwide survey. *Computers in Human Behavior, 60*, 483-491. doi:10.1016/j.chb.2016.02.077

Zhao, G., Li, C., Ford, E. S., Fulton, J. F., Carlson, S. A., Okoro, C. A., . . . Balluz, L. S. (2014). Leisure-time aerobic physical activity, muscle-strengthening activity and mortality risks among US adults: the NHANES linked mortality study. *British Journal of Sports Medicine, 48*(3), 244-249. doi:10.1136/bjsports-2013-092731

Zizzi, S., Goodrich, D., Wu, Y., Parker, L., Rye, S., Pawar, V., . . . Tessaro, I. (2006). Correlates of physical activity in a community sample of older adults in Appalachia. *Journal of Aging and Physical Activity, 14*(4), 423-438. doi:10.1123/japa.14.4.423

2.7 How the Publication Contributes to the Advancement of the Research Area

To my knowledge, this systematic literature review was the first to extensively synthesise the current evidence regarding the instruments used to assess MSE participation within public health surveillance. This review showed that globally, there is large heterogeneity within the instruments used to assess MSE at the population level. This is concerning, as the ability to compare data across different populations and monitor MSE, is likely to be hampered by these inconsistencies. Moreover, physical activity policymakers require consistent data when developing programs to aid the prevention of NCDs (Hallal et al., 2012). Importantly, if the current surveillance systems do not provide efficacious measurement and assessment of MSE at the population level, then policymakers and health professionals are somewhat blindfolded in their efforts to understand the benefits of MSE to heath.

> *'Count what is countable, measure what is measurable. What is not measurable, make measurable'* [Galileo Galilei].

Furthermore, this review showed that the examples used to describe the types/modes of MSE included within the instruments varied considerably throughout the surveillance systems. This disparity between included modes of MSE further impedes the understanding of MSE prevalence at the population level. Overall there appears to be a more unified and consistent approach in the assessment of MVPA participation such as through the use of the GPAQ and IPAQ (Troiano et al., 2020) and is also emerging within sedentary behaviour (Prince et al., 2020).

Moreover, while MSE guidelines consist of multiple components, including frequency, intensity, and muscle groups targeted, this review highlighted that, in most cases, only frequency of participation (50.6% of the included studies) is assessed. This limits the understanding of the remaining components, including intensity and muscle groups targeted, and their relationship with health. While MVPA guidelines effectively include a volume component ('*minutes per week*'), MSE guidelines do not. This highlights a further limitation to the current understanding of the relationship between the duration/volume of weekly MSE and health. Furthermore, the review highlighted that the questions used to assess MSE participation are rarely tested for reliability or validity. This is a concern for epidemiologists and policymakers as data obtained from untested surveillance instruments may not be valid or reliable.

As a postscript to this study, a copy of the full search strategy used for the literature review is located within Appendix F of this thesis.

To address some of the identified research gaps, the next two studies (Study 2 and Study 3) explore the relationship between the weekly frequency and duration of MSE and common chronic health conditions. Using a large cross-sectional sample of adult MSE participation data, secondary data analyses examine the relationship between the frequency and duration of two specific MSE modalities and the odds of having one or multiple common chronic conditions.

CHAPTER 3: PAPER 2 - Associations between muscle-strengthening exercise and prevalent chronic health conditions in 16,301 adults: Do session duration and weekly volume matter?

This paper has been peer-reviewed and was accepted for publication in the *Journal of Science and Medicine in Sport* on 5 January 2022 as an original investigation. It was published online on 7 January 2022 and appears in the literature at the time of writing as:

Shakespear-Druery, J., De Cocker, K., Biddle, S. J. H., & Bennie, J. (2022). Associations between muscle-strengthening exercise and prevalent chronic health conditions in 16,301 adults: Do session duration and weekly volume matter? *Journal of Science and Medicine in Sport*, *25*(5), 407-418. https://doi.org/10.1016/j.jsams.2022.01.001

The format may differ from the accepted pre-copyedited version. It has been reformatted to remain consistent with the rest of the thesis.

3.0 Abstract

Objectives: Muscle-strengthening exercise (MSE) has multiple health benefits and is part of the global physical activity guidelines. However, with epidemiological research largely focussing on participation frequency (times/week), little is known about the health associations of other parameters. Hence, this study aimed to determine if MSE duration and volume are associated with prevalent chronic health conditions.

Design: Cross-sectional

Methods: Cross-sectional data (*n*=16,301 adults ≥16 years) were pooled from the Health Survey for England (2012, 2016). Respondents self-reported MSE mode (own-bodyweight, gym-based), duration and volume, and the prevalence of five chronic conditions (diabetes, anxiety/depression, heart, respiratory, or musculoskeletal condition). Poisson regressions with robust error variance were used to calculate the prevalence ratios (PR) of each chronic condition (outcome variable) across MSE parameters [exposure variables: duration (0 [reference]; 10-20; 21-59; ≥60minutes/session); and volume (0 [reference]; low <mean; high ≥mean minutes/week)] for each mode and the modes combined.

Results: Most adults (81.5%) did no MSE. Undertaking any MSE regardless of mode, duration or volume was associated with a reduced likelihood of diabetes (APRs 0.25-0.39), heart (APRs 0.32-0.60), respiratory (APRs 0.49-0.67), and musculoskeletal conditions (APRs 0.43-0.63), and anxiety/depression (APRs 0.46-0.68). Associations remained after adjustment for potential socio-demographic and behavioural confounders.

Conclusion: While participation in own-bodyweight or gym-based-strength MSE is low, irrespective of mode, duration or volume, MSE was associated with a lower prevalence of chronic health conditions. Studies with

longitudinal study designs are needed to confirm these cross-sectional findings.

Keywords: Chronic health conditions, Exercise, Muscle-strengthening exercise, Physical activity, Prevalence, Public Health

3.1 Introduction

Chronic diseases, such as hypertension, cardiovascular disease, type-2 diabetes, and depression, are leading causes of morbidity and mortality (World Health Organization, 2020a). Regular physical activity (PA) participation is key in preventing and managing chronic disease (World Health Organization, 2018). The 2020 World Health Organization's (WHO) guidelines on PA and sedentary behaviour (SB) states adults (18–64 years) should not only engage in "moderate and/or vigorous-intensity aerobic physical activity" throughout the week, they should also undertake muscle-strengthening exercise (MSE) "at moderate or greater intensity" targeting "all the major muscle groups on two or more days a week" (Bull et al., 2020). Presently, most of the evidence on PA for health is based on the benefits of aerobic moderate-to-vigorous PA (aerobic-MVPA), with limited insight into other PA exercise-related behaviours, such as MSE (Bull et al., 2020).

MSE is undertaken voluntarily by individuals during leisure-time, in multiple settings (Bennie, Shakespear-Druery, & De Cocker, 2020). This exercise mode increases strength, power, endurance, or mass of skeletal muscle (Bennie et al., 2020). MSE typically involves using equipment such as weight machines, hand-held weights, resistance bands, or own-bodyweight (Bennie et al., 2020). Assessment of MSE within public-health-surveillance is relatively new compared to the assessment of aerobic PA (Bennie et al., 2020) (World Health Organization, 2010), with data predominantly obtained through self-reported instruments (Bennie et al., 2020).

Strong clinical and emerging epidemiological evidence supports the performance of MSE in the efforts to reduce morbidity risks associated with chronic disease (Steele et al., 2017). For example, clinical studies have shown that MSE is positively associated with metabolic health (Minges et al., 2013) through improved glucose and lipid metabolism, and lowering of blood pressure (Ashton et al., 2018). Moreover, Gordon et al., (2018) identified a significant reduction in depressive symptoms for MSE participants. Additionally, epidemiological evidence has linked the benefits of undertaking MSE (independent of other PA modalities) with a reduced risk of mortality (Saeidifard et al., 2019), diabetes (Grnøtved et al., 2014), cardiovascular disease (Shiroma et al., 2016), and colon/kidney cancer (Mazzilli, Matthews, Salerno, & Moore, 2019).

A limitation of current epidemiological evidence on MSE and health is that most studies implement a crude classification for MSE based on weekly frequency (0-1 vs. ≥2 times/week) (Bennie, Teychenne, De Cocker, & Biddle, 2019; Dankel, Loenneke, & Loprinzi, 2016; Saeidifard et al., 2019). Clinical studies demonstrate that duration/session and volume/week of MSE may positively influence health as well as increasing muscle mass/strength (Schoenfeld, Ogborn, & Krieger, 2017). However, because these components are rarely assessed in population-based studies, there is limited understanding of the dose-dependent relationship that MSE volume has on participant health among population-surveillance (Bull et al., 2020). Moreover, the influence that specific MSE modalities (such as using weight machines, or own-bodyweight) have on health is under-researched (Bennie et al., 2020).

This study aims to describe the association between the duration and volume of two MSE modalities (own-bodyweight, gym-based-strength) and the prevalence of common chronic health conditions (e.g., cardiovascular, mental health, and musculoskeletal), among a large population-based sample of adults.

3.2 Methods

The Health Survey for England (HSE) has been collecting health and related participant data from free-living members of the English population since 1991 (Bridges & Mindell, 2016). The HSE assesses PA every four years. This survey targets a nationally representative population consisting of English-speaking people aged ≥16 years, providing information regarding public-health trends, specified health conditions, and related prevalence rates (Bridges et al., 2013). HSE data are collected through a standardised survey instrument, administered face-to-face by trained researchers (Bridges et al., 2013). For this study, we pooled the two most recent HSE waves that included cross-sectional data for MSE activities (2012 and 2016) (*n*=20,400). These data have historic ethics approval from East Midlands Nottingham 2 Research Ethics Committee (Bridges & Mindell, 2016), and Oxford A Research Ethics Committee (Bridges et al., 2013). Informed consent was obtained from all participants (Health and Social Care Information Centre, 2017).

Our study used cross-sectional data from participants aged ≥16 years. Participants were excluded if they had missing age information (9.5%, *n*=4,099). Our final sample contained 16,301 individual participants.

MSE was assessed by self-report using an interview-administered questionnaire (Bridges et al., 2013; Bridges & Mindell, 2016). To assess PA, respondents were initially shown a card (see Appendix-A) (Bridges et al., 2013) and asked: *"Can you tell me if you have done any activities on this card during the last 4 weeks,? Please include teaching, coaching, training and practice sessions".* We selected MSE-related activities from the show card: *"Workout at a gym/Exercise bike/Weight training"* and *"Exercises (e.g. press-ups, sit-ups)"*.

Participants were then asked *"Can you tell me on how many separate days you did (name of activity) for at least 10 minutes a time during the past four weeks*"; and *"How much time did you usually spend doing (name of activity) on each day? Only count times you did it for at least 10 minutes".* If participants reported *"Workout at a gym/Exercise bike/Weight training"* they were shown a card (see Appendix-B) (Bridges et al., 2013) and asked: *"What did you do specifically?"*. Five options were provided (see Appendix-B) (Bridges et al., 2013), in this study we selected *"Strength work out at a gym using machines or free weights"*. Participants were again asked about the frequency and duration spent doing the activity each day (for at least 10 minutes). Similar questions are used in other large population-surveillance surveys, which have shown evidence of excellent test-retest reliability (Cohen's kappa (κ) =0.85; 95%CI: 0.71-0.99) and moderate validity (κ=0.40; 95%CI:0.20-0.60) for MSE (Yore et al., 2007). Moreover, the HSE asks participants about times spent in 'weight-training' and 'using-free-weights'. Comparatively the Behavioral Risk Factor Surveillance System (Yore et al., 2007) asks respondents to report 'own-body-weight-exercises', 'weight-machines', 'free-weights' or 'elastic-bands'. Therefore, while there may be some minor differences between the MSE related modes assessed between instruments, each survey instrument is essentially measuring the same construct. For this study, we labelled *"Exercises (e.g. press-ups, sit-ups)"* as 'own-bodyweight exercises'; and *"Strength work out at a gym using machines or free weights"* as 'gym-based-strength exercise' (working out with weights). These data were then combined to create a third category 'total MSE' (total-MSE). For own-bodyweight exercises, gym-based-strength exercise, and total-MSE, session duration (minutes) data were collapsed into one of four groups: (i) none/0 minutes; (ii) low (10-20 minutes); (iii) moderate (21-59 minutes); or (iv) high (≥60 minutes) (see

Table 1, Figure 1, Supplementary Table 1.1, Appendix-C, Appendix-D, and Appendix F).

For the volume of reported MSE (own-bodyweight and gym-based-strength), we first multiplied frequency (days in the last four weeks) by duration (session), then divided this total volume by four for the average weekly volume for each respective mode. For total-MSE, we first summed the total volume (own-bodyweight and gym-based-strength), then divided this by four to arrive at the average weekly volume for total-MSE. Consistent with previous research (Stamatakis et al., 2018), we then derived the mean values for each of the three exposure variables: (i) own-bodyweight exercises (76.1 minutes/week [SE 4.09; SD 193.60]); (ii) gym-based-strength exercise (99.4 minutes/week [SE 3.74; SD 147.07]); and (iii) total-MSE (107.6 minutes/week [SE 3.79; SD 208.06]). The resulting data for each of the three exposure variables were then collapsed into one of three groups: (i) none; (ii) low (<mean minutes/week); or (iii) high (≥mean) (see Table 1, Supplementary Table 1.1, Figure 2, Appendix-C, Appendix-E and Appendix-G).

Participants were asked to self-report whether a health professional had told them that they had a chronic condition. Five chronic conditions, i.e., type-2 diabetes, conditions affecting the heart, respiratory and musculoskeletal systems, and anxiety/depression were chosen for our analyses. The selected chronic conditions, featured in the WHO's target non-communicable diseases reduction strategy, present a significant impact on rates of morbidity and mortality globally (World Health Organization, 2018). For diabetes, participants were asked "*Do you now have, or have you ever had diabetes?*" (yes/no). For conditions affecting the heart, respiratory and musculoskeletal systems and anxiety/depression participants were asked "*Do you have any physical or mental health conditions or illnesses lasting or expected to last 12 months or more?"* (yes/no). To calculate the number of chronic diseases, we combined the responses (yes/no) for each of the five conditions. These data were then collapsed into having either: (i) 0 conditions; (ii) 1 condition; or (iii) ≥2 conditions.

Sociodemographic, lifestyle factors, aerobic-MVPA participation, and SB were selected a priori, as previous literature has shown the possible influence these factors have on MSE participation (Bauman et al., 2012; Rhodes, Lubans, Karunamuni, Kennedy, & Plotnikoff, 2017). Sex was self-reported (male or female). As continuous age data was not available for both waves, we used 'age in 10-year brackets'. Education was assessed as the highest level obtained or qualification. Total household income was equivalised into income tertiles. Alcohol consumption was collapsed into participants with either (i) 'less than weekly/not at all/non-drinkers', or (ii) 'weekly alcohol consumption'. Smoking status was collapsed into participants who (i) 'never smoked', (ii) 'ex-smoker', or (iii) 'current smoker'. Taking drugs prescribed for blood pressure was collapsed into participants (i) 'not taking drug' or (ii) 'taking drug'. For longstanding illness, participants were asked "*Do you have any physical or mental health conditions or illnesses lasting or expected to last 12 months or more?*". These data were collapsed into either (i) 'no' or (ii) 'yes'.

Objective anthropometric measurements included: (i) height (recorded to the nearest millimetre); and (ii) weight (recorded in kilograms and grams) and were assessed by a nurse, using standard measurement protocols (Bridges & Mindell, 2016). We calculated body mass index (BMI), by dividing participant weight by their height in metres squared (Health and Social Care Information Centre, 2017). These data were further collapsed and reported as standard BMI classifications: (i) underweight <18.5kg/m^2; (ii) normal weight ≥18.5kg/m^2 to <25kg/m^2; (iii) overweight 25kg/m^2 to <30kg/m^2; and (iv) obese ≥30kg/m^2.

Aerobic-MVPA was reported in minutes/week, with this data combined and then collapsed into those participants who were classified as: (i) ‘inactive’ (0 minutes/week,), (ii) ‘insufficiently active’ (1-149 minutes/week) and not meeting the guideline or (iii) ‘active’ (≥150 minutes/week) (Scholes et al., 2014). For sedentary time, participants self-reported their daily (i) time spent watching TV; and (ii) time spent in any other sitting on both a usual weekday and weekend day. We combined the data for these two contexts, into ‘time spent sitting (in minutes)’ on a weekday and a weekend day. Then collapsed these data into total sedentary time using the following formula: (weekday sitting time x 5 + weekend sitting x 2). For our analysis, we collapsed these into either: (i) low SB (<3,359 minutes/week); or (ii) high SB (≥3,360 minutes/week). Based on existing literature, (Van Der Ploeg, Chey, Korda, Banks, & Bauman, 2012) high SB was classed if the respondent self-reported ≥480 minutes/day.

We pooled cross-sectional data from the 2012 and 2016 HSE waves. SPSS version 26 (SPSS Inc., an IBM Company, Armonk, NY) was used for all analyses. Descriptive statistics were used to describe the profile of the sample according to the covariates and outcome variables (see Supplementary Table 1) and the MSE exposure variables (see Table 1). Throughout, significance was set at $p<0.05$.

To analyse the associations of the respective modes/duration/volume of MSE with the individual/multiple chronic health conditions, we used Poisson regression analysis, with robust error variance to calculate prevalence ratios (PR) with their 95% confidence intervals (CI). Due to the binary nature of having an adverse health condition (yes vs. no), Poisson regression examined the PR for each chronic health condition (outcome variable) according to the three MSE categories (exposure variable). The reference category was those doing no MSE (duration=0 minutes/session; and volume=none).

To examine the effects of covariates, we conducted four models: Model-A 'unadjusted', Model-B (adjusted for sociodemographic factors: sex; age; education; and income tertiles); Model-C (adjusted for Model-B and lifestyle factors: BMI; weekly alcohol consumption; smoking status; taking blood pressure medication; and longstanding illness); and Model-D (adjusted for Model-C in addition to weekly aerobic-MVPA and weekly sedentary time). Before conducting our analysis, we tested for multicollinearity among potential covariates and the five chronic conditions using tests for the variance inflation factor (VIF), with VIF ≥2 indicating multicollinearity (Cohen, Cohen, West, & Aiken, 2003). The VIF values ranged from 1.05 to 1.31, indicating no evidence of collinearity.

3.3 Results

Data from 16,301 adults aged 16-75 years+ were included in our analysis. The participant characteristics are shown in Supplementary Table 1. In brief, over half were female (55.6%), aged between 16-54 years (59.3%), and classified overweight/obese (63.7%). Approximately half had never smoked and just under three quarters self-reported not having a longstanding illness. Well over half were considered 'active' in aerobic-MVPA. Approximately '10%' of participants reported having diabetes, a heart or respiratory condition, and around '20%' reported having a musculoskeletal condition or anxiety/depression. Over a quarter of participants reported having at least one chronic condition, with approximately '15%' reporting ≥2 chronic conditions.

Table 1 describes the MSE behavioural characteristics of the participants. Briefly, >80% reported doing no own-bodyweight exercise, and >90% reported doing no gym-based-strength exercise. Participants reporting own-bodyweight exercise or gym-based-strength exercise mostly completed their exercise in bouts of 10-20 minutes duration.

Table 1: Muscle-strengthening exercise behaviour characteristics (exposure variable) of participants included in the analysis

Total sample of 2012 and 2016 Health Survey for England (n = 16,301)	
Total	**% (n)**
Muscle-strengthening exercise – Session duration	
Own-Bodyweight (minutes/session)	
0 minutes	86.2 (14,057)
10-20 minutes	8.6 (1,406)
21-59 minutes	3.3 (533)
60+ minutes	1.9 (305)
Gym-based-strength (minutes/session)	
0 minutes	90.5 (14,752)
10-20 minutes	3.7 (603)
21-59 minutes	3.4 (558)
60+ minutes	2.4 (388)
Total-MSE (minutes/session)	
0 minutes	81.5 (13,285)
10-20 minutes	7.8 (1,278)
21-59 minutes	6.0 (982)
60+ minutes	4.6 (756)
Muscle-strengthening exercise – Weekly volume	
Own-Bodyweight (minutes x frequency)	
None	86.2 (14,057)
Low < mean	10.3 (1,672)
High ≥ mean	3.5 (572)
Gym-based-strength (minutes x frequency)	

None	90.5 (14,757)
Low < mean	6.5 (1,062)
High ≥ mean	3.0 (482)
Total-MSE (minutes x frequency)	
None	81.5 (13,287)
Low < mean	13.4 (2,177)
High ≥ mean	5.1 (837)

MSE: muscle-strengthening exercise

Total-MSE = own-bodyweight exercise + gym-based-strength exercise

Mean values: own-bodyweight 76.1 min/week, gym-based-strength 99.4 min/week, total-MSE 107.6 min/week

The unadjusted and adjusted prevalence ratios (APRs), and their 95% (CI) for each of the health conditions (diabetes, heart condition, respiratory condition, musculoskeletal condition, anxiety/depression), and number of chronic conditions (1 condition, ≥2 conditions), are shown in Appendix-C. The prevalence ratios (PRs) were similar after adjusting for confounders. Therefore here we will only present the results of the most adjusted model (Model-D).

For diabetes, shown in Figure 1-Panel A, compared to the reference group (0 minutes), the APRs followed an inverse linear-gradient for own-bodyweight (APRs 0.40, 95%CI [0.25-0.59]; 0.36, 95%CI [0.17-0.68]; 0.26, 95%CI [0.06-0.66]) and total-MSE, (0.47, 95%CI [0.30-0.68]; 0.39, 95%CI [0.23-0.62]; 0.31, 95%CI [0.15-0.57]) session duration. However, for gym-based-strength session duration, the APRs for diabetes was lowest among those reporting 21-59 minutes (APR=0.31, 95%CI [0.13-0.61]). For volume, PRs and APRs were very similar for each MSE mode (see Appendix-C, and Figure 2-Panel A).

For a heart condition, in each MSE category, the APRs followed an inverse linear-gradient (see Figure 1-Panel B) for minutes/session (APRs ranged from 0.19-0.58 across the three modes) when compared to those who did none. For volume, APRs were mixed, with high volumes of gym-based-strength (APR=0.22, 95%CI [0.09-0.44]) and total-MSE (APR=0.30, 95%CI [0.18-0.48]) having a lower likelihood for a heart condition, compared to own-bodyweight (APR=0.45, 95%CI [0.33-0.59]) for <mean (low volume) (see Figure 2-Panel B), however, all were lower when compared to the reference group (none).

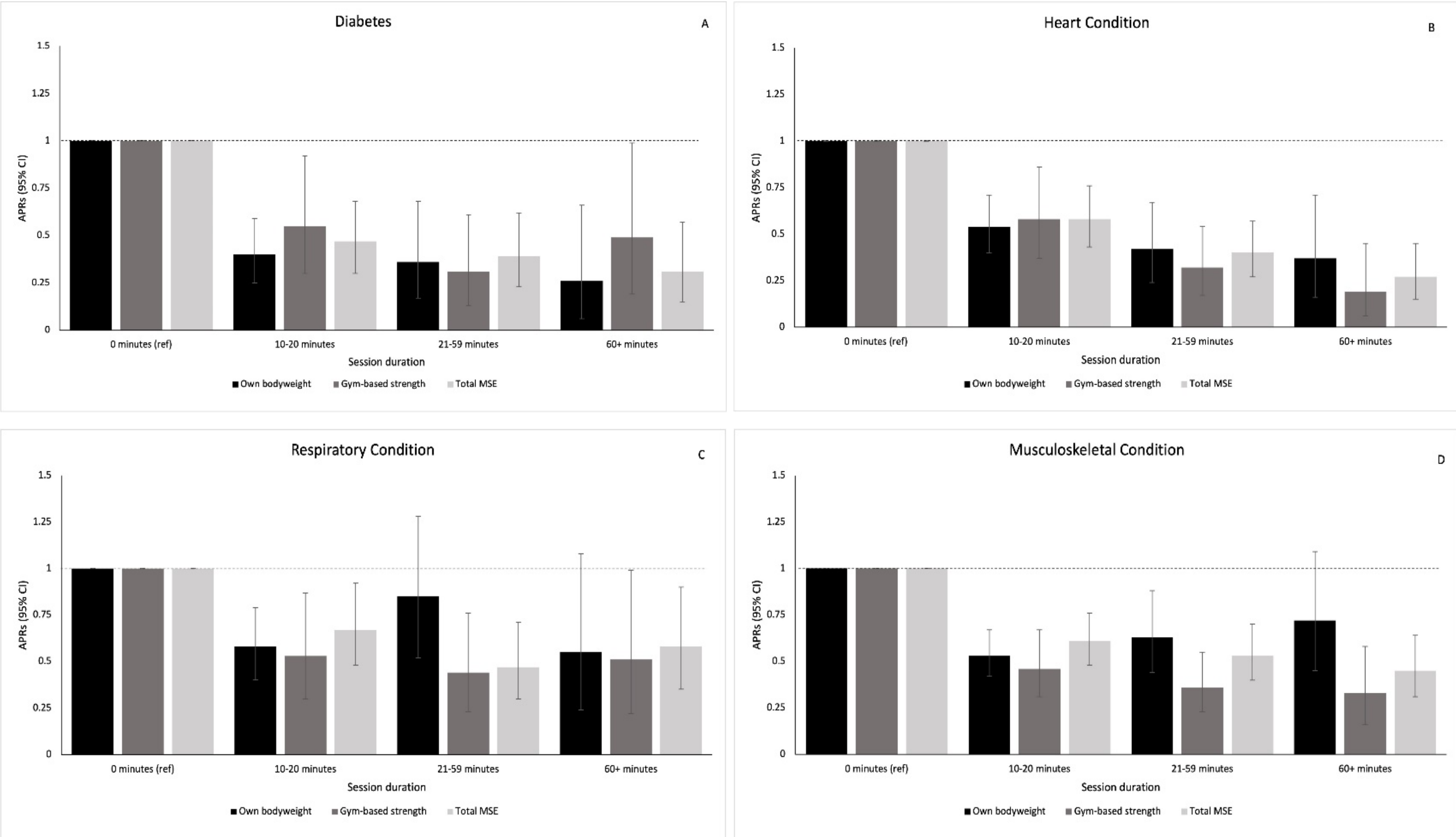
For a respiratory condition, (see Figure 1-Panel C), compared to the reference group (none), participants reporting 60+ minutes of own-bodyweight exercise (APR=0.55, 95%CI [0.24-1.08]); 21-59 minutes of gym-based-strength exercise (APR=0.44, 95%CI [0.23-0.76]), and people reporting both modes (total-MSE, APR=0.47, 95%CI [0.30-0.71]) had a lower likelihood for a respiratory condition. For volume, compared with the sample who did none, both those with a low and high volume had a lower likelihood for a respiratory condition for gym-based-strength (APR=0.49, 95%CI [0.23-0.89]) and total-MSE (APR=0.52, 95%CI [0.31-0.80]), whereas, for participants undertaking own-bodyweight exercise, this was only true for those with a low volume (APR=0.57, 95%CI [0.41-0.77]) (see Figure 2-Panel C).

For a musculoskeletal condition (Figure 1-Panel D), 10-20 minutes of own-bodyweight exercises (APR=0.53, 95%CI [0.42-0.67]), 60+ minutes of gym-based-strength (APR= 0.33, 95%CI [0.16-0.58]), and 60+ minutes of all MSE (APR=0.45, 95%CI [0.31-0.64]) were associated with the lowest likelihood of a musculoskeletal condition when compared with the respective reference groups (0 minutes). For volume, the likelihood of having a musculoskeletal condition was lowest among those doing a high volume of gym-based-strength (APR=0.30, 95%CI [0.16-

0.50]) and total-MSE (APR=0.46, 95%CI [0.32-0.63]), whereas doing a low volume of own-bodyweight exercise (APR=0.53, 95%CI [0.43-0.66]) seemed to be better than doing high volumes (see Figure 2-Panel D) compared to the reference group (none).

For anxiety/depression (Figure 1-Panel E) compared to the duration reference group (0 minutes), participants reporting 60+ minutes of own-bodyweight exercise (APR=0.34, 95%CI [0.12-0.73]) or total-MSE (APR=0.46, 95%CI [0.27-0.72]) had the lowest likelihood of having anxiety/depression, whereas those doing 21-59 minutes of gym-based-strength exercise had the lowest likelihood (APR=0.39, 95%CI [0.21-0.66]). For volume, all APRs are lower when compared to those reporting none (reference group) (see Figure 2-Panel E), however, the APRs seem lowest for doing <mean (low volumes) than for the high volumes for each MSE category (APRs ranging from 0.38-0.51).

In the fully adjusted model (Model-D), the lowest likelihood of having multiple (≥2) chronic conditions, (see Figure 1-Panel F) compared to the reference group (0 minutes), the APRs were mixed, with undertaking 60+ minutes of own-bodyweight (APR=0.16, 95%CI [0.03-0.48]) or total-MSE (APR=0.09, 95%CI [0.02-0.24]) representing the lowest likelihood for ≥2 chronic conditions, whereas those reporting 21-59 minutes of gym-based-strength (APR=0.07, 95%CI [0.01-0.23]) had the lowest likelihood for ≥2 chronic conditions for that exercise mode. For volume, (see Figure 2-Panel F) the resulting APRs were similar, when compared to the reference group, for both low (<mean) and high (≥mean) volume across all three modes.


Diabetes
A
Heart Condition
B
Respiratory Condition
C
Musculoskeletal Condition
D
APRs (95% CI)
1.5
1.25
1
0.75
0.5
0.25
0
0 minutes (ref)
10-20 minutes
21-59 minutes
60+ minutes
Session duration
Own bodyweight
Gym-based strength
Total MSE

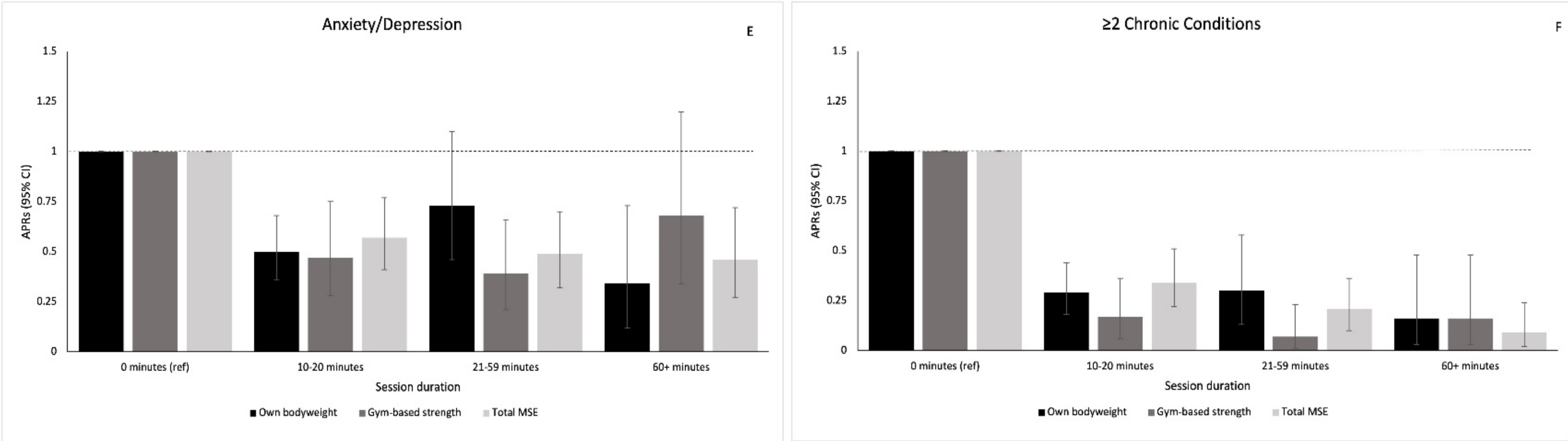
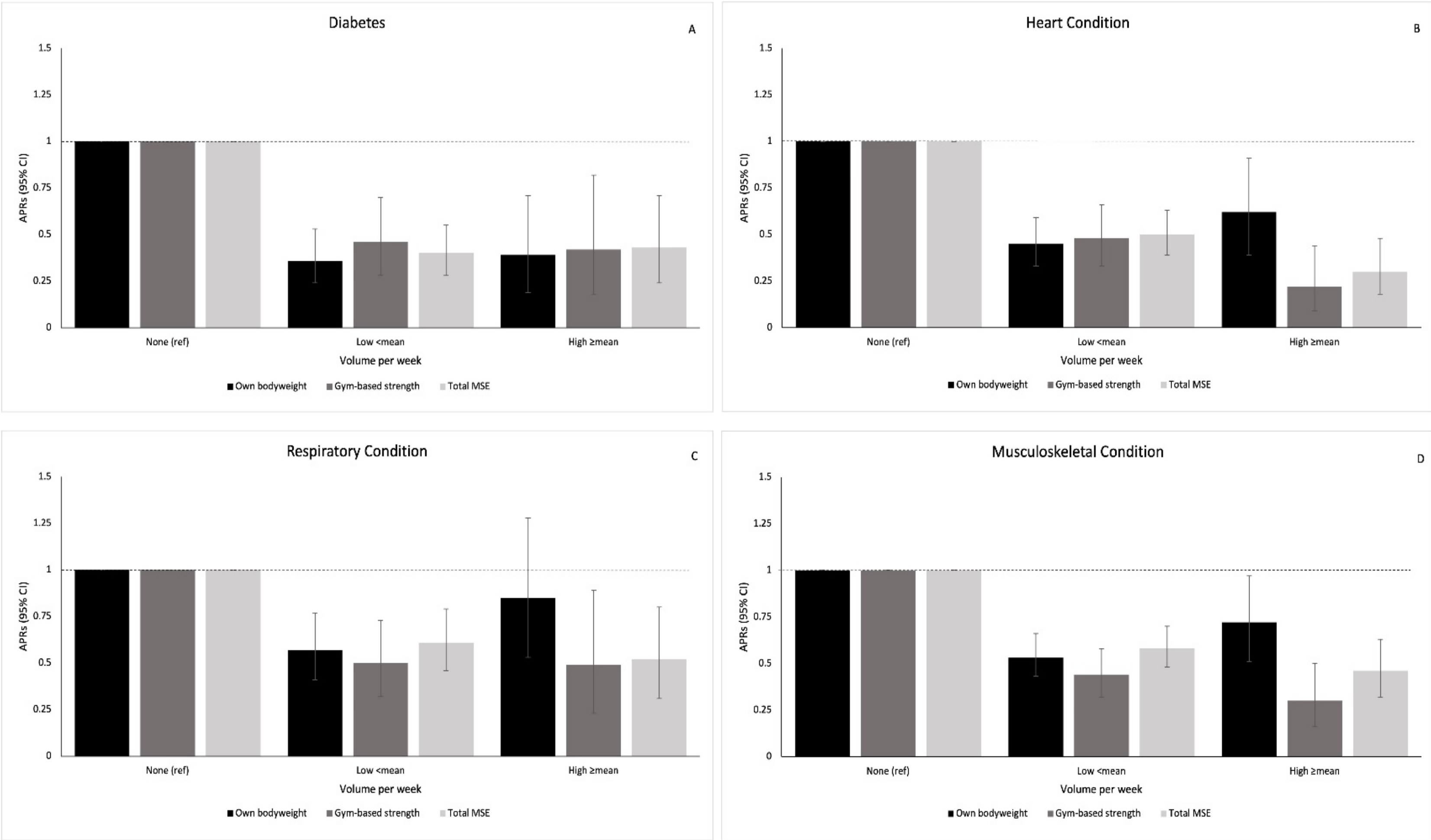


Figure 1; (Panels A-F). Analysis of the relationship between muscle-strengthening exercise (duration/session) between five chronic conditions and having one or two or more chronic conditions relative to two specific modes of muscle-strengthening exercise, and with the two modes combined (APRs; 95%CI).

APRs: adjusted prevalence ratios
MSE: muscle-strengthening exercise
Total-MSE = own-bodyweight exercise + gym-based-strength



Diabetes
A
Heart Condition
B
Respiratory Condition
C
Musculoskeletal Condition
D
APRs (95% CI)
None (ref)
Low <mean
High ≥mean
Volume per week
Own bodyweight
Gym-based strength
Total MSE

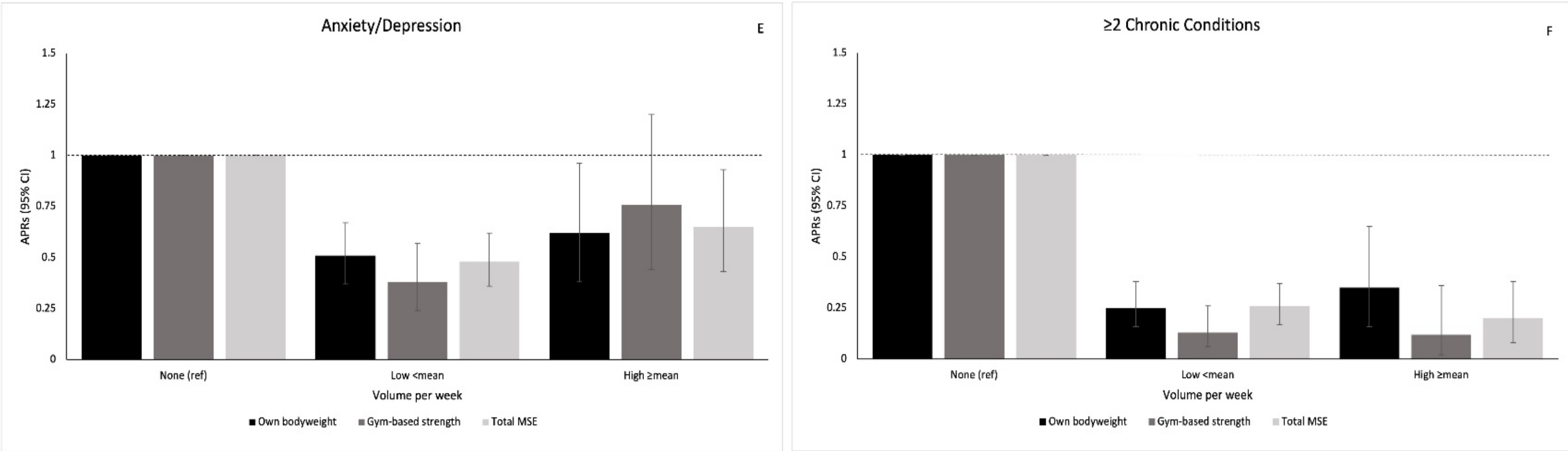


Figure 2; (Panels A-F). Analysis of the relationship between muscle-strengthening exercise (volume/week: frequency/week x duration/session) between five chronic conditions and having two or more chronic conditions relative to two specific modes of muscle-strengthening exercise, and combined (APRs; 95%CI).

APRs: adjusted prevalence ratios

MSE: muscle-strengthening exercise

Total-MSE = own-bodyweight exercise + gym-based-strength

Mean values: own-bodyweight 76.1 min/week, gym-based-strength 99.4 min/week, total-MSE 107.6 min/week

Age-based stratified analysis, based on the most adjusted model (Model-D) and total-MSE, was completed for each of the five chronic conditions, and having one or two or more chronic conditions (see Appendix-F and Appendix-G). Overall, with minimal exceptions, the results are similar across all conditions. In brief, for both duration/session and volume/week the lowest APRs were observed amongst 16–54-year-olds for those reporting having a heart condition (APR=0.08, 95%CI [0.00-0.37], 0.08, 95%CI [0.00-0.34]) when compared to adults aged 55+ years. However, the lowest APRs (for duration/session and total volume/week) were observed amongst adults aged 55+ years reporting anxiety/depression (APR=0.16, 95%CI [0.01-0.70], 0.36, 95%CI [0.09-0.93]) when compared to adults aged 16-54 years.

3.4 Discussion

The key finding was that compared to those doing no or insufficient MSE, with minimal exceptions, irrespective of mode, volume, or duration, engaging in this exercise modality for ≥10 minutes was associated with a lower likelihood of chronic conditions. Moreover, these associations remained after adjustment for age, sex, BMI, smoking, alcohol, aerobic-MVPA, and sedentary time. While these data need to be confirmed in future prospective studies, our cross-sectional study suggests that MSE at any volume and duration or mode is likely to have health benefits.

While there is a large body of evidence describing the relationship between volume and duration of aerobic-MVPA and health, the corresponding relationship with MSE is less understood (Bennie et al., 2020; World Health Organization, 2010). With most of the evidence on MSE and health-based assessments of weekly frequency (0-1 vs. ≥2 times/week) (Bennie et al., 2019; Dankel et al., 2016; Saeidifard et al., 2019), the current study is important because it is the first to provide an insight into other participation parameters and their relationship with health.

While our study shows overall that there was minimal difference between volume and duration and the likelihood of individual health conditions, there were some discrepancies observed. In brief, our findings suggest a lower likelihood for heart, respiratory or musculoskeletal conditions, or multiple chronic conditions, among those undertaking high volumes/week of total-MSE. Whereas those with diabetes, anxiety/depression, or having one chronic condition, completing a low volume/week of total-MSE had the most favourable association. Age-stratified associations remained consistent for both diabetes and those with one chronic condition, however, mixed for all other conditions (heart, respiratory, musculoskeletal, anxiety/depression, and having two or more chronic conditions). For comparison, there is limited research amongst large population samples on the dose-dependent relationship of MSE session duration and health. Our findings are somewhat consistent with Minges et al., which also did not show a clear dose-dependent association between MSE duration and impaired glucose metabolism (Minges et al., 2013). However, they did not differentiate between different modes of MSE (Minges et al., 2013). Our recent systematic review (Shakespear-Druery et al., 2021) highlighted several limitations in the way MSE is currently assessed in large population health-surveillance. For example, while the HSE obtains participant data concerning MSE intensity, the question limits response options to either yes or no (i.e., "*During the past four weeks, was the effort of … usually enough to make you out of breath or sweaty?"*). Future population-level research may benefit from the inclusion of additional MSE factors (e.g., perceived exercise intensity, set/repetition volume, modes/exercise type), to gain a greater understanding of the potential relationship that these factors may have on health-related outcomes, such as NCDs.

Worldwide, prevalence rates for MSE participation are low when compared to self-reported aerobic-MVPA participation (Bennie et al., 2020). Approximately 26% of our sample were assessed as meeting the MSE guideline of ≥2sessions/week (however this percentage may be lower as some reported MSE may have performed at less than a moderate intensity), compared to 59.4% who met the aerobic-MVPA guideline. Globally, recommendations for adult MSE participation remain at ≥2times/week (Bull et al., 2020). Moreover, there is a lack of evidence supporting higher frequencies of MSE for health (Bull et al., 2020). Albeit cross-sectional, our data is among the first to show a similar relationship with MSE duration and volume and associations between the prevalence of health conditions. While further research is needed, this finding is important because it provides some preliminary insights into parameters of MSE beyond frequency and their associations with health.

For the promotion of MSE, our data suggest that small-to-moderate increases in MSE at the population-level are likely to have health benefits. Furthermore, our data suggest that this is the case irrespective of MSE mode. Therefore, to increase MSE participation, the focus of PA messaging must align with those promoted in the 2020 WHO 'good practice statements' (World Health Organization, 2020b) that state "doing some is better than doing none". Moreover, highlighting that MSE is not limited to a gym/fitness centre environment and can be undertaken by performing simple bodyweight exercises in the home (Chen et al., 2020).

A key strength of this study is that it is the first to explore the relationship between specific MSE modes and adverse health outcomes, in a large population sample of adults. We have used data obtained through standardised recruitment and data collection procedures, therefore our findings can be compared with future HSE data and other large population-surveillance studies.

The key limitation of this study was the use of cross-sectional analyses, hence causality cannot be inferred. Our results should therefore be used with caution. Additional limitations include the risk of responder recall bias, through self-reported responses (e.g., social desirability or over/under-reporting of actual behaviour) and the indicator of having a chronic condition/s does not account for the temporality/severity of the condition/s. A further limitation was the non-assessment of MSE for durations less than 10 minutes, nor MSE intensity. Additionally, we are unable to exclude data from 16-17-year-old participants from our analyses.

3.5 Conclusion

Among a large community-based sample of adults, regardless of mode, volume, or duration, any MSE was associated with a lower likelihood of prevalent chronic diseases. While these findings need to be confirmed in prospective cohort studies, our findings suggest that small-to-moderate increases in MSE at the population-level are likely to have public-health benefits.

3.5.1 Practical implications

- While epidemiological evidence links muscle-strengthening exercise with health, since existing studies focus on weekly frequency, little is known about the health consequences of other training parameters, such as exercise mode, duration, and volume.
- Among a sample of 16,301 adults, irrespective of the mode, session duration or volume, there were similar odds for a reduced likelihood of chronic diseases such as diabetes, cardiovascular disease, musculoskeletal health, and anxiety/depression.
- These findings suggest that small-to-moderate increases in muscle-strengthening exercise at the population level are likely to have public health benefits.

3.6 References

Ashton, R. E., Tew, G. A., Aning, J. J., Gilbert, S. E., Lewis, L., & Saxton, J. M. (2018). Effects of short-term, medium-term and long-term resistance exercise training on cardiometabolic health outcomes in adults: Systematic review with meta-analysis. *British Journal of Sports Medicine*, 1-9. doi:10.1136/bjsports-2017-098970

Bauman, A. E., Reis, R. S., Sallis, J. F., Wells, J. C., Loos, R. J. F., Martin, B. W., & Lancet Phys Activity Series, W. (2012). Correlates of physical activity: Why are some people physically active and others not? *Lancet, 380*(9838), 258-271. doi:10.1016/s0140-6736(12)60735-1

Bennie, J. A., Shakespear-Druery, J., & De Cocker, K. (2020). Muscle-strengthening exercise epidemiology: A new frontier in chronic disease prevention. *Sports Medicine - Open, 6*(1), 1-8. doi:10.1186/s40798-020-00271-w

Bennie, J. A., Teychenne, M. J., De Cocker, K., & Biddle, S. J. H. (2019). Associations between aerobic and muscle-strengthening exercise with depressive symptom severity among 17,839 U.S. adults. *Preventive Medicine, 121*, 121-127. doi:10.1016/j.ypmed.2019.02.022

Bridges, S., Doyle, M., Fuller, E., Knott, C., Mindell, J., Moody, A., . . . Whalley, R. (2013). *Health Survey for England 2012: Volume 2: Methods and documentation*. Health and Social Care Information Centre Retrieved from https://files.digital.nhs.uk/publicationimport/pub13xxx/pub13218/hse2012-methods-and-docs.pdf.

Bridges, S., & Mindell, J. (2016). *Health Survey for England 2016: Field documents and measurement protocols*. Health and Social Care Information Centre Retrieved from https://files.digital.nhs.uk/pdf/q/j/hse2016-documentation.pdf.

Bull, F. C., Al-Ansari, S. S., Biddle, S., Borodulin, K., Buman, M. P., Cardon, G., . . . Willumsen, J. F. (2020). World Health Organization

2020 guidelines on physical activity and sedentary behaviour. *British Journal of Sports Medicine, 54*(24), 1451. doi:10.1136/bjsports-2020-102955

Chen, P., Mao, L., Nassis, G. P., Harmer, P., Ainsworth, B. E., & Li, F. (2020). Coronavirus disease (COVID-19): The need to maintain regular physical activity while taking precautions. *Journal of Sport and Health Science, 9*(2), 103-104. doi:10.1016/j.jshs.2020.02.001

Cohen, J., Cohen, P., West, S., & Aiken, L. (2003). *Applied multiple regression/correlation analysis for the behavioral sciences* (3rd ed.). New York: Routledge.

Dankel, S. J., Loenneke, J. P., & Loprinzi, P. D. (2016). The individual, joint, and additive interaction associations of aerobic-based physical activity and muscle strengthening activities on metabolic syndrome. *International Journal of Behavioral Medicine, 23*(6), 707-713. doi:10.1007/s12529-016-9570-y

Gordon, B. R., McDowell, C. P., Hallgren, M., Meyer, J. D., Lyons, M., & Herring, M. P. (2018). Association of efficacy of resistance exercise training with depressive symptoms: Meta-analysis and meta-regression analysis of randomized clinical trials. *JAMA Psychiatry, 75*(6), 566-576. doi:10.1001/jamapsychiatry.2018.0572

Grnøtved, A., Pan, A., Mekary, R. A., Stampfer, M., Willett, W. C., Manson, J. E., & Hu, F. B. (2014). Muscle-strengthening and conditioning activities and risk of type 2 diabetes: A prospective study in two cohorts of US women. *PLoS Medicine, 11*(1), 15. doi:10.1371/journal.pmed.1001587

Health and Social Care Information Centre. (2017). *Health Survey for England 2016: Methods*. NHS Digital Retrieved from http://healthsurvey.hscic.gov.uk/media/63778/HSE2016-Methods-text.pdf.

Mazzilli, K. M., Matthews, C. E., Salerno, E. A., & Moore, S. C. (2019). Weight training and risk of 10 common types of cancer. *Medicine &*

Science in Sports & Exercise, 51(9), 1845-1851. doi:10.1249/mss.0000000000001987

Minges, K. E., Magliano, D. J., Owen, N., Daly, R. M., Salmon, J., Shaw, J. E., . . . Dunstan, D. W. (2013). Associations of strength training with impaired glucose metabolism: The AusDiab study. *Medicine & Science in Sports & Exercise, 45*(2), 299-303. doi:10.1249/MSS.0b013e31826e6cd1

Rhodes, R. E., Lubans, D. R., Karunamuni, N., Kennedy, S., & Plotnikoff, R. (2017). Factors associated with participation in resistance training: A systematic review. *British Journal of Sports Medicine, 51*(20), 1-9. doi:10.1136/bjsports-2016-096950

Saeidifard, F., Medina-Inojosa, J. R., West, C. P., Olson, T. P., Somers, V. K., Bonikowske, A. R., . . . Lopez-Jimenez, F. (2019). The association of resistance training with mortality: A systematic review and meta-analysis. *European Journal of Preventive Cardiology, 26*(15), 1647-1665. doi:10.1177/2047487319850718

Schoenfeld, B. J., Ogborn, D., & Krieger, J. W. (2017). Dose-response relationship between weekly resistance training volume and increases in muscle mass: A systematic review and meta-analysis. *Journal of Sports Sciences, 35*(11), 1073-1082. doi:10.1080/02640414.2016.1210197

Scholes, S., Coombs, N., Pedisic, Z., Mindell, J. S., Bauman, A., Rowlands, A. V., & Stamatakis, E. (2014). Age- and sex-specific criterion validity of the Health Survey for England physical activity and sedentary behavior assessment questionnaire as compared with accelerometry. *American Journal of Epidemiology, 179*(12), 1493-1502. doi:10.1093/aje/kwu087

Shakespear-Druery, J., De Cocker, K., Biddle, S. J. H., Gavilán-Carrera, B., Segura-Jiménez, V., & Bennie, J. (2021). Assessment of muscle-strengthening exercise in public health surveillance for adults: A systematic review. *Preventive Medicine, 148*, 106566 1-11. doi:10.1016/j.ypmed.2021.106566

Shiroma, E. J., Cook, N. R., Manson, J. E., Moorthy, M., Buring, J. E., Rimm, E. B., & Lee, I. M. (2016). Strength training and the risk of type 2 diabetes and cardiovascular disease. *Medicine & Science in Sports & Exercise, 49*(1), 40-46. doi:10.1249/MSS.0000000000001063

Stamatakis, E., Lee, I.-M., Bennie, J., Freeston, J., Hamer, M., O'Donovan, G., . . . Mavros, Y. (2018). Does strength-promoting exercise confer unique health benefits? A pooled analysis of data on 11 population cohorts with all-cause, cancer, and cardiovascular mortality endpoints. *American Journal of Epidemiology, 187*(5), 1102-1112. doi:10.1093/aje/kwx345

Steele, J., Fisher, J., Skivington, M., Dunn, C., Arnold, J., Tew, G., . . . Winett, R. (2017). A higher effort-based paradigm in physical activity and exercise for public health: Making the case for a greater emphasis on resistance training. *BMC Public Health, 17*, 8. doi:10.1186/s12889-017-4209-8

Van Der Ploeg, H. P., Chey, T., Korda, R. J., Banks, E., & Bauman, A. (2012). Sitting time and all-cause mortality risk in 222 497 Australian adults. *Archives of Internal Medicine, 172*(6), 494-500. doi:10.1001/archinternmed.2011.2174

World Health Organization. (2010). *Global recommendations on physical activity for health*. Geneva, Switzerland: WHO Press.

World Health Organization. (2018). *Global Action Plan on Physical Activity 2018–2030: More Active People for a Healthier World*. Geneva: World Health Organization.

World Health Organization. (2020a). *Noncommunicable diseases progress monitor 2020*. Retrieved from Geneva: https://www.who.int/publications-detail/ncd-progress-monitor-2020

World Health Organization. (2020b). *WHO guidelines on physical activity and sedentary behaviour*. Geneva: World Health Organization Retrieved from https://www.who.int/publications/i/item/9789240015128.

Yore, M. M., Ham, S. A., Ainsworth, B. E., Kruger, J., Reis, J. P., Kohl, H. W., III, & Macera, C. A. (2007). Reliability and validity of the instrument used in BRFSS to assess physical activity. *Medicine & Science in Sports & Exercise, 39*(8), 1267-1274. doi:10.1249/mss.0b013e3180618bbe

3.7 How the Publication Contributes to the Advancement of the Research Area

This study provides a unique understanding of how duration per session and volume per week of MSE is associated with common self-reported chronic health conditions (diabetes, anxiety/depression, and conditions affecting the heart, musculoskeletal and respiratory systems) in a population-representative sample of adults.

Among the sample of U.K. adults, who reported undertaking MSE behaviours, it was evident that regardless of MSE mode, duration/session, or volume/week there was a reduced likelihood of having one or more of the target chronic conditions. Moreover, these associations remained after adjustments for socio-demographic and lifestyle factors, MVPA participation, and self-reported sedentary time. This finding is important because it indicates that doing any MSE is likely to benefit health. However, future prospective studies are needed to confirm these cross-sectional observations. Additionally, World Health Organisation (WHO) member states have been tasked with increasing their efforts in both the management of NCDs and health promotion. Specifically, mass media campaigns that target physical activity behaviour change using motivational messaging may find the study results valuable, as not all the population can (or are motivated to) undertake aerobic physical activity.

This study has increased the body of knowledge regarding the associations between MSE and the prevalence of chronic diseases at the population level beyond the frequency of MSE participation alone. Moreover, this study highlighted the large proportion of the sample that reportedly undertook no MSE (albeit MSE data for durations less than 10 minutes per session were not captured within the instrument used to assess MSE behaviours). Due to limitations in the methodologies used to obtain the self-reported data, the analyses did not include an assessment of the potential influence that MSE intensity may have on health. Therefore, this presents an opportunity for future research to identify and implement a valid and reliable method of assessing MSE intensity at the population level. Efforts to address this knowledge gap are explored in Chapter 5 of this thesis.

The next study expands the understanding of associations between MSE and clinically measured hypertension among a sub-sample of U.K. adults (N = 10,519) used in this study.

CHAPTER 4: PAPER 3 - Associations between duration and volume of muscle-strengthening exercise and clinically assessed hypertension among 10 519 UK adults: A cross- sectional study

This paper has been peer-reviewed and was accepted for publication in the *Journal of Hypertension* on 15 January 2022 as an original investigation. It was published online on 23 February 2022 and appears in the literature at the time of writing as:

Shakespear-Druery, J., De Cocker, K., Biddle, S. J. H., & Bennie, J. (2022). Associations between duration and volume of muscle-strengthening exercise and clinically assessed hypertension among 10519 UK adults: A cross-sectional study. *Journal of Hypertension*, *40*(5), 947-955. https://doi.org/10.1097/HJH.0000000000003098

The format may differ from the accepted pre-copyedited version. It has been reformatted to remain consistent with the rest of the thesis.

4.0 Abstract

Background: Clinical evidence shows that muscle-strengthening exercise (MSE) is important for the treatment and management of hypertension. However, the links between MSE and hypertension in epidemiological research are currently poorly understood. This study examines the association between MSE duration and volume with clinically assessed hypertension.

Methods: Cross-sectional data (*n* = 10,519, adults ≥16 years) were pooled from the Health Survey for England (2012, 2016). Self-reported MSE mode (own bodyweight; gym-based), duration, and volume were tested for associations with sphygmomanometer measured hypertension (SBP ≥130 mmHg or DBP ≥ 80 mmHg). Poisson regressions with robust error variance were used to calculate the prevalence ratios (PR) of hypertension (outcome variable) across MSE (exposure variables: duration (minutes (0 [reference]; 10-20; 21-59; ≥60/session); and volume (0 [reference]; low <mean; high ≥mean/week)) for each mode and the modes combined.

Results: Most adults (81.1%) did no MSE. However, in those who did (n=1,984), undertaking any MSE, regardless of mode, duration or volume, was associated with a reduced likelihood of hypertension (adjusted prevalence ratios (APRs) 0.61-0.90). When compared to the reference groups (no MSE), some modes had more favourable associations (e.g., ≥60 minutes/session of own bodyweight MSE; ≥mean minutes/week of gym-based MSE).

Conclusions: Irrespective of duration or volume, MSE was associated with a lower prevalence of clinically assessed hypertension. Public-health campaigns and other interventions that successfully promote small-to-moderate increases in MSE participation may reduce the prevalence of hypertension.

Keywords: resistance exercise, prevalence, blood pressure, physical activity, duration

4.1 Introduction

Hypertension and cardiovascular disease are globally among the leading causes of morbidity and mortality (World Health Organization, 2020a) and are associated with over 10 million deaths annually (Forouzanfar et al., 2017). Regular physical activity is a key non-pharmacological and relatively side-effect-free treatment option for the prevention and management of hypertension. For overall health and well-being, including blood pressure control, the 2020 World Health Organisation (WHO) 'Guidelines on physical activity and sedentary behaviour' state that adults (18–64 years) should undertake *"at least 150-300 minutes of moderate-intensity aerobic physical activity"* or do *"at least 75-150 minutes of vigorous-intensity aerobic physical activity"* or *"an equivalent combination of moderate- and vigorous-intensity activity"* throughout the week (Bull et al., 2020) and muscle-strengthening exercise (MSE) *"at moderate or greater intensity"* targeting *"all the major muscle groups ... on two or more days a week"* (Bull et al., 2020). At present, the epidemiological evidence on linking physical activity to a reduced risk of hypertension is largely based on studies of aerobic physical activity, i.e. walking, running or cycling (Huai et al., 2013; Liu et al., 2017). Meta-analysis of cohort studies shows a negative dose-response association between aerobic moderate-to-vigorous physical activity (aerobic MVPA: walking, cycling, running etc.) and risk of hypertension (Huai et al., 2013; Liu et al., 2017).

More recently, several meta-analyses of evidence from clinical exercise studies suggest that MSE may also be important in the treatment management of hypertension. For example, a meta-analyses by MacDonald et al. (2016) found positive dose-response associations between dynamic MSE and reductions in blood pressure in hypertensive, prehypertensive and normotensive populations. Similarly, Cornelissen and Smart (2013) found the strongest dose-response associations within prehypertensive participants rather than in hypertensive/normotensive participants. Furthermore, Ashton et al. (2018) identified negative blood pressure associations amongst participants who undertook MSE (Ashton et al., 2018).

While these studies provide insights into the benefits of MSE on hypertension in controlled laboratory settings, few studies have examined these associations at the population level. A recent large cross-sectional study showed that among a sample of 1.5 million adults, compared to those doing none, any MSE was associated with a lower prevalence of hypertension (Bennie, Lee, Brellenthin, & De Cocker, 2020). However, the key limitations of that study were the sole focus on the frequency of MSE participation (times/week), self-reported hypertension, and non-reporting of anti-hypertensive medications (Bennie, Lee, et al., 2020). Therefore, at the population level, there is a limited understanding of the links to other MSE participation parameters (i.e., duration, volume) and the association with clinically assessed blood pressure. It is important to develop an understanding of the dose-dependent associations between the duration and volume of different MSE modes, and associations with blood pressure. Such information will be essential for future adjunct therapy recommendations in the treatment and management of hypertension. Moreover, this research may be used to develop physical activity guidelines aimed at reducing the risk of hypertension at the population level.

Therefore, the aim of this study is to describe the association between duration and volume of MSE and the prevalence of clinically assessed hypertension, among a large population-based sample of adults.

4.2 Methods

<u>Sample</u>

In this cross-sectional study, we drew data from The Health Survey for England (HSE). Since the background information on the HSE has been described elsewhere (Bridges & Mindell, 2016), we will provide details relevant to the current study. Since 1991 the HSE has collected health and related data from free-living members of the English public (Health and Social Care Information Centre, 2017; Mindell et al., 2012). Physical activity-related data are assessed every four years from a targeted national representative population sample of English-speaking children, and adults aged 16 years and older, living in private households (Bridges et al., 2013). Each iteration of the HSE is subject to ethical approval (Bridges et al., 2013; Bridges & Mindell, 2016). Data are collected face-to-face by trained researchers using a standard survey instrument, and informed consent was obtained from all participants (Bridges et al., 2013), with data subsequently made available for research purposes. In the current study, we used the data from the two most recent HSE waves (2012 and 2016) (n = 20,400).

Data inclusion/exclusion

Data from participants aged 16 years and older, who undertook a clinical blood pressure assessment, were included in our study. Participants were excluded if they had missing demographic (age) information (20.1%, n = 4,099) or they did not respond to the question about taking prescribed drugs for blood pressure (28.3%, n = 5,782). The final sample in the present study, therefore, contained 10,519 participants (see Supplemental Digital Content 1, for the participant flow diagram).

Exposure variable: Muscle-strengthening exercise (mode, frequency, and duration)

Self-reported MSE was assessed using an interview-led questionnaire (Bridges et al., 2013; Bridges & Mindell, 2016). Participants were shown a card (see Supplemental Digital Content 2) (UK Data Service, 2016) and asked: *"Can you tell me if you have done any activities* *on this card during the last 4 weeks?"* including *"teaching, coaching, training and practice sessions".* In the current study, we selected the responses: *"Workout at a gym/Exercise bike/Weight training"* and *"Exercises (e.g. press-ups, sit-ups)"* for inclusion. The frequency of participation was assessed by asking *"Can you tell me on how many separate days you did (name of activity) for at least 10 minutes a time during the past four weeks?"*; and duration (reported in minutes) was assessed by asking *"How much time did you usually spend doing (name of activity) on each day?"* Participants were asked to only include "*times you did it for at least 10 minutes".*

Participants who reported *"Workout at a gym/Exercise bike/Weight training"* were then shown a card (see Supplemental Digital Content 3) (UK Data Service, 2016) and asked: *"What did you do specifically?"* (options included: (i) strength work out at the gym using machines or free weights; (ii) exercise bike; (iii) spinning classes; (iv) stepping machine, rowing machine or cross trainer; and (v) treadmill running). Participants reporting *"Strength work out at a gym using machines or free weights"* were included in our study, along with their frequency (number of separate days) and duration (time [reported in minutes] spent doing the activity on each day, for at least 10 minutes) data. While the reliability and validity of the muscle-strengthening items contained within the HSE surveillance instrument have not been examined (Strain, Milton, Dall, Standage, & Mutrie, 2019), similar items have shown evidence of excellent test-retest reliability (Cohen's kappa (κ) = 0.85; 95% CI: 0.71-0.99) and moderate validity (κ = 0.40; 95% CI: 0.20-0.60) (Yore et al., 2007).

Based on the above questions, we categorised MSE into two modes: (i) 'own bodyweight exercises', or (ii) 'gym-based strength work' (working out with weights). We then combined these data to create a third category 'all muscle-strengthening exercise' (all MSE).

Classification of muscle-strengthening exercise (duration and volume)

Data for MSE session duration (minutes) were collapsed into one of four groups: (i) none/0 minutes; (ii) low duration (10-20 minutes); (iii) moderate duration (21-59 minutes); or (iv) high duration (≥60 minutes) for each MSE mode (own bodyweight exercises, gym-based strength work, and all MSE) (see Table 2, Figure 1, and Supplemental Digital Content 4).

To classify the weekly volume of MSE (own bodyweight exercises and gym-based strength work), we first multiplied the reported frequency (days in the last four weeks) by the reported duration (session), then divided this result by four to obtain the average weekly volume for each mode respectively. For all MSE, we combined the total volume for each mode (own bodyweight exercises and gym-based strength work), then divided this result by four to arrive at the average weekly figure. We then derived the mean volume values (minutes/week) for each of the three exposure variables: (i) own bodyweight exercises (76.5 minutes/week); (ii) gym-based strength work (96.3 minutes/week); and (iii) all MSE (106.2 minutes/week). Data for each of the three exposure variables were then collapsed into one of three groups: (i) none (0); (ii) low volume (< mean minutes/week); or (iii) high volume (≥ mean) (see Table 2, Figure 2, and Supplemental Digital Content 4).

Outcome variable: Clinically assessed blood pressure (Hypertension)

Following standard protocols, resting blood pressure was measured three times by a trained research nurse. Using an Omron HEM 907 monitor, systolic (SBP) and diastolic (DBP) blood pressure was measured in millimetres of mercury (mmHg) (Bridges & Mindell, 2016). The mean values for each measure (SBP and DBP) were computed and reported in the available research data.

Based on existing research and established cut points (P. K. Whelton et al., 2018), we classified blood pressure as follows: (i) normal (<120 mmHg SBP and <80 mmHg DBP); (ii) elevated (120-129 mmHg SBP and <80 mmHg DBP); (iii) hypertensive (≥130 mmHg SBP or ≥80 mmHg DBP). We categorised the mean values for SBP (as either <130 mmHg or ≥ 130 mmHg) and DBP (as either <80 mmHg or ≥ 80 mmHg). According to the established cut points (P. K. Whelton et al., 2018), we combined these data and then collapsed them further, categorising each participant as either: (i) not hypertensive (SBP <130 mmHg and DBP <80 mmHg) or (ii) hypertensive (SBP ≥130 mmHg or DBP ≥80 mmHg).

Covariates/confounders

Sociodemographic factors, modifiable lifestyle factors, aerobic MVPA, and sedentary behaviour were selected a priori because previous literature has highlighted their potential influence on participation in MSE and hypertension (Carnethon et al., 2003; Gordon et al., 2018; Hubert, Feinleib, McNamara, & Castelli, 1983; Mente et al., 2014; Rhodes, Lubans, Karunamuni, Kennedy, & Plotnikoff, 2017; Saeidifard et al., 2019). Self-reported data included: (i) sex, (either male or female); (ii) age in 10-year brackets; (iii) education (assessed as the highest level obtained or level of qualification), and (iv) total household income before tax (equivalised into income tertiles). Additionally, data for the consumption of alcohol were collapsed into those who reported either (i) 'less than weekly/not at all/non-drinkers', or (ii) 'weekly alcohol consumption'. Smoking status was collapsed into those who (i) 'never smoked cigarettes at all', (ii) 'ex-smoker', or (iii) 'current cigarette smoker'. Data for the taking of medication due to high blood pressure were collapsed into those either (i) 'not taking drug' or (ii) 'taking drug'. Concerning longstanding illness, participants were asked "*Do you have any physical or mental health conditions or illnesses lasting or expected to last 12 months or more?*", with response options either (i) 'yes' or (ii) 'no'.

Anthropometric measures were assessed by a nurse using standard measurement protocols and included: (i) height (using a portable stadiometer, recorded to the nearest millimetre) and (ii) weight (using SECA 877 scales, and recorded in kilograms and grams) (Bridges & Mindell, 2016). Body mass index (BMI) was calculated by dividing participant weight by their height in metres squared (Health and Social Care Information Centre, 2017). Standard classifications for BMI were applied: (i) underweight <18.5 kg/m^2; (ii) normal weight ≥18.5 kg/m^2 to <25 kg/m^2; (iii) overweight 25 kg/m^2 to <30 kg/m^2; (iv) obese ≥30 kg/m^2 (Health and Social Care Information Centre, 2017).

For minutes/week of aerobic MVPA (including activities such as heavy housework, gardening, work-based occupational activities, brisk walking, athletics, aerobic, and swimming) (Scholes, 2017), based on current global guidelines, we classified participants as either: (i) 'inactive'(<30 minutes/week), (ii) 'insufficiently active' (30-149 minutes/week) and not meeting the aerobic MVPA guideline; or (iii) 'active' (≥ 150 minutes/week) (Health and Social Care Information Centre, 2017). To assess sedentary time, participants were asked to report their average daily time spent: (i) watching TV (including DVDs and videos) and (ii) in any other sitting (reading, studying, and computer use). High levels of sedentary time are often classified within the literature as those with sitting time ≥480 minutes a day (Van Der Ploeg, Chey, Korda, Banks, & Bauman, 2012). Therefore, we combined the data for these two contexts (watching TV, and other sitting) then collapsed them into either (i) low sedentary behaviour (<480 mins/day) or (ii) high sedentary behaviour (≥480 mins/day).

<u>Statistical analysis</u>

We pooled data from two existing HSE data sets (2012 and 2016), and harmonised and reviewed the data for missing values prior to our analysis. To improve the population representativeness of our analysis we weighted the data, with weighting factors provided by the HSE (Health and Social Care Information Centre, 2017), to account for clustering and non-response. Descriptive statistics were used to describe the profile of the sample according to the outcome variable and covariates (see Table 1) and the three respective MSE exposure variables (see Table 2). Significance was set at $p < 0.05$ throughout our analyses.

The associations of having hypertension with each MSE mode (for duration/session and volume/week) were assessed using Poisson regression analysis, with robust error variance to calculate prevalence ratios (PR) with 95% confidence intervals. Poisson regression examined the PR for clinically assessed hypertension (outcome variable) according to the three MSE categories (exposure variable). In all regression models, the reference category was those doing no MSE (0 minutes = duration; and none = volume). We conducted four models to examine the potential effects of covariates: Model A 'unadjusted', Model B (adjusted for sociodemographic factors: sex; age; education; and income tertiles); Model C (adjusted for Model B and lifestyle factors: BMI; weekly alcohol consumption; smoking status; taking blood pressure medication; and longstanding illness); and Model D (adjusted for Model C in addition to weekly aerobic MVPA and weekly sedentary time). Prior to our analysis, we tested for multicollinearity among the potential covariates, using tests for the variance inflation factor (VIF). A VIF ≥2 indicates multicollinearity (Cohen, Cohen, West, & Aiken, 2003). The VIF values ranged from 1.04 to 1.30, indicating no evidence of multicollinearity.

To enable a more robust interpretation of the results, we performed several sensitivity analyses. First, given that hypertension (Karmali et al., 2017; Kearney et al., 2005) and MSE have been shown to differ by sex and age (Ashton et al., 2018; Bennie, Lee, et al., 2020; Ciccolo, Gabriel, Macera, & Ainsworth, 2010), we conducted sex (males vs females) and age (16-54 years vs ≥55 years) stratified analyses. Second, since BMI

(Kotsis, Stabouli, Papakatsika, Rizos, & Parati, 2010) and smoking (Ussher, Taylor, & Faulkner, 2014) can impact both hypertension and MSE (Bennie, Lee, et al., 2020), we also stratified the sample by BMI (underweight/normal vs overweight/obese) and smoking status (never smoked vs current smoker). Third, as the presence of having a longstanding illness (Gordon et al., 2018) is likely to affect MSE participation, to minimise the risk of reverse causation, we stratified the sample by reporting having a longstanding illness (‘no’ vs ‘yes'). Last, to compare the effects of participation in aerobic MVPA (MacDonald et al., 2016), we created two groups (i) ‘insufficiently active’ (<149 minutes/week); and (ii) ‘sufficiently active’ (≥150 minutes/week).

In further analysis we compared the HSE data using the American (P. K. Whelton et al., 2018) and European (Williams et al., 2018) hypertension cut points. For this analyses we applied the established European cut points (Williams et al., 2018) which classify blood pressure as: (i) optimal (<120 mmHg SBP and <80 mmHg DBP); (ii) normal (120-129 mmHg SBP and/or 80-84 mmHg DBP); (iii) high normal (130-139 mmHg SBP and/or 85-89 mmHg DBP); hypertensive (≥140 mmHg SBP and/or ≥90 mmHg DBP). We categorised the mean values for SBP (as either <140 mmHg or ≥ 140 mmHg) and DBP (as either <90 mmHg or ≥ 90 mmHg). According to the established cut points (Williams et al., 2018) we combined these data and then collapsed them further, categorising each participant as either: (i) not hypertensive (SBP <140 mmHg and DBP <90 mmHg) or (ii) hypertensive (SBP ≥140 mmHg or DBP ≥90 mmHg). Furthermore, additional analysis was conducted using mean values for SBP and DBP. All data analyses were conducted using Statistical Package for the Social Sciences version 26 (SPSS Inc., an IBM Company, Armonk, NY).

Table 1: Characteristics of participants included in the analysis [a]

Total sample of 2012 and 2016 Health Survey for England (n = 10,519)	
	Total sample % (n)
Sex	
Male	43.7 (4,594)
Female	56.3 (5,925)
Age (years)	
16-34	20.6 (2,171)
35-54	32.8 (3,452)
55-74	34.5 (3,625)
≥75	12.1 (1,271)
Education	
Graduate /degree	26.0 (2,732)
Higher education (below degree)	47.1 (4, 955)
No qualification	21.7 (2,277)
Student (full-time)	5.2 (546)
Income Tertiles	
Highest	35.3 (3,026)
Middle	34.0 (2,917)
Lowest	30.7 (2,638)
Body Mass Index (kg/m^2)	
Underweight (<18.5)	1.4 (132)
Normal (≥18.5-<25)	33.9 (3,184)
Overweight (25– <30)	37.7 (3,541)
Obese (≥30)	27.1 (2,548)
Smoking status	
Never smoked	50.3 (5,271)
Ex-smoker	33.5 (3,505)
Current smoker	16.2 (1,701)
Alcohol	
None (0)/less than weekly	45.9 (4,805)

Weekly	54.1 (5,670)
Hypertension (≥130 mmHg or ≥80 mmHg)[b]	
Yes	45.2 (4,003)
No	54.8 (4,858)
Prescribed medication for blood pressure	
Yes	18.6 (1,960)
No	81.4 (8,559)
Longstanding illness	
Yes	27.3 (2,865)
No	72.7 (7,647)
Aerobic MVPA level (minutes/week)	
<30 minutes/week 'inactive'	23.2 (2,438)
30-149 minutes/week 'insufficiently active'	16.6 (1,724)
≥ 150 minutes/week 'active'	60.0 (6,233)
Sedentary behavior (min/ day)	
Low (<480 minutes/day)	86.9 (9,114)
High (≥480 minutes/day)	13.1 (1,369)

[a] Numbers vary slightly because of missing data for some characteristic variables

Missing data equated to: education 0.1% (n=9), household income 18.4% (n=1,938), BMI 10.6% (n=1,114), alcohol consumption 0.4% (n=44), smoking status 0.4% (n=42), hypertension 15.8% (n=1,658), longstanding illness 0.1% (n=7), aerobic MVPA 1.2% (n=124), and sedentary behaviour 0.3% (n=36).

[b] Defined in 2017 ACC/AHA/AAPA/ABC/ACPM/AGS/APhA/ASH/ASPC/NMA/PCNA guideline for the prevention, detection, evaluation, and management of high blood pressure in adults: A report of the American college of cardiology/American heart association task force on clinical practice guidelines.

4.3 Results

Sample description

Data from 10,519 adults aged ≥16 years were included in our analysis. The sample characteristics are shown in Table 1. In brief, over half were female (56.3%), one-third were either aged between 35-54 years (32.8%) or 55-74 years (34.5%), and 35.3% represented in the highest household income. Over half were classified as either overweight or obese (64.8%), reported weekly alcohol consumption, approximately half had never smoked, and just over a quarter self-reported having a longstanding illness. Over half (60%) reported sufficient MVPA, and most (86.9%) had low levels of sedentary behaviour. Just under half were classified as hypertensive (according to the ACC/AHA guidelines), with is number reducing to ~22% when adopting the ESC/ESH classification for hypertension, with under a quarter of the sample taking prescribed medication of blood pressure (18.6%) (see Table 1).

Table 2: Muscle-strengthening exercise behaviour characteristics of participants included in the analysis

Total sample of 2012 and 2016 Health Survey for England (n = 10,519)	
	Total Sample % (n)
Muscle-strengthening exercise – Duration (minutes/session)	
Own Bodyweight	
0 minutes	85.6 (9,006)
10-20 minutes	9.1 (960)
21-59 minutes	3.4 (355)
60+ minutes	1.9 (198)
Gym-based strength	
0 minutes	90.6 (9,530)

10-20 minutes	3.9 (406)
21-59 minutes	3.4 (362)
60+ minutes	2.1 (221)
All MSE [a]	
0 minutes	81.1 (8,533)
10-20 minutes	8.3 (875)
21-59 minutes	6.1 (637)
60+ minutes	4.5 (474)
Muscle-strengthening exercise – Volume (minutes/week)	
Own Bodyweight	
None	85.6 (9,006)
Low < mean [b]	10.8 (1,141)
High ≥ mean [b]	3.5 (372)
Gym-based strength	
None	90.6 (9,533)
Low < mean [c]	6.6 (694)
High ≥ mean [c]	2.8 (292)
All MSE [a]	
None	81.1 (8,535)
Low < mean [d]	13.9 (1,459)
High ≥ mean [d]	5.0 (525)

[a] All MSE: Own bodyweight and gym-based strength combined

[b] Mean value: Own bodyweight 76.5 minutes/week

[c] Mean value: Gym-based strength 96.3 minutes/week

[d] Mean value: All MSE 106.2 minutes/week

The MSE behaviour characteristics of the sample are described in Table 2. In brief, over 85% of participants reported doing no own bodyweight exercise, with just over 90% reporting doing no gym-based strength work. Some participants (18.9%) reported doing both modes of MSE. The highest prevalence of those who reported doing either mode (own bodyweight or gym-based strength work) or the modes combined (all MSE) was for bouts of between 10-20 minutes/session.

Prevalence ratios for clinically assessed hypertension

The unadjusted and adjusted prevalence ratios (APRs) for hypertension are shown in Supplemental Digital Content 4. Since the prevalence ratios (PRs) were similar, after adjusting for sociodemographic characteristics, sedentary time, and MVPA, we will only present the results of the most adjusted model (Model D) here (all data shown in Supplemental Digital Content 4).

Figure 1 shows the associations between the session duration categories of the three MSE exposure modes and hypertension. When compared to the reference group (0 minutes), the APRs for each MSE mode followed an inverse linear-gradient for own bodyweight (APRs 0.78; 0.75; 0.61), gym-based strength (APRs 0.90; 0.76; 0.66); and all MSE (APRs 0.83; 0.78; 0.65) for 10-20; 21-59; and 60+ minutes/session respectively.

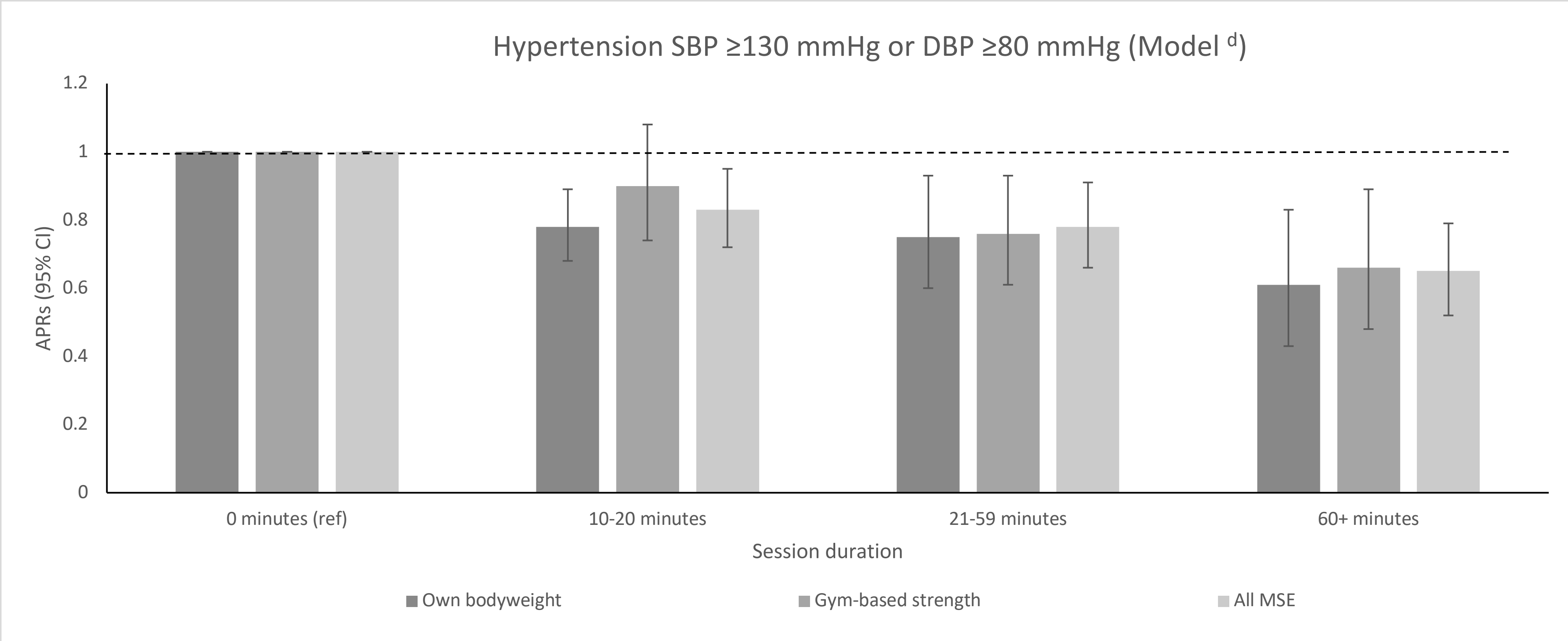


Figure 1. Analysis of the relationship between muscle-strengthening exercise (duration/ session) between clinically assessed hypertension relative to two specific modes of muscle-strengthening exercise, and modes combined (APRs; 95% CI).

APRs:	adjusted prevalence ratios, with 95% Confidence Interval (CI)
All MSE:	Own bodyweight and Gym-based strength combined

Model [d] adjusted for sociodemographic factors (sex, age, education, income tertiles) and lifestyle factors (BMI, weekly alcohol consumption, smoking status, blood pressure medication, longstanding illness), weekly aerobic MVPA, and weekly sedentary time

Figure 2 shows the associations between MSE volume (none, <mean, ≥mean) and hypertension. An inverse linear-gradient (< mean; ≥ mean respectively) was observed for the total weekly volumes for gym-based strength (APRs 0.84; 0.70) and all MSE (APRs 0.79; 0.74) with the lowest APRs observed when undertaking high volumes (≥mean), compared to those doing none (reference group). However, a linear trend was observed among those doing own bodyweight exercise (APRs 0.74; 0.80) with the lowest APRs for undertaking < mean (low volume) when compared to the reference group (none).

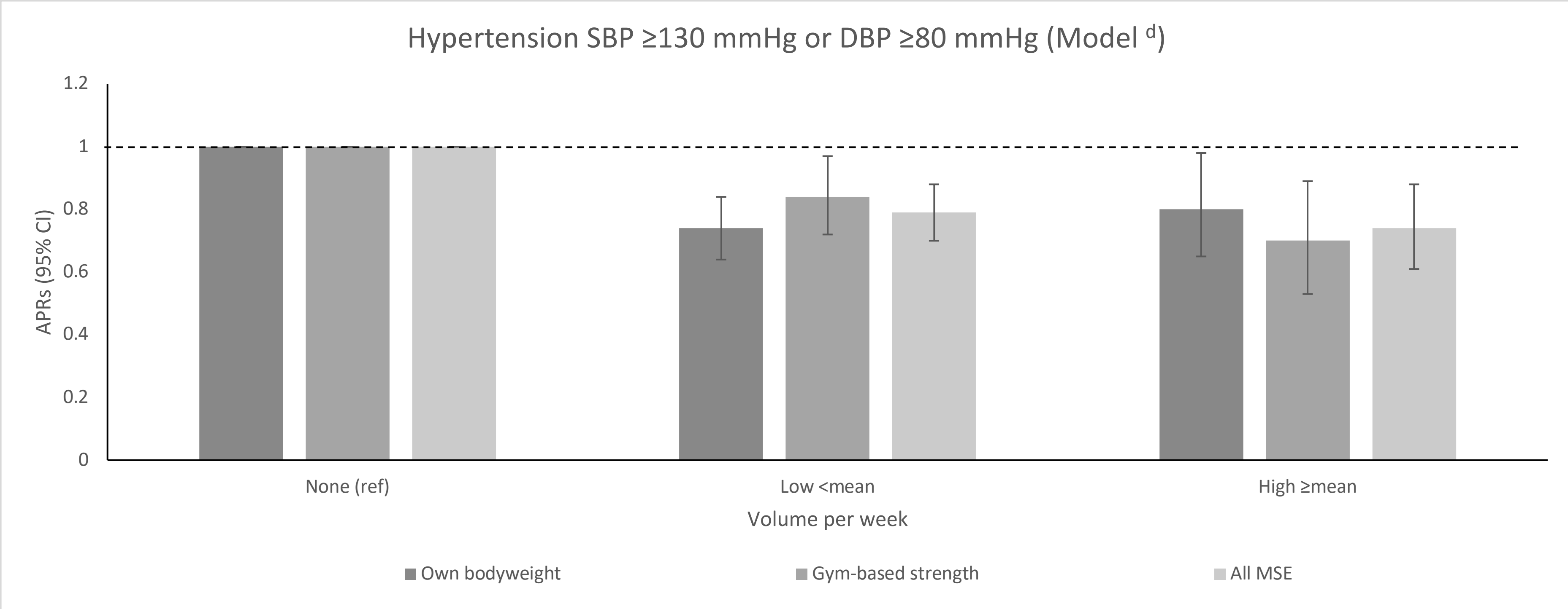


Figure 2. Analysis of the relationship between muscle-strengthening exercise (volume/week: frequency/week x duration/session) between clinically assessed hypertension relative to two specific modes of muscle-strengthening exercise, and modes combined (APRs; 95%CI).

APRs: adjusted prevalence ratios and 95% Confidence Intervals (CI)

All MSE: Own bodyweight and Gym-based strength combined

Model [d] adjusted for sociodemographic factors (sex, age, education, income tertiles) and lifestyle factors (BMI, weekly alcohol consumption, smoking status, blood pressure medication, longstanding illness), weekly aerobic MVPA, and weekly sedentary time

Mean values: own bodyweight 76.5 minutes/week, gym-based strength 96.3 minutes/week, all MSE 106.2 minutes/week

Analyses using mean data

Furthermore, we completed unadjusted analyses using the calculated mean values for both SBP and DBP (Supplemental Digital Content 4.3). Overall, the inverse linear trends remained similar for each MSE mode (own bodyweight and gym-based strength), and the modes combined. However, the most favourable reductions in combined SBP and DBP were seen amongst those who reported ≥ 60 minutes/session of gym-based strength exercise. We observed an overall difference in SBP of 4.99 mmHg in this group, when compared to those who did none (0 minutes/session), and a difference of 5.61 mmHg in DBP. The most favourable reductions in SBP and DBP were also seen in those reporting ≥mean/week of gym-based strength exercise, compared to those reporting none (-4.26 mmHg SBP, and -4.98 mmHg DBP).

Sensitivity analyses

Analyses stratified for sex, age, BMI, smoking status, longstanding illness, and aerobic MVPA variables are shown in the supplemental digital content files (Supplemental Digital Content 5 and Supplemental Digital Content 6). In brief, similar associations between 'all MSE' (duration/session) and hypertension were observed among males (APR range: 0.64-0.92) vs. females (APR range: 0.58-0.72), younger (16-54 years) (APR range: 0.77-0.90) vs. older adults (≥55 years) (APR range: 0.76-0.98), and underweight/normal BMI (≤ 24.99 kg/m^2) (APR range 0.63-0.70) vs. overweight/obese (BMI ≥ 25.0 kg/m^2) (APR range 0.73-0.99).

When compared to those who had never smoked (APR range: 0.62-0.84), the associations between all MSE (duration/session) and hypertension were generally stronger among current smokers (APR range: 0.57-0.72). Compared to those who reported having a longstanding illness, (APR range: 0.73-1.05), the associations were mixed, with only those who reported having no longstanding illness and a duration/session greater than 60 minutes (APR 0.61; 95% CI: 0.47-0.76) showing the strongest association. Amongst those assessed as either sufficiently active (≥150 MVPA minutes/week) (APR range 0.68-0.87), or insufficiently active (≤149 MVPA minutes/week), all APRs were lower (APR range 0.66-0.84). For all MSE durations/session (compared to those doing none), with the strongest associations for both groups (sufficient/insufficient) amongst those reporting ≥60 minutes of all MSE.

For volume per week of all MSE, for the sensitivity analyses, we found similar associations with hypertension as those for duration/session. Briefly, the associations were stronger in females (APR range 0.59-0.69) vs males (APR range 0.74-0.85), younger (APR range 0.79-0.84) vs. older adults (APR range 0.92-0.97), underweight/normal BMI (APR range 0.63-0.76) vs. overweight/obese (0.80-0.94), current smokers (APR range 0.51-0.72) vs. those who had never smoked (APR range 0.78-0.79), without longstanding illness (APR range 0.72-0.81) vs. reporting having a longstanding illness (APR range 0.76-0.92), and those assessed as sufficiently active (APR range 0.76-0.82) vs. insufficiently active (APR range 0.78-1.10).

Additional stratified analyses were completed using the ESC/ESH classification for hypertension (Williams et al., 2018), with adjustments for sex, age, BMI, smoking status, longstanding illness, and aerobic MVPA variables shown in the supplemental digital content files (Supplemental Digital Content 5.1 and Supplemental Digital Content 6.1). In brief, similar associations between 'all MSE' (duration/session; volume/week) and hypertension were found, with the trends remaining similar using the American and European classifications, except for age (duration per session and volume per week) and smoking status (duration per session) (see Supplemental Digital Content 5.2 and 6.2).

4.4 Discussion

Among a large community sample of adults, any MSE, irrespective of mode, duration or volume, was associated with a lower prevalence of clinically assessed hypertension. In addition, there was evidence for a dose-dependent association between the duration and volume of MSE and hypertension. Moreover, all associations remained after the adjustment for key confounding factors (e.g. age, sex, income, aerobic MVPA, sedentary behaviour). Additionally, associations between MSE remained overall similar regardless of the classification used to define hypertension, and when SBP and DBP were expressed as mean values. While these findings need to be replicated in future prospective studies, our results suggest that undertaking any MSE (regardless of mode, duration or volume) may be protective against hypertension.

The epidemiological evidence describing the relationship between hypertension and the volume and duration of aerobic MVPA is well established (Huai et al., 2013; Liu et al., 2017; S. P. Whelton, Chin, Xin, & He, 2002). However, despite the strong clinical evidence linking MSE to a reduced risk of hypertension (Cornelissen & Smart, 2013; Gordon et al., 2018; Saeidifard et al., 2019), few epidemiological studies have examined this relationship at the population level. In comparison to the limited previous research, we found similar associations between MSE and prevalent hypertension as those from large cross-sectional studies by Bennie, Lee, et al. (2020) and Loprinzi and Loenneke (2015) . However, those studies only focused on MSE frequency (times/week). Our study is important because it is the first to assess the additional components of duration and volume of MSE and their relationship with prevalent hypertension.

Due to the cross-sectional nature of this study, we are not able to comment on the length of time that participants have been undertaking MSE (data not provided). However, in comparison to a recent review and meta-analysis (Ashton et al., 2018), on the effects of MSE on cardiometabolic health outcomes, our data showed similar reductions in SBP and DBP compared to those reporting no MSE. These results add to the body of knowledge regarding the positive effects of undertaking MSE on clinically assessed blood pressure. Reaffirming the benefit of this exercise modality as possible adjunct therapy in the treatment and management of hypertension.

The multiple sensitivity analyses (sex, age, BMI, smoking status, longstanding illness, and aerobic MVPA) suggested that with very few exceptions most associations between MSE and the risk of hypertension were similar. Amongst our sample, however, those with a longstanding illness (undertaking all MSE for a duration/session of ≥60 minutes), or those reporting insufficient aerobic MVPA (undertaking all MSE at volumes >106 minutes/week), were at an increased risk of hypertension (APR range 1.05-1.10). This possible negative relationship between hypertension, insufficient aerobic MVPA and higher volumes of MSE was also evident in the study by Bennie et al. (2018). Despite this, overall our results add further support to future health promotion messaging that doing some MSE is better than none. Additionally, these findings support the continued prescription of MSE might be a valid adjunct therapy in the prevention and treatment management of hypertension.

There are several physiological mechanisms that may explain the relationship between MSE and hypertension observed in the current study. However, it should be acknowledged that there is limited, and often conflicting, evidence concerning the specific mechanisms of this exercise mode and its hypotensive effect (Brook et al., 2013; Simão, Fleck, Polito, Monteiro, & Farinatti, 2005). Some studies report mixed findings concerning changes in endothelial function (e.g., altered sympathetic tone) (Rakobowchuk, McGowan, de Groot, Hartman, et al., 2005), arterial compliance (Rakobowchuk, McGowan, de Groot, Bruinsma, et al., 2005), sympathetic activity (Carter, Ray, Downs, & Cooke, 2003; Collier et al., 2009; Rezk, Marrache, Tinucci, Mion, & Forjaz, 2006), variability in cardiac output (Rezk et al., 2006), and arterial elasticity (Brook et al., 2013; Collier et al., 2008) as potential mechanisms explaining the relationship between MSE and hypertension. Importantly, however from a health promotion perspective, within these studies (Brook et al., 2013; Carter et al., 2003; Collier et al., 2008; Rakobowchuk, McGowan, de Groot, Bruinsma, et al., 2005; Rossi, Moullec, Lavoie, Gour-Provençal, & Bacon, 2013) there is no evidence of harm linked with doing MSE. Moreover, it has been argued that the additional physiological benefits of doing MSE (increase in lean body mass, improved VO_2max, reduced abdominal fat (Ashton et al., 2018; Cornelissen, Fagard, Coeckelberghs, & Vanhees, 2011), and improved insulin sensitivity (Ashton et al., 2018)) may provide for alternative mechanisms in reducing blood pressure in prehypertensive and hypertensive populations.

While most physical activity guidelines include recommendations for undertaking MSE "*on at least two days a week*" (World Health Organization, 2010), currently they do not include recommendations for duration nor volume. This ongoing gap in research, that there need to be more studies examining the dose-response association between MSE and health outcomes, was highlighted in the 2020 WHO guidelines (Bull et al., 2020). The largest portion of our sample undertook own bodyweight exercise for session durations between 10-20 minutes, and at a lower total weekly volume. However, it should be highlighted that over 85% of our sample did no own bodyweight exercise, which suggests most adults do not routinely engage in this exercise mode.

From a public health promotion perspective, our findings suggest that among those currently doing none, small to moderate increases in MSE may have a positive influence on hypertension, regardless of MSE mode (own body weight vs gym-based). Globally the level of participation in MSE is low when compared to other exercise modes such as aerobic MVPA (Bennie, De Cocker, Teychenne, Brown, & Biddle, 2019; Bennie et al., 2018; Bennie, Shakespear-Druery, & De Cocker, 2020). Therefore, a way to increase participation in MSE, at the population level, could be to include messaging that highlights the relative simplistic nature of performing such exercise, such as own bodyweight exercises (i.e. no; special equipment; facilities; knowledge; or support required from trained professionals). Our results may suggest that future promotion of MSE should also contain the message that "doing some is better than doing none", and this is consistent with the 2020 WHO 'good practice statements' (World Health Organization, 2020b). As the world continues to face the challenges associated with the COVID-19 pandemic, it is timely that simple health promotion messaging is at the forefront, as many people may have had to modify their usual work and or exercise behaviours due to periods of lockdown or restrictions. Therefore, this portion of the population may be more receptive to what could be considered simple changes to their exercise behaviours that may indeed have a long-lasting and positive benefit on their health.

Strengths and limitations

A key strength of this study is that it is the first to explore the relationship between specific modes of MSE and clinically assessed hypertension, in a large population sample of adults. The use of data that has been gathered through standardised recruitment and data collection procedure is another strength, as our findings will be able to be compared with future HSE data and other large population surveillance studies.

Limitations of this study primarily include the use of cross-sectional data, this precluding statements regarding causality (Setia, 2016). A further limitation includes the risks associated with using self-reported data, as the responses may have been influenced by responder recall bias (e.g., social desirability or over/under reporting of actual behaviour). The

HSE survey instrument limits participant responses to those undertaking MSE bouts of at least 10 minutes or more, hence, we were not able to analyse if bouts of less than 10 minutes influenced the prevalence of hypertension. Furthermore, the HSE does not assess MSE parameters such as sets, repetitions, target muscle-groups, tempo, or rest periods between exercises, which further limits the understanding of the benefits of this exercise modality and hypertension at the population level. Additionally, the indicator of having hypertension does not account for the temporality or severity of the condition, or for participant management of their condition. A further limitation was that our sample had a higher prevalence of those meeting the aerobic MVPA recommendations (Scholes, 2017). Additional research, amongst large populations, that includes the measurement of MSE intensity is also needed, as exercising at a lower intensity may have greater hypotensive effects than performing MSE at higher intensities (Rezk et al., 2006).

4.5 Conclusion

Among a large sample of adults, compared to those doing no MSE, engaging in any (irrespective of mode, duration, or volume) was associated with a lower prevalence of clinically assessed hypertension. While prospective cohort studies are needed to confirm these preliminary findings, among those currently doing no MSE, small-to-moderate increase in participation in this exercise mode are likely to be beneficial in the prevention and management of hypertension at the population level.

Acknowledgements

This research has been supported by an Australian Government Research Training Program Scholarship and a University of Southern Queensland Research Training Program Stipend Scholarship.

Authors' contributions

JSD, KDC, SJHB, and JAB conceptualised the study and developed the research plan. JSD conducted the data analysis. JSD drafted the initial manuscript. JAB, KDC, and SJHB provided guidance on the study and critically reviewed the manuscript. All authors read and approved the final version of the manuscript, and agree with the order of presentation of the authors.

4.6 References

Ashton, R. E., Tew, G. A., Aning, J. J., Gilbert, S. E., Lewis, L., & Saxton, J. M. (2018). Effects of short-term, medium-term and long-term resistance exercise training on cardiometabolic health outcomes in adults: Systematic review with meta-analysis. *British Journal of Sports Medicine, 0*, 1-9. doi:10.1136/bjsports-2017-098970

Bennie, J. A., De Cocker, K., Teychenne, M. J., Brown, W. J., & Biddle, S. J. H. (2019). The epidemiology of aerobic physical activity and muscle-strengthening activity guideline adherence among 383,928 U.S. adults. *International Journal of Behavioral Nutrition and Physical Activity, 16*(1), 1-11. doi:10.1186/s12966-019-0797-2

Bennie, J. A., Ding, D., Khan, A., Stamatakis, E., Biddle, S. J. H., & Kim, J. (2018). Run, lift, or both? Associations between concurrent aerobic–muscle strengthening exercise with adverse cardiometabolic biomarkers among Korean adults. *European Journal of Preventive Cardiology, 0*(0), 1-11. doi:10.1177/2047487318817899

Bennie, J. A., Lee, D.-c., Brellenthin, A. G., & De Cocker, K. (2020). Muscle-strengthening exercise and prevalent hypertension among 1.5 million adults: A little is better than none. *Journal of Hypertension, 38*(8), 1466-1473. doi:10.1097/hjh.0000000000002415

Bennie, J. A., Shakespear-Druery, J., & De Cocker, K. (2020). Muscle-strengthening exercise epidemiology: A new frontier in chronic disease prevention. *Sports Medicine - Open, 6*(1), 1-8. doi:10.1186/s40798-020-00271-w

Bridges, S., Doyle, M., Fuller, E., Knott, C., Mindell, J., Moody, A., . . . Whalley, R. (2013). *Health Survey for England 2012: Volume 2: Methods and documentation*. England: Health and Social Care Information Centre Retrieved from https://files.digital.nhs.uk/publicationimport/pub13xxx/pub13218/hse2012-methods-and-docs.pdf.

Bridges, S., & Mindell, J. (2016). *Health Survey for England 2016: Field documents and measurement protocols*. England: Health and Social Care Information Centre Retrieved from https://files.digital.nhs.uk/pdf/q/j/hse2016-documentation.pdf.

Brook, R. D., Appel, L. J., Rubenfire, M., Ogedegbe, G., Bisognano, J. D., Elliott, W. J., . . . Rajagopalan, S. (2013). Beyond medications and diet: Alternative approaches to lowering blood pressure: A scientific statement from the American Heart Association. *Hypertension, 61*(6), 1360-1383. doi:10.1161/HYP.0b013e318293645f

Bull, F. C., Al-Ansari, S. S., Biddle, S., Borodulin, K., Buman, M. P., Cardon, G., . . . Willumsen, J. F. (2020). World Health Organization 2020 guidelines on physical activity and sedentary behaviour. *British Journal of Sports Medicine, 54*(24), 1451. doi:10.1136/bjsports-2020-102955

Carnethon, M. R., Gidding, S. S., Nehgme, R., Sidney, S., Jacobs, D. R., Jr., Liu, K., . . . Liu, K. (2003). Cardiorespiratory fitness in young adulthood and the development of cardiovascular disease risk factors. *JAMA: Journal of the American Medical Association, 290*(23), 3092-3100.

Carter, J. R., Ray, C. A., Downs, E. M., & Cooke, W. H. (2003). Strength training reduces arterial blood pressure but not sympathetic neural activity in young normotensive subjects. *Journal of Applied Physiology, 94*(6), 2212-2216. doi:10.1152/japplphysiol.01109.2002

Ciccolo, J. T., Gabriel, K. K. P., Macera, C., & Ainsworth, B. E. (2010). Association between self-reported resistance training and self-rated health in a national sample of U.S. men and women. *Journal of Physical Activity and Health, 7*(3), 289-298. doi:10.1123/jpah.7.3.289

Cohen, J., Cohen, P., West, S., & Aiken, L. (2003). *Applied multiple regression/correlation analysis for the behavioral sciences* (3rd ed.). New York: Routledge.

Collier, S. R., Kanaley, J. A., Carhart Jr, R., Frechette, V., Tobin, M. M., Hall, A. K., . . . Fernhall, B. (2008). Effect of 4 weeks of aerobic or resistance exercise training on arterial stiffness, blood flow and blood pressure in pre- and stage-1 hypertensives. *Journal of Human Hypertension, 22*(10), 678-686. doi:10.1038/jhh.2008.36

Collier, S. R., Kanaley, J. A., Carhart, R., Jr., Frechette, V., Tobin, M. M., Bennett, N., . . . Fernhall, B. (2009). Cardiac autonomic function and baroreflex changes following 4 weeks of resistance versus aerobic training in individuals with pre-hypertension. *Acta Physiol (Oxf), 195*(3), 339-348. doi:10.1111/j.1748-1716.2008.01897.x

Cornelissen, V. A., Fagard, R. H., Coeckelberghs, E., & Vanhees, L. (2011). Impact of resistance training on blood pressure and other cardiovascular risk factors: A meta-analysis of randomized, controlled trials. *Hypertension, 58*(5), 950-958. doi:10.1161/HYPERTENSIONAHA.111.177071

Cornelissen, V. A., & Smart, N. A. (2013). Exercise training for blood pressure: A systematic review and meta-analysis. *Journal of the American Heart Association, 2*(1), 1-9. doi:10.1161/JAHA.112.004473

Forouzanfar, M. H., Liu, P., Roth, G. A., Ng, M., Biryukov, S., Marczak, L., . . . Murray, C. J. L. (2017). Global burden of hypertension and systolic blood pressure of at least 110 to 115 mm Hg, 1990-2015. *Jama, 317*(2), 165-182. doi:10.1001/jama.2016.19043

Gordon, B. R., McDowell, C. P., Hallgren, M., Meyer, J. D., Lyons, M., & Herring, M. P. (2018). Association of efficacy of resistance exercise training with depressive symptoms: Meta-analysis and meta-regression analysis of randomized clinical trials. *JAMA Psychiatry, 75*(6), 566-576. doi:10.1001/jamapsychiatry.2018.0572

Health and Social Care Information Centre. (2017). *Health Survey for England 2016: Methods*. England: NHS Digital Retrieved from http://healthsurvey.hscic.gov.uk/media/63778/HSE2016-Methods-text.pdf.

Huai, P., Xun, H., Reilly, K. H., Wang, Y., Ma, W., & Xi, B. (2013). Physical activity and risk of hypertension: A meta-analysis of prospective cohort studies. *Hypertension, 62*(6), 1021-1026. doi:10.1161/HYPERTENSIONAHA.113.01965

Hubert, H. B., Feinleib, M., McNamara, P. M., & Castelli, W. P. (1983). Obesity as an independent risk factor for cardiovascular disease: A 26-year follow-up of participants in the Framingham Heart Study. *Circulation, 67*(5), 968-977. doi:10.1161/01.CIR.67.5.968

Karmali, K. N., Persell, S. D., Perel, P., Lloyd-Jones, D. M., Berendsen, M. A., & Huffman, M. D. (2017). Risk scoring for the primary prevention of cardiovascular disease. *Cochrane Database of Systematic Reviews, 2017*(3), 1-130. doi:10.1002/14651858.CD006887.pub4

Kearney, P. M., Whelton, M., Reynolds, K., Muntner, P., Whelton, P. K., & He, J. (2005). Global burden of hypertension: Analysis of worldwide data. *The Lancet, 365*(9455), 217-223. doi:10.1016/S0140-6736(05)17741-1

Kotsis, V., Stabouli, S., Papakatsika, S., Rizos, Z., & Parati, G. (2010). Mechanisms of obesity-induced hypertension. *Hypertension Research, 33*(5), 386-393. doi:10.1038/hr.2010.9

Liu, X., Zhang, D., Liu, Y., Sun, X., Han, C., Wang, B., . . . Zhang, M. (2017). Dose-response association between physical activity and incident hypertension: A systematic review and meta-analysis of cohort studies. *Hypertension, 69*(5), 813-820. doi:10.1161/hypertensionaha.116.08994

Loprinzi, P. D., & Loenneke, J. P. (2015). Engagement in muscular strengthening activities is associated with better sleep. *Preventive Medicine Reports, 2*, 927-929. doi:10.1016/j.pmedr.2015.10.013

MacDonald, H. V., Johnson, B. T., Huedo-Medina, T. B., Livingston, J., Forsyth, K. C., Kraemer, W. J., . . . Pescatello, L. S. (2016). Dynamic resistance training as stand-alone antihypertensive lifestyle therapy: A meta-analysis. *Journal of the American Heart Association, 5*(10), 1-34. doi:10.1161/JAHA.116.003231

Mente, A., O'Donnell, M. J., Rangarajan, S., McQueen, M. J., Poirier, P., Wielgosz, A., . . . Yusuf, S. (2014). Association of urinary sodium and potassium excretion with blood pressure. *New England Journal of Medicine, 371*(7), 601-611. doi:10.1056/NEJMoa1311989

Mindell, J., Biddulph, J. P., Hirani, V., Stamatakis, E., Craig, R., Nunn, S., & Shelton, N. (2012). Cohort profile: The Health Survey for England. *International Journal of Epidemiology, 41*(6), 1585-1593. doi:10.1093/ije/dyr199

Rakobowchuk, M., McGowan, C. L., de Groot, P. C., Bruinsma, D., Hartman, J. W., Phillips, S. M., & MacDonald, M. J. (2005). Effect of whole body resistance training on arterial compliance in young men. *Exp Physiol, 90*(4), 645-651. doi:10.1113/expphysiol.2004.029504

Rakobowchuk, M., McGowan, C. L., de Groot, P. C., Hartman, J. W., Phillips, S. M., & MacDonald, M. J. (2005). Endothelial function of young healthy males following whole body resistance training. *J Appl Physiol, 98*(6), 2185-2190. doi:10.1152/japplphysiol.01290.2004

Rezk, C. C., Marrache, R. C., Tinucci, T., Mion, D., Jr., & Forjaz, C. L. (2006). Post-resistance exercise hypotension, hemodynamics, and heart rate variability: Influence of exercise intensity. *Eur J Appl Physiol, 98*(1), 105-112. doi:10.1007/s00421-006-0257-y

Rhodes, R. E., Lubans, D. R., Karunamuni, N., Kennedy, S., & Plotnikoff, R. (2017). Factors associated with participation in resistance training: A systematic review. *British Journal of Sports Medicine, 51*(20), 1-9. doi:10.1136/bjsports-2016-096950

Rossi, A. M., Moullec, G., Lavoie, K. L., Gour-Provençal, G., & Bacon, S. L. (2013). The evolution of a Canadian hypertension education program recommendation: The impact of resistance training on resting blood pressure in adults as an example. *Canadian Journal of Cardiology, 29*(5), 622-627. doi:10.1016/j.cjca.2013.02.010

Saeidifard, F., Medina-Inojosa, J. R., West, C. P., Olson, T. P., Somers, V. K., Bonikowske, A. R., . . . Lopez-Jimenez, F. (2019). The association of resistance training with mortality: A systematic review and meta-analysis. *European Journal of Preventive Cardiology, 26*(15), 1647-1665. doi:10.1177/2047487319850718

Scholes, S. (2017). *Health Survey for England 2016: Physical activity in adults*. (ISBN: 978-1-78734-099-2). NHS Digital Retrieved from http://healthsurvey.hscic.gov.uk/media/63730/HSE16-Adult-phy-act.pdf.

Setia, M. S. (2016). Methodology series module 3: Cross-sectional studies. *Indian Journal of Dermatology, 61*(3), 261-264. doi:10.4103/0019-5154.182410

Simão, R., Fleck, S. J., Polito, M., Monteiro, W., & Farinatti, P. (2005). Effects of resistance training intensity, volume, and session format on the postexercise hypotensive response. *Journal of Strength and Conditioning Research, 19*(4), 853-858. doi:10.1519/00124278-200511000-00022

Strain, T., Milton, K., Dall, P., Standage, M., & Mutrie, N. (2019). How are we measuring physical activity and sedentary behaviour in the four home nations of the UK? A narrative review of current surveillance measures and future directions. *British Journal of Sports Medicine*, 1-9. doi:10.1136/bjsports-2018-100355

UK Data Service. (2016). *HSE 2016: HSE Questionnaires and Showcards*. England: Health and Social Care Information Centre Retrieved from https://beta.ukdataservice.ac.uk/datacatalogue/studies/study?id=8334&type=Data%20catalogue#!/documentation.

Ussher, M. H., Taylor, A. H., & Faulkner, G. E. (2014). Exercise interventions for smoking cessation. *Cochrane Database of Systematic Reviews, 8*(CD002295), 1-80.

Van Der Ploeg, H. P., Chey, T., Korda, R. J., Banks, E., & Bauman, A. (2012). Sitting time and all-cause mortality risk in 222 497

Australian adults. *Archives of Internal Medicine, 172*(6), 494-500. doi:10.1001/archinternmed.2011.2174

Whelton, P. K., Carey, R. M., Aronow, W. S., Casey, D. E., Collins, K. J., Himmelfarb, C. D., . . . Wright, J. T. (2018). 2017 ACC/AHA/AAPA/ABC/ACPM/AGS/APhA/ASH/ASPC/NMA/PCNA guideline for the prevention, detection, evaluation, and management of high blood pressure in adults: A report of the American college of cardiology/American heart association task force on clinical practice guidelines. *Hypertension, 71*(6), e13-e115. doi:10.1161/HYP.0000000000000065

Whelton, S. P., Chin, A., Xin, X., & He, J. (2002). Effect of aerobic exercise on blood pressure: A meta-analysis of randomized, controlled trials. *Annals of Internal Medicine, 136*(7), 493-503. doi:10.7326/0003-4819-136-7-200204020-00006

Williams, B., Mancia, G., Spiering, W., Agabiti Rosei, E., Azizi, M., Burnier, M., . . . Group, E. S. D. (2018). 2018 ESC/ESH Guidelines for the management of arterial hypertension: The task force for the management of arterial hypertension of the European Society of Cardiology (ESC) and the European Society of Hypertension (ESH). *European Heart Journal, 39*(33), 3021-3104. doi:10.1093/eurheartj/ehy339

World Health Organization. (2010). *Global recommendations on physical activity for health*. Geneva, Switzerland: WHO Press.

World Health Organization. (2020a). *Noncommunicable diseases progress monitor 2020*. Retrieved from Geneva: https://www.who.int/publications-detail/ncd-progress-monitor-2020

World Health Organization. (2020b). *WHO guidelines on physical activity and sedentary behaviour*. Geneva: World Health Organization Retrieved from https://www.who.int/publications/i/item/9789240015128.

Yore, M. M., Ham, S. A., Ainsworth, B. E., Kruger, J., Reis, J. P., Kohl, H. W., III, & Macera, C. A. (2007). Reliability and validity of the instrument used in BRFSS to assess physical activity. *Medicine & Science in Sports & Exercise, 39*(8), 1267-1274. doi:10.1249/mss.0b013e3180618bbe

4.7 How the Publication Contributes to the Advancement of the Research Area

This study presented a novel assessment of the associations between MSE and clinically assessed hypertension. Adults (*N* = 10,519) provided self-reported MSE participation data, inclusive of weekly frequency and session duration, in addition to having their blood pressure measured by a trained clinician using a sphygmomanometer. Consistent with the findings reported within the previous chapter, most participants reported doing no or <10 minutes of MSE (~80%). Among those reporting MSE, associations were positive between clinically assessed hypertension and undertaking any MSE. These associations were consistent regardless of the cut-points used to classify the participants as hypertensive (i.e., using either the US or European guidelines) and remained following adjustments for confounders. These findings are important as they add to the body of knowledge regarding the associations between MSE and hypertension at the population level. Hypertension is a non-communicable disease (NCD) that is of great concern globally (World Health Organization, 2014). Financial investment into the promotion of MSE, as a suitable adjunct therapy in the treatment of hypertension, could benefit national health systems/global economies from both a financial perspective (e.g., a reduction in the costs associated with pharmacological interventions due to decreased demand), in addition to the reduced human costs through reductions in mortality and morbidity associated with hypertension (World Health Organization, 2020a).

Related to the aims of this PhD (examining the relationship between multiple constructs of MSE and chronic health), a specific limitation of the two preceding studies is that the associations only explored two specific modes of MSE, session duration and calculated weekly volumes of MSE. Data limitations precluded the analyses of other critical exercise and MSE guideline components, namely intensity and muscle groups targeted, as no instruments were available to measure these components. The next chapter will discuss the development and testing of a new surveillance instrument designed to overcome these limitations, along with some of the methodological gaps identified in chapter two (Study 1) for example through the inclusion of a preamble to describe the types of MSE to be included within participant responses and the use of consistent terminology to describe MSE.

CHAPTER 5: PAPER 4 - Muscle-Strengthening Exercise Questionnaire (MSEQ): An assessment of concurrent validity and test–retest reliability

This paper has been peer-reviewed and was accepted for publication in *BMJ Open Sport & Exercise Medicine* on 21 December 2021 as an original investigation. It was published online on 14 February 2022 and appears in the literature at the time of writing as:

Shakespear-Druery, J., De Cocker, K., Biddle, S. J. H., & Bennie, J. (2022). Muscle-Strengthening Exercise Questionnaire (MSEQ): An assessment of concurrent validity and test–retest reliability. *BMJ Open Sport & Exercise Medicine*, *8*(e001225), 1-10. https://doi.org/10.1136/bmjsem-2021-001225

The format may differ from the accepted pre-copyedited version. It has been reformatted to remain consistent with the rest of the thesis.

5.0 Abstract

Objectives: Muscle-strengthening exercise (MSE) has multiple independent health benefits and is a component of global physical activity guidelines. However, the assessment of MSE in health surveillance is often limited to the constructs of frequency (days/week), with little focus on constructs such as MSE type, muscle groups targeted, and intensity. This study describes the test-retest reliability and concurrent validity of the Muscle-Strengthening Exercise Questionnaire (MSEQ), which was developed to assess multiple MSE participation constructs.

Methods: The MSEQ was developed to assess the weekly frequency, session duration and intensity, types of MSE (e.g., weight machines, bodyweight exercise), and muscle groups targeted. Two convenience samples of adult participants were recruited. Test-retest reliability was completed online by 85 participants. Concurrent validity was assessed for 54 participants using an online 7-day MSE log.

Results: The MSEQ shows high test-retest reliability for frequency, duration, and level of intensity for each of the four MSE types (using weight machines, bodyweight exercises, resistance exercises, and holistic exercises), and for the four types combined (ρ range 0.76-0.91). For muscle groups targeted, the reliability ranged mostly from moderate-to-substantial for each of the four MSE types (κ range 0.44-0.78), and fair-to-moderate for the four types combined (κ range 0.35-0.51). Concurrent validity for frequency, duration, and level of intensity for each of the four MSE types, and the four types combined, was moderate-to-high (ρ range 0.30-0.77).

Conclusion: The MSEQ shows acceptable reliability and validity for four key MSE constructs. This new MSEQ survey instrument could be used to assess adults' MSE.

Keywords: resistance training, test-retest reliability, concurrent validity, health surveillance, questionnaire instrument

5.1 Introduction

Strong scientific evidence demonstrates that regular muscle-strengthening exercise (MSE: including using weight training equipment and machines, resistance bands, and doing bodyweight exercises) is linked to optimal health and wellbeing in adults (Garber et al., 2011; Piercy et al., 2018). In brief, meta-analyses and systematic reviews of controlled clinical exercise studies show that MSE leads to enhanced cardiometabolic (Ashton et al., 2018), musculoskeletal (Grgic et al., 2018), and mental health (Gordon et al., 2018), and reductions in visceral fat (Khalafi, Malandish, Rosenkranz, & Ravasi, 2021). Recent data from prospective cohort studies suggest that MSE is independently associated with a reduced risk of all-cause and disease-specific mortality (Nascimento et al., 2021; Saeidifard et al., 2019), cardiovascular disease (Shiroma et al., 2016), type 2 diabetes (Grnøtved et al., 2014; Grnøtved, Rimm, Willett, Andersen, & Hu, 2012), obesity (Brellenthin, Lee, Bennie, Sui, & Blair, 2021; Mekary et al., 2015), and some cancers (Nascimento et al., 2021).

Despite its multiple independent health benefits, and the fact that MSE was first included as part of the U.S. physical activity guidelines in 2008 (U.S. Department of Health and Human Services, 2008), and global guidelines since 2010 (Bull et al., 2020), in comparison to moderate-to-vigorous aerobic physical activity (MVPA: e.g., walking, running, or cycling) and sedentary behaviour (low energy sitting, reclining or lying posture in waking hours), this exercise modality has received little attention in physical activity epidemiology (Bennie, Shakespear-Druery, & De Cocker, 2020; Strain, Fitzsimons, Kelly, & Mutrie, 2016). In particular, research has shown that the assessment of MSE is rare in physical activity surveillance (Milton et al., 2018). Moreover, our recent systematic review of the assessment of MSE within health surveillance highlighted two key limitations in the current assessment of MSE at the population level (Shakespear-Druery et al., 2021). First, few surveillance instruments assess MSE participation constructs beyond weekly frequency. Second, unlike aerobic MVPA and sedentary behaviour (Armstrong & Bull, 2006; Craig et al., 2003; Prince, LeBlanc, Colley, & Saunders, 2017), there is no standardized instrument for assessing MSE in health surveillance (Shakespear-Druery et al., 2021).

Developing an understanding of the surveillance of multiple MSE participation constructs is important because clinical exercise studies demonstrate that factors such as type (single vs. multi-joint; bodyweight vs. use of weight machines etc.), duration, and intensity of MSE, affect some key outcomes such as skeletal muscle size/endurance/strength (Nunes et al., 2021; Paoli, Gentil, Moro, Marcolin, & Bianco, 2017). The assessment of MSE participation constructs at the population level that goes beyond simply frequency is critical for establishing the optimal dose of this exercise modality for health in future studies (Bennie, Shakespear-Druery, et al., 2020). Furthermore, a standardized MSE assessment instrument will be essential for the population-level tracking and monitoring of this important and currently understudied health behaviour. In addition, accurate and consistent assessments of physical activity-related behaviours are key for identifying at-risk population sub-groups most in need of future large-scale public health interventions (Troiano, Stamatakis, & Bull, 2020).

This study aimed to describe the development of the Muscle-Strengthening Exercise Questionnaire (MSEQ) – a newly designed MSE assessment instrument for adults, with a specific focus on the assessment of its test-retest reliability and concurrent validity.

5.2 Methods

Study population

From January through March 2021, a sub-sample of participants was recruited from a larger online study on MSE participation, barriers/facilitators, and attitudes towards this exercise mode ('Main Study'). In this Main Study, we recruited a convenience sample of 461 adults (aged ≥18 years) via the use of social media (e.g., Facebook, Twitter, Instagram) and professional networks. At the end of the Main Study, respondents were invited to participate in further follow-up research for assessing the reliability and validity of survey items concerning their MSE participation during a usual week (MSEQ, described below). If they agreed, they were allocated, on an alternating (one for one) basis, to either: (i) Reliability Sample; or (ii) Validity Sample. Ethical approval was obtained from the University of Southern Queensland Human Ethics Committee in May 2020 (H20REA233). Informed consent was obtained from all participants. Patient and Public Involvement was not applicable for this study.

Measures

Muscle-Strengthening Exercise Questionnaire (MSEQ). The MSEQ was designed to be a brief assessment instrument for delivery in an online format. Specifically, we created a 9-item instrument that assesses key MSE constructs for use in future physical activity surveillance. The final version of the MSEQ is shown in Supplemental Digital Content 1. The initial development of the MSEQ was broadly guided by several key MSE resources, including the 2009 'American College of Sports Medicine Position Stand on Progression Models in Resistance Training for Healthy Adults' (Ratamess et al., 2009), Gaber et al.'s (2011) 'Guidance for Prescribing Exercise', and the 2018 Physical Activity Guidelines for Americans (U.S. Department of Health and Human Services, 2018). After a review of these sources and consideration of what is practical to include in a surveillance instrument, five MSE participation constructs were assessed: (i) type; (ii) frequency; (iii) duration; (iv) intensity; and (v) the muscle groups targeted. The preamble of the MSEQ, the key justifications for choosing each MSE construct and their response items are now described.

Preamble. When developing self-report instruments of physical activity-related behaviours, it is important to provide respondents with some examples of the behaviours of interest to enhance comprehension (Baranowski, 1988). Given that at the population level, ~60% of adults do no MSE (Bennie, Kolbe-Alexander, Seghers, Biddle, & Cocker, 2020), an understanding of what constitutes MSE may be limited among the general population (Shakespear-Druery et al., 2021). Therefore, to assist respondents, we provided the following statement at the beginning of the survey:

"The next set of questions are about your participation in muscle-strengthening exercise, sometimes called weight or resistance training. When thinking about muscle-strengthening exercise, we are only interested in exercises that you do during your leisure or free time, and NOT done as part of your work/job, or as a part of household activities (chores).

The types of muscle-strengthening exercise we are interested in include:

- *Using weight machines - typically in a gym or fitness centre.*
- *Bodyweight exercises - including push-ups or sit-ups.*
- *Resistance exercises – using free weights like dumbbells or resistance bands.*
- *Holistic exercises - including Yoga, Tai-Chi or Pilates".*

This phrasing was initially tested with a subset of participants (n=10) to assess readability and comprehension. After this consultation, minor changes were made to the final preamble.

Type. At present, MSE surveillance instruments typically include a wide variety of MSE-related activities grouped into one category (Shakespear-Druery et al., 2021). For example, the Behavioral Risk Factor

Surveillance System (BRFSS), the most commonly used MSE surveillance instrument (Shakespear-Druery et al., 2021), combines diverse activities such as 'using weight machines', 'free weights', 'elastic bands', 'yoga', or 'sit-ups or push-ups' (Yore et al., 2007). The limitation of combining all MSE types into a single group is that it is not possible to examine patterns and prevalence of different MSE-related behaviours and, most importantly, determine the relationship between separate MSE types and health. To address this limitation, in the MSEQ, we selected four MSE types. These were: (i) 'Use of weight machines' (e.g. leg press, chest press, lat pulldown); (ii) 'Bodyweight exercises' (including push-ups, sit-ups); (iii) 'Resistance exercises' (using resistance bands or free weights like dumbbells); and (iv) 'Holistic exercises' (including Yoga, Tai-Chi and Pilates)'. The terminology for, and examples of, the MSE types are largely consistent with those within the key texts in this field (American College of Sports Medicine, 2009; Garber et al., 2011; U.S. Department of Health and Human Services, 2018). For each of these four MSE types, participants were asked to complete the following items (see Supplemental Digital Content 1).

Frequency (**Items 2 and 3):** In MSE surveillance, weekly frequency is the most commonly assessed MSE construct (Shakespear-Druery et al., 2021). Accordingly, for comparisons to previous instruments, we included a similar question to that used in the BRFSS survey (Yore et al., 2007), where respondents were asked for all MSE: "*How many days, in a usual week, do you do muscle-strengthening exercise?* (Item 2). Response selections were: (i) 'none'; (ii) '1'; (iii) '2'; (iv) '3'; (v) '4'; (vi) '5', (vii) '6', and (viii) '7 days'. This question was asked separately for each type to understand the frequency of the four specific MSE types given above (Item 3). The response options for this question were the same as all MSE (e.g., [i] 'none' to [viii] '7 days').

Duration (Item 4). Despite clinical studies showing a positive dose-response relationship between time spent doing MSE and muscle size and strength (Dankel et al., 2017), duration is rarely assessed in MSE surveillance (Bennie, Shakespear-Druery, et al., 2020). Therefore, to gain a better understanding of this construct, respondents were asked: *"In a usual week please indicate how long you spend doing each of the following types of muscle-strengthening exercise? ... in a usual session".* Response options in minutes were: (i) '0'; (ii) 'less than 10'; (iii) '10-20', (iv) '21-30'; (v) '31-40'; (vi) '41-50', (vii) '51-60', (viii) '≥ 60 minutes spent in a usual session'. This question was asked separately for each of the four MSE types.

Muscle groups targeted (Items 5-8): The 2008 Physical Activity Guidelines for Americans first introduced the recommendation that when doing MSE, an adult should engage all major muscle groups (U.S. Department of Health and Human Services, 2008). This recommendation is based on the clinical evidence that suggests that using several large muscle groups is more effective in maintaining and increasing muscle strength and bone mineral density (Zhao, Zhao, & Xu, 2015), compared to using the smaller muscle groups (Physical Activity Guidelines Advisory Committee, 2008). However, few existing MSE instruments assess muscle groups targeted (Loustalot, Carlson, Kruger, Buchner, & Fulton, 2013). To guide which muscle groups to include in the MSEQ, we used the ACSM definitions, which define all major muscle groups as seven separate groups: legs, hips, back, abdomen, chest, shoulders, and arms (Pollock et al., 1998). Accordingly, in the MSEQ, respondents were asked, "*In a usual week please indicate which muscle groups you use when you do each of the following types of muscle-strengthening exercise?"*

Response options of (i) 'yes' or (ii) 'no' were provided for the following seven different muscle groups, and to assist with respondent comprehension, we provided examples of MSE activities that target each group: (i) 'legs (e.g. squats, lunges, bridges)'; (ii) 'hips (e.g. side leg raises, bridges)'; (iii) 'back (e.g. lat pulldown, bent-over row)'; (iv) 'abdomen (e.g. crunches, sit-ups)'; (v) 'chest (e.g. bench press, push-ups)'; (vi) 'shoulders (e.g. lat raise, overhead press)'; and (vii) 'arms (e.g. bicep curl, tricep dips)'. This question was asked separately for each of the four MSE types.

Intensity (Item 9). Current global physical activity guidelines state: "*Adults should also do muscle-strengthening activities at moderate or greater intensity*" (Bull et al., 2020). However, current MSE surveillance instruments do not generally assess intensity (Shakespear-Druery et al., 2021). To assess this key MSE participation construct, the MSEQ utilized the previously validated visual analogue scale developed by Robertson et al. (2003) (See Supplemental Digital Content 1). Specifically, participants were asked: "*For each of the following types of muscle-strengthening exercises, please say how hard (level of intensity) you usually exercise*". The response options were provided on a 12-point scale: (i) 'not applicable' (ii) '0 extremely easy'; (iii) '1'; (iv) '2 easy'; (v) '3'; (vi) '4 somewhat easy'; (vii) '5'; (viii) '6 somewhat hard'; (ix) '7'; (x) '8 hard'; (xi) '9'; and (xii) '10 extremely hard'. This question was asked for each of the four MSE types.

Test-test reliability assessments. To examine test-test reliability, participants allocated to the reliability sample were sent an individualized survey link approximately 7 days after completing the first online survey. Each participant responded to the same set of questions described above.

Concurrent assessments (7-day MSE log). To examine concurrent validity, participants allocated to the validity sample were asked to complete a 7-day MSE log. Approximately 7 days after completing the first online survey, participants were sent an individualized link to complete an MSE log for 7 consecutive days. During this week and on each day, participants were asked, "*Did you do any muscle-strengthening exercise today?"* (response options: [i] 'yes'; or [ii] 'no'). Those reporting no MSE were automatically taken to the end of the survey, advising them they would receive the invitation to complete the MSE log the next day, or if day 7, they were directed to the end of the survey.

Participants who responded "*yes*" to doing MSE on a given day were then asked to respond to the same set of questions described above. All response options were the same as the original survey. Based on the 7-day MSE log responses, we created weekly averages for all MSE and each MSE type for comparison to the original survey. To calculate the average data for the frequency, duration, muscle groups used, and intensity, we collated each response to these items from the 7-day MSE log, then divided the respective values by the total number of days of reported MSE in the 7-day log. For example, for frequency, the original 'times per usual week' value (from the baseline responses to the MSEQ) was compared to the total times per week value calculated from the 7-day MSE log.

Statistical analysis

Statistical Package for the Social Sciences version 26 (SPSS Inc., an IBM Company, Armonk, NY) was used to conduct all data analyses. Descriptive statistics were used to describe the characteristics of the participants included in the two individual samples (see Table 1), and significance was set at $p < 0.05$ throughout.

To examine the test-retest reliability of the MSEQ items, four statistical tests were used to assess the relative agreement between the participant responses to the initial MSEQ survey (test) against the responses to the follow-up survey (retest). For the continuous variables (frequency, duration, and intensity), we used intraclass correlation coefficients (ICC) and Spearman's rank correlation coefficients

(Spearman's rho; ρ). For the dichotomous variable (muscle groups used), we used Kappa coefficients (κ) and percentage agreement. We applied a two-way random effects model for ICC analysis, including tests for absolute agreement. We presented ICC and Spearman's rho value and its 95% confidence interval (CI) for each frequency, duration, and level of intensity question. We present the κ value and 95% CI and the percentage agreement for the muscle groups used. Using previously established ICC correlation coefficient thresholds (Shrout, 1998), a value of 0.00-0.10 suggests virtually no agreement, 0.11-0.40 slight agreement, 0.41-0.60 fair agreement, 0.61-0.80 moderate agreement, and ≥ 0.80 substantial agreement. Applying standard classifications (Cohen, 1988) we interpreted Spearman's rho as <0.30 low, 0.30-0.50 moderate, or >0.50 high agreement. For κ, we classified the strength of agreement as either <0.00 poor, 0.00-0.20 slight, 0.21-0.40 fair, 0.41-0.60 moderate, 0.61-0.80 substantial, or 0.81-1.00 almost perfect (Landis & Koch, 1977), For percentage agreement, we adopted the following classifications: <60% poor, 60-74% moderate, or ≥75% excellent (Saelens et al., 2006).

To examine the concurrent validity of the MSEQ items on frequency, duration and intensity, ICCs and Spearman's rho are presented to show the relative agreement between the responses to the initial MSEQ survey against the 7-day MSE log as the standard. For validity assessments, we used the same ICC and Spearman's rho thresholds for the level of agreement used for the reliability.

To investigate the viability of a short version of the MSEQ (see Discussion), we combined the response of all four MSE types (using weight machines, bodyweight exercises, resistance exercises, and holistic exercises) to create a fifth type ('all types of muscle-strengthening exercise'). We examined the validity and reliability using the same for each of the individual types described above.

5.3 Results

A summary of the participant characteristics and weekly frequency of MSE for each sub-sample is shown in Table l. Full data were available from 85 participants included in the reliability sample and 54 in the validity sample. Overall, the sociodemographic characteristics were similar for each sample (see Supplemental Digital Content 3 for a copy of the sociodemographic questions). In brief, over half were female, ~70% aged between 18-54 years, ~54% living in Australia and ~60% living in urban areas. Most were university qualified and self-rated their health as good-excellent, just under half were married, and over half were employed and working ≥ 40 hours in a usual week. While the validity sample met the MSE guideline ≥2 days/week, ~30% of the reliability sample did not.

Table 1: Sample characteristics of the test-retest reliability and concurrent validity samples and weekly frequency of muscle-strengthening exercise

	Test-retest reliability Sample (n=85)	**Concurrent validity Sample (n=54)**
Characteristic	**% (n)**	**% (n)**
Sex		
Male	40.0 (34)	38.9 (21)
Female	60.0 (51)	61.1 (33)
Age (years)		
18-34	32.9 (28)	37.0 (20)
35-54	38.8 (33)	35.2 (19)
≥55	28.3 (24)	27.8 (15)
Country		
Australia	63.5 (54)	38.9 (21)
Other	36.5 (31)	61.1 (33)

Region		
Urban	62.4 (53)	59.3 (32)
Regional/remote	37.6 (32)	40.7 (22)
Education		
Primary school/some high school	2.4 (2)	7.4 (4)
Year 12 or equivalent	10.6 (9)	3.7 (2)
Higher education (below degree)	11.8 (10)	9.3 (5)
University qualification	75.3 (64)	79.6 (43)
Marital status		
Married	47.1 (40)	53.7 (29)
Not married (Defacto/separated/divorced/widowed)	24.7 (21)	18.5 (10)
Never married	28.2 (24)	27.8 (15)
Work situation		
School/university (full-time)	20.0 (17)	18.5 (10)
Paid employment/self-employed/unpaid work	58.8 (50)	64.8 (35)
Not working/other	21.2 (18)	16.7 (9)
Self-rated health		
Excellent	20.0 (17)	33.3 (18)
Very good	41.2 (35)	50.0 (27)
Good	27.1 (23)	13.0 (7)

Fair/poor	11.8 (10)	3.7 (2)
Body Mass Index classification		
Underweight or normal weight	51.8 (44)	48.1 (26)
Overweight	30.6 (26)	29.6 (16)
Obese	16.5 (14)	20.4 (11)
Frequency of muscle-strengthening exercise (days/week)		
0	27.1 (23)	0 (0)
1	3.5 (3)	0 (0)
2	16.5 (14)	13.0 (7)
3	18.8 (16)	25.9 (14)
4	10.6 (9)	16.7 (9)
≥ 5	23.5 (20)	44.4 (24)

Test-retest reliability

The results of the test-retest reliability of the MSEQ are shown in Table 2 and Table 3. For the frequency of MSE days during a usual week, there was a substantial agreement for all four types of MSE (ICC range: 0.85-0.95) and fair agreement when all types were combined (ICC= 0.58; 95% CI 0.40-0.73). For MSE duration, items for each type showed substantial agreement (ICC range: 0.88-0.96), and moderate agreement for all types combined (ICC= 0.69; 95% CI 0.55-0.80). For the level of intensity, there was substantial agreement across all four types (ICC range: 0.89-0.93) and moderate agreement for the combined analysis (ICC= 0.51; 95% CI 0.31-0.68). Spearman's rank correlations were high for all four MSE types, and all types combined for the frequency, duration and level of intensity of MSE (ρ range 0.76-0.91).

For the muscle groups used (see Table 3), there was substantial to an almost perfect agreement for using weight machines (κ range 0.61-0.85) for all groups, except for 'abdomen' (κ=0.33; 95% CI -0.01-0.65). Moderate to almost perfect agreement was shown for muscle groups used when doing body weight exercises (κ range 0.51-0.83) except for 'back' (κ=0.40; 95% CI 0.14-0.64). The agreement for muscle groups using resistance bands or free weights (κ range 0.44-0.84) was similar to body weight exercises. However, the 'chest' agreement was only fair (κ=0.33; 95% CI 0.02-0.60). Agreements for holistic exercises were less diverse for all seven muscle groups (moderate to substantial), with κ ranges from 0.57-0.76. When all MSE types were combined, the agreement for each of the muscle groups was moderate (κ range 0.41-0.51) except for 'abdomen' (κ=0.35; 95% CI 0.17-0.52). Percentage agreement for four types of MSE and the types combined was excellent (range 75.9-96.3%), except for 'back' when doing body weight exercises and 'abdomen' when using resistance bands or free weights (range 72.2-72.7%).

Concurrent validity

The concurrent validity of the MSEQ are shown in Table 4. Compared to the 7-day MSE log, days in a usual week displayed fair-to-moderate concurrent validity for each MSE type and all types combined (ICC range: 0.56-0.78). The results for Spearman's rank correlation analyses were 'high' for the frequency of all four MSE types and all types combined (ρ range 0.58-0.77). For the duration, the MSEQ items for the use of machines, resistance bands, holistic exercise and all types combined showed a fair-to-moderate agreement (ICC range: 0.46-0.78) and slight agreement for bodyweight exercise (ICC= 0.39; 95% CI -0.04-0.64). The correlation was high for the duration of all types combined (ρ=0.73; 95% CI 0.59-0.83), with similar results observed for the individual MSE types (ρ range 0.73-0.74), except for body weight exercises that were moderate (ρ=0.34; 95% CI 0.08-0.56). For the level of intensity, a moderate agreement was shown for the use of weight machines, resistance bands/free weights, and holistic exercises (ICC range: 0.69-0.78), and slight agreement was observed for bodyweight exercises and all types combined (ICC range: 0.18-0.35). The results of the Spearman's rank correlation analyses for the level of intensity were mixed, ranging from moderate (body weight exercises: $\rho=0.30$; 95% CI 0.03-0.55) to high (ρ range 0.63-0.71) for the individual MSE types, and a moderate result for all MSE types combined ($\rho=0.45$; 95% CI 0.18-0.67).

Table 2: Test-retest reliability[a] of the Muscle-Strengthening Exercise Questionnaire (MSEQ) assessing days per week, duration, and level of intensity for each type of muscle-strengthening exercise and all types combined.

	Test-retest reliability[a]	
	Interclass correlations coefficient[b] (95% CI)	**Spearman's Rho[c] (95% CI)**
How many days, in a usual week, do you do muscle-strengthening exercise?	0.92 (0.86-0.95)	0.85 (0.72-0.94)
Days per week by type		
Use weight machines	0.85 (0.74-0.91)	0.79 (0.60-0.94)
Body weight exercises	0.93 (0.88-0.96)	0.86 (0.73-0.93)
Use resistance bands or free weights	0.95 (0.92-0.97)	0.87 (0.73-0.95)
Holistic exercises	0.95 (0.91-0.97)	0.83 (0.65-0.95)
All types of muscle-strengthening exercise	0.58 (0.40-0.73)	0.91 (0.85-0.95)
Duration (minutes/session)		
Use weight machines	0.90 (0.82-0.94)	0.82 (0.67-0.93)
Body weight exercises	0.88 (0.79-0.93)	0.77 (0.60-0.87)
Use resistance bands or free weights	0.89 (0.82-0.94)	0.79 (0.62-0.90)
Holistic exercises	0.96 (0.94-0.98)	0.88 (0.74-0.96)

All types of muscle-strengthening exercise	0.69 (0.55-0.80)	0.89 (0.78-0.95)
Level of intensity		
Use weight machines	0.90 (0.83-0.94)	0.82 (0.66-0.95)
Body weight exercises	0.93 (0.89-0.96)	0.78 (0.61-0.90)
Use resistance bands or free weights	0.93 (0.88-0.96)	0.76 (0.59-0.88)
Holistic exercises	0.89 (0.82-0.94)	0.81 (0.63-0.94)
All types of muscle-strengthening exercise	0.51 (0.31-0.68)	0.82 (0.66-0.92)

[a] Test and retest of MSEQ were conducted a maximum of 14 days apart.

[b] Intraclass correlations coefficient between test and retest and its 95% confidence interval (CI).

[c] Spearman’s rank correlation between test and retest and its 95% confidence interval.

Table 3: Test-retest reliability [a] of the Muscle-Strengthening Exercise Questionnaire (MSEQ) items assessing muscle groups targeted for each type of muscle-strengthening exercise and all types combined.

Type of muscle-strengthening exercise	Kappa Statistic[b] (95% CI)	% Agreement
Use weight machines		
Legs	0.70 (0.49-0.88)	85.2
Hips	0.61 (0.34-0.85)	87.0
Back	0.74 (0.54-0.89)	87.0
Abdomen	0.33 (-0.01-0.65)	81.5
Chest	0.78 (0.59-0.93)	88.9
Shoulders	0.85 (0.67-0.96)	92.6
Arms	0.81 (0.63-0.96)	90.7
Body weight exercises		
Legs	0.51 (0.19-0.79)	85.2
Hips	0.83 (0.65-0.96)	92.6
Back	0.40 (0.14-0.64)	72.7
Abdomen	0.71 (0.41-0.93)	90.7
Chest	0.54 (0.23-0.80)	85.2
Shoulders	0.53 (0.26-0.74)	77.8
Arms	0.57 (0.33-0.79)	79.6
Use resistance bands or free weights		
Legs	0.55 (0.23-0.81)	87.0
Hips	0.66 (0.45-0.85)	83.3
Back	0.49 (0.16-0.74)	81.5
Abdomen	0.44 (0.19-0.67)	72.2
Chest	0.33 (0.02-0.60)	75.9
Shoulders	0.84 (0.55-1.00)	96.3
Arms	0.63 (0.22-0.92)	92.6
Holistic exercises		

Legs	0.58 (0.34-0.79)	79.6
Hips	0.61 (0.38-0.81)	81.5
Back	0.74 (0.50-0.91)	88.9
Abdomen	0.66 (0.45-0.85)	83.3
Chest	0.69 (0.44-0.88)	87.0
Shoulders	0.57 (0.34-0.78)	81.5
Arms	0.76 (0.53-0.94)	90.7
All types of muscle-strengthening exercise		
Legs	0.41 (0.22-0.58)	79.6
Hips	0.51 (0.34-0.66)	79.6
Back	0.45 (0.26-0.63)	81.5
Abdomen	0.35 (0.17-0.52)	77.8
Chest	0.41 (0.22-0.59)	77.8
Shoulders	0.44 (0.24-0.60)	83.3
Arms	0.47 (0.29-0.64)	77.8

[a] Test and retest of MSEQ were conducted a maximum of 14 days apart.

[b] Kappa coefficient of agreement between test and retest and its 95% confidence interval (CI).

Table 4: Concurrent validity[a] of the Muscle-Strengthening Exercise Questionnaire (MSEQ) assessing days per week, duration, and level of intensity for each type of muscle-strengthening exercise and all types combined.

	Concurrent validity[a]	
	Interclass correlations coefficient [b] (95% CI)	**Spearman's Rho [c] (95% CI)**
How many days, in a usual week, do you do muscle-strengthening exercise?	0.64 (0.37-0.80)	0.49 (0.25-0.70)
Days per week by type		
Use weight machines	0.69 (0.16-0.86)	0.76 (0.59-0.89)
Body weight exercises	0.74 (0.56-0.85)	0.59 (0.36-0.76)
Use resistance bands or free weights	0.72 (0.35-0.86)	0.64 (0.38-0.84)
Holistic exercises	0.78 (0.45-0.89)	0.77 (0.60-0.89)
All types of muscle-strengthening exercise	0.56 (0.37-0.71)	0.58 (0.35-0.76)
Duration (minutes/session)		
Use weight machines	0.60 (0.18-0.79)	0.73 (0.56-0.87)
Body weight exercises	0.39 (-0.04-0.64)	0.34 (0.08-0.56)
Use resistance bands or free weights	0.78 (0.37-0.90)	0.74 (0.55-0.86)

Holistic exercises	0.70 (0.38-0.84)	0.73 (0.54-0.87)
All types of muscle-strengthening exercise	0.46 (0.24-0.64)	0.73 (0.59-0.83)
Level of intensity		
Use weight machines	0.73 (0.38-0.87)	0.71 (0.52-0.85)
Body weight exercises	0.35 (-0.07-0.61)	0.30 (0.03-0.55)
Use resistance bands or free weights	0.78 (0.21-0.91)	0.68 (0.52-0.82)
Holistic exercises	0.69 (0.43-0.83)	0.63 (0.41-0.78)
All types of muscle-strengthening exercise	0.18 (-0.06-0.42)	0.45 (0.18-0.67)

[a] To assess the concurrent validity, MSEQ baseline responses were compared to a 7-day MSE log.

[b] Intraclass correlations coefficient between test and retest and its 95% confidence interval (CI).

[c] Spearman's rank correlation between test and retest and its 95% confidence interval.

5.4 Discussion

This study describes the test-retest reliability and concurrent validity of a newly developed online survey instrument assessing muscle-strengthening exercise. The MSEQ was specifically designed to assess multiple MSE participation constructs (e.g., frequency, duration, intensity, muscle groups) across different types of MSE (e.g. use weight machines, body weight exercises, use resistance bands or free weights, and holistic exercises) in adults. Overall, among our active, young, and well-educated sample, the MSEQ showed substantial test-retest reliability and adequate validity when using a 7-day MSE log as the standard. While these findings need to be replicated in studies with a more representative sample, the present study suggests that the MSEQ has potential for use in future physical activity surveillance.

Few studies have reported on the reliability and validity of existing MSE survey instruments (Shakespear-Druery et al., 2021), but comparing our findings to similar studies is limited. For weekly MSE frequency, the MSEQ shows similar reliability and stronger validity compared to the MSE item from the BRFSS using a physical activity log (Yore et al., 2007). However, the MSEQ expands on the BRFSS by assessing the frequency of four different types of MSE and muscle groups targeted, duration, and intensity. A recent study examined the reliability and validity of MSE items (using a 7-day diary) from the Cancer Prevention Study-3 (Subbiah, Rees-Punia, & Patel, 2021). That study assessed the MSE frequency and duration of similar MSE types using a single MSE question. In comparison, the MSEQ shows stronger reliability and similar validity to that study. While the study (Subbiah et al., 2021) included similar MSE types, expanding on the BRFSS, the MSEQ is more extensive as it allows for the additional assessment of intensity and muscle groups targeted.

Compared to commonly used MVPA surveillance instruments, the MSEQ showed stronger reliability and validity. For example, compared to the frequency and duration items in the Global Physical Activity Questionnaire (GPAQ), the MSEQ was superior for both 7-day test-retest reliability and concurrent validity using activity logs (Keating et al., 2019). Validity of the MSEQ is stronger when compared to the leisure-time frequency and duration items contained in the International Physical Activity Questionnaire (IPAQ)-Long (Hagströmer, Oja, & Sjöström, 2006). The potential reason for stronger reliability and validity observed in MSE, compared to MVPA, is likely because MSE is easier to recall and a more memorable physical activity (Bennie, Shakespear-Druery, et al., 2020). Moreover, that in this study a high percentage of participants also meet the MSE guidelines.

When designing the MSEQ, we decided to solely target MSE-related behaviours within the context of leisure time, and consequently not to include any activities accrued during occupational (e.g., labouring/lifting) and domestic tasks (e.g., carry shopping bags, gardening). This decision was to avoid any potential misclassification of other MSE-related behaviours. Furthermore, occupation-related physical activity is often undertaken at low/moderate intensity for long durations with limited time for recovery (Holtermann, Krause, van der Beek, & Straker, 2018). Moreover, it has been argued that the repetitive nature of undertaking MSE outside the context of leisure time may negatively influence health. For example, MSE within the occupational and domestic context may result in an increased risk of musculoskeletal disorders (e.g. back, shoulder, neck injuries/pain) and arthritis/rheumatic diseases (e.g. osteoarthritis, rheumatoid arthritis) (Centers for Disease Control and Prevention).

Muscle-strengthening Exercise Questionnaire: short and long format

For potential use in future health surveillance, we adapted the MSEQ to be consistent with existing self-reported physical activity surveillance instruments, such as the widely used IPAQ (Craig et al., 2003) and GPAQ (World Health Organization, 2020). Specifically, we developed two versions of the MSEQ, the MSEQ-Short and MSEQ-Long, each designed to be used in either a self-administered or interview-administered format (full versions shown in Supplemental Digital Content 2). The MSEQ-Short is a brief 6-item instrument that assesses any engagement in MSE ('yes' or 'no'), the usual weekly frequency (number of days), duration (minutes spent), intensity (range from 0 to 10), type of muscle-strengthening exercise ('yes' or 'no' response to the four types of MSE), and muscle groups targeted ('yes' or 'no' response to seven muscle groups). The MSEQ-Long is a 20-item instrument that assesses the usual weekly frequency, duration, intensity, and the muscle groups targeted (similar responses as in MSEQ-Short), separately for all four types of MSE (weight machines, bodyweight exercises, resistance exercises, and holistic exercises). As shown in Table Supplemental Digital Content 3, the reliability and validity of the MSEQ-Short items displayed mostly fair-to-moderate agreement and was moderate-to-high for most of the MSEQ-Long items (see Table, Supplemental Digital Content 4). These preliminary data suggest that the MSEQ-Short and MSEQ-Long have promise as a standardized MSE surveillance instrument. However, we urge caution, as both instruments have not yet been tested for reliability and validity in the format provided in Supplemental Digital Content 2. We now call for future studies to assess the psychometric properties of the MSEQ-Short and MSEQ-Long, with diverse population sub-groups (e.g. older adults, those from differing income/education levels) and translated into different languages.

Limitations

A key limitation of this study was our recruitment of a non-representative sample, which is likely to affect the generalizability of our findings. A further limitation was the self-reported nature of the online responses to the survey. There is a risk of responder recall bias (e.g., social desirability or over/under-reporting of actual behaviour). However, there is no device-based measurement available for the assessment of MSE. This behaviour is routinely assessed by self-report in physical activity surveillance. A further limitation is that we were unable to establish the validity of the muscle groups targeted items, as this was not possible when comparing a single 'yes' or 'no' response in the 'main survey' to the daily 'yes' or 'no' response in the 7-day diary. A key strength of this study is that it is one of the first to assess the test-retest reliability and concurrent validity of questions specifically developed to explore the constructs of MSE beyond frequency and duration. Moreover, the inclusion of the assessment of MSE intensity is a unique and important component that is not currently well understood (Giovannucci, Rezende, & Lee, 2021).

5.5 Conclusion

The newly developed MSEQ displayed adequate test-retest reliability and concurrent validity in assessing multiple MSE participating constructs. Given that the current study included a sample of young, well-educated, and active adults, further research is needed to examine whether these findings are generalizable to more representative samples.

Acknowledgements

This research has been supported by an Australian Government Research Training Program Scholarship and a University of Southern Queensland Research Training Program Stipend Scholarship.

Contributorship

JSD, KDC, SJHB, and JAB conceptualised the study and developed the research plan. JSD created the online survey, collected all data and conducted the data analysis. JSD and JAB drafted the initial manuscript. JAB, KDC, and SJHB provided guidance on the study and critically reviewed the manuscript. All authors read and approved the final version of the manuscript, and agree with the order of presentation of the authors.

Competing interests

The authors declare that they have no competing interests.

Funding

Not applicable.

Key messages

'What is already known'

- Muscle-strengthening exercise has multiple independent health benefits.
- Assessment of muscle-strengthening exercise is rare in physical activity surveillance.
- Surveillance instruments assessing muscle-strengthening exercise are mostly limited to frequency (days/week) and duration (minutes/session).

'What are the new findings'

- We developed a new online muscle-strengthening exercise assessment instrument, the Muscle-Strengthening Exercise Questionnaire (MSEQ).
- The MSEQ has shown acceptable 7-day test-retest reliability.
- The MSEQ has shown adequate validity when using a 7-day muscle-strengthening exercise log as the standard.
- Future population-level health surveillance of muscle-strengthening exercise may include the MSEQ.

5.6 References

American College of Sports Medicine. (2009). American College of Sports Medicine position stand. Progression models in resistance training for healthy adults. *Medicine and Science in Sports and Exercise, 41*(3), 687-708. doi:10.1249/MSS.0b013e3181915670

Armstrong, T., & Bull, F. (2006). Development of the World Health Organization Global Physical Activity Questionnaire (GPAQ). *Journal of Public Health, 14*(2), 66-70. doi:10.1007/s10389-006-0024-x

Ashton, R. E., Tew, G. A., Aning, J. J., Gilbert, S. E., Lewis, L., & Saxton, J. M. (2018). Effects of short-term, medium-term and long-term resistance exercise training on cardiometabolic health outcomes in adults: Systematic review with meta-analysis. *British Journal of Sports Medicine, 0*, 1-9. doi:10.1136/bjsports-2017-098970

Baranowski, T. (1988). Validity and reliability of self report measures of physical-activity - An information-processing perspective. *Research Quarterly for Exercise and Sport, 59*(4), 314-327. doi:10.1080/02701367.1988.10609379

Bennie, J. A., Kolbe-Alexander, T., Seghers, J., Biddle, S. J. H., & Cocker, K. D. (2020). Trends in muscle-strengthening exercise among nationally representative samples of United States adults between 2011 and 2017. *Journal of Physical Activity and Health, 17*(5), 512. doi:10.1123/jpah.2019-0472

Bennie, J. A., Shakespear-Druery, J., & De Cocker, K. (2020). Muscle-strengthening exercise epidemiology: A new frontier in chronic disease prevention. *Sports Medicine - Open, 6*(1), 1-8. doi:10.1186/s40798-020-00271-w

Brellenthin, A. G., Lee, D.-c., Bennie, J. A., Sui, X., & Blair, S. N. (2021). Resistance exercise, alone and in combination with aerobic exercise, and obesity in Dallas, Texas, US: A prospective cohort study. *PLoS Medicine, 18*(6), e1003687. doi:10.1371/journal.pmed.1003687

Bull, F. C., Al-Ansari, S. S., Biddle, S., Borodulin, K., Buman, M. P., Cardon, G., . . . Willumsen, J. F. (2020). World Health Organization

2020 guidelines on physical activity and sedentary behaviour. *British Journal of Sports Medicine, 54*(24), 1451. doi:10.1136/bjsports-2020-102955

Centers for Disease Control and Prevention. Work-related musculoskeletal disorders & ergonomics. Retrieved from https://www.cdc.gov/workplacehealthpromotion/health-strategies/musculoskeletal-disorders/index.html

Cohen, J. (1988). *Statistical power analysis for the behavioral sciences* (2nd ed.): Lawrence Erlbaum Associates.

Craig, C. L., Marshall, A. L., Sjöström, M., Bauman, A. E., Booth, M. L., Ainsworth, B. E., . . . Oja, P. (2003). International physical activity questionnaire: 12-Country reliability and validity. *Medicine and Science in Sports and Exercise, 35*(8), 1381-1395. doi:10.1249/01.MSS.0000078924.61453.FB

Dankel, S. J., Mattocks, K. T., Jessee, M. B., Buckner, S. L., Mouser, J. G., & Loenneke, J. P. (2017). Do metabolites that are produced during resistance exercise enhance muscle hypertrophy? *European Journal of Applied Physiology, 117*(11), 2125-2135. doi:10.1007/s00421-017-3690-1

Garber, C. E., Blissmer, B., Deschenes, M. R., Franklin, B. A., Lamonte, M. J., Lee, I. M., . . . Amer Coll Sports, M. (2011). Quantity and quality of exercise for developing and maintaining cardiorespiratory, musculoskeletal, and neuromotor fitness in apparently healthy adults: Guidance for prescribing exercise. *Medicine & Science in Sports & Exercise, 43*(7), 1334-1359. doi:10.1249/MSS.0b013e318213fefb

Giovannucci, E. L., Rezende, L. F. M., & Lee, D. H. (2021). Muscle-strengthening activities and risk of cardiovascular disease, type 2 diabetes, cancer and mortality: A review of prospective cohort studies. *Journal of Internal Medicine*. doi:10.1111/joim.13344

Gordon, B. R., McDowell, C. P., Hallgren, M., Meyer, J. D., Lyons, M., & Herring, M. P. (2018). Association of efficacy of resistance exercise training with depressive symptoms: Meta-analysis and meta-regression analysis of randomized clinical trials. *JAMA Psychiatry, 75*(6), 566-576. doi:10.1001/jamapsychiatry.2018.0572

Grgic, J., Schoenfeld, B. J., Davies, T. B., Lazinica, B., Krieger, J. W., & Pedisic, Z. (2018). Effect of resistance training frequency on gains in muscular strength: A systematic review and meta-analysis. *Sports Medicine, 48*(5), 1207-1220. doi:10.1007/s40279-018-0872-x

Grnøtved, A., Pan, A., Mekary, R. A., Stampfer, M., Willett, W. C., Manson, J. E., & Hu, F. B. (2014). Muscle-strengthening and conditioning activities and risk of type 2 diabetes: A prospective study in two cohorts of US women. *PLoS Medicine, 11*(1), 15. doi:10.1371/journal.pmed.1001587

Grnøtved, A., Rimm, E. B., Willett, W. C., Andersen, L. B., & Hu, F. B. (2012). A prospective study of weight training and risk of type 2 diabetes mellitus in men. *Archives of Internal Medicine, 172*(17), 1306-1312. doi:10.1001/archinternmed.2012.3138

Hagströmer, M., Oja, P., & Sjöström, M. (2006). The International Physical Activity Questionnaire (IPAQ): A study of concurrent and construct validity. *Public Health Nutrition, 9*(6), 755-762. doi:10.1079/PHN2005898

Holtermann, A., Krause, N., van der Beek, A. J., & Straker, L. (2018). The physical activity paradox: Six reasons why occupational physical activity (OPA) does not confer the cardiovascular health benefits that leisure time physical activity does. *British Journal of Sports Medicine, 52*(3), 149. doi:10.1136/bjsports-2017-097965

Keating, X. D., Zhou, K., Liu, X., Hodges, M., Liu, J., Guan, J., . . . Castro-Piñero, J. (2019). Reliability and concurrent validity of global physical activity questionnaire (GPAQ): A systematic review. *Int J Environ Res Public Health, 16*(21). doi:10.3390/ijerph16214128

Khalafi, M., Malandish, A., Rosenkranz, S. K., & Ravasi, A. A. (2021). Effect of resistance training with and without caloric restriction on visceral fat: A systemic review and meta-analysis. *Obes Rev*, e13275. doi:10.1111/obr.13275

Landis, J. R., & Koch, G. G. (1977). The measurement of observer agreement for categorical data. *Biometrics, 33*(1), 159-174. doi:10.2307/2529310

Loustalot, F., Carlson, S., Kruger, J., Buchner, D., & Fulton, J. (2013). Muscle-strengthening activities and participation among adults in the United States. *Research Quarterly for Exercise and Sport, 84*(1), 30-38. doi:10.1080/02701367.2013.762289

Mekary, R. A., Grontved, A., Despres, J. P., De Moura, L. P., Asgarzadeh, M., Willett, W. C., . . . Hu, F. B. (2015). Weight training, aerobic physical activities, and long-term waist circumference change in men. *Obesity, 23*(2), 461-467. doi:10.1002/oby.20949

Milton, K., Varela, A. R., Strain, T., Cavill, N., Foster, C., & Mutrie, N. (2018). A review of global surveillance on the muscle strengthening and balance elements of physical activity recommendations. *Journal of Frailty, Sarcopenia and Falls, 3*(2), 114-124. doi:10.22540/JFSF-03-114

Nascimento, W., Ferrari, G., Martins, C. B., Rey-Lopez, J. P., Izquierdo, M., Lee, D. H., . . . Rezende, L. F. M. (2021). Muscle-strengthening activities and cancer incidence and mortality: a systematic review and meta-analysis of observational studies. *International Journal of Behavioral Nutrition and Physical Activity, 18*(1), 69. doi:10.1186/s12966-021-01142-7

Nunes, J. P., Grgic, J., Cunha, P. M., Ribeiro, A. S., Schoenfeld, B. J., de Salles, B. F., & Cyrino, E. S. (2021). What influence does resistance exercise order have on muscular strength gains and muscle hypertrophy? A systematic review and meta-analysis. *Eur J Sport Sci, 21*(2), 149-157. doi:10.1080/17461391.2020.1733672

Paoli, A., Gentil, P., Moro, T., Marcolin, G., & Bianco, A. (2017). Resistance training with single vs. multi-joint exercises at equal total load volume: Effects on body composition, cardiorespiratory fitness, and muscle strength. *Frontiers in Physiology, 8*. doi:10.3389/fphys.2017.01105

Physical Activity Guidelines Advisory Committee. (2008). *Physical Activity Guidelines Advisory Committee Report, 2008*. Washington, DC: U.S. Department of health and Human Services,.

Piercy, K. L., Troiano, R. P., Ballard, R. M., Carlson, S. A., Fulton, J. E., Galuska, D. A., . . . Olson, R. D. (2018). The physical activity guidelines for Americans. *JAMA: Journal of the American Medical Association, 320*(19), 2020-2028. doi:10.1001/jama.2018.14854

Pollock, M. L., Gaesser, G. A., Butcher, J. D., Després, J. P., Dishman, R. K., Franklin, B. A., & Garber, C. E. (1998). The recommended quantity and quality of exercise for developing and maintaining cardiorespiratory and muscular fitness, and flexibility in healthy adults. *Medicine and Science in Sports and Exercise, 30*(6), 975-991. doi:10.1097/00005768-199806000-00032

Prince, S. A., LeBlanc, A. G., Colley, R. C., & Saunders, T. J. (2017). Measurement of sedentary behaviour in population health surveys: a review and recommendations. *Peerj, 5*. doi:10.7717/peerj.4130

Ratamess, N. A., Alvar, B. A., Evetoch, T. E., Housh, T. J., Ben Kibler, W., Kraemer, W. J., & Triplett, N. T. (2009). Progression models in resistance training for healthy adults. *Medicine and Science in Sports and Exercise, 41*(3), 687-708. doi:10.1249/MSS.0b013e3181915670

Robertson, R. J., Goss, F. L., Rutkowski, J., Lenz, B., Dixon, C., Timmer, J., . . . Andreacci, J. (2003). Concurrent validation of the OMNI perceived exertion scale for resistance exercise. *Medicine & Science in Sports & Exercise, 35*(2), 333-341. doi:10.1249/01.mss.0000048831.15016.2a

Saeidifard, F., Medina-Inojosa, J. R., West, C. P., Olson, T. P., Somers, V. K., Bonikowske, A. R., . . . Lopez-Jimenez, F. (2019). The association of resistance training with mortality: A systematic review and meta-analysis. *European Journal of Preventive Cardiology, 26*(15), 1647-1665. doi:10.1177/2047487319850718

Saelens, B. E., Frank, L. D., Auffrey, C., Whitaker, R. C., Burdette, H. L., & Colabianchi, N. (2006). Measuring physical environments of parks and playgrounds: EAPRS instrument development and inter-rater reliability. *J Phys Act Health, 3*(s1), s190-s207. doi:10.1123/jpah.3.s1.s190

Shakespear-Druery, J., De Cocker, K., Biddle, S. J. H., Gavilán-Carrera, B., Segura-Jiménez, V., & Bennie, J. (2021). Assessment of muscle-strengthening exercise in public health surveillance for adults: A systematic review. *Preventive Medicine*, 106566. doi:10.1016/j.ypmed.2021.106566

Shiroma, E. J., Cook, N. R., Manson, J. E., Moorthy, M., Buring, J. E., Rimm, E. B., & Lee, I. M. (2016). Strength training and the risk of type 2 diabetes and cardiovascular disease. *Medicine & Science in Sports & Exercise, 49*(1), 40-46. doi:10.1249/MSS.0000000000001063

Shrout, P. E. (1998). Measurement reliability and agreement in psychiatry. *Statistical Methods in Medical Research, 7*(3), 301-317. doi:10.1191/096228098672090967

Strain, T., Fitzsimons, C., Kelly, P., & Mutrie, N. (2016). The forgotten guidelines: Cross-sectional analysis of participation in muscle strengthening and balance & co-ordination activities by adults and older adults in Scotland. *BMC Public Health, 16*, 1108. doi:10.1186/s12889-016-3774-6

Subbiah, K., Rees-Punia, E., & Patel, A. V. (2021). Reliability and validity of self-reported muscle-strengthening exercise in the Cancer Prevention Study-3. *Medicine & Science in Sports & Exercise, 53*(5), 888-893. doi:10.1249/mss.0000000000002547

Troiano, R. P., Stamatakis, E., & Bull, F. C. (2020). How can global physical activity surveillance adapt to evolving physical activity guidelines? Needs, challenges and future directions. *British Journal* *of Sports Medicine, 54*(24), 1468. doi:10.1136/bjsports-2020-102621

U.S. Department of Health and Human Services. (2008). *2008 physical activity guidelines for Americans*. Washington, DC.

U.S. Department of Health and Human Services. (2018). *Physical activity guidelines for Americans, 2nd edition*. Washington, DC Retrieved from https://health.gov/paguidelines/second-edition/pdf/Physical_Activity_Guidelines_2nd_edition.pdf.

World Health Organization. (2020). *Global Physical Activity Questionnaire (GPAQ)*. Geneva, Switzerland: World Health Organization.

Yore, M. M., Ham, S. A., Ainsworth, B. E., Kruger, J., Reis, J. P., Kohl, H. W., III, & Macera, C. A. (2007). Reliability and validity of the instrument used in BRFSS to assess physical activity. *Medicine & Science in Sports & Exercise, 39*(8), 1267-1274. doi:10.1249/mss.0b013e3180618bbe

Zhao, R., Zhao, M., & Xu, Z. (2015). The effects of differing resistance training modes on the preservation of bone mineral density in postmenopausal women: A meta-analysis. *Osteoporosis International, 26*(5), 1605-1618. doi:10.1007/s00198-015-3034-0

5.7 How the Publication Contributes to the Advancement of the Research Area

As noted in Study 1, at present, there is large heterogeneity in the assessment of MSE within population health surveillance. Furthermore, research into the prevalence and participation of MSE predominantly focuses on assessing frequency alone. Importantly, however, the reliability and validity of instruments used to understand and explore MSE participation at the population level have rarely been tested for their reliability or validity. This study advances this limited research area by providing a reliable and valid MSE assessment instrument, which could be used by researchers to assess not only MSE participation at the population level but also assess concordance with the complete MSE guideline (frequency, intensity, and muscle groups) at a national or global level. Moreover, the MSEQ explores additional MSE behaviour factors not currently included in physical activity guidelines that may influence health at the population level such as MSE type and duration. Increasing our understanding of how factors, such as MSE type/mode, and duration (in addition to sets and repetitions completed), are associated with health is critical not only for the monitoring of health trends but also for consideration in the establishment and review of specific physical activity recommendations for non-pharmacological therapies used in the management and prevention of NCDs.

While this study showed acceptable reliability and validity of the MSEQ to assess MSE participation, the instrument also gathered data on potential influencing factors that may be associated with participation in MSE. Understanding why people do or do not engage in MSE is vital, especially when compared to the engagement in MVPA, rates of MSE participation are low globally. The remaining study of this thesis will use a subset of participants who responded to the MSEQ (N = 435) to explore the behavioural factors that may influence participation or non-participation.

In addition to the development of the MSEQ, the ‘Scoring protocol for the Muscle-Strengthening Exercise Questionnaire (MSEQ)’ has also been developed. A copy of this protocol document is located within Appendix J of this thesis.

CHAPTER 6: PAPER 5 - Associations between behavioural correlates of muscle-strengthening exercise guideline adherence in adults: A cross-sectional study

This paper has been submitted as a manuscript to the *International Journal of Sport and Exercise Psychology* on 5 July 2022 and is under review at the time of writing. The manuscript is formatted in accordance with the referencing style as specified by the journal.

6.0 Abstract

Epidemiological evidence links muscle-strengthening exercise (MSE: using weights or own bodyweight) to a reduced risk of non-communicable diseases. However, few studies have examined factors that influence MSE participation beyond frequency. Therefore, this study aimed to investigate likely factors influencing MSE participation, including three components (i.e., frequency, muscle groups, and intensity) in adults. English-speaking adults aged ≥18 years (n=435) completed the previously validated Muscle-Strengthening Exercise Questionnaire (MSEQ) including MSE components (frequency, muscle groups, intensity) and agreement with 13 statements of potential behavioural correlates of physical activity. Adjusted multiple-factor logistic regression analyses were conducted. Participants having positive perceptions of time availability; sufficient energy; confidence in their skills and knowledge; and who prioritise and enjoy MSE are more likely to report health-enhancing MSE (≥2 times/week). Moreover, these influencing factors remained irrespective of the MSE components (frequency, muscle groups, intensity). Among the sample of highly active participants, we identified five behavioural correlates that appear to have significant associations with meeting the MSE guidelines. Public health approaches to increase MSE participation within currently inactive populations may benefit from focusing on these specific enabling factors.

Keywords: muscle-strengthening exercise, participation, perceptions, beliefs, correlates

6.1 Introduction

Regular participation in physical activity is important in the prevention and management of non-communicable diseases (NCDs such as diabetes, hypertension, and cardiovascular disease) (World Health Organization, 2014). While most of the research on the health benefits of physical activity has focussed on moderate-to-vigorous intensity aerobic physical activity (MVPA: brisk walking, jogging, cycling) (Handy & Blaha, 2017), evidence from controlled experimental studies suggest that muscle-strengthening exercise (MSE) is strongly associated with improved health outcomes (e.g., blood pressure management (MacDonald et al., 2016), glucose and lipid metabolism (Dunstan et al., 2002), positive mental health (Gordon et al., 2018; Gordon, McDowell, Lyons, & Herring, 2017)). More recently, epidemiological studies have shown that MSE is independently linked to a reduced risk of mortality (Loprinzi, Addoh, & Mann, 2017; Saeidifard et al., 2019), and incidence of diabetes (Grnøtved et al., 2014; Grnøtved, Rimm, Willett, Andersen, & Hu, 2012), and cardiovascular disease (Bennie, Shakespear-Druery, & De Cocker, 2020; Steele et al., 2017).

In addition to promoting aerobic exercise, the current ‘Guidelines on Physical Activity and Sedentary Behaviour’ from the World Health Organization state that adults (18–64 years) should undertake MSE “*at moderate or greater intensity*” targeting “*all the major muscle groups*” with a recommended frequency of being “*completed on two or more days a week*” (Bull et al., 2020). Moreover, the guidelines for older adults (aged 65 years+) include recommendations for multi-component physical activity inclusive of MSE (Bull et al., 2020).

MSE (i.e., weight or resistance training) is most often undertaken during an individuals’ leisure-time using equipment (such as weight machines, free weights, resistance bands) or ones’ body weight (e.g., doing push-ups, sit-ups) (Bennie, Shakespear-Druery, et al., 2020). Despite the clear benefits of MSE, rates of participation remain low. For example, data from health surveillance suggests that only 17.3% of European (Bennie, De Cocker, Smith, & Wiesner, 2020), 18.6% of Australian (Bennie et al., 2016), and 29.3% of U.S. (Harris et al., 2013) adults meet the MSE recommendation (≥2 days per week). Moreover, a recent study of 1.7 million U.S. adults identified a significant disparity between the number of respondents reportedly undertaking no MSE (57.2%) compared to the 32.2% reportedly undertaking no aerobic physical activity (Bennie, Shakespear-Druery, et al., 2020). Given the large difference in participation between the two exercise modes it is important to understand the reasons why people do or do not engage in MSE as these may differ from the reasons they engage in aerobic physical activity (Bauman et al., 2012; Biddle, Mutrie, Gorely, & Faulkner, 2021).

While epidemiological research has examined the potential correlates of MSE, the focus has predominantly been on sociodemographic factors such as age and sex (Vezina, Der Ananian, Greenberg, & Kurka, 2014). Studies have shown that those who are older (e.g., >45 years), female, have a body mass index (BMI) >25 kg/m^2, poor self-rated health, or attained a lower level of education, are less likely to meet the MSE guidelines (Bennie et al., 2018; Kamil-Rosenberg, Greaney, & Garber, 2021; Nakamura & Harada, 2015; Rhodes, Lubans, Karunamuni, Kennedy, & Plotnikoff, 2017; Vezina et al., 2014). While these studies (Bennie et al., 2018; Kamil-Rosenberg et al., 2021; Nakamura & Harada, 2015; Rhodes et al., 2017; Vezina et al., 2014) provide some insight into who is less likely to meet the MSE recommendations, there is currently a limited understanding of the behavioural factors that may impact participation in this important health behaviour (Bennie, Shakespear-Druery, et al., 2020), and if the factors differ by sex. Moreover, existing research has focussed on assessing the correlates related to the frequency of MSE participation (i.e., only one component of the MSE guidelines) rather than an assessment of multiple MSE participation components (i.e., frequency, intensity, and muscle groups) (Bennie, Shakespear-Druery, et al., 2020). A recent review by Rhodes et al. (2017) identified key predictive demographic, intrapersonal, and interpersonal factors linked to positive MSE participation behaviour. Identified intrapersonal factors included affective judgements (pleasure in undertaking MSE), self-efficacy/perceived behavioural control (confidence in and perceived difficulty of undertaking MSE), self-regulation (planning and setting goals to undertake MSE), and intention (Rhodes et al., 2017). While their review included 51 studies, only 11 of these studies were linked to positive intrapersonal associations and assessed MSE participation (Rhodes et al., 2017). Of these less than half (~45%) assessed more than MSE frequency, with only one study assessing all three components (frequency, duration, and muscle groups), generally containing small samples.

Furthermore, a recent study by Rhodes and Lithopoulos (2022) explored the relationship between the theories of action control and MSE participation. This study comprised 1338 respondents who reported their weekly MSE frequency (lasting at least 15 minutes). Twenty-eight percent were assessed as meeting the MSE frequency guideline, with 24% having positive intentions towards MSE. The constructs of 'perceived capability' and 'perceived opportunity' were associated with MSE intention, with a small effect size. Importantly, a limitation of this study was the authors' caveat in including only MSE bouts over 15 minutes in duration, along with the single assessment of MSE frequency.

Many frameworks, and psychological and behavioural theories, are associated with physical activity participation (Bauman et al., 2012; Biddle et al., 2021). Specific theories, such as self-determination theory, the theory of planned behaviour, and social cognitive theory, have previously been used to explore how complex and multiple factors may influence MSE participation (Rhodes et al., 2017). Although, overwhelming and consistent evidence associates self-efficacy (situational self-confidence), a fundamental component of social cognitive theory, with participation among adults (Biddle et al., 2021). While, individual beliefs (Ryan, Frederick, Lepes, Rubio, & Sheldon, 1997) (e.g., a person's general attitude towards their health) (McLeroy, Steckler, Goodman, & Burdine, 1992), behaviour skills, confidence, support, and perceptions such as time availability (Trost, Owen, Bauman, Sallis, & Brown, 2002), are identified as correlates of aerobic exercise participation (Sallis & Hovell, 1990) and walking research, these factors are not often a focus in MSE research.

Therefore, this study aimed to firstly explore the associations between behavioural influences (including participant perceptions, beliefs, and confidence in MSE) and meeting the MSE guidelines among adults aged 18 years and older. A secondary aim was to examine whether the behavioural influences differed across meeting the frequency, intensity, and muscle groups targeted proportion of the MSE guidelines.

6.2 Method

The Main Study assessed multiple participation constructs of MSE, and possible factors influencing MSE participation or non-participation during leisure-time, using the recently developed valid and reliable 'Muscle-Strengthening Exercise Questionnaire' (MSEQ) (Shakespear-Druery, De Cocker, Biddle, & Bennie, 2022).

Study population

From December 2020 through to March 2021, a convenience sample of 461 adults (over the age of 18 years) were recruited through social media platforms such as Facebook, Instagram, Twitter, and professional networks ('Main Study'). Ethical approval was obtained from the University of Southern Queensland Human Ethics Committee in May 2020 (H20REA233). Informed consent was obtained from all participants before they completed the online study.

Data from English-speaking adults aged ≥18 years were included. For this study, participants were excluded if they did not respond to the questions contained in the "*Factors influencing leisure-time muscle-strengthening exercise"* section of the questionnaire (see Electronic Supplementary Material 1). The final sample in the present study included 435 individual participants. The characteristics of the excluded participants (*n*=26) were overall similar to those in this study (see Electronic Supplementary Material 2).

Measures

The MSEQ (Shakespear-Druery et al., 2022) was designed to assess key MSE participation constructs (type, frequency, duration, intensity, and muscle groups targeted) in MSE. The MSEQ participation constructs have been shown to have acceptable test-retest reliability and concurrent validity (Shakespear-Druery et al., 2022). A detailed description of the development of the MSEQ participation constructs has been discussed elsewhere (Shakespear-Druery et al., 2022).

Muscle-strengthening exercise (frequency)

Self-reported MSE was assessed using the MSEQ (Shakespear-Druery et al., 2022). Participants were first asked: *"Do you usually do muscle-strengthening exercise?"* ('yes' or 'no'). The frequency of their participation was then assessed by asking *"How many days, in a usual week, do you do muscle-strengthening exercise?*" ('none', '1 day in a usual week', '2 days in a usual week', '3 days in a usual week', '4 days in a usual week', '5 days in a usual week', '6 days in a usual week', or '7 days in a usual week'). According to the global physical activity guidelines, the number of 'days in a usual week', were then collapsed into two categories. Those either 'meeting' the MSE guideline of ≥2 times/week, or 'not meeting' the guideline (none, 1 day in a usual week).

Muscle-strengthening exercise (Muscle groups targeted)

To assess muscle groups targeted (legs, hips, back, abdomen, chest, shoulders, and arms) we asked participants "*In a usual week please indicate which muscle groups you use when you do each of the following types of muscle-strengthening exercises*." ('yes' or 'no') (Shakespear-Druery et al., 2022). This question was asked for each type of MSE (weight machines, body weight, resistance, holistic exercises). To classify the number of muscle groups used (maximum of seven) we first collapsed the participant responses to each type of MSE (four types) into two categories. Participants who reported using a total of '5' or more muscle groups were classified as: (i) 'meeting the guideline', and those reporting 'none to 4' muscle groups were classified as: (ii) 'not meeting' the guideline. We then combined these data for each of the four MSE types, collapsing them again into either: (i) those using ≥5 muscle groups and considered to be 'meeting' the guideline, and (ii) those using <5 muscle groups considered as 'not meeting' the guideline.

Muscle-strengthening exercise (Intensity)

To assess MSE intensity, for each of the four types, we asked participants to report "*How hard (level of intensity) you usually exercise*" (Shakespear-Druery et al., 2022). Response options ranged from 'not applicable', '*0 extremely easy*' through to '*10 extremely hard*'. Similarly, to classify the 'level of intensity' (rating of perceived effort: RPE) we first collapsed the participant responses for each type of MSE (four types) into two categories. Participants who reported 'not applicable' through to an RPE of '5' were classified as (i) 'not meeting' the guideline, and those reporting an RPE of '6 somewhat hard' through to '10 extremely hard' (Robertson et al., 2003) were classified as (ii) 'meeting the guideline'. We then combined these data for each of the four MSE types, collapsing them again into either: (i) those 'meeting' the guideline (RPE ≥6), or (ii) those 'not meeting' the guideline (RPE <6).

Multiple muscle-strengthening exercise guideline concordance

A secondary aim was to explore how behavioural influences may differ across three specific components of the MSE guidelines (frequency, muscle groups targeted, and intensity). To assess these associations, we used the 'collapsed' data as described above. For 'frequency only' we used (i) 'meeting' the MSE guideline of ≥2 times/week, or (ii) 'not meeting' the guideline (none, 1 day in a usual week). To assess two components (frequency and muscle groups targeted) we combined and then split the data into either (i) 'meeting' the MSE guideline of ≥2 times/week plus muscle groups targeted (≥5 muscle groups) or (ii) 'not meeting' (none, 1 day in a usual week and <5 muscle groups used). Last, to assess the three components (frequency, muscle groups targeted, and intensity) we combined and then split the data into either (i) 'meeting' the MSE guideline of ≥2 times/week plus muscle groups targeted (≥5 muscle groups) plus MSE intensity (RPE ≥6) or (ii) 'not meeting' the complete three components guideline (none, 1 day in a usual week, <5 muscle groups used, and RPE <6).

Factors influencing MSE participation

Questions on factors influencing MSE participation or non-participation were assessed. A copy of the questions contained within this component is shown in Electronic Supplementary Material 1. The development of these questions was broadly based on several key constructs that explore the correlates of exercise behaviour (Bandura, 2004; Hoare, Stavreski, Jennings, & Kingwell, 2017; Lubans et al., 2011; Ryan et al., 1997; Sallis & Hovell, 1990; Sallis, Owen, & Fotheringham, 2000; Stokols, 1996). Moreover, items used within previous studies (Bennie, Timperio, Crawford, Dunstan, & Salmon, 2011; Hoare et al., 2017; Lubans et al., 2011; Picorelli et al., 2014; Ryan et al., 1997) were adapted and modified for the purposes of assessing their relationship within the context of MSE. Following perusal of these key resources (e.g., Bandura's 'Health promotion by social cognitive means' (Bandura, 2004), Stokols' 'Translating social ecological theory into guidelines for community health promotion' (Stokols, 1996), and Ryan et al.'s 'Intrinsic motivation and exercise adherence' (Ryan et al., 1997)) three key constructs were assessed and are the focus of this study: (i) perceptions, (ii) beliefs, and (iii) confidence. A justification for each of these constructs and their respective response items will now be discussed. To examine test-retest reliability of our newly developed survey items, a sub-sample of participants (n=85) of the Main Study completed the MSEQ twice approximately 7 days apart.

Preamble

The Main Study (Shakespear-Druery et al., 2022) provided participants with a definition of MSE, and a description of the types of MSE to be considered in their responses (see Electronic Supplementary Material 3). For participants responding to the statements included in the '*Factors influencing leisure-time muscle-strengthening exercise*' component, we included additional contextual statements (see Electronic Supplementary Material 1).

Perceptions

Social ecological frameworks, including Health Education and Change Process theories, explore how peoples' intrapersonal knowledge and attitudes affect their health related behaviours (McLeroy et al., 1992). Therefore, to explore peoples' potential perceptions of MSE, participants were asked to indicate their level of agreement, based on a five point Likert scale, with five statements: (i) '*I don't have enough time to do muscle-strengthening exercise'*, (ii) '*I need expensive equipment to do muscle-strengthening exercise*', (iii) '*I feel I don't have enough knowledge about muscle-strengthening exercise to do it*', (iv) '*I do not have enough energy to do muscle-strengthening exercise*', and (v) '*Doing muscle-strengthening exercise is a low priority for me*'. Five response options were provided for each of the five statements: (i) 'strongly disagree'; (ii) 'disagree'; (iii) 'neutral'; (iv) 'agree'; (v) 'strongly agree'. For our analysis, based on previous research (Bennie, Timperio, Dunstan, Crawford, & Salmon, 2010), we collapsed these data into either (i) disagree (strongly disagree/disagree/neutral), or (ii) agree (agree/strongly agree).

Beliefs

Research has shown that people's attitudes towards specific physical activity modes are a strong predictor of participation in the respective activity (Sallis & Hovell, 1990). Moreover, a persons' beliefs, perceptions, and motivators (Ryan et al., 1997) can be influenced by many factors

(Bauman et al., 2012; Hoare et al., 2017; MacDougall, Cooke, Owen, Willson, & Bauman, 1997). Therefore, based on previous studies (Hoare et al., 2017; Picorelli et al., 2014; Ryan et al., 1997), to examine peoples' beliefs about undertaking MSE, participants were asked to respond to their level of agreement with four statements: (i) '*I am scared that I will injure myself doing muscle-strengthening exercise'*, (ii) '*I would not enjoy doing muscle-strengthening exercise*', (iii) '*I am not healthy enough to do muscle-strengthening exercise*', and (iv) '*I do not feel comfortable doing muscle-strengthening exercise in a gym/fitness centre*'. Similar to 'Perceptions' above we provided participants with the same five response options, again collapsing these data into two categories (agree or disagree) for our analysis.

Confidence

Perceived self-efficacy is a key component of social cognitive theory and a prime determinant of many health-related behaviours (Bandura, 1977) including physical activity (Bandura, 2004; McAuley & Blissmer, 2000). Social cognitive theory suggests that people are more likely to undertake a behaviour if they have confidence in their personal ability to perform the behaviour. Therefore to explore the construct of self-efficacy (Lubans et al., 2011) participants were asked to indicate how likely they were to agree or disagree with four statements regarding their confidence in undertaking MSE: (i) '*I have the physical capacity to complete muscle-strengthening exercises*', (ii) '*I can complete muscle-strengthening exercises without the help of someone else (e.g. friend, trainer)*', (iii) '*If I don't have access to a gym I can still do muscle-strengthening exercise (e.g. body weight exercises)*', and '*I have the skill and technique to complete muscle-strengthening exercises safely*'. Similar questions, used to explore resistance training self-efficacy among adolescent populations, have shown acceptable agreement for test-retest reliability (Lubans et al., 2011). The five response options, described above (see 'Perceptions'), were provided for this construct and for our analysis collapsed into either

(i) disagree (strongly disagree/disagree/neutral), or (ii) agree (agree/strongly agree).

Covariates

Sociodemographic factors (sex, age, education, and work situation) and lifestyle factors (self-rated health, and body mass index [BMI]), were selected a priori, as previous literature has highlighted the potential influence these factors have on participation in MSE (Gordon et al., 2018; Rhodes et al., 2017; Saeidifard et al., 2019). These included: (i) sex at birth (male or female); (ii) age (at last birthday); (iii) education (assessed as the highest level obtained); and (iv) usual work situation (collapsed into either (i) 'Paid employment/self-employed/unpaid work', (ii) 'School/University (full-time)', or (iii) 'Not working/other'). Additionally, data concerning marital status (collapsed into either (i) 'married', (ii) 'not married (defacto/separated/divorced/widowed)', or (iii) 'never married'), and alcohol consumption (collapsed into either (i) 'Non-drinker', or (ii) 'Drinker') were obtained. Participant smoking status was reported, with these data then collapsed into those who (i) 'Never smoked', or (ii) 'Smoker (current or former)'. Self-rated health was assessed by asking "*How would you rate your general health?*" with participants selecting from five options ranging from 'poor' through to 'excellent'. Participant BMI was calculated using self-reported height and weight. We applied standard classifications for BMI (Jensen et al., 2014): (i) underweight <18.5 kg/m^2; (ii) normal weight ≥ 18.5 kg/m^2 to <25 kg/m^2; (iii) overweight 25 kg/m^2 to <30 kg/m^2; (iv) obese ≥ 30 kg/m^2 (Jensen et al., 2014).

Statistical analysis

Statistical Package for the Social Sciences version 26 (SPSS Inc., an IBM Company, Armonk, NY) was used to conduct all data analysis. We used descriptive statistics to describe the characteristics of the participants (see Table 1). Throughout, significance was set at $p < 0.05$.

For the first aim, we used unadjusted and then adjusted logistic regression models to examine the associations between meeting the MSE guideline of ≥2 times/week (dependent variable) and the single behavioural factors (perceptions, beliefs, and confidence) (independent variables). We then conducted multiple-factor logistic regression model analyses including all the factors identified as significant ($p < 0.05$) within the single factor logistic regression analysis model (see Table 2 for the adjusted analyses). As previous research indicates that females are less likely to undertake MSE than males (Bennie et al., 2018; Kamil-Rosenberg et al., 2021; Nakamura & Harada, 2015; Rhodes et al., 2017; Vezina et al., 2014), we undertook additional model analyses, split by sex, to examine if the associations remained consistent between males and females (see Electronic Supplementary Material 4 and Electronic Supplementary Material 5).

For the secondary aim, we explored the likelihood of meeting multiple components of the MSE guidelines (i.e., frequency, muscle groups, and intensity). Specifically, we used unadjusted and adjusted logistic regression models to examine the associations between meeting the MSE guideline of ≥2 times/week plus meeting the ≥5 muscle groups (i.e., two components of the MSE guidelines) and the single behavioural factors (perceptions, beliefs, and confidence). We then conducted multiple-factor logistic regression model analyses, including all the factors identified as significant ($p < 0.05$) within the single factor analysis model. Furthermore, we used unadjusted and adjusted logistic regression models to examine the associations between meeting the 'two components' plus meeting the moderate-intensity guideline (i.e., three components of the MSE guidelines) and the single behavioural factors (perceptions, beliefs, and confidence).

To examine the test-retest reliability of the 13 behavioural statements, we conducted two statistical tests to assess the relative agreement between the participant responses to the initial MSEQ survey (test) against the responses to the follow-up survey (retest). We used intraclass correlation coefficients (ICC), and Spearman's rank correlation coefficients (Spearman's rho; ρ). For ICC analysis, we applied a two-way random effects model, including tests for absolute agreement, and present ICC and Spearman's rho values and their 95% confidence intervals (CI) in Electronic Supplementary Material 6. Based on established ICC correlation coefficient thresholds (Shrout, 1998), a value of 0.00-0.10 suggests virtually no agreement, 0.11-0.40 slight agreement, 0.41-0.60 fair agreement, 0.61-0.80 moderate agreement, and ≥ 0.80 substantial agreement. Standard Spearman's rho classifications were used to interpret the level of agreement as either: <0.30 low, 0.30-0.50 moderate, or >0.50 high (Cohen, 1988).

6.3 Results

Sample description

Data from 435 adults aged ≥18 years were included in our analysis. The sample characteristics for those either meeting (76.8%) or not meeting (23.2%) the MSE frequency guideline of ≥2 times/week are shown in Table 1 and Electronic Supplementary Material 7. In brief, among those meeting the frequency guideline over half were female, had a mean age of 39.3 years (±14.0 years), and a mean BMI of 26.0 kg/m^2 (±5.5 kg/m^2). Moreover, the sample characteristics remained similar regardless of the number of MSE guideline components met (frequency, muscle groups targeted, and intensity) (see Electronic Supplementary Material 7). Among those reporting <2 times/week ~75% were female, had a mean age of 43.0 years (±14.0 years), and a mean BMI of 27.0 kg/m^2 (±7.0 kg/m^2).

The proportion of participants (*n*=435) agreeing with the statements regarding the behavioural influencing factors are included in Electronic Supplementary Material 8. Most of the sample (82.3% to 86.9%) disagreed they don't have enough 'time', 'knowledge', and 'energy', or they 'need expensive equipment' to do MSE and disagreed that MSE is 'a low priority'. Similarly for beliefs, most of the sample (82.3% to 95.9%) disagreed they are 'scared' of 'injury', 'would not enjoy', are 'not healthy enough' and 'not feel comfortable' to do MSE. Conversely for confidence, most of the sample (82.7% to 93.8%) agreed they have the 'physical capacity' and 'skill and technique' to do MSE and are able to do MSE without 'access to a gym' or 'help'.

Table 1. Sociodemographic characteristics [a] of participants classified as either 'meeting' or 'not meeting' the muscle-strengthening exercise guideline of ≥2 times/week included in the analysis.

		Not Meeting % (n)	Meeting % (n)	*p*-value [b]
Total sample (*n*=435)		**23.2 (101)**	**76.8 (334)**	**<0.000**
Sex				
	Female	73.3 (74)	56.6 (189)	0.003*
	Male	26.7 (27)	43.4 (145)	
Age (years)				
	18-34	30.7 (31)	47.3 (158)	
	35-54	46.5 (47)	35.3 (118)	0.013*
	55-74	22.8 (23)	17.4 (58)	
Education				
	Higher education (below degree)/University qualification	78.2 (79)	87.2 (287)	
	Year 12 or equivalent	15.8 (16)	9.1 (30)	0.083
	Primary school/ Some high school	5.9 (6)	3.6 (12)	

Work situation				
	Paid employment/self-employed/unpaid work	70.3 (71)	68.9 (230)	
	School/University (full-time)	11.9 (12)	17.7 (59)	0.269
	Not working/other	17.8 (18)	13.5 (45)	
Self-rated health				
	Excellent	9.9 (10)	26.6 (89)	
	Very good	32.7 (33)	48.8 (163)	<0.000*
	Good	34.7 (35)	19.2 (64)	
	Fair/poor	22.8 (23)	5.4 (18)	
Body Mass Index classification				
	Underweight or normal weight	44.4 (44)	52.1 (173)	
	Overweight	32.3 (32)	32.8 (109)	0.142
	Obese	23.2 (23)	15.1 (50)	

Note.

[a] Numbers vary slightly because of missing data. Missing data equated to; education (1.5% n=5), calculated body mass index (2.6% n=4)

[b] Pearson Chi-square test of independence

* Indicates significance i.e., <0.05

Odds of being classified as meeting the muscle-strengthening exercise frequency guideline

The adjusted odds ratios (AOR: adjusted for sex, age, work situation, education, self-rated health, and BMI [selected due to their potential influence on MSE participation (Gordon et al., 2018; Rhodes et al., 2017; Saeidifard et al., 2019)]), and their 95% confidence interval

(CI), between the respective behaviour factor constructs and being classified as meeting the MSE frequency guideline, are shown in Table 2. In the single-factor model analysis, with the exception for 'perceptions' regarding the need for 'expensive equipment' (p=0.719) and 'belief' of being 'not healthy enough' (p=0.580), all other statements (n=11) were statistically significant (AOR range=0.03-6.56) (also see Electronic Supplementary Material 9). The multi-factor model only included the significant single-factors (n=11), resulting in five of the statements (p range=<0.000-0.020) remaining statistically significant (AOR range=0.07-3.75) (see Table 2, and Electronic Supplementary Material 10). Results of the unadjusted odds ratio analyses are contained in Electronic Supplementary Material 11 and Electronic Supplementary Material 12.

Table 2. Single-factor, and multiple factor adjusted[a] odds ratios (OR) and their 95% confidence intervals (95% CI) for being classified as meeting the muscle-strengthening exercise (frequency) guideline according to individual behavioural factors – for the total sample (n=435).

	Dependent variable: Odds of being classified as meeting the muscle-strengthening guidelines (≥2 times/week)			
	Single-factor models AOR[a] (95% CI)		**Multiple-factor model AOR[a] (95% CI)**	
		***p*-value**		***p*-value**
Perceptions				
I don't have enough time to do muscle-strengthening exercise	0.35 (0.19-0.65)	0.001	0.38 (0.17-0.86)	0.020
I need expensive equipment to do muscle-strengthening exercise	1.14 (0.56-2.30)	0.719		
I feel I don't have enough knowledge about muscle-strengthening exercise to do it	0.16 (0.08-0.31)	<0.000	0.70 (0.26-1.84)	0.467
I do not have enough energy to do muscle-strengthening exercise	0.15 (0.08-0.28)	<0.000	0.26 (0.12-0.59)	0.001
Doing muscle-strengthening exercise is a low priority for me	0.07 (0.03-0.14)	<0.000	0.25 (0.10-0.64)	0.004

Belief factors				
I am scared that I will injure myself doing muscle-strengthening exercise	0.45 (0.22-0.90)	0.024	1.81 (0.61-5.42)	0.287
I would not enjoy doing muscle-strengthening exercise	0.03 (0.01-0.08)	<0.000	0.07 (0.02-0.23)	<0.000
I am not healthy enough to do muscle-strengthening exercise	0.74 (0.26-2.12)	0.580		
I do not feel comfortable doing muscle-strengthening exercise in a gym/fitness centre	0.26 (0.15-0.46)	<0.000	1.13 (0.47-2.69)	0.789
Confidence/Belief factors [b]				
I have the physical capacity to complete muscle-strengthening exercises	3.42 (1.32-8.90)	0.012	1.05 (0.28-3.95)	0.946
I can complete muscle-strengthening exercises without the help of someone else (e.g. friend, trainer)	3.44 (1.89-6.28)	<0.000	1.44 (0.56-3.67)	0.448
If I don’t have access to a gym I can still do muscle-strengthening exercise (e.g. body weight exercises)	2.00 (1.07-3.72)	0.029	1.05 (0.41-2.67)	0.919
I have the skill and technique to complete muscle-strengthening exercises safely	6.56 (3.56-12.10)	<0.000	3.75 (1.44-9.81)	0.007

Note.

[a] Adjusted for: sex, age, work situation, education, self-rated health, body mass index (BMI).

[b] Missing data: Confidence 0.5% (n=2)

We conducted additional analyses based on sex at birth, as previous studies have associated sex as an influencing factor in MSE participation (Rhodes et al., 2017). In the multi-factor model, split by sex, we only included the significant single-factors (n=8) for both sexes (see Electronic Supplementary Material 4). While the multi-factor analysis produced similar results (see Electronic Supplementary Material 5) to the previous multi-factor model shown in Table 2 (i.e., not split by sex), only the belief factor 'not enjoy doing' (AOR=0.05) was statistically significant for both sexes (*p* range=0.001-0.010). The remaining statements (*n*=4) appeared statistically significant for only males ('time' and 'skill and technique') or females ('energy' and 'priority'), indicating an association with meeting the MSE guideline of ≥ 2 times/week.

Further analyses were conducted to explore if the behavioural correlates varied across meeting multiple components of the MSE guidelines. Overall, the results remained consistent across each model analyses completed (meeting two components i.e., frequency + muscle groups [see Electronic Supplementary Material 13 and Electronic Supplementary Material 14], and meeting three components i.e., frequency + muscle groups + intensity [see Electronic Supplementary Material 15 and Electronic Supplementary Material 16]), regardless of the number of MSE guideline components assessed (see Electronic Supplementary Material 12, Electronic Supplementary Material 9, and Electronic Supplementary Material 10).

Test-retest reliability

The results of the test-retest reliability of the 13 behavioural statements are shown in Electronic Supplementary Material 6. For 'perceptions' of MSE, there was a substantial agreement for 'equipment', 'knowledge', 'energy', and 'priority' (ICC range: 0.81-0.89), and moderate agreement, for 'time' (ICC= 0.75; 95% CI 0.62-0.84). For 'belief' factors, each question ('scared', 'enjoy', 'healthy', and 'comfortable') showed substantial agreement (ICC range: 0.80-0.93). For MSE 'confidence', there was substantial agreement for 'physical capacity', 'help', and 'skill' (ICC range: 0.80-0.87), and moderate agreement for 'access' (ICC= 0.69; 95% CI 0.53-0.80). Spearman's rank correlations were high for all behavioural factors; 'perceptions' (ρ range 0.59-0.82), 'belief' (ρ range 0.67-0.85), and 'confidence' (ρ range 0.58-0.77).

6.4 Discussion

To our knowledge, this is the first study describing the associations between behavioural factors influencing participation in guideline-concordant MSE among a sample of active adults. The key findings are that respondents who have positive perceptions of time availability, prioritise this exercise modality, and have sufficient energy, are more likely to meet the MSE guideline (≥ 2 times/week). Moreover, having confidence in their skills and technique, along with enjoying MSE, has a significant association with MSE guideline compliance. Furthermore, the identified influencing factors remained consistent and significant, regardless of the number of participation components (frequency, muscle groups, intensity) assessed. However, it is equally important to highlight that the majority of participants in this study met the MSE guideline. Despite this biased sample, implications from this study may be useful for future research and health promotion activities.

While research into the relationship between MSE and health is relatively new compared to aerobic physical activity, this study has presented novel findings regarding factors that may positively influence MSE participation. From a public health perspective, the present finding suggests that the promotion of MSE may benefit from highlighting concepts such as the enjoyment of this exercise mode (such as through photographic/video imaging of positive experiences among diverse populations). Moreover, ways for individuals to build their skill and technique in undertaking MSE (e.g., displays of simple body weight exercises or the use of readily available 'household items' used for added resistance) may influence an increase in participation. Health promotion initially targeting those at most risk of chronic disease and demographically underrepresented (e.g., older adults, lower educated, female) in MSE participation would be beneficial. Consideration should also be given to sex-specific campaigns in the case of the enjoyment of MSE. We now call for further research to examine the effectiveness of such approaches in increasing the uptake of MSE. Furthermore, future research could explore the practical use of these statements among health professionals, in their efforts to overcome barriers to MSE participation within their patients.

Comparatively, our findings are similar to those by Rhodes et al. (2017) relating to intrapersonal factors of self-efficacy and affective judgements (enjoyment and feeling states) with positive associations found amongst those undertaking MSE. Furthermore, in a study of 293 older adults, having access to facilities for MSE was positively correlated with regular MSE participation compared to those who did not have access (Harada et al., 2011). In our study (adults aged 18-74 years), the associations were positive and significant in each of the single-factor models, however, the result was not significant in each of the multi-factor model analyses. Therefore indicating 'access to facilities' is less of a factor for guideline concordance in our sample of participants.

These findings could be used to reinforce current public health campaigns that endorse or highlight the relative ease of performing body weight MSE in small time periods. This may positively influence perceptions of time availability, which was in general not an issue in this sample, as most (~90%) agreed they had enough time to do MSE. Promotional materials, similar to that used in 'Spoon Theory' (Miserandino, 2017) (which relates to coping with a chronic condition), could be utilised to explain the 'energy cost' of MSE in efforts to reduce the perception of people not having enough energy to do MSE. Research suggests that providing individuals with general or paper-based materials promoting physical activity (such as pamphlets) may only be effective in the short term (Marcus, Owen, Forsyth, Cavill, & Fridinger, 1998). However tailored promotional materials based on social cognitive theory and the use of mediated interventions and emerging technologies have proven to be effective among participants in their long-term efforts to meet the physical activity guidelines (Napolitano & Marcus, 2002). Moreover, applying social marketing theories within physical activity promotion (e.g., using motivationally matched materials) has shown to be effective (Marcus et al., 1998). Indeed, a cross-sectional study of Japanese older adults found that having access to sources of MSE information (e.g., internet, health care providers) significantly increased the odds of respondents regularly meeting the MSE guideline (≥ 2 times/week) (Harada, Shibata, Lee, Oka, & Nakamura, 2014). Given ~98% of our sample (meeting the MSE frequency guideline) agreed that they enjoyed doing MSE, efforts to promote the enjoyment 'aspect' of this exercise modality may positively influence MSE participation among those not currently meeting the MSE guideline. This might enable more people to prioritise some of their time to MSE rather than to alternative sedentary pursuits. Moreover, visual representations containing various populations (e.g., older adults, females, and those from lower socioeconomic and demographic profiles) that display participants enjoying MSE either alone, in a group setting, at home, or in a fitness facility may enhance positive perceptions of MSE.

Interestingly, while we found that only ~30% of participants, not meeting the MSE guideline, agreed with the perception of 'not having enough time', previous studies (Dishman, Sallis, & Orenstein, 1985; Rhodes et al., 2017; Steele et al., 2017) suggest that this may not be the case. Furthermore, this observation could be influenced more so by how people chose to use their time, rather than it being a factor of time availability (Biddle et al., 2021). Moreover, we also acknowledge that this observation may be due to the highly active and therefore biased sample. Among those assessed as not meeting the MSE frequency guideline more females (~30%) agreed with the statement '*I don't have enough time to* *do muscle-strengthening exercise*' compared to males (~26%). Furthermore, even amongst participants assessed as meeting the frequency guideline more females (~13%) agreed with the 'enough time' statement compared to males (~7%). However, it could be argued that strong beliefs in an individuals' physical capacity and skill and technique may influence this time availability perception.

In a recent population-level study investigating the concept of the MSE intention-behaviour gap, Rhodes and Lithopoulos (2022) found 'skill perception' (perceived capability) differed between males and females, with the strongest predictors found amongst those classified as 'successful intenders' (i.e., reportedly engaged in MSE) and higher in both younger and older females than males. While our study did not directly explore this concept, we did undertake brief sub-analyses on the differences between the sexes across behavioural factors, including confidence factors regarding skill and technique (data not shown). We found a positive and significant association in males and females who undertook guideline-concordant MSE. However, males displayed more than three times greater odds than females (single-factor models).

While acknowledging our relatively biased sample, most participants who reported undertaking MSE two or more times/week also did so at a moderate or greater level of intensity using most of the major muscle groups. Furthermore, this study has expanded on previous predictive MSE research that has predominantly involved students or solely clinical populations (Rhodes & Lithopoulos, 2022). Consistent with findings by Rhodes et al. (2017) the majority of our sample undertaking guideline-concordant MSE were highly educated, but this was also the case for those not meeting the guidelines. In our study, the comparison between education and meeting or not meeting the guideline of ≥2 times/week was not statistically significant. Moreover, undertaking a higher frequency of MSE participation and having a positive perception of self-rated health, was a consistent finding across both studies.

Strengths and limitations

A key strength of this study is that it is one of the first cross-sectional studies to explore factors influencing MSE participation among a sample of adults. However, since the participants within this study were highly educated and more likely to meet the MSE guideline, our findings, therefore, may not be truly representative of the general population. To improve the generalisability of our results we now call for further studies using large cross-sectional samples of the population to explore these associations with MSE participation. Further, given the self-reported nature of the responses, there is a risk that these data may be influenced by responder recall bias (e.g., social desirability, or over/under-reporting of actual behaviour) (Duffy, Smith, Terhanian, & Bremer, 2005). Additionally, due to the cross-sectional design of this study, inferences of causality cannot be made. An additional strength of this study included the assessment of test-retest reliability of the statements, which were found to be acceptable.

6.5 Conclusion

Currently, the global MSE guidelines include three key components (frequency, intensity, and muscle groups targeted), however, these three components are rarely assessed in health surveillance at the population level. Our study, containing a highly active sample of adults, has shown that participants who met the frequency guideline were also likely to be undertaking multi-guideline concordant MSE. Five behavioural factors appear to be linked to MSE guideline compliance: perceptions of time availability and available energy, prioritisation of MSE, and beliefs including enjoyment and confidence. While globally participation in MSE is low, approaches to increase MSE participation at the population level would benefit from focussing on these enabling factors within currently inactive populations.

Conflicts of interest: The authors declare that they have no conflict of interest.

Data availability statement: The data that support the findings of this study are available from the corresponding author, [JSD], upon reasonable request.

Sources of any support: JSD is supported by an Australian Government Research Training Program Scholarship and a University of Southern Queensland Research Training Program Stipend Scholarship, all other authors declare no relevant sources of support.

Authors' contributions: JSD, KDC, SJHB, and JAB conceptualised the study and developed the research plan. JSD created the online survey, collected all the data, and conducted the data analysis. JSD drafted the initial manuscript. JAB, KDC, and SJHB provided guidance on the study and critically reviewed the manuscript. All authors read and approved the final version of the manuscript and agree with the order of authorship.

6.6 References

Bandura, A. (1977). Self-efficacy: Toward a unifying theory of behavioral change. *Psychological Review, 84*(2), 191-215. doi: 10.1037/0033-295X.84.2.191

Bandura, A. (2004). Health promotion by social cognitive means. *Health Education & Behavior, 31*(2), 143-164. doi: 10.1177/1090198104263660

Bauman, A. E., Reis, R. S., Sallis, J. F., Wells, J. C., Loos, R. J. F., Martin, B. W., & Lancet Physical Activity Series Working Group. (2012). Correlates of physical activity: Why are some people physically active and others not? *Lancet, 380*(9838), 258-271. doi: 10.1016/s0140-6736(12)60735-1

Bennie, J. A., De Cocker, K., Smith, J. J., & Wiesner, G. H. (2020). The epidemiology of muscle-strengthening exercise in Europe: A 28-country comparison including 280,605 adults. *PLoS One, 15*(11), e0242220. doi: 10.1371/journal.pone.0242220

Bennie, J. A., Lee, D.-c., Khan, A., Wiesner, G. H., Bauman, A. E., Stamatakis, E., & Biddle, S. J. H. (2018). Muscle-strengthening exercise among 397,423 U.S. adults: Prevalence, correlates, and associations with health conditions. *American Journal of Preventive Medicine, 55*(6), 864-874. doi: 10.1016/j.amepre.2018.07.022

Bennie, J. A., Pedišić, Ž., van Uffelen, J. G. Z., Gale, J., Banting, L. K., Vergeer, I., . . . Biddle, S. J. H. (2016). The descriptive epidemiology of total physical activity, muscle-strengthening exercises and sedentary behaviour among Australian adults -Results from the national nutrition and physical activity survey. *BMC Public Health, 16*(73), 1-13. doi: 10.1186/s12889-016-2736-3

Bennie, J. A., Shakespear-Druery, J., & De Cocker, K. (2020). Muscle-strengthening exercise epidemiology: A new frontier in chronic disease prevention. *Sports Medicine - Open, 6*(1), 1-8. doi: 10.1186/s40798-020-00271-w

Bennie, J. A., Timperio, A., Dunstan, D., Crawford, D., & Salmon, J. (2010). Environmental correlates of physical activity in Australian workplaces. *International Journal of Workplace Health Management, 3*(1), 25-33. doi: 10.1108/17538351011031911

Bennie, J. A., Timperio, A. F., Crawford, D. A., Dunstan, D. W., & Salmon, J. L. (2011). Associations between social ecological factors and self-reported short physical activity breaks during work hours among desk-based employees. *Preventive Medicine, 53*(1-2), 44-47. doi: 10.1016/j.ypmed.2011.05.015

Biddle, S., Mutrie, N., Gorely, T., & Faulkner, G. E. J. (2021). *Psychology of physical activity: Determinants, well-being and interventions* (4th ed.). New York, NY: Routledge.

Bull, F. C., Al-Ansari, S. S., Biddle, S., Borodulin, K., Buman, M. P., Cardon, G., . . . Willumsen, J. F. (2020). World Health Organization 2020 guidelines on physical activity and sedentary behaviour. *British Journal of Sports Medicine, 54*(24), 1451. doi: 10.1136/bjsports-2020-102955

Cohen, J. (1988). *Statistical power analysis for the behavioral sciences* (2nd ed.). Hillsdale, N.J.: Lawrence Erlbaum Associates.

Dishman, R. K., Sallis, J. F., & Orenstein, D. R. (1985). The determinants of physical activity and exercise. *Public Health Reports, 100*(2), 158-171

Duffy, B., Smith, K., Terhanian, G., & Bremer, J. (2005). Comparing data from online and face-to-face surveys. *International Journal of Market Research, 47*(6), 615-639. doi: 10.1177/147078530504700602

Dunstan, D. W., Daly, R. M., Owen, N., Jolley, D., De Courten, M., Shaw, J., & Zimmet, P. (2002). High-intensity resistance training improves glycemic control in older patients with type 2 diabetes. *Diabetes Care, 25*(10), 1729-1736. doi: 10.2337/diacare.25.10.1729

Gordon, B. R., McDowell, C. P., Hallgren, M., Meyer, J. D., Lyons, M., & Herring, M. P. (2018). Association of efficacy of resistance exercise training with depressive symptoms: Meta-analysis and meta-regression analysis of randomized clinical trials. *JAMA Psychiatry, 75*(6), 566-576. doi: 10.1001/jamapsychiatry.2018.0572

Gordon, B. R., McDowell, C. P., Lyons, M., & Herring, M. P. (2017). The effects of resistance exercise training on anxiety: A meta-analysis and meta-regression analysis of randomized controlled trials. *Sports Medicine, 47*(12), 2521-2532. doi: 10.1007/s40279-017-0769-0

Grnøtved, A., Pan, A., Mekary, R. A., Stampfer, M., Willett, W. C., Manson, J. E., & Hu, F. B. (2014). Muscle-strengthening and conditioning activities and risk of type 2 diabetes: A prospective study in two cohorts of US women. *PLoS Medicine, 11*(1), 15. doi: 10.1371/journal.pmed.1001587

Grnøtved, A., Rimm, E. B., Willett, W. C., Andersen, L. B., & Hu, F. B. (2012). A prospective study of weight training and risk of type 2 diabetes mellitus in men. *Archives of Internal Medicine, 172*(17), 1306-1312. doi: 10.1001/archinternmed.2012.3138

Handy, C. E., & Blaha, M. J. (2017). Strong implications but weak evidence for strength training. *Journal of the American Heart Association, 6*(11), 1-4. doi: 10.1161/JAHA.117.007761

Harada, K., Oka, K., Shibata, A., Ishii, K., Nakamura, Y., Inoue, S., & Shimomitsu, T. (2011). Strength-training behavior and perceived environment among Japanese older adults. *Journal of Aging and Physical Activity, 19*(3), 262-272. doi: 10.1123/japa.19.3.262

Harada, K., Shibata, A., Lee, E., Oka, K., & Nakamura, Y. (2014). Sources of strength-training information and strength-training behavior among Japanese older adults. *Health Promotion International, 31*(1), 5-12. doi: 10.1093/heapro/dau052

Harris, C. D., Watson, K. B., Carlson, S. A., Fulton, J. E., Dorn, J. M., & Elam-Evans, L. (2013). *Adult participation in aerobic and muscle-strengthening physical activities-United States, 2011* (Report No. 0149-2195). Retrieved from MMWR: Morbidity & Mortality Weekly Report:

https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4604926/pdf/326-330.pdf.

Hoare, E., Stavreski, B., Jennings, G. L., & Kingwell, B. A. (2017). Exploring motivation and barriers to physical activity among active and inactive Australian adults. *Sports, 5*(3), 8. doi: 10.3390/sports5030047

Jensen, M. D., Ryan, D. H., Donato, K. A., Apovian, C. M., Ard, J. D., Comuzzie, A. G., . . . Yanovski, S. Z. (2014). Executive summary: Guidelines (2013) for the management of overweight and obesity in adults. *Obesity, 22*(S2), S5-S39. doi: 10.1002/oby.20821

Kamil-Rosenberg, S., Greaney, M. L., & Garber, C. E. (2021). Health-related and sociodemographic correlates of meeting the muscle strengthening exercise recommendations in middle-aged and older adults with and without disabilities. *Sport Sciences for Health, 17*(1), 201-211. doi: 10.1007/s11332-020-00674-y

Loprinzi, P. D., Addoh, O., & Mann, J. R. (2017). Association between muscle strengthening physical activities and mortality among American adults with mobility limitations. *Preventive Medicine, 99*, 207-210. doi: 10.1016/j.ypmed.2017.02.013

Lubans, D. R., Morgan, P., Callister, R., Plotnikoff, R. C., Eather, N., Riley, N., & Smith, C. J. (2011). Test–retest reliability of a battery of field-based health-related fitness measures for adolescents. *Journal of Sports Sciences, 29*(7), 685-693. doi: 10.1080/02640414.2010.551215

MacDonald, H. V., Johnson, B. T., Huedo-Medina, T. B., Livingston, J., Forsyth, K. C., Kraemer, W. J., . . . Pescatello, L. S. (2016). Dynamic resistance training as stand-alone antihypertensive lifestyle therapy: A meta-analysis. *Journal of the American Heart Association, 5*(10), 1-34. doi: 10.1161/JAHA.116.003231

MacDougall, C., Cooke, R., Owen, N., Willson, K., & Bauman, A. (1997). Relating physical activity to health status, social connections and community facilities. *Australian and New Zealand Journal of Public Health, 21*(6), 631-637. doi: 10.1111/j.1467-842x.1997.tb01768.x

Marcus, B. H., Owen, N., Forsyth, L. H., Cavill, N. A., & Fridinger, F. (1998). Physical activity interventions using mass media, print media, and information technology. *American Journal of Preventive Medicine, 15*(4), 362-378. doi: 10.1016/s0749-3797(98)00079-8

McAuley, E., & Blissmer, B. (2000). Self-efficacy determinants and consequences of physical activity. *Exercise and Sport Sciences Reviews, 28*(2), 85-88

McLeroy, K. R., Steckler, A. B., Goodman, R. M., & Burdine, J. N. (1992). Health education research: Theory and practice-future directions. *Health Education Research, 7*(1), 1-8. doi: 10.1093/her/7.1.1

Miserandino, C. (2017). The spoon theory. In L. J. Davis (Ed.), *Beginning with disability: A primer* (pp. 174-178). New York, NY: Routledge.

Nakamura, Y., & Harada, K. (2015). Promotion of strength training. In K. Kanosue, S. Oshima, Z. B. Cao & K. Oka (Eds.), *Physical activity, exercise, sedentary behavior and health* (pp. 29-42). Tokyo: Springer.

Napolitano, M. A., & Marcus, B. H. (2002). Targeting and tailoring physical activity information using print and information technologies. *Exercise and Sport Sciences Reviews, 30*(3), 122-128. doi: 10.1097/00003677-200207000-00006

Picorelli, A. M. A., Pereira, D. S., Felicio, D. C., Dos Anjos, D. M., Pereira, D. A. G., Dias, R. C., . . . Pereira, L. S. M. (2014). Adherence of older women with strength training and aerobic exercise. *Clinical Interventions in Aging, 9*, 323-331. doi: 10.2147/cia.s54644

Rhodes, R. E., & Lithopoulos, A. (2022). Understanding action control of resistance training among adults. *Psychology of Sport and Exercise, 59*, 102108. doi: 10.1016/j.psychsport.2021.102108

Rhodes, R. E., Lubans, D. R., Karunamuni, N., Kennedy, S., & Plotnikoff, R. (2017). Factors associated with participation in resistance training: A systematic review. *British Journal of Sports Medicine, 51*(20), 1-9. doi: 10.1136/bjsports-2016-096950

Robertson, R. J., Goss, F. L., Rutkowski, J., Lenz, B., Dixon, C., Timmer, J., . . . Andreacci, J. (2003). Concurrent validation of the OMNI perceived exertion scale for resistance exercise. *Medicine & Science in Sports & Exercise, 35*(2), 333-341. doi: 10.1249/01.mss.0000048831.15016.2a

Ryan, R. M., Frederick, C. M., Lepes, D., Rubio, N., & Sheldon, K. M. (1997). *Intrinsic motivation and exercise adherence*. Retrieved from https://selfdeterminationtheory.org/SDT/documents/1997_RyanFrederickLepesRubioSheldon.pdf

Saeidifard, F., Medina-Inojosa, J. R., West, C. P., Olson, T. P., Somers, V. K., Bonikowske, A. R., . . . Lopez-Jimenez, F. (2019). The association of resistance training with mortality: A systematic review and meta-analysis. *European Journal of Preventive Cardiology, 26*(15), 1647-1665. doi: 10.1177/2047487319850718

Sallis, J. F., & Hovell, M. F. (1990). Determinants of exercise behavior. *Exercise and Sport Sciences Reviews, 18*(1), 307-330

Sallis, J. F., Owen, N., & Fotheringham, M. J. (2000). Behavioral epidemiology: A systematic framework to classify phases of research on health promotion and disease prevention. *Annals of Behavioral Medicine, 22*(4), 294-298. doi: 10.1007/BF02895665

Shakespear-Druery, J., De Cocker, K., Biddle, S. J. H., & Bennie, J. (2022). Muscle-Strengthening Exercise Questionnaire (MSEQ): An assessment of concurrent validity and test–retest reliability. *BMJ Open Sport & Exercise Medicine 8*(e001225), 1-10. doi: 10.1136/bmjsem-2021-001225

Shrout, P. E. (1998). Measurement reliability and agreement in psychiatry. *Statistical Methods in Medical Research, 7*(3), 301-317. doi: 10.1191/096228098672090967

Steele, J., Fisher, J., Skivington, M., Dunn, C., Arnold, J., Tew, G., . . . Winett, R. (2017). A higher effort-based paradigm in physical activity and exercise for public health: Making the case for a greater emphasis on resistance training. *BMC Public Health, 17*, 8. doi: 10.1186/s12889-017-4209-8

Stokols, D. (1996). Translating social ecological theory into guidelines for community health promotion. *American Journal of Health Promotion, 10*(4), 282-298. doi: 10.4278/0890-1171-10.4.282

Trost, S. G., Owen, N., Bauman, A. E., Sallis, J. F., & Brown, W. (2002). Correlates of adults' participation in physical activity: Review and update. *Medicine & Science in Sports & Exercise, 34*(12), 1996-2001. doi: 10.1097/00005768-200212000-00020

Vezina, J. W., Der Ananian, C. A., Greenberg, E., & Kurka, J. (2014). Sociodemographic correlates of meeting US department of health and human services muscle strengthening recommendations in middle-aged and older adults. *Preventing Chronic Disease, 11*(E162), 1-10. doi: 10.5888/pcd11.140007

World Health Organization. (2014). *Global status report on noncommunicable diseases 2014*. World Health Organization https://apps.who.int/iris/handle/10665/148114.

6.7 How the Publication Contributes to the Advancement of the Research Area

While sociodemographic and behavioural correlates associated with MVPA participation are well researched, comparatively, an understanding of these associations within the context of MSE participation is less well developed. Moreover, most research regarding the correlates of MSE has been assessed based on the frequency of participation, with a limited exploration into the influence of the other components included in global MSE guidelines (i.e., muscle groups targeted and exercise intensity). Based on the above, there is currently limited research regarding the possible behavioural correlates influencing MSE participation or non-participation. This study adds to the emerging body of evidence regarding these important research gaps.

Using the previously validated Muscle-Strengthening Exercise Questionnaire (MSEQ) discussed in chapter 5, we identified five behavioural correlates significantly associated with participants meeting the MSE guidelines (i.e., frequency, muscle groups, and/or exercise intensity). These correlates included: three correlates relating to **perceptions** (time, energy, and priority), and one each relating to **belief factors** (enjoy), and **confidence** (skill and technique). While acknowledging the limitations of this cross-sectional study of highly active adults, these findings are important for both promotors of MSE and policymakers alike as they provide an insight into specific areas of focus for public health messaging. Moreover, these findings may prove valuable in the efforts to produce MSE specific education and promotional materials focused on gaining the attention of the inactive population. Furthermore, this may translate into increased MSE participation, leading to a positive influence on health at the population level, given the established benefits of MSE participation.

Applying a 'real-world application lens' the findings from this study may prove valuable to exercise and health professionals who identify within their client base with those who are non-compliant with the MSE guidelines. Acknowledging the ‘success factors’ of those who meet the MSE guideline, health professionals may look to provide solutions to overcome perceived time barriers by presenting options for home-based MSE.

Additional large-scale population-level studies are now called upon to confirm the generalisability of these findings. This study also builds upon previous gaps identified throughout this research program.

CHAPTER 7: DISCUSSION AND CONCLUSION

7.1 Overview of the Chapter

The objective of this chapter is to discuss and interpret the significance of the findings contained within this thesis by publication within the context of assessing adult muscle-strengthening exercise participation at the population level. First, presenting a summary of the aims, key research findings and discussion of the interpretations of these findings. Then a discussion on the implications and recommendations for future research pursuits, relative to the findings. Strengths and limitations of the thesis are then discussed, with the chapter ending in an overall conclusion of the thesis.

7.2 Summary of Aims, Key Research Findings, and Interpretations of Findings

The primary aim of the studies presented in this thesis was to improve the understanding of how the muscle-strengthening exercise behaviours of adults are assessed and monitored in the context of public health surveillance. **Five discrete research studies** were used to achieve this aim. The **first study** consisted of a <u>systematic literature review</u> of MSE surveillance studies that described the current methods used to assess adult MSE participation at the population level (Shakespear-Druery et al., 2021). Samples (k=156) of >1000 English-speaking adults (≥ 18 years) were analysed. Study 1 resulted in clear recommendations for future research. First, a collaborative and consistent approach in the way participation data is collected at the population level, is required for the accurate assessment and comparability of MSE participation data globally. Second, the overarching need identified with this literature review is for a surveillance instrument that will collect reliable and valid MSE population-level data that is consistent with and assesses, the MSE behaviours included in the current National and Global MSE guidelines (i.e., frequency, muscle groups targeted, and intensity).

Last, to gain a deeper understanding of the relationship between MSE participation (beyond assessments of frequency alone) and health, at the population level, further studies are required.

Therefore, to begin to address this last observation, and to increase the body of knowledge regarding the relationship between MSE participation and health (beyond that of frequency alone), Study Two was undertaken. **Study Two** comprised the secondary data analysis of a large pooled cross-sectional study of adults ≥16 years (*N* = 16,301) who reported MSE participation (or non-participation) and having either none or one or more chronic conditions (i.e., diabetes, anxiety/depression, and/or a heart, respiratory, or musculoskeletal condition) within the HSE administrations completed in 2012 and 2016 (Shakespear-Druery, De Cocker, Biddle, & Bennie, 2022c). Using Poisson regression analysis we found that regardless of the mode, duration/session, or volume/week of MSE there was a reduced likelihood of participants having one or more of the included chronic conditions, compared to participants who reported no or insufficient MSE.

This study also highlighted that a majority of the participants (~80%) reported undertaking no MSE. Among those who did report MSE participation for durations ≥ 10 minutes, we found that only approximately 26% met the MSE frequency guideline of ≥2 times/week. While this finding is consistent with previous research (Bennie et al., 2018), the large disparity between those who do and do not undertake MSE is of concern.

While further cohort studies are required to confirm our cross-sectional observations, these data are important as they suggest that, at the population level, small-to-moderate increases in MSE are likely to have public health benefits. Moreover, research has shown that increases in physical activity can lead to reduced healthcare costs amongst the type 2 diabetic population (Sarria-Santamera et al., 2022; Su et al., 2020). Importantly, increases in physical activity need to be maintained for long-term benefits in health care costs (Gomes, Brown, Codogno, & Mielke, 2020). If we view these findings from an Australian perspective they are important as the economic burden (including the cost of subsidised medications and lost productivity) of physical inactivity is high (Australian Government Department of Health, 2021; Crosland, Ananthapavan, Davison, Lambert, & Carter, 2019). Therefore, reducing physical inactivity through the successful health promotion of physical activity at the population level, inclusive of MSE, could ease this high economic burden.

While it is important to assess MSE participation against recommended global guidelines, it is of equal if not greater importance to understand why most people do no MSE. These two aspects (assessment of guideline concordance, and the factors influencing participation) were discussed in Chapters 5 and 6 respectively.

Expanding on Study Two (Paper 2) we then explored the same MSE relationships (mode, duration, and volume) but for associations with hypertension. **Study Three**, therefore, comprised the secondary data analysis of a subset of adults ≥16 years from the HSE (waves 2012 and 2016) used in Study Two (*N* = 10,519) who reported participation (or non-participation) in MSE and were objectively assessed as either having (or not having) hypertension (Shakespear-Druery, De Cocker, Biddle, & Bennie, 2022b). Both the 'American' (Whelton et al., 2018) and 'European' (Williams et al., 2018) guidelines for the classification of hypertension were adopted in our analyses, along with the calculated participant mean 'systolic' (SBP) and 'diastolic' (DBP) values. Overall, the findings in Study 3 were consistent with those found in Study 2. Specifically, the key findings were that most of the sample (~81%) reported doing no or insufficient gym-based strength or own-bodyweight MSE. Furthermore, irrespective of factors such as MSE mode, duration, or volume, the prevalence of being classified as hypertensive (regardless of the definition applied) was reduced amongst those who did report participation in MSE. While again acknowledging the limitations of the findings, as they are based on cross-sectional data, they provide further support to increasing the focus of MSE participation at the population level, especially amongst those within the population that are physically inactive.

In Australia the human and financial costs associated with hypertension are large (Hird et al., 2019). In 2017 over a quarter of Australians of working age (4.1 million) were estimated as having hypertension, among which over ~61% were classed as having untreated hypertension (Hird et al., 2019). While multiple factors can influence the prevalence of hypertension (including genetic, diet, and environmental factors), our findings suggest (albeit based on data from U.K. adults) that population-level efforts to increase MSE participation (even by a small-to-moderate increase) could be considered, in an effort to reduce these costs. As the health promotion of physical activity has been shown to reduce health care costs (Eckermann & Willan, 2022).

Consistent with remarks made in Study 2, it remains important for researchers to not only assess MSE participation to the full extent of the guidelines (frequency, intensity, and muscle groups) we must expand the body of knowledge regarding the factors that influence non-participation in this valuable and health-enhancing exercise modality. Given the limitations and key findings discussed as a result of Study 1 (above) the key research findings of Study 4, and Study 5 will now be presented.

Study Four consisted of the <u>development of a new online questionnaire,</u> designed to be used in the assessment of multiple MSE participation constructs at the population level. The focus of this study was on the <u>tests conducted for reliability and validity</u> of the newly-developed Muscle-Strengthening Exercise Questionnaire (MSEQ) (Shakespear-Druery, De Cocker, Biddle, & Bennie, 2022d). Overall our analyses found that the MSEQ evidenced acceptable reliability (*n* = 85) and validity (*n* = 54) for the four key constructs examined. Three of these constructs directly aligned with current global guidelines for MSE participation (i.e., frequency, intensity, and muscle groups targeted). The remaining construct of ‘duration’, while not included in MSE guidelines currently, remains a strong focus in aerobic physical activity guidelines. Moreover, an instrument that reliably and validly assesses MSE duration is important in the efforts to increase our understanding of the relationship between MSE and health at the population level, as there is currently insufficient evidence regarding this dose-response relationship (World Health Organization, 2020b). Therefore, it remains unclear if the current MSE guidelines would benefit from the inclusion of this construct. However, given that participation in MSE at the population level is currently low, the addition of this construct within MSE guidelines may encourage higher levels of participation. This study has also begun to address some of the research gaps regarding the uniformity and consistency of instruments identified within the literature review contained in Study 1 (Paper 1). To further aid the understanding and interpretation of future results from the use of the online MSEQ, a scoring protocol document has been developed (see Appendix J).

The final study of this thesis aimed to begin unpacking the reasons why people do or do not engage in this valuable health-enhancing exercise modality. Therefore, **Study Five** used the online MSEQ to explore the potential behavioural correlates that might influence compliance with Global and National muscle-strengthening exercise guidelines (Shakespear-Druery, De Cocker, Biddle, & Bennie, 2022a). Participant agreement (*N* = 435 adults) and test-retest reliability (*n* = 85) was measured against 13 statements, previously identified as possible correlates of exercise behaviour.

To analyse the associations between meeting one or more of the components included in the MSE guidelines (frequency, intensity, muscle groups targeted), and the selected behavioural correlates, we conducted unadjusted and adjusted multiple-factor logistic regression analyses. We found that five behavioural correlates were key to MSE guideline compliance (meeting one, two, or all three of the global guidelines). Three factors were linked to peoples' *perceptions* (time and energy availability, and a willingness to prioritise the exercise mode), one was linked to peoples' *beliefs* (enjoyment factor), with the remaining factor linked to peoples' *confidence* (having the skill and technique). Test-retest reliability was assessed using intraclass correlations coefficients and Spearman's rank coefficients. Moderate-to-substantial agreement was observed for test-retest reliability of the 13 statements.

This study (Study 5) was unique as it is one of the first to explore the behavioural correlates that are associated with multi-component MSE guideline compliance. Moreover, this study has begun to bridge the knowledge gap identified in Study 1 (Paper 1) specifically concerning the concept of assessing MSE intensity. The findings from this study may be informative for those charged with public health and physical activity promotion at the population level, in their endeavours to increase MSE participation. Implications and recommendations from this and the four previous studies will now be discussed.

7.3 Implications and Recommendations for Future Research and Practice

One overarching and concerning observation has been evident throughout each chapter of this thesis by publication, and that is the fact that most people do not report engaging in any MSE, regardless of how participation is assessed. This would therefore appear to be by far the biggest challenge for researchers, policymakers, and health professionals alike. Inconsistency also hampers the ability for participation characteristics of MSE to be accurately compared and monitored globally, and with populations most at risk of physical inactivity. Therefore, it is not surprising that there is currently insufficient evidence, for organisations, such as WHO, to provide population-level health advice concerning the optimal dose or duration of MSE. These data are, however, important in our efforts to overcome, reduce, and manage the risks associated with many of the NCDs that are prevalent globally. Furthermore, it is plausible that individuals living with NCDs are less prone to do MSE than their healthier counterparts. Therefore, future research may look to better understand and describe the practice of MSE by duration and volume, and sociodemographic characteristics, among participants living with common chronic conditions.

While a disproportionate amount of physical activity research, at the population-level, is conducted in high-income countries, the global cost of NCDs is no stranger to both low and middle-income countries (World Health Organization, 2014, 2020a). Given the known health-enhancing effects of MSE (Bennie, Shakespear-Druery, et al., 2020; Gordon et al., 2018; Gordon et al., 2017; Grnøtved et al., 2014; Grnøtved et al., 2012; Loprinzi, Addoh, & Mann, 2017; Saeidifard et al., 2019; Steele et al., 2017), further research into MSE participation (and influencing factors of non-participation) within low and middle-income countries is warranted and recommended. Furthermore, public health promotion inclusive of MSE in all countries is recommended as a way to counter the human cost of physical inactivity (Ding et al., 2016).

Future research will benefit from consistency in the assessment of MSE and also a stronger focus on the enabling factors exhibited by those who currently undertake MSE. Using this knowledge could help to develop materials that promote the factors known to be positively associated with MSE participation, while equally looking to address and mitigate the barriers that are faced by non-participants. There is a plethora of education and promotional material that exists for aerobic physical activity (Milton et al., 2018; Shaw, Shaw, & Brown, 2015), however a search for materials that are MSE related highlights a gap between the two exercise modalities, at the population level. This presents an opportunity and challenge for government officials, charged with increasing the prevalence of physical activity, to consider and reflect on the lack of promotional material (targeted at the general population) that exists, and that which promotes the undertaking of MSE.

Findings from this thesis by publication add justification and support to the call for MSE to share an equal part of the health promotion stage, in conjunction with, and stepping out of the shadows of aerobic physical activity. Aerobic physical activity has been the default of public health messaging for physical activity (Bellew, Schöeppe, Bull, & Bauman, 2008), whereas MSE promotion at the population level was only introduced some 8 years ago in Australia. Furthermore, albeit while the findings from Study 2 are based on data obtained from U.K. adults, the guidelines for MSE within the U.K. (in place at the time of data collection) could be argued as superior to that currently evident within Australia. This is because the U.K. physical activity guidelines include recommendations for the frequency of, and muscle groups used when doing MSE (Department of Health and Social Care et al., 2019), whereas the Australian guidelines continue to solely focus on the frequency of participation alone (Australian Government Department of Health, 2014; Bellew, Nau, Smith, & Bauman, 2020). Now we have better measurement of physical activity, an important future direction of the field is to not only consider how we encourage populations to increase levels of physical activity amongst those not meeting physical activity guidelines (MSE <u>and</u> aerobic physical activity), but to also maintain their ongoing involvement and engagement in these health enhancing behaviours. This will require a much stronger focus using behaviour change science and is beyond the focus of the current thesis. However, a mixture of structured MSE alongside integrated 'lifestyle' MSE activities (e.g., bodyweight exercises at home and work for short durations) is likely to be most effective.

7.4 Strengths and Limitations

This thesis is the first to explore five discrete yet integral components of MSE participation, within the context of population-level health surveillance. Study 1 contained the first known synthesis of MSE participation instruments used globally to assess health at the population level. A further strength of this thesis by publication was the use of a large population-representative data set (HSE: Study 2 and Study 3) to explore the associations between MSE (mode, session duration, and weekly volume) and the prevalence having one or more key NCDs. The investigated NCDs were amongst those targeted in the WHO's global action plan to reduce the burden of mortality and morbidity associated with chronic disease globally. While the analysed data contained responses from U.K. adults, the HSE is one of the few surveillance systems to assess more than just the frequency of MSE participation and is likely to be highly relevant to the Australian context. Study 1 presented some clear opportunities for future research to expand the knowledge of MSE behaviours, beyond that of frequency of participation, and encouraged an increase in tests for reliability and validity of surveillance instruments. These future opportunities have begun to be addressed within Study 4 and Study 5. The key strength of Study 4 was the development and implementation of the MSEQ, with the survey instrument found to have acceptable reliability and validity. This study presented a valid questionnaire that could be considered suitable for assessing MSE behaviour in future population-level surveillance. Furthermore, the MSEQ has begun to address some of the research gaps identified in the three preceding studies of this thesis, particularly concerning MSE mode, duration, intensity, and muscle groups. A further strength of this thesis is demonstrated in the unique understanding of the behavioural factors likely to influence guideline-concordant MSE participation (meeting one or more of the three guideline components) obtained through Study 5. Moreover, the study begins to make some initial inroads into broadening our knowledge of barriers and enablers of MSE participation.

This thesis also has some limitations. These include excluding studies with less than 1000 participants in the systematic literature review

(Study 1). This exclusion criterion may have led to the omission of assessment instruments useful in informing our development of the MSEQ. Furthermore, the limitations inherent within the HSE data waves used in Study 2 and Study 3 precluded our analysis from exploring the potential relationship that MSE intensity has on health, additionally recognising the potential for reverse causality given the use of cross-section data within these studies. Data collection methods applied in Study 4 and 5 resulted in a biased sample of respondents who were highly active in MSE, and therefore cannot be considered representative of the wider population. As cross-sectional data were used in Study 2, Study 3, Study 4, and Study 5, this limits our ability to infer causality from the findings, therefore caution is warranted. Furthermore, while test-retest reliability and concurrent validity were established for the online version of the MSEQ, this has not been in undertaken using the developed MSEQ-Long or MSEQ-Short.

Researchers appear no closer to finding a suitable alternative to 'self-report' to effectively and efficiently measure MSE intensity (or other MSE metrics) at the population level. While technological advances have and continue to be made for other physical activity domains (e.g., through the use of accelerometers which have become an integrated component of aerobic and sedentary behaviour assessment in large population health surveillance) there remains no equivalent solution for MSE.

7.5 Conclusion

Muscle-strengthening exercise is a multifaceted and complex form of physical activity, factors which have been repeatedly identified and discussed throughout this research endeavour. This thesis includes novel research findings, using mostly quantitative research methods, that present new knowledge about MSE participation behaviours at the population level. It includes a history of MSE assessment, expanding the knowledge regarding MSE participation and the relationship between MSE and different health outcomes (specifically exploring the role of mode, duration, and volume of MSE), and presents a valid and reliable survey instrument that may be considered as an addition to current surveillance instruments used to monitor health at the population level globally. Increasing levels of health-enhancing MSE is important as MSE has been shown as a suitable non-pharmacological therapy for many chronic conditions (Ambrose & Golightly, 2015; Cormie et al., 2018; Whelton et al., 2018; Zhang et al., 2008) and is, therefore, a feasible exercise mode to consider in countering the human and financial costs associated with physical inactivity (Ding et al., 2016).

This thesis has presented health officials with the challenge of increasing participation in levels of health-enhancing MSE among members of the population who are currently insufficiently active. Exercise professionals are equally challenged with increasing their understanding of MSE, and providing sufficient education about MSE to their clients and participants to reduce potential barriers to exercise, thereby increasing MSE participation and reducing physical inactivity.

REFERENCES

Ambrose, K. R., & Golightly, Y. M. (2015). Physical exercise as non-pharmacological treatment of chronic pain: Why and when. *Best Practice & Research in Clinical Rheumatology, 29*(1), 120-130. doi:10.1016/j.berh.2015.04.022

Appelqvist-Schmidlechner, K., Vaara, J. P., Vasankari, T., Häkkinen, A., Mäntysaari, M., & Kyröläinen, H. (2020). Relationship between different domains of physical activity and positive mental health among young adult men. *BMC Public Health, 20*(1), 1116. doi:10.1186/s12889-020-09175-6

Ashton, R. E., Tew, G. A., Aning, J. J., Gilbert, S. E., Lewis, L., & Saxton, J. M. (2018). Effects of short-term, medium-term and long-term resistance exercise training on cardiometabolic health outcomes in adults: Systematic review with meta-analysis. *British Journal of Sports Medicine, 0*, 1-9. doi:10.1136/bjsports-2017-098970

Australian Government Department of Health. (2014). *Australia's physical activity & sedentary behaviour guidelines for adults (18–64 years)*. Retrieved from https://www.health.gov.au/resources/publications/make-your-move-sit-less-be-active-for-life-adults-18-to-64-years

Australian Government Department of Health. (2021). *PBS expenditure and prescriptions report 1 July 2020 to 30 June 2021*. Canberra ACT: Department of Health Retrieved from https://www.pbs.gov.au/statistics/expenditure-prescriptions/2020-2021/PBS_Expenditure_and_Prescriptions_Report_1-July-2020_to_30-June-2021.pdf

Bauman, A. E., Reis, R. S., Sallis, J. F., Wells, J. C., Loos, R. J. F., Martin, B. W., & Lancet Physical Activity Series Working Group. (2012). Correlates of physical activity: Why are some people physically active and others not? *Lancet, 380*(9838), 258-271. doi:10.1016/s0140-6736(12)60735-1

Bellew, B., Nau, T., Smith, B. J., & Bauman, A. (2020). *Getting Australia active III: A systems approach to physical activity for policy makers*. Retrieved from Sydney, Australia: https://preventioncentre.org.au/wp-content/uploads/2020/05/Getting-Australia-Active-III-April-2020.pdf

Bellew, B., Schöeppe, S., Bull, F. C., & Bauman, A. (2008). The rise and fall of Australian physical activity policy 1996 – 2006: A national review framed in an international context. *Australia and New Zealand Health Policy, 5*(1), 18. doi:10.1186/1743-8462-5-18

Bennie, J. A., De Cocker, K., Smith, J. J., & Wiesner, G. H. (2020). The epidemiology of muscle-strengthening exercise in Europe: A 28-country comparison including 280,605 adults. *PLoS ONE, 15*(11), e0242220. doi:10.1371/journal.pone.0242220

Bennie, J. A., De Cocker, K., Teychenne, M. J., Brown, W. J., & Biddle, S. J. H. (2019). The epidemiology of aerobic physical activity and muscle-strengthening activity guideline adherence among 383,928 U.S. adults. *International Journal of Behavioral Nutrition and Physical Activity, 16*(1), 1-11. doi:10.1186/s12966-019-0797-2

Bennie, J. A., Lee, D.-c., Khan, A., Wiesner, G. H., Bauman, A. E., Stamatakis, E., & Biddle, S. J. H. (2018). Muscle-strengthening exercise among 397,423 U.S. adults: Prevalence, correlates, and associations with health conditions. *American Journal of Preventive Medicine, 55*(6), 864-874. doi:10.1016/j.amepre.2018.07.022

Bennie, J. A., Pedišić, Ž., Suni, J. H., Tokola, K., Husu, P., Biddle, S. J. H., & Vasankari, T. (2017). Self-reported health-enhancing physical activity recommendation adherence among 64,380 Finnish adults. *Scandinavian Journal of Medicine & Science in Sports, 27*(12), 1842-1853. doi:10.1111/sms.12863

Bennie, J. A., Pedišić, Ž., van Uffelen, J. G. Z., Charity, M. J., Harvey, J. T., Banting, L. K., . . . Eime, R. M. (2016). Pumping iron in Australia: Prevalence, trends and sociodemographic correlates of

muscle strengthening activity participation from a national sample of 195,926 adults. *PLoS ONE, 11*(4), 1-15. doi:10.1371/journal.pone.0153225
Bennie, J. A., Pedišić, Ž., van Uffelen, J. G. Z., Gale, J., Banting, L. K., Vergeer, I., . . . Biddle, S. J. H. (2016). The descriptive epidemiology of total physical activity, muscle-strengthening exercises and sedentary behaviour among Australian adults -Results from the national nutrition and physical activity survey. *BMC Public Health, 16*(73), 1-13. doi:10.1186/s12889-016-2736-3
Bennie, J. A., Shakespear-Druery, J., & De Cocker, K. (2020). Muscle-strengthening exercise epidemiology: A new frontier in chronic disease prevention. *Sports Medicine - Open, 6*(1), 1-8. doi:10.1186/s40798-020-00271-w
Bennie, J. A., Teychenne, M., & Tittlbach, S. (2020). Muscle-strengthening exercise and depressive symptom severity among a nationally representative sample of 23,635 German adults. *Journal of Affective Disorders, 266*, 282-287. doi:10.1016/j.jad.2020.01.172
Bennie, J. A., Teychenne, M. J., De Cocker, K., & Biddle, S. J. H. (2019). Associations between aerobic and muscle-strengthening exercise with depressive symptom severity among 17,839 U.S. adults. *Preventive Medicine, 121*, 121-127. doi:10.1016/j.ypmed.2019.02.022
Bennie, J. A., & Tittlbach, S. (2020). Muscle-strengthening exercise and sleep quality among a nationally representative sample of 23,635 German adults. *Preventive Medicine Reports, 20*, 101250-101250. doi:10.1016/j.pmedr.2020.101250
Branscum, P., & Fairchild, G. (2019). Differences in determinants of aerobic and muscle strengthening physical activity among college students: A reasoned action approach. *Journal of Sports Sciences, 37*(1), 90-99. doi:10.1080/02640414.2018.1483179
Brodie, M. A., Pliner, E. M., Ho, A., Li, K., Chen, Z., Gandevia, S. C., & Lord, S. R. (2018). Big data vs accurate data in health research:

Large-scale physical activity monitoring, smartphones, wearable devices and risk of unconscious bias. *Medical Hypotheses, 119*, 32-36. doi:10.1016/j.mehy.2018.07.015

Bull, F. C., Al-Ansari, S. S., Biddle, S., Borodulin, K., Buman, M. P., Cardon, G., . . . Willumsen, J. F. (2020). World Health Organization 2020 guidelines on physical activity and sedentary behaviour. *British Journal of Sports Medicine, 54*(24), 1451. doi:10.1136/bjsports-2020-102955

Campbell, E., Petermann-Rocha, F., Welsh, P., Celis-Morales, C., Pell, J. P., Ho, F. K., & Gray, S. R. (2021). The effect of exercise on quality of life and activities of daily life in frail older adults: A systematic review of randomised control trials. *Experimental Gerontology, 147*, 111287. doi:10.1016/j.exger.2021.111287

Caspersen, C. J., Powell, K. E., & Christenson, G. (1985). Physical activity, exercise and physical fitness: Definitions and distinctions for health-related research. *Public Health Reports, 100*(2), 126-131. Retrieved from https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1424733/

Cohen, L., Manion, L., & Morrison, K. (2017). *Research methods in education* (8th ed.). London, United Kingdom: Routledge.

Cormie, P., Atkinson, M., Bucci, L., Cust, A., Eakin, E., Hayes, S., . . . Adams, D. (2018). Clinical oncology society of Australia position statement on exercise in cancer care. *Medical Journal of Australia, 209*(4), 184-187. doi:10.5694/mja18.00199

Crespo, C. J., Keteyian, S. J., Heath, G. W., & Sempos, C. T. (1996). Leisure-time physical activity among US adults - Results from the third National Health and Nutrition Examination Survey. *Archives of Internal Medicine, 156*(1), 93-98. doi:10.1001/archinte.156.1.93

Crosland, P., Ananthapavan, J., Davison, J., Lambert, M., & Carter, R. (2019). The economic cost of preventable disease in Australia: A systematic review of estimates and methods. *Australian and New Zealand Journal of Public Health, 43*(5), 484-495. doi:10.1111/1753-6405.12925

Dankel, S. J., Loenneke, J. P., & Loprinzi, P. D. (2016). The individual, joint, and additive interaction associations of aerobic-based physical activity and muscle strengthening activities on metabolic syndrome. *International Journal of Behavioral Medicine, 23*(6), 707-713. doi:10.1007/s12529-016-9570-y

Department of Health and Social Care, Llwodraeth Cymru Welsh Government, Department of Health Northern Ireland, & Scottish Government. (2019). *UK chief medical officers' physical activity guidelines* London, UK: GOV.UK Retrieved from https://www.gov.uk/government/publications/physical-activity-guidelines-uk-chief-medical-officers-report

Ding, D., Lawson, K. D., Kolbe-Alexander, T. L., Finkelstein, E. A., Katzmarzyk, P. T., van Mechelen, W., & Pratt, M. (2016). The economic burden of physical inactivity: A global analysis of major non-communicable diseases. *The Lancet, 388*(10051), 1311-1324. doi:10.1016/S0140-6736(16)30383-X

Duffy, B., Smith, K., Terhanian, G., & Bremer, J. (2005). Comparing data from online and face-to-face surveys. *International Journal of Market Research, 47*(6), 615-639. doi:10.1177/147078530504700602

Eckermann, S., & Willan, A. R. (2022). Active lives South Australia health economic analysis: An evidence base for the potential of health promotion strategies supporting physical activity guidelines to reduce public health costs while improving wellbeing. *Journal of Public Health, 30*(7), 1791-1807. doi:10.1007/s10389-021-01649-0

Freeston, J., Gale, J., Mavros, Y., Bennie, J. A., Pedisic, Z., Bauman, A. E., & Stamatakis, E. (2017). Associations between multiple indicators of socio-economic status and muscle-strengthening activity participation in a nationally representative population sample of Australian adults. *Preventive Medicine*, 44-48. doi:10.1016/j.ypmed.2017.06.020

Garber, C. E., Blissmer, B., Deschenes, M. R., Franklin, B. A., Lamonte, M. J., Lee, I. M., . . . Amer Coll Sports, M. (2011). Quantity and quality of exercise for developing and maintaining cardiorespiratory, musculoskeletal, and neuromotor fitness in apparently healthy adults: Guidance for prescribing exercise. *Medicine & Science in Sports & Exercise, 43*(7), 1334-1359. doi:10.1249/MSS.0b013e318213fefb

Gomes, G. A. O., Brown, W. J., Codogno, J. S., & Mielke, G. I. (2020). Twelve year trajectories of physical activity and health costs in mid-age Australian women. *International Journal of Behavioral Nutrition and Physical Activity, 17*(1), 101. doi:10.1186/s12966-020-01006-6

Gordon, B. R., McDowell, C. P., Hallgren, M., Meyer, J. D., Lyons, M., & Herring, M. P. (2018). Association of efficacy of resistance exercise training with depressive symptoms: Meta-analysis and meta-regression analysis of randomized clinical trials. *JAMA Psychiatry, 75*(6), 566-576. doi:10.1001/jamapsychiatry.2018.0572

Gordon, B. R., McDowell, C. P., Lyons, M., & Herring, M. P. (2017). The effects of resistance exercise training on anxiety: A meta-analysis and meta-regression analysis of randomized controlled trials. *Sports Medicine, 47*(12), 2521-2532. doi:10.1007/s40279-017-0769-0

Grandner, M. A. (2017). Sleep, health, and society. *Sleep Medicine Clinics, 12*(1), 1-22. doi:10.1016/j.jsmc.2016.10.012

Grnøtved, A., Pan, A., Mekary, R. A., Stampfer, M., Willett, W. C., Manson, J. E., & Hu, F. B. (2014). Muscle-strengthening and conditioning activities and risk of type 2 diabetes: A prospective study in two cohorts of US women. *PLoS Medicine, 11*(1), 15. doi:10.1371/journal.pmed.1001587

Grnøtved, A., Rimm, E. B., Willett, W. C., Andersen, L. B., & Hu, F. B. (2012). A prospective study of weight training and risk of type 2 diabetes mellitus in men. *Archives of Internal Medicine, 172*(17), 1306-1312. doi:10.1001/archinternmed.2012.3138

Hallal, P. C., Andersen, L. B., Bull, F. C., Guthold, R., Haskell, W., Ekelund, U., . . . Wells, J. C. (2012). Global physical activity levels: Surveillance progress, pitfalls, and prospects. *The Lancet, 380*(9838), 247-257. doi:10.1016/S0140-6736(12)60646-1

Hird, T. R., Zomer, E., Owen, A. J., Magliano, D. J., Liew, D., & Ademi, Z. (2019). Productivity burden of hypertension in Australia. *Hypertension, 73*(4), 777-784. doi:10.1161/hypertensionaha.118.12606

Holtermann, A., Hansen, J. V., Burr, H., Søgaard, K., & Sjøgaard, G. (2012). The health paradox of occupational and leisure-time physical activity. *British Journal of Sports Medicine, 46*(4), 291. doi:10.1136/bjsm.2010.079582

Humphries, B., Stanton, R., Scanlan, A., & Duncan, M. J. (2018). The prevalence and performance of resistance exercise training activities in an Australian population in relation to health authority guidelines. *Journal of Science and Medicine in Sport, 21*(6), 616-620. doi:10.1016/j.jsams.2017.09.018

Isath, A., Howard, C. E., Virani, S. S., Wang, Z., Lavie, C. J., Naidu, S. S., & Krittanawong, C. (2022). Strength training and cardiovascular health: A meta-analysis. *Progress in Cardiovascular Diseases*. doi:10.1016/j.pcad.2022.05.001

João, K. A. D. R., Jesus, S. N. d., Carmo, C., & Pinto, P. (2018). The impact of sleep quality on the mental health of a non-clinical population. *Sleep Medicine, 46*, 69-73. doi:10.1016/j.sleep.2018.02.010

Liu, C. J., & Latham, N. K. (2009). Progressive resistance strength training for improving physical function in older adults. *Cochrane Database of Systematic Reviews*(3), 277. doi:10.1002/14651858.CD002759.pub2

Liu, C. K., & Fielding, R. A. (2011). Exercise as an intervention for frailty. *Clinics in Geriatric Medicine, 27*(1), 101-110. doi:10.1016/j.cger.2010.08.001

Loprinzi, P. D., Addoh, O., & Mann, J. R. (2017). Association between muscle strengthening physical activities and mortality among American adults with mobility limitations. *Preventive Medicine, 99*, 207-210. doi:10.1016/j.ypmed.2017.02.013

Loustalot, F., Carlson, S., Kruger, J., Buchner, D., & Fulton, J. (2013). Muscle-strengthening activities and participation among adults in the United States. *Research Quarterly for Exercise and Sport, 84*(1), 30-38. doi:10.1080/02701367.2013.762289

Mangione, K. K., Miller, A. H., & Naughton, I. V. (2010). Cochrane review: Improving physical function and performance with progressive resistance strength training in older adults. *Physical Therapy, 90*(12), 1711-1715. doi:10.2522/ptj.20100270

Martyn-St James, M., & Carroll, S. (2009). A meta-analysis of impact exercise on postmenopausal bone loss: The case for mixed loading exercise programmes. *British Journal of Sports Medicine, 43*(12), 898-908. doi:10.1136/bjsm.2008.052704

Martyn-St James, M., & Carroll, S. (2010). Effects of different impact exercise modalities on bone mineral density in premenopausal women: A meta-analysis. *Journal of Bone and Mineral Metabolism, 28*(3), 251-267. doi:10.1007/s00774-009-0139-6

Mazzilli, K. M., Matthews, C. E., Salerno, E. A., & Moore, S. C. (2019). Weight training and risk of 10 common types of cancer. *Medicine & Science in Sports & Exercise, 51*(9), 1845-1851. doi:10.1249/mss.0000000000001987

McLeod, J. C., Stokes, T., & Phillips, S. M. (2019). Resistance exercise training as a primary countermeasure to age-related chronic disease. *Frontiers in Physiology, 10*, 645. doi:10.3389/fphys.2019.00645

Milton, K., Varela, A. R., Strain, T., Cavill, N., Foster, C., & Mutrie, N. (2018). A review of global surveillance on the muscle strengthening and balance elements of physical activity recommendations. *Journal* *of Frailty, Sarcopenia and Falls, 3*(2), 114-124. doi:10.22540/JFSF-03-114

Momma, H., Kawakami, R., Honda, T., & Sawada, S. S. (2022). Muscle-strengthening activities are associated with lower risk and mortality in major non-communicable diseases: A systematic review and meta-analysis of cohort studies. *British Journal of Sports Medicine*(0), 1-10. doi:10.1136/bjsports-2021-105061

Nascimento, W., Ferrari, G., Martins, C. B., Rey-Lopez, J. P., Izquierdo, M., Lee, D. H., . . . Rezende, L. F. M. (2021). Muscle-strengthening activities and cancer incidence and mortality: A systematic review and meta-analysis of observational studies. *International Journal of Behavioral Nutrition and Physical Activity, 18*(1), 69. doi:10.1186/s12966-021-01142-7

National Center for Health Statistics. (1977). *Current estimates from the Health Interview Survey United States - 1975* Rockville, Md.: Public Health Service Retrieved from https://www.cdc.gov/nchs/data/series/sr_10/sr10_115.pdf

National Center for Health Statistics. (1994). *Plan and operation of the third National Health and Nutrition Examination Survey, 1988-94*. Washington, DC: Department of Health and Human Services Retrieved from https://www.cdc.gov/nchs/data/series/sr_01/sr01_032.pdf

Oja, P., & Titze, S. (2011). Physical activity recommendations for public health: Development and policy context. *EPMA Journal, 2*(3), 253-259. doi:10.1007/s13167-011-0090-1

Pate, R. R., Macera, C. A., Pratt, M., Heath, G. W., Blair, S. N., Bouchard, C., . . . Wilmore, J. H. (1995). Physical activity and public health: A recommendation from the centers for disease control and prevention and the American college of sports medicine. *The Journal of the American Medical Association, 273*(5), 402-407. doi:10.1001/jama.1995.03520290054029

Pedišić, Ž., & Bauman, A. (2014). Accelerometer-based measures in physical activity surveillance: Current practices and issues. *British Journal of Sports Medicine, 49*(4), 219-223. doi:10.1136/bjsports-2013-093407

Physical Activity Guidelines Advisory Committee. (2018). *2018 physical activity guidelines advisory committee scientific report*. Washington, DC Retrieved from https://health.gov/paguidelines/second-edition/report/pdf/PAG_Advisory_Committee_Report.pdf

Pinheiro, M. B., Oliveira, J., Bauman, A., Fairhall, N., Kwok, W., & Sherrington, C. (2020). Evidence on physical activity and osteoporosis prevention for people aged 65+ years: A systematic review to inform the WHO guidelines on physical activity and sedentary behaviour. *International Journal of Behavioral Nutrition and Physical Activity, 17*(1), 150. doi:10.1186/s12966-020-01040-4

Prado, C. M., Purcell, S. A., Alish, C., Pereira, S. L., Deutz, N. E., Heyland, D. K., . . . Heymsfield, S. B. (2018). Implications of low muscle mass across the continuum of care: A narrative review. *Annals of Medicine, 50*(8), 675-693. doi:10.1080/07853890.2018.1511918

Prince, S. A., Cardilli, L., Reed, J. L., Saunders, T. J., Kite, C., Douillette, K., . . . Buckley, J. P. (2020). A comparison of self-reported and device measured sedentary behaviour in adults: A systematic review and meta-analysis. *International Journal of Behavioral Nutrition and Physical Activity, 17*(1), 31. doi:10.1186/s12966-020-00938-3

Ralston, G. W., Kilgore, L., Wyatt, F. B., & Baker, J. S. (2017). The effect of weekly set volume on strength gain: A meta-analysis. *Sports Medicine, 47*(12), 2585-2601. doi:10.1007/s40279-017-0762-7

Rhodes, R. E., Lubans, D. R., Karunamuni, N., Kennedy, S., & Plotnikoff, R. (2017). Factors associated with participation in resistance training: A systematic review. *British Journal of Sports Medicine, 51*(20), 1-9. doi:10.1136/bjsports-2016-096950

Rizzoli, R., Reginster, J. Y., Arnal, J. F., Bautmans, I., Beaudart, C., Bischoff-Ferrari, H., . . . Bruyere, O. (2013). Quality of life in sarcopenia and frailty. *Calcified Tissue International, 93*(2), 101-120. doi:10.1007/s00223-013-9758-y

Saeidifard, F., Medina-Inojosa, J. R., West, C. P., Olson, T. P., Somers, V. K., Bonikowske, A. R., . . . Lopez-Jimenez, F. (2019). The association of resistance training with mortality: A systematic review and meta-analysis. *European Journal of Preventive Cardiology, 26*(15), 1647-1665. doi:10.1177/2047487319850718

Sandercock, G. R. H., Moran, J., & Cohen, D. D. (2022). Who is meeting the strengthening physical activity guidelines by definition: A cross-sectional study of 253 423 English adults? *PLoS ONE, 17*(5), e0267277. doi:10.1371/journal.pone.0267277

Santilli, V., Bernetti, A., Mangone, M., & Paoloni, M. (2014). Clinical definition of sarcopenia. *Clinical cases in mineral and bone metabolism: The official journal of the Italian society of osteoporosis, mineral metabolism, and skeletal diseases, 11*(3), 177-180. Retrieved from https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4269139/

Sarria-Santamera, A., Alexeyeva, Z., Yen Chan, M., Ortega, M. A., Asunsolo-Del-Barco, A., & Navarro-García, C. (2022). Direct and indirect costs related to physical activity levels in patients with diabetes mellitus in Spain: A cross-sectional study. *Healthcare (Basel), 10*(4). doi:10.3390/healthcare10040752

Schoenfeld, B. J., Ogborn, D., & Krieger, J. W. (2017). Dose-response relationship between weekly resistance training volume and increases in muscle mass: A systematic review and meta-analysis. *Journal of Sports Sciences, 35*(11), 1073-1082. doi:10.1080/02640414.2016.1210197

Shailendra, P., Baldock, K. L., Li, L. S. K., Bennie, J. A., & Boyle, T. (2022). Resistance training and mortality risk: A systematic review and meta-analysis. *American Journal of Preventive Medicine*, 1-9. doi:10.1016/j.amepre.2022.03.020

Shakespear-Druery, J., De Cocker, K., Biddle, S. J. H., & Bennie, J. (2022a). *Associations between behavioural correlates of muscle-strengthening exercise guideline adherence: A cross-sectional study*. Manuscript under review. Centre for Health Research. University of Southern Queensalnd.

Shakespear-Druery, J., De Cocker, K., Biddle, S. J. H., & Bennie, J. (2022b). Associations between duration and volume of muscle-strengthening exercise and clinically assessed hypertension among 10519 UK adults: A cross-sectional study. *Journal of Hypertension, 40*(5), 947-955. doi:10.1097/HJH.0000000000003098

Shakespear-Druery, J., De Cocker, K., Biddle, S. J. H., & Bennie, J. (2022c). Associations between muscle-strengthening exercise and prevalent chronic health conditions in 16,301 adults: Do session duration and weekly volume matter? *Journal of Science and Medicine in Sport, 25*(5), 407-418. doi:10.1016/j.jsams.2022.01.001

Shakespear-Druery, J., De Cocker, K., Biddle, S. J. H., & Bennie, J. (2022d). Muscle-strengthening exercise questionnaire (MSEQ): An assessment of concurrent validity and test–retest reliability. *BMJ Open Sport & Exercise Medicine 8*(e001225), 1-10. doi:10.1136/bmjsem-2021-001225

Shakespear-Druery, J., De Cocker, K., Biddle, S. J. H., Gavilán-Carrera, B., Segura-Jiménez, V., & Bennie, J. (2021). Assessment of muscle-strengthening exercise in public health surveillance for adults: A systematic review. *Preventive Medicine, 148*, 106566. doi:10.1016/j.ypmed.2021.106566

Shaw, B. S., Shaw, I., & Brown, G. A. (2015). Resistance exercise is medicine: Strength training in health promotion and rehabilitation. *International Journal of Therapy and Rehabilitation, 22*(8), 385-389. doi:10.12968/ijtr.2015.22.8.385

Shiroma, E. J., Cook, N. R., Manson, J. E., Moorthy, M., Buring, J. E., Rimm, E. B., & Lee, I. M. (2016). Strength training and the risk of type 2 diabetes and cardiovascular disease. *Medicine & Science in Sports & Exercise, 49*(1), 40-46. doi:10.1249/MSS.0000000000001063

Stamatakis, E., Lee, I.-M., Bennie, J., Freeston, J., Hamer, M., O'Donovan, G., . . . Mavros, Y. (2018). Does strength-promoting exercise confer unique health benefits? A pooled analysis of data on 11 population cohorts with all-cause, cancer, and cardiovascular mortality endpoints. *American Journal of Epidemiology, 187*(5), 1102-1112. doi:10.1093/aje/kwx345

Steele, J., Fisher, J., Skivington, M., Dunn, C., Arnold, J., Tew, G., . . . Winett, R. (2017). A higher effort-based paradigm in physical activity and exercise for public health: Making the case for a greater emphasis on resistance training. *BMC Public Health, 17*, 8. doi:10.1186/s12889-017-4209-8

Strain, T., Fitzsimons, C., Foster, C., Mutrie, N., Townsend, N., & Kelly, P. (2016). Age-related comparisons by sex in the domains of aerobic physical activity for adults in Scotland. *Preventive Medicine Reports, 3*, 90-97. doi:10.1016/j.pmedr.2015.12.013

Strain, T., Fitzsimons, C., Kelly, P., & Mutrie, N. (2016). The forgotten guidelines: Cross-sectional analysis of participation in muscle strengthening and balance & co-ordination activities by adults and older adults in Scotland. *BMC Public Health, 16*, 1108. doi:10.1186/s12889-016-3774-6

Strain, T., Milton, K., Dall, P., Standage, M., & Mutrie, N. (2019). How are we measuring physical activity and sedentary behaviour in the four home nations of the UK? A narrative review of current surveillance measures and future directions. *British Journal of Sports Medicine*, 1-9. doi:10.1136/bjsports-2018-100355

Strain, T., Wijndaele, K., & Brage, S. (2019). Physical activity surveillance through smartphone apps and wearable trackers: Examining the UK potential for nationally representative sampling. *Jmir Mhealth and Uhealth, 7*(1), 1-13. doi:10.2196/11898

Strain, T., Wijndaele, K., Pearce, M., & Brage, S. (2022). Considerations for the use of consumer-grade wearables and smartphones in population surveillance of physical activity. *Journal for the Measurement of Physical Behaviour, 5*(1), 8-14. doi:10.1123/jmpb.2021-0046

Strasser, B., Siebert, U., & Schobersberger, W. (2010). Resistance training in the treatment of the metabolic syndrome: A systematic review and meta-analysis of the effect of resistance training on metabolic clustering in patients with abnormal glucose metabolism. *Sports Medicine, 40*(5), 397-415. doi:10.2165/11531380-000000000-00000

Su, C. L., Wang, L., Ho, C. C., Nfor, O. N., Hsu, S. Y., Lee, C. T., . . . Liaw, Y. P. (2020). Physical activity is associated with lower health care costs among Taiwanese individuals with diabetes mellitus. *Medicine (Baltimore), 99*(14), e19613. doi:10.1097/md.0000000000019613

Troiano, R. P., Stamatakis, E., & Bull, F. C. (2020). How can global physical activity surveillance adapt to evolving physical activity guidelines? Needs, challenges and future directions. *British Journal of Sports Medicine, 54*(24), 1468. doi:10.1136/bjsports-2020-102621

U.S. Department of Health and Human Services. (2008). *2008 physical activity guidelines for Americans*. Washington, DC Retrieved from https://health.gov/paguidelines/2008/pdf/paguide.pdf

U.S. Department of Health and Human Services. (2018). *Physical Activity Guidelines for Americans, 2nd edition*. Washington, DC.

Umpierre, D., Ribeiro, P. A. B., Kramer, C. K., Leitão, C. B., Zucatti, A. T. N., Azevedo, M. J., . . . Schaan, B. D. (2011). Physical activity advice only or structured exercise training and association with HbA1c levels in type 2 diabetes: A systematic review and meta-analysis. *Journal of the American Medical Association, 305*(17), 1790-1799. doi:10.1001/jama.2011.576

Vasudevan, A., & Ford, E. (2022). Motivational factors and barriers towards initiating and maintaining strength training in women: A systematic review and meta-synthesis. *Prevention Science, 23*(4), 674-695. doi:10.1007/s11121-021-01328-2

Waters, D. L., Baumgartner, R. N., Garry, P. J., & Vellas, B. (2010). Advantages of dietary, exercise-related, and therapeutic interventions to prevent and treat sarcopenia in adult patients: An update. *Clinical Interventions in Aging, 5*, 259-270. doi:10.2147/cia.s6920

Whelton, P. K., Carey, R. M., Aronow, W. S., Casey, D. E., Collins, K. J., Himmelfarb, C. D., . . . Wright, J. T. (2018). 2017 ACC/AHA/AAPA/ABC/ACPM/AGS/APhA/ASH/ASPC/NMA/PCNA guideline for the prevention, detection, evaluation, and management of high blood pressure in adults: A report of the American college of cardiology/American heart association task force on clinical practice guidelines. *Hypertension, 71*(6), e13-e115. doi:10.1161/HYP.0000000000000065

White, R. L., Babic, M. J., Parker, P. D., Lubans, D. R., Astell-Burt, T., & Lonsdale, C. (2017). Domain-specific physical activity and mental health: A meta-analysis. *American Journal of Preventive Medicine, 52*(5), 653-666. doi:10.1016/j.amepre.2016.12.008

Williams, B., Mancia, G., Spiering, W., Agabiti Rosei, E., Azizi, M., Burnier, M., . . . ESC Scientific Document Group. (2018). 2018 ESC/ESH Guidelines for the management of arterial hypertension: The task force for the management of arterial hypertension of the European society of cardiology (ESC) and the European society of hypertension (ESH). *European Heart Journal, 39*(33), 3021-3104. doi:10.1093/eurheartj/ehy339

World Health Assembly. (1968). *Report of the technical discussions at the twenty-first World Health Assembly on "national and global surveillance of communicable diseases"*. Geneva: World Health

Organization Retrieved from https://apps.who.int/iris/handle/10665/143808

World Health Organization. (2010). *Global recommendations on physical activity for health*. Geneva, Switzerland: WHO Press Retrieved from https://apps.who.int/iris/bitstream/handle/10665/44399/9789241599979_eng.pdf?s

World Health Organization. (2014). *Global status report on noncommunicable diseases 2014*. Retrieved from https://apps.who.int/iris/handle/10665/148114

World Health Organization. (2020a). *Noncommunicable diseases progress monitor 2020*. Retrieved from Geneva: https://www.who.int/publications-detail/ncd-progress-monitor-2020

World Health Organization. (2020b). *WHO guidelines on physical activity and sedentary behaviour*. Geneva: World Health Organization Retrieved from https://www.who.int/publications/i/item/9789240015128

Zach, S., & Lissitsa, S. (2016). Internet use and leisure time physical activity of adults - A nationwide survey. *Computers in Human Behavior, 60*, 483-491. doi:10.1016/j.chb.2016.02.077

Zhang, W., Moskowitz, R. W., Nuki, G., Abramson, S., Altman, R. D., Arden, N., . . . Tugwell, P. (2008). OARSI recommendations for the management of hip and knee osteoarthritis, Part II: OARSI evidence-based, expert consensus guidelines. *Osteoarthritis and Cartilage, 16*(2), 137-162. doi:10.1016/j.joca.2007.12.013

APPENDIX A: STUDY 1

Appendix A

We used the search terms, “strength training" OR "resistance training" OR “muscle strengthening exercise” OR “muscle strengthening activity” OR “muscle strengthening activities” OR "weight training" OR "weight lifting" OR "muscle strengthening" OR "muscular strengthening" OR "muscle training" OR "muscle toning" OR "weight bearing training" OR "weight bearing strengthening" OR toning OR exercise OR “resistance band” OR “anaerobic” OR “muscular conditioning” OR “muscle strength” OR “elastic band exercise” OR “Weight-Bearing Exercise Program” OR “Weight-Lifting Exercise Program” OR “Weight-Lifting Strengthening Program” OR Calisthenics OR “resistance bands” OR “weight machines” OR “free weights” OR “handheld weights” AND “Public health surveillance” OR “Public health” OR surveillance OR Population OR Prevalence OR Correlate? OR Assess* OR Measure* OR “physical activity epidemiology” OR adherence OR Guideline? AND Adult?

Date	**Search Strategy**	**Database**	**Number of results**	**Field**	**Notes**
18.6.19	TITLE-ABS-KEY ((("strength training" OR "resistance training" OR "muscle strengthening exercise" OR "muscle strengthening activity" OR "muscle strengthening activities" OR "weight training" OR "weight lifting" OR "muscle	Scopus	25871	Title, Abstract, Keyword	limited to English language

strengthening" OR "muscular strengthening" OR "muscle training" OR "muscle toning" OR "weight bearing training" OR "weight bearing strengthening" OR toning OR exercise OR "resistance band" OR "anaerobic" OR "muscular conditioning" OR "muscle strength" OR "elastic band exercise" OR "Weight-Bearing Exercise Program" OR "Weight-Lifting Exercise Program" OR "Weight-Lifting Strengthening Program" OR calisthenics OR "resistance bands" OR "weight machines" OR "free weights" OR "handheld weights") AND ("Public health surveillance" OR "Public health" OR surveillance OR population OR prevalence OR correlate? OR assess* OR measure* OR "physical activity epidemiology" OR adherence OR guideline?) AND adult?)) AND (LIMIT-TO (LANGUAGE , "English"))

Online Supplementary Table 1. Studies assessing strength-training activities - Individual study characteristics

Country	Surveillance system/survey used	Ref.	Population	Data year	Time Frame [a]	MSA % [b]	MSA [c]	Freq [d]	Int. [e]	Type [f] (Mode)	Dur [g]	Rel [h]	Val [i]
Australia	Active Australia Survey	Brown et al. (2013)	≥18 years 42% M	~	P12m	✗	✗	✓	✗	3	✓	≞	≞
	Australian Diabetes, Obesity and Lifestyle Study	Minges et al. (2013)	Mean age 56.0 ± 12.7 years 55% F	2004-2005	PW	16.5% M 14.8% W	✓	✓	✗	4	✓	✗	✗
	Central Queensland Social Survey	Dalbo et al. (2015)	≥18 years 50.7% F	2010	P6m	✗	✓	✓	✗	1	✗	≞	≞
		Humphries, Duncan, and Mummery (2008)	≥18 years	2006	PW	✗	✓	✗	✗	1	✗	✗	✗
		Humphries, Stanton, Scanlan, and Duncan (2018)	≥18 years 49.9% F	~	DPW	5.2% 6.5% M 3.6% F	✓	✓	✓	4	✗	✗	✗
	Concord Health and Aging in Men Project	Hsu et al. (2018)	≥70 years 100% M	2005-2007	P7d	✗	✓	✓	✗	1	✗	✗	≞
	Exercise, Recreation and Sport Survey	Bennie, Pedišić, van Uffelen, Charity, et al. (2016)	15-98 years 49.4% M	2001-2010	P2w/PY	10.4% P2w 9.3% PY	✓	✓	✗	10	✓	≞	✗

Country	Surveillance system/survey used	Ref.	Population	Data year	Time Frame [a]	MSA % [b]	MSA [c]	Freq [d]	Int. [e]	Type [f] (Mode)	Dur [g]	Rel [h]	Val [i]
		Merom, Cosgrove, Venugopal, and Bauman (2012)	≥ 65 years 58.9% F	2001-2009	P12 m	✗	✓	✓	✗	1	✗	✗	✗
		Eime et al. (2015)	≥15 years	2010	P12m/P2w	✗	✓	✓	✗	1	✗	✗	✗
		Mealing, Bowles, Merom, and Bauman (2011)	≥15 years 53.6% F	2006	PY/P2w	✗	✓	✓	✗	1	✓	✗	✗
	National Nutrition and Physical Activity Survey	Bennie, Pedišić, van Uffelen, Gale, et al. (2016)	18-85 years 54.1% F	2011-2012	PW	18.6%	✗	✓	✗	2	✗	≞	✗
		Freeston et al. (2017)	≥18 years 45.9% M	2011-2012	PW	17.9% 19.7% M 16.1% F	✗	✓	✗	4	✓	≞	✗
	New South Wales Fall Prevention telephone survey	Merom, Pye, et al. (2012)	≥65 years	2009	PW	9.4%	✓	✓	✗	4	✗	✗	✗
Brazil	Surveillance System of Risk Factors and Protection for Chronic Noncommunicable Diseases	de Lima, Lima, and do Carmo Luiz (2017)	≥18 years	2014	P3m	✗	✓	✓	✗	1	✓	✗	✗

Country	Surveillance system/survey used	Ref.	Population	Data year	Time Frame [a]	MSA % [b]	MSA [c]	Freq [d]	Int. [e]	Type [f] (Mode)	Dur [g]	Rel [h]	Val [i]
	Brazilian Living Standards Measurement Survey	Monteiro et al. (2003)	≥20 years 47.4% M	1996-1997	D/W	✗	✓	✓	✗	2	✓	✗	✓I
Canada	Canadian Community Health Survey	Garriguet and Colley (2014)	12-79 years	2007-2011	P3m	✗	✓	✓	✗	1	✓	✗	✗
	Canadian Longitudinal Study on Aging	Copeland, Good, and Dogra (2019)	≥60 years	2012-2015	PW	✗	✓	✓	✗	6	✗	≞	≞
		Dogra et al. (2018)	45-85 years	2012-2015	P7d	✗	✗	✓	✗	1	✓	≞	≞
	General Social Survey	Panten, Stone, and Baker (2017)	≥65 years	2010	D	✗	✓	✗	✗	1	✓	✗	✗
	National College Health Assessment	Scarapicchia, Sabiston, and Faulkner (2015)	Mean age 22.11 ± 5.24 years 71.60% F	2013	PW	36.4 % M 19.9% F	✗	✓	✗	2	✗	≞	≞
	National Population Health Survey	Da Costa, Lowensteyn, and Dritsa (2003)	20-79 years	1996-1997	P3m	✗	✓	✗	✗	1	✗	✗	✗
		Perks (2017)	≥18 years 48.8% M	1994-2011	P3m	✗	✓	✓	✗	1	✓	✗	✗
Finland	Finnish Regional Health and Well-being Study	Bennie et al. (2017)	18-98 years 52% F	2013-2014	PY	17.2%	✗	✓	✓	3	✗	≞	✗

Country	Surveillance system/survey used	Ref.	Population	Data year	Time Frame [a]	MSA % [b]	MSA [c]	Freq [d]	Int. [e]	Type [f] (Mode)	Dur [g]	Rel [h]	Val [i]
Guatemala	Nutritional supplementation trial	Gregory, Ramirez-Zea, Martorell, and Stein (2007)	24-49 years 54.6% F	1969-1977	PY	✗	✓	✓	✗	1	✓	✗	✗
Ireland	North/South Ireland Food Consumption Survey	Livingstone et al. (2001)	18-64 years 47.9% M	1997-1999	PY	✗	✓	✓	✗	1	✗	✗	≞
Israel	Social Survey	Zach and Lissitsa (2016)	20-65 years.	2010	P3m	✗	✓	✗	✗	3	✗	✗	✗
Italy	Longevity check-up 7+	Landi et al. (2018)	18-98 years 57% F	2015-2017	PY	✗	✓	✓	✗	1	✗	✗	✗
Japan	Not disclosed	Harada, Shibata, Ishii, Liao, and Oka (2014)	40–69 years 47.57% F	2011	W	13.6% 15.2% M 11.8% F	✗	✓	✗	`	✗	✗	✗
		Harada, Shibata, Oka, and Nakamura (2015)	65–74 years 49.6% F	2011	DPW	9.2% E 26.2% B	✗	✓	✓	8	✗	✗	✗
	COMMUNIty-wide CAmpaign To promote Exercise study	Kamada et al. (2018)	40-79 years 46.4% M	2009-2014	DPW	38% Cb 37.7% Ib 34.9% Cf5 37.2% If5	✗	✓	✗	1	✗	≞	✗

Country	Surveillance system/survey used	Ref.	Population	Data year	Time Frame [a]	MSA % [b]	MSA [c]	Freq [d]	Int. [e]	Type [f] (Mode)	Dur [g]	Rel [h]	Val [i]
		Kamada et al. (2013)	40-79 years 46.4% M	2009-2010	DPW	38% Cb 37.7% Ib 32.5% Cf1 24.2% If1	✗	✓	✗	1	✗	✓ T	✗
		Masamitsu et al. (2015)	40 - 79 years	2012	DPW	38% Cb 37.7% Ib 32.8% Cf3 35.8% If3	✗	✓	✗	1	✗	≞	✗
	Japan Epidemiology Collaboration on Occupational Health Study	Kuwahara et al. (2015)	30–64 years	2006-2013	Re	✗	✓	✓	✗	1	✓	✗	✗
	SSF National Sports-Life Survey	Harada, Oka, Ota, Shibata, and Nakamura (2008)	≥20 years, 52.1% F	2006	PY	3.9% A 0.6% - 9.9% R	✓	✓	✗	1	✗	✗	✗
Korea	Korea National Health and Nutrition Examination Survey	Bennie, Lee, et al. (2018)	20-80 years 50.3% F	2014-2015	Pe	6%	✗	✓	✗	3	✗	≞	≞

Country	Surveillance system/survey used	Ref.	Population	Data year	Time Frame [a]	MSA % [b]	MSA [c]	Freq [d]	Int. [e]	Type [f] (Mode)	Dur [g]	Rel [h]	Val [i]
		Hong, Kim, and Lee (2013)	>20 years 40.4% M	2008-2009	DPW	18.9% 29.5% M 11.68% F	✓	✓	✗	1	✗	✗	✗
		Kim, Lee, Kye, Chung, and Kim (2015)	≥65 years 45.2% M	2008 - 2011	PW	22.2% M 6.1% F	✗	✓	✗	4	✗	✗	✗
		E. Y. Lee, Carson, Jeon, Spence, and Tremblay (2019)	18-64 years 50% M older adults aged ≥65 44.4% M	2014 – 2015	PW	30.8% M, 14.4% F 30.6% OM 8.9% OF	✗	✓	✗	1	✗	≞	≞
		J. Lee, Kim, and Jeon (2016)	19-60 years, 43% M	1999-2012	CW	✗	✗	✓	✗	1	✗	✗	✗
		Oh, Son, et al. (2017)	≥ 65 years 43.4% M	2014	PW	✗	✓	✓	✗	4	✗	✗	✗
		Oh, Kim, Lee, Jung, and Lee (2017)	adults with MetS ≥ 20 years 44.5% M	2014	PW	✗	✓	✓	✗	4	✗	✗	✗

Country	Surveillance system/survey used	Ref.	Population	Data year	Time Frame [a]	MSA % [b]	MSA [c]	Freq [d]	Int. [e]	Type [f] (Mode)	Dur [g]	Rel [h]	Val [i]
		Yeom, Jung, and Choi (2011)	≥65 years 40.4% M	2007 - 2008	DPW	✗	✓	✓	✗	1	✗	✗	✗
Libya	General Student Health Survey	El Ansari, Khalil, Crone, and Stock (2014)	Mean age 20.9 ±2.4 years 66.2% F	2008-2009	P7d	43.7% 33.9% F 62.9% M	✗	✓	✗	3	✗	≞	✗
Pakistan	7 Day recall	Ahmad et al. (2015)	Junior doctors ≤ 30 years Senior doctors > 30 years 41.3% M	2013	P7d	✗	✓	✗	✗	1	✗	✗	✗
South Korea	Korean Survey on Citizens' Sports Participation	Curtin, Lee, Yun, and Spence (2018)	18-64 years 45.8% F	2015	DpM	✗	✓	✓	✗	3	✗	✗	✗
Sweden	PEAK-25 Cohort Self-administered questionnaire	Callréus, McGuigan, Ringsberg, and Åkesson (2012)	25 years 100% F	1999-2004	CA	✗	✓	✓	✗	1	✓	✓ T	✗
Taiwan	Taiwanese version of the International Physical Activity Questionnaire-long version (IPAQ-LV)	Lin, Park, Hsueh, Sun, and Liao (2018)	≥65 years	~	PW	25.4%	✗	✓	✗	1	✗	≞	≞
	British Regional Heart Study	Aggio et al. (2018)	40-59 years	~	PM	✗	✓	✓	✗	2	✗	✗	✗

Country	Surveillance system/survey used	Ref.	Population	Data year	Time Frame [a]	MSA % [b]	MSA [c]	Freq [d]	Int. [e]	Type [f] (Mode)	Dur [g]	Rel [h]	Val [i]
United Kingdom	General Student Health Survey	El Ansari et al. (2011)	University students 77.8% F	2007–2008	P7d	19.4% F 38.3% M	✗	✓	✗	3	✗	✗	✗
	Health Survey for England	Stamatakis and Chaudhury (2008)	>16 years 55.3% F	1997-2006	P4w	✗	✓	✓	✗	4	✓	✗	≞
	Health Survey for England + Scottish Health Survey	Stamatakis et al. (2018)	≥30 years	1994–2008	P4w	3.4%	✓	✓	✗	5	✓	✗	✗
	MRC National Survey of Health and Development	Kuh and Cooper (1992)	36 years 50.3% F	1982	PrM	✗	✓	✓	✗	1	✗	✗	✗
	Scottish Health Survey	Strain, Fitzsimons, Kelly, and Mutrie (2016)	≥16 years	2012–2014	P28d	31% M 24% F	✓	✓	✗	1	✗	✗	✗
		Strain (2018)	≥16 years	2012-2015	P28d	31% M 24% F	✓	✓	✗	1	✗	≞	≞
United States	Aerobics Center Longitudinal Study	Bakker et al. (2017)	Mean age 46 ± 9.5 years 19% F	1987-2006	P3m	35%	✓	✓	✗	4	✓	✗	✗
		Bowles (2005)	≥40 years 79.9% M	1980-1992	P3m	✗	✓	✗	✗	1	✗	✗	✗
		Sandler et al. (2014)	20-81 years 83.4% M	2005	CI	✗	✓	✗	✗	4	✗	✗	✗

Country	Surveillance system/survey used	Ref.	Population	Data year	Time Frame [a]	MSA % [b]	MSA [c]	Freq [d]	Int. [e]	Type [f] (Mode)	Dur [g]	Rel [h]	Val [i]
	American Time Use Survey	Dunton, Berrigan, Ballard-Barbash, Graubard, and Atienza (2009)	≥21 years 52% M	2003–2006	PD	✗	✓	✓	✗	2	✓	✗	✗
	Behavioral Risk Factor Surveillance System	Bennie, De Cocker, Teychenne, Brown, and Biddle (2019)	≥18 years	2015	M/W	30.2%	✗	✓	✗	7	✗	≞	≞
		Bennie, Ding, et al. (2018)	18-80 years 51.5% F	2015	M/W	30.2%	✓	✓	✗	6	✗	≞	≞
		Bennie, Teychenne, De Cocker, and Biddle (2019)	18-85 years 47.9% M	2015	PrM	9.6%	✗	✓	✗	7	✗	≞	≞
		Churilla et al. (2018)	≥18 years 50.2% M	2015	✗	10.1%	✗	✓	✗	1	✗	≞	≞
		Desmond, Jackson, and Hunter (2015)	≥18 years	2013	PrM	7.7%	✗	✓	✗	6	✗	✗	✗
		Dipietro, Williamson, Caspersen, and Eaker (1993)	≥18 years 67.2% F	1989	M/W	✗	✓	✓	✗	1	✓	✗	✗
		Ford et al. (2003)	≥18 years 50.1% M	2000	PrM	✗	✓	✓	✗	2	✓	≞	≞

Country	Surveillance system/survey used	Ref.	Population	Data year	Time Frame [a]	MSA % [b]	MSA [c]	Freq [d]	Int. [e]	Type [f] (Mode)	Dur [g]	Rel [h]	Val [i]
		Kamil-Rosenberg, Greaney, Hochman, and Garber (2019)	≥18 years 39.2% M	2011	DPW	7.1%	✗	✓	✗	1	✗	✗	✗
		Mu, Cohen, and Mukamal (2014)	≥18 years	2011	PrM	13.4% M 10.5% F WD	✗	✓	✗	5	✗	✗	✗
		Mu, Cohen, and Mukamal (2015)	≥18 years	2011	PrM	9.5% NH 7.3% H	✗	✓	✗	2	✗	✗	✗
		Pabayo, Fuller, Lee, Horino, and Kawachi (2018)	≥18 years 52.7% F	2011	PrM	27.7%	✗	✓	✗	6	✗	$\overset{m}{=}$	$\overset{m}{=}$
		Scarola (2016)	≥18 years 52% F	2013	PrM	16.06%	✗	✓	✗	1	✓	✗	✗
		Sciamanna et al. (2017)	18-99 years 51.9% F	2000	PrM	✗	✓	✗	✗	2	✗	✗	✗
		Vezina, Der Ananian, Greenberg, and Kurka (2014)	≥45 years 53.1% F	2011	PrM	23.7% 25.9% M 21.9% F	✗	✓	✗	6	✗	✗	✗
	Cardiovascular Health Study	Monin et al. (2015)	≥65 years	1989-1990 1992-1993	P2W	✗	✓	✓	✗	1	✗	✗	✗

Country	Surveillance system/survey used	Ref.	Population	Data year	Time Frame [a]	MSA % [b]	MSA [c]	Freq [d]	Int. [e]	Type [f] (Mode)	Dur [g]	Rel [h]	Val [i]
	College Student Health Survey	Vankim, Ehlinger, Lust, Story, and Laska (2010)	15-99 years 37.8% M	2007	P7d	✗	✓	✗	✗	4	✓	✗	✗
	Education and Research Towards Health Study	Redwood et al. (2009)	18-94 years 37.5% M	2004	PrM	✗	✓	✓	✗	2	✓	✗	≞
	Go for the Gold employee wellness program	Byrne et al. (2016)	Mean age 41.2 ± 10.8 years 68.1% F	2003-2012	CA	29.7% (2003)	✓	✗	✗	4	✗	✗	✗
	Health Information National Trends Survey	Robertson, Song, Taylor, Durand, and Basen-Engquist (2018)	≥18 years 51.6% F	2011-2014	TW	✗	✗	✗	✗	2	✗	✗	≞
	Health Professionals Follow-up Study	Mekary et al. (2015)	Mean age 58 ± 7 years 100% M	2008	Py	✗	✓	✓	✗	4	✓	✗	≞
	Health risk survey	Nelson, Lust, Story, and Ehlinger (2008)	Mean age 24.2 ± 5.9 years 39% M	2004	PW	✗	✓	✓	✗	1	✗	✗	✗
	HealthStyles Survey	Kruger, Blanck, and Gillespie (2006)	≥18 years 61.9% F	2004	Re	✗	✓	✗	✗	1	✗	✗	✗

Country	Surveillance system/survey used	Ref.	Population	Data year	Time Frame [a]	MSA % [b]	MSA [c]	Freq [d]	Int. [e]	Type [f] (Mode)	Dur [g]	Rel [h]	Val [i]
		Loustalot, Carlson, Kruger, Buchner, and Fulton (2013)	≥18 years 50.8% F	2009	UW/PrM	37.1% 34% M 29.5% F 6% MG 5.7% M/MG 6.2% F/MG	✗	✓	✗	7	✗	✗	✗
	Millennium Cohort Study	de la Motte et al. (2019)	19-39 years 68% M	2007-2008	Tw	69.9% 49.1% M 20.8% F	✗	✓	✗	4	✗	✗	✗
	Modified CHAMPS questionnaire	Zizzi et al. (2006)	≥18 years 34.2% M	2003	PrM	✗	✓	✓	✗	1	✓	✗	✗
	National College Health Assessment	Wald, Muennig, O'Connell, and Garber (2014)	18-24 years 70.3% F	2008	P7d	32.4%	✓	✓	✗	1	✗	≞	≞
	National Health and Nutrition Examination Survey	Alnojeidi, Johnson, Richardson, and Churilla (2017)	≥20 years 50.2% M	1999-2004	P30d	34.4% M 36.5% F	✗	✓	✗	3	✗	✗	✗
		Bertera (2003)	≥60 years 42.8% M	1997	PrM	✗	✓	✗	✗	1	✗	✗	✗

Country	Surveillance system/survey used	Ref.	Population	Data year	Time Frame [a]	MSA % [b]	MSA [c]	Freq [d]	Int. [e]	Type [f] (Mode)	Dur [g]	Rel [h]	Val [i]
		Buckner, Loenneke, and Loprinzi (2017)	20-85 years 48.2% M	2003-2006	P30d	21.7%	✗	✓	✗	3	✗	✗	≞
		Cangin (2017)	18-80 years 53.5% F	1999-2000, 2005-2006 (pooled)	P30d	✗	✓	✓	✗	7	✗	✗	✗
		Cangin, Harris, Binkley, Schwartzbaum, and Focht (2018)	≥18 years 53.5% F	1999-2006	P30d	✗	✓	✓	✗	6	✗	✗	✗
		Cheng et al. (2007)	20 -79 years 48.9% M	1999-2004 (pooled)	P30d	✗	✓	✓	✗	3	✗	✗	✗
		Churilla, Johnson, Magyari, and Crouter (2012)	≥20 years 51.% M	1999-2006 (pooled)	P30d	20.3%	✓	✓	✗	3	✗	✗	✗
		Churilla, Magyari, Ford, Fitzhugh, and Johnson (2012)	≥20 years 50.5% M	1999–2004 (pooled)	P30d	43.9% Ds 28.3% Ig 37.9% H 37.3% Aw	✗	✓	✗	3	✗	✗	✗

Country	Surveillance system/survey used	Ref.	Population	Data year	Time Frame [a]	MSA % [b]	MSA [c]	Freq [d]	Int. [e]	Type [f] (Mode)	Dur [g]	Rel [h]	Val [i]
		Crespo, Keteyian, Heath, and Sempos (1996)	≥20 years	1988-1994	PrM	✗	✓	✓	✗	3	✗	✗	✗
		Czwornog and Austin (2015)	20-74 years	2005-2006	P30d	✗	✓	✗	✗	1	✗	✗	✗
		Dankel, Loenneke, and Loprinzi (2015)	≥20 years old 50.6% M	2003-2006	P30d	✗	✗	✓	✗	3	✗	✗	≞
		Dankel, Loenneke, and Loprinzi (2016a)	≥50 years old 52.6% F	1999-2002	P30d	14.7%	✗	✓	✗	3	✗	✗	≞
		Dankel, Loenneke, and Loprinzi (2016b)	≥20 years 52.7% F	2003-2006	P30d	16.6%	✓	✓	✗	3	✗	✗	≞
		Dankel, Loenneke, and Loprinzi (2016c)	20-85 years old 51.6% F	2003-2006	P30d	21.6%	✗	✓	✗	3	✗	✗	≞
		Dankel, Loenneke, and Loprinzi (2017a)	≥20 years, 51% M	2003-2006	P30d	8.9%	✗	✓	✗	3	✗	✗	≞
		Dankel, Loenneke, and Loprinzi (2017b)	≥50 years 50.4% F	1999-2002	P30d	13.8%	✗	✓	✗	3	✗	✗	≞
		Daumit et al. (2005)	18-65 years	1988-1994	PrM	✗	✓	✓	✗	2	✗	✗	✗

Country	Surveillance system/survey used	Ref.	Population	Data year	Time Frame [a]	MSA % [b]	MSA [c]	Freq [d]	Int. [e]	Type [f] (Mode)	Dur [g]	Rel [h]	Val [i]
		Edwards and Loprinzi (2016)	20 -85 years 52.0% F	1999-2006	P30d	22.2%	✗	✓	✗	3	✗	✗	≞
		Edwards and Loprinzi (2018)	50 -85 years 51.2% F	1999-2002 (pooled)	✗	13.3%	✗	✓	✗	1	✗	✗	✗
		Evenson, Wen, and Herring (2016)	≥40 years 54.6% F	2003-2006	PrM	19.2%	✓	✓	✗	1	✗	✗	✗
		Fan, Ham, Muppidi, and Mokdad (2009)	≥18 years 48% M	2003-2004	PrM	✗	✗	✓	✗	5	✗	✗	✗
		Galuska, Earle, and Fulton (2002)	≥17 years 52.1% F	1988-1994	PrM	8.7%	✓	✓	✗	1	✗	✗	✗
		Gao and Zhu (2011)	≥18 years 49.7% M	2003-2004	P30d	✗	✓	✓	✗	1	✓	✗	✗
		Jensen-Otsu and Austin (2015)	20-74 years	2005-2006	P30d	✗	✓	✓	✗	1	✓	✗	✗
		Kruger, Carlson, and Buchner (2007)	≥18 years 49.1% M	1999-2002	P30d	✗	✓	✓	✗	1	✓	✗	✗
		Kurka et al. (2015)	20-49 years 51.3% M.	1999-2000, 2001-2002, 2003-2004	D/W/M	30.4% M 20.3% F	✓	✓	✗	3	✗	✗	≞

Country	Surveillance system/survey used	Ref.	Population	Data year	Time Frame [a]	MSA % [b]	MSA [c]	Freq [d]	Int. [e]	Type [f] (Mode)	Dur [g]	Rel [h]	Val [i]
				(pooled)									
		Loenneke and Loprinzi (2018)	50–85 years 52.6% F	1999–2002	P30d	✗	✓	✗	✗	1	✗	✗	✗
		Loprinzi (2016a)	60-85 years 54.9% F	1999-2002	P30d	13.3%	✗	✓	✗	4	✗	✗	≞
		Loprinzi (2016b)	20-85 years	2003–2006	P30d	✗	✗	✓	✗	4	✗	✗	≞
		Loprinzi and Loenneke (2015)	20-85 years	2005-2006	P30d	✗	✓	✓	✗	3	✗	✗	≞
		Loprinzi and Loenneke (2018)	20-85 years 51.1% F	1999-2002	P30d	✗	✓	✗	✗	3	✗	✗	✗
		Loprinzi, Addoh, and Mann (2017)	20-85 years 60.9% F	2003-2006	P30d	15.8%	✗	✓	✗	3	✗	✗	≞
		Loprinzi, Addoh, Wong Sarver, Espinoza, and Mann (2017)	20-39 years 56.1% F	1999-2004	P30d	✗	✗	✓	✗	3	✗	✗	≞
		Loprinzi, Loenneke, and Abe (2015)	≥20 years 48.6% M	2003-2006	P30d	✗	✓	✓	✗	3	✗	✗	≞

Country	Surveillance system/survey used	Ref.	Population	Data year	Time Frame [a]	MSA % [b]	MSA [c]	Freq [d]	Int. [e]	Type [f] (Mode)	Dur [g]	Rel [h]	Val [i]
		Loprinzi, Loenneke, and Blackburn (2015)	20-84 years	1999-2002	P30d	✗	✓	✗	✗	3	✗	✗	✗
		Magyari and Churilla (2012)	≥20 years 50.5% M	1999-2004	P30d	✗	✓	✗	✗	3	✗	✗	✗
		Spees, Scott, and Taylor (2012)	18-50 years	1999-2006	P30d	✗	✓	✓	✗	1	✓	✗	✗
		Zhao et al. (2014)	≥20 years 51.5% M	1999-2004	P30d	17.66%	✗	✓	✗	3	✗	✗	✗
	National Health Interview Survey	Adams and Schoenborn (2006)	≥18 years	2002-2004	UB	28.1% M 21.4% F	✗	✓	✗	2	✗	✗	✗
		Blackwell and Clarke (2016)	18-64 years (employed)	2008-2014 (pooled)	CA	3.2%	✗	✓	✗	3	✗	✗	✗
		Carlson, Fulton, Schoenborn, and Loustalot (2010)	≥18 years	1998-2008 (pooled)	D/W/M/Y	17.7% (1998) 21.9% (2008)	✗	✓	✗	2	✗	✗	✗
		Chevan (2008)	≥18 years	2003	W	20.8%	✓	✓	✗	1	✗	✗	✗
		Kraschnewski et al. (2014)	≥65 years 44% M	2011	W/M	18.8% M 14% F	✗	✓	✗	2	✗	✗	✗

Country	Surveillance system/survey used	Ref.	Population	Data year	Time Frame [a]	MSA % [b]	MSA [c]	Freq [d]	Int. [e]	Type [f] (Mode)	Dur [g]	Rel [h]	Val [i]
		Kraschnewski et al. (2016)	≥65 years 42.4% M	1997-2001	W/M	9.6%	✗	✓	✗	2	✗	✗	✗
		Kruger, Carlson, and Kohl III (2006)	≥18 years	1998-2004	W	17.7% - 1998 19.6% - 2004 21.9% M 17.5% F	✗	✓	✗	2	✗	✗	✗
		Kruger, Yore, and Kohl (2007)	≥50 years 46.5% M	2001	W	13.7% 15.3% M 12.4% F	✗	✓	✗	2	✗	✗	≞
		Kruger et al. (2009)	≥50 years	2005	D/W/M/Y	16.7% HW/M 17.2% OW/M 11.4% OB/M 18.3% HW/F 13.1% OW/F	✗	✓	✗	2	✗	✗	✗

Country	Surveillance system/survey used	Ref.	Population	Data year	Time Frame [a]	MSA % [b]	MSA [c]	Freq [d]	Int. [e]	Type [f] (Mode)	Dur [g]	Rel [h]	Val [i]
						11.0% OB/F							
		Murphy et al. (2017)	≥18 years 37.5% M	2015	UW	20.7% M 18.5% F	✗	✓	✗	1	✗	✗	✗
		Schoenborn and Adams (2010)	≥18 years 48.2% M	2005–2007	UB	✗	✓	✓	✗	3	✗	✗	✗
		Schoenborn, Adams, Barnes, Vickerie, and Schiller (2004)	≥18 years	1999–2001	UB	✗	✓	✓	✗	2	✗	✗	✗
		Schoenborn, Adams, and Peregoy (2013)	≥18 years 48.3% M	2008–2010 -	UB	23% 27% M 19.1% F	✓	✓	✗	2	✗	✗	✗
		Schoenborn and Stommel (2011)	≥18 years	1997-2004	✗	3.4%	✗	✓	✗	2	✗	✗	✗

Country	Surveillance system/survey used	Ref.	Population	Data year	Time Frame [a]	MSA % [b]	MSA [c]	Freq [d]	Int. [e]	Type [f] (Mode)	Dur [g]	Rel [h]	Val [i]
		Sciamanna et al. (2014)	≥65 years 56% F	2011	W/PM	16.1% 18.8% M 14% F	✗	✓	✗	2	✗	✗	✗
		Siahpush et al. (2019)	≥18 years	1998–2009	W	20.4%	✗	✓	✗	2	✗	✗	✗
		Swan, Friis, and Turner (2008)	≥18 years	1999–2001	W	✗	✓	✓	✗	2	✗	✗	✗
		Tarasenko, Chen, and Schoenberg (2017)	≥45 years	2014	W	✗	✗	✓	✗	1	✗	✗	✗
		Tarasenko, Linder, and Miller (2018)	≥18 years 61.6% F	1999–2009	✗	4.3% 4.2% M 4.4% F	✗	✓	✗	1	✗	✗	✗
		Wu et al. (2016)	≥18 years 46.9% M	2012	✗	✗	✓	✗	✗	2	✗	✗	✗
		Xu, Dahlhamer, Zammitti, Wheaton, and Croft (2018)	≥18 years 60.9% F	2015-2016	✗	3.4% IBD 3.5% xIBD	✗	✗	✗	✗	✗	✗	✗
		Yusuf et al. (1996)	≥65 years 64.3% F	1990	P2w	✗	✓	✓	✗	2	✓	✗	✗

Country	Surveillance system/survey used	Ref.	Population	Data year	Time Frame [a]	MSA % [b]	MSA [c]	Freq [d]	Int. [e]	Type (Mode) [f]	Dur [g]	Rel [h]	Val [i]
	National Health Interview Survey + Behavioral Risk Factor Surveillance System + National Health and Nutrition Examination Activity Survey	Keadle, McKinnon, Graubard, and Troiano (2016)	adult population, ≥65 years 37.2% M	2013 2013 2011-2012	TpW	6.7% 17.4% M 16.2% F (NHIS) 21.6% 24.7% M 19.9% F (BRFSS)	✗	✓	✗	1	✗	✗	✗
	National Health Interview Survey + Behavioral Risk Factor Surveillance System + National Physical Activity Survey	Ham, Macera, Jones, Ainsworth, and Turczyn (2004)	≥18 years 42.3% male	2000 1999 1999-2000	✗ UW UW	18.2% (NHIS), 28.1% (BRFSS), 34.5% (NPAS)	✗	✓	✗	5	✗	≞	≞
	National Physical Activity and Weight Loss Survey	Ciccolo, Gabriel, Macera, and Ainsworth (2010)	≥18 years 56% F	2002	W	38% 55.3% M 44.7% F	✗	✓	✗	3	✗	✗	✗
		Kruger, Yore, Ainsworth, and Macera (2008)	≥18 years 43.4% M	2002	UW	40% M 34% F	✗	✓	✗	4	✗	✗	✗

Country	Surveillance system/survey used	Ref.	Population	Data year	Time Frame [a]	MSA % [b]	MSA [c]	Freq [d]	Int. [e]	Type [f] (Mode)	Dur [g]	Rel [h]	Val [i]
	New York City Neighborhood and Mental Health in the Elderly Study II, longitudinal study	Mooney et al. (2018)	65–75 years 39% M	2011-2013	PW	✗	✓	✓	✗	3	✓	≞	≞
		Mooney et al. (2015)	65–75 years at baseline	2011	PW	✗	✓	✓	✗	3	✓	✗	≞
	New York County Health Census	Eaton, Nafziger, Strogatz, and Pearson (1994)	≥17 years	1992	PW	✗	✓	✓	✗	3	✗	≞	≞
	Nurses' Health Study PLUS Nurses' Health Study II	Grnøtved et al. (2014)	53–81 years 36–55 years 100% F	2000–2008 2001–2009	W	20.43%	✓	✓	✗	6	✓	✗	≞
	Structured questionnaire	Tucker and Silvester (1996)	≥20 years 100% M		W	✗	✓	✓	✗	2	✓	✗	✗
	VITamins And Lifestyle study	Littman, Kristal, and White (2005)	53-57 years 51.2% F	2000-2002	W/Y/P 10y	✗	✓	✓	✗	1	✓	≞	≞
	Women's Health Study	Kamada, Shiroma, Buring, Miyachi, and Lee (2017)	Mean age 62.2 ± 6.8 years 100% F	1992 - 2004	PrM	✗	✓	✗	✗	2	✓	≞	≞
		Shiroma et al. (2016)	Mean age 62.6 ± 6.9 years 100% F	1992-2004	Py	✗	✓	✗	✗	2	✓	≞	≞

Country	Surveillance system/survey used	Ref.	Population	Data year	Time Frame [a]	MSA % [b]	MSA [c]	Freq [d]	Int. [e]	Type [f] (Mode)	Dur [g]	Rel [h]	Val [i]

Time frame [a]	✗ = not disclosed; CA = current activity; CI = currently involved; CW = current week; D = day/s; DpM = days per month; DPW = days per week; M = month/ly; P10y = previous 10 years; P12m = past 12 months; P28d = past 28 days; P2w = past 2 weeks; P30d = past 30 days; P3m = past 3 months; P4w = past 4 weeks; P6m = past 6 months; P7d = past 7 days; PD = previous day; Pe = periodically; PM = per month; PrM = previous month/past month; PW = past week; PY = past year; Re = regular engagement/participation; TpW = times per week; TW = typical week; UB = usual behaviour; UW = usual week; W = week/ly; Y = year
MSA % [b]	Met muscle-strengthening exercise guideline of ≥ 2 times each week - ✗ = not reported A = average; Au = augmented waist circumference; B = body weight; Cb = control baseline; Cf = control follow-up; Ds = dyslipidaemia; E = using equipment; F = female; H = hypertensive; HW = healthy weight; Ib = intervention baseline; If = intervention follow-up; Ig = impaired fasting glucose; IBD = with irritable bowel disease; M = male; MG = muscle groups; NH = non-hypertensive; OB = obese; OF = older female; OM = older male; OW = overweight; R = range; WD = with diabetes; xIBD = without irritable bowel syndrome
MSA [c]	✗ = participation rate not reported, ✓ = participation rate reported
Freq. [d]	✗ = Frequency assessment not reported, ✓ = Frequency assessment reported
Int. [e]	✗ = Intensity assessment not reported, ✓ = Intensity assessment reported
Type [f]	Number of different modalities used to describe muscle-strengthening exercises
Dur [g]	✗ = Duration assessment not reported, ✓ = Duration assessment reported
Rel [h]	✗ = Reliability not reported, ≞ = Reliability referenced, ✓T = Reliability tested (test retest)
Val [i]	✗ = Validity not reported, ≞ = Validity referenced, ✓I = Validity tested (internal validity)

Online Supplementary Table 2: Chronological order of questions assessing muscle-strengthening exercise behaviours within the included studies.

Year	Surveillance system/survey	Question/s contained within each included article [additional notes]	Ref
1969	Nutritional supplementation trial (Physical activity questionnaire)	Field workers administered a physical activity questionnaire asking about the frequency and duration of activities performed over the preceding year on a typical workday	Gregory, Ramirez-Zea, Martorell, and Stein (2007)
1978	British Regional Heart Study	How often they participated in sport/exercise. Men reporting frequent sport/exercise participation were also asked to state the type of sport/exercise they engaged in.	Aggio et al. (2018)
1980	Aerobics Center Longitudinal Study	Self-reported resistance exercise was assessed in the medical history questionnaire. Participants were asked about the weekly frequency and average exercise duration (minutes) for each session of muscle-strengthening PA using either free weights or weight training machines over the past 3 months.	Bowles (2005)
1982	MRC National Survey of Health and Development (Minnesota leisure time physical activity questionnaire)	Sports and recreational activities: List of 27 activities (eg, … exercises such as press ups at home,…	Kuh and Cooper (1992)
1987	Aerobics Center Longitudinal Study	Self-reported resistance exercise was assessed in the medical history questionnaire. Participants were asked about the weekly frequency and average exercise duration (minutes) for each session of muscle-strengthening PA using either free weights or weight training machines over the past 3 months.	Bakker et al. (2017)

Year	Surveillance system/survey	Question/s contained within each included article [additional notes]	Ref
1988	National Health and Nutrition Examination Survey (NHANES)	Participants were asked to specify their frequency of LTPA during the past month for the following: …calisthenics or floor exercises, and weight lifting. "In the past month, did you lift weights?" Participants who responded "yes" were then asked, "In the past month, how often did you lift weights?"	Crespo, Keteyian, Heath, and Sempos (1996) Galuska, Earle, and Fulton (2002)
		Using standard NHANES questions, participants reported types of leisure time physical activity they performed in the past month (e.g. jogging, biking, swimming) and the number of times they performed each activity. For example, "We are interested in exercise, sports, physically active hobbies that you may do in your leisure time. In the past month did you … jog or run? How many times during the month?"	Daumit et al. (2005)
1989	Behavioral Risk Factor Surveillance System	~	Dipietro, Williamson, Caspersen, and Eaker (1993)
1989	Cardiovascular Health Study	~ [duration per session × number of sessions in the last 2 weeks/2.]	Monin et al. (2015)

Year	Surveillance system/survey	Question/s contained within each included article [additional notes]	Ref
1990	National Health Interview Survey	The Health Promotion and Disease Prevention supplement includes questions about physical activity. Regular LTPA was defined as participation for 30 minutes or more at least 3 times a week during the past 2 weeks in 1 or more of the following physical activities: …, calisthenics, ... weight lifting, ... or up to 2 unspecified other activities.	Yusuf et al. (1996)
1992	Women's Health Study	During the past month, what was your approximate time per week spent at each of the following recreational activities? Weight lifting/strength training.	Kamada, Shiroma, Buring, Miyachi, and Lee (2017)
		During the past year, what was your approximate time per week spent at each of the following recreational activities? Weight lifting/strength training.	Shiroma et al. (2016)
1994	National Population Health Survey (NPHS)	It is based on responses to questions asking respondents if they had participated in any of 23 activities in the past 3 months specified in the NPHS questionnaire and, if so, their duration and frequency of participation in these activities. For Cycle 1, the listed activities were: ..., weight training, …, and up to three other activities.	Perks (2017)

Year	Surveillance system/survey	Question/s contained within each included article [additional notes]	Ref
	Health Survey for England + Scottish Health Survey	Physical activity was assessed using a questionnaire that inquired about participation in sports and exercises during the 4 weeks prior to the interview. Participants were shown a card. For each positive response, participants were asked whether they had participated in the activity for at least 15 minutes, the frequency of activity (number of occasions), and the duration of activity per occasion.	Stamatakis et al. (2018)
1996	National Population Health Survey	Forms of LTPA were assessed by asking respondents whether they had participated in the past 3 months in LTPA, that is, activities not related to work. The interviewer read from a list of 20 such activities (i.e., walking for exercise, gardening or yardwork, swimming) and also inquired on any other activity not listed.	Da Costa, Lowensteyn, and Dritsa (2003)
	Brazilian Living Standards Measurement Survey	The questionnaire included six questions: (1) Do you engage in any physical exercise or sport?; (2) What kind of exercise or sport do you perform? (Please mark the most frequent group: ..., gym/muscular exercise, ..., other sports.); (3) Do you perform exercise or a sport every week?; (4) How many days per week? (Please include all exercise and sports.); (5) How many minutes or hours in each day? (Please include all exercise and sports.); (6) What is your main reason for engaging in exercise or sport? (recreation, health/medical counseling, esthetics/ beauty, other reason).	Monteiro et al. (2003)

Year	Surveillance system/survey	Question/s contained within each included article [additional notes]	Ref
1997	National Health and Nutrition Examination Survey	During the past month, did you ..., do calisthenics, or do other exercises or sports?	Bertera (2003)
	National Health Interview Survey	"How often do you do leisure-time physical activities specifically designed to strengthen your muscles, such as lifting weight or doing calisthenics?" Participant responses included both the number of times strength training was performed and the unit of time (i.e. "per week,""per month")	Kraschnewski et al. (2016)
	North/South Ireland Food Consumption Survey (NSIFCS based on the validated Minnesota Leisure Time Activity Questionnaire)	Levels of customary physical activity were assessed by a self-administered questionnaire that was developed at the Institute of Public Health, University of Cambridge. In each case, questions were closed rather than open-ended, to make them easy to complete and to facilitate large-scale data entry. Respondents were asked to identify the frequency and duration of their participation in 36 named recreational pursuits, including sports and gardening activities. For each activity, respondents indicated the number of times they performed the activity in the past year and the average duration per episode.	Livingstone et al. (2001)
	National Health Interview Survey	(5) How often do you do LEISURE-TIME physical activities specifically designed to STRENGTHEN your muscles such as lifting weights or doing calisthenics?	Schoenborn and Stommel (2011)

Year	Surveillance system/survey	Question/s contained within each included article [additional notes]	Ref
	Health Survey for England	Sport and exercise participation was measured by showing respondents a card listing common activities such as, gym workout, ..., keep-fit, and calisthenics.	Stamatakis and Chaudhury (2008)
1998	National Health Interview Survey	Respondents were also asked about their participation in leisure-time physical activities specifically designed to strengthen their muscles, such as lifting weights or doing calisthenics. Respondents were classified as meeting the muscle-strengthening guideline if they reported engaging in muscle-strengthening activity two or more times/week.	Carlson, Fulton, Schoenborn, and Loustalot (2010)
		"How often do you do physical activities designed to strengthen your muscles, such as lifting weights or doing calisthenics?"	Kruger, Carlson, and Kohl III (2006)
		"How often do you do leisuretime physical activities specifically designed to strengthen your muscles such as lifting weights or doing calisthenics?"	Siahpush et al. (2019)
1999	Korea National Health and Nutrition Examination Survey	used five answers from IPAQ, which for that week of the survey identified the number of days the participants did vigorous physical activity, moderate physical activity, walking, strength, and flexibility, for at least 10 min at a time.	J. Lee, Kim, and Jeon (2016)

Year	Surveillance system/survey	Question/s contained within each included article [additional notes]	Ref
	National Health and Nutrition Examination Survey	Over the past 30 days, did you do any physical activities specifically designed to strengthen your muscles such as lifting weights, push-ups or sit-ups? Include all such activities even if you have mentioned them before in the past 12 months; … Over the past 30 days, how often did you do these activities? [Activities designed to strengthen your muscles such as lifting weights, push-ups or sit-ups].	Alnojeidi, Johnson, Richardson, and Churilla (2017)
		"any physical activity designed to strengthen muscles such as lifting weights, push-ups or sit-ups, over the past 30 days" 75, and by asking what specific leisure time strength training activity they performed over the past 30 days 76	Cangin (2017)
		Participants reported whether they performed 'any physical activity designed to strengthen muscles such as weight-lifting, push-ups or sit-ups, over the past 30 days'.	Cangin, Harris, Binkley, Schwartzbaum, and Focht (2018)
		"Over the past 30 days, how often did you do any physical activities designed to strengthen your muscles such as lifting weights, push-ups, or sit-ups? Include all such activities even if you have mentioned them before."	Cheng et al. (2007)

Year	Surveillance system/survey	Question/s contained within each included article [additional notes]	Ref
		'Over the past 30 days, did you do any physical activities specifically designed to strengthen your muscles such as lifting weights, push-ups or sit-ups?' 'Over the past 30 days, how often did you do these physical activities?' Activities designed to strengthen your muscles such as lifting weights, push-ups or sit-ups.	Churilla, Johnson, Magyari, and Crouter (2012) Churilla, Magyari, Ford, Fitzhugh, and Johnson (2012)
		"During the past 30 days, did you do any PAs specifically designed to strengthen your muscles, such as weight lifting, push-ups, or sit-ups?", "During the past 30 days, how many times did you do these MSAs (eg, weight lifting, push-ups, or sit-ups)?"	Dankel, Loenneke, and Loprinzi (2016a)
		"During the past 30 days, did you do any physical activities specifically designed to strengthen your muscles, such as weight lifting, push-ups, or sit-ups?" and if so "During the past 30 days, how many times did you do these muscle strengthening activities (e.g., weight lifting, push-ups, or sit-ups)?".	Dankel, Loenneke, and Loprinzi (2017a)

Year	Surveillance system/survey	Question/s contained within each included article [additional notes]	Ref
		1) "Over the past 30 days, did you do any physical activities specifically designed to strengthen your muscles such as lifting weights, push-ups or sit-ups?" (response option: yes or no), and 2) "Over the past 30 days, how many times did you do these activities designed to strengthen your muscles such as lifting weights, push-ups, or sit-ups?"	Edwards and Loprinzi (2016)
		~ [self-report of meeting muscle-strengthening activities guidelines (yes/no; ≥2 sessions per week)]	Edwards and Loprinzi (2018)
		''[Over the past 30 d], did you do moderate activities for at least 10 min that caused only light sweating or a slight to moderate increase in breathing or heart rate? Some examples are brisk walking, bicycling for pleasure, golf, or dancing.'' Individuals who reported that they had engaged in moderate-intensity activity were asked to report the frequency and duration of any of the 32 moderate activities.	Kruger, Carlson, and Buchner (2007)
		"Over the past 30 days, did you do any physical activities specifically designed to strengthen your muscles such as lifting weights, push-ups, or sit-ups?" … "How often did you do these physical activities?"	Kurka et al. (2015)
		'Over the past 30 days, did you do any physical activities specifically designed to strengthen your muscles such as lifting weights, push-ups or sit-ups?' (response yes/no).	Loenneke and Loprinzi (2018)

Year	Surveillance system/survey	Question/s contained within each included article [additional notes]	Ref
		(1) ''Over the past 30 days, did you do any physical activities specifically designed to strengthen your muscles such as lifting weights, pushups or sit-ups?'' (response option: yes or no) and (2) among those answering yes to this first question, they were asked, ''Over the past 30 days, how many times did you do these activities designed to strengthen your muscles such as lifting weights, push-ups, or sit-ups?''	Loprinzi (2016a); Loprinzi, Addoh, Wong Sarver, Espinoza, and Mann (2017)
		"Over the past 30 days, did you do any physical activities specifically designed to strengthen your muscles such as lifting weights, push-ups or sit-ups?"	Loprinzi and Loenneke (2018) Loprinzi, Loenneke, and Blackburn (2015)
		''Over the past 30 days, did you do any physical activity specifically designed to strengthen your muscles such as LW, push-ups or sit-ups?''	Magyari and Churilla (2012)

Year	Surveillance system/survey	Question/s contained within each included article [additional notes]	Ref
		Participants were asked which vigorous activities from a list of examples they performed over the past 30 days. Vigorous activity was defined as those "that caused heavy sweating, or large increases in breathing or heart rate?" VPA activities were defined as a having corresponding metabolic equivalent level (MET) level of 6.0. For each activity reported, the number of times performed over the past 30 days and the average duration in minutes was collected. The same process was used to collect the frequency and duration of moderate activities performed over the past 30 days, defined as activities "that caused light sweating or a slight to moderate increase in your heart rate or breathing." MPA activity was defined by NHANES as an activity with a corresponding MET level of 3.0–5.9.	Spees, Scott, and Taylor (2012)
		(1) "Over the past 30 days, did you do any physical activities specifically designed to strengthen your muscles such as lifting weights, push-ups or sit-ups?" and (2) "Over the past 30 days, how many times did you do these physical activities?"	Zhao et al. (2014)

Year	Surveillance system/survey	Question/s contained within each included article [additional notes]	Ref
	National Health Interview Survey	AHB.130 How often do you do physical activities specifically designed to STRENGTHEN your muscles such as lifting weights or doing calisthenics? (Include all such activities even if you mentioned them before.) [Asked of all adults.]	Schoenborn, Adams, Barnes, Vickerie, and Schiller (2004)
		How often do you do physical activities specifically designed to strengthen your muscles such as lifting weights or doing calisthenics?	Swan, Friis, and Turner (2008)
		~	Tarasenko, Linder, and Miller (2018)
	National Health Interview Survey (NHIS)+ Behavioral Risk Factor Surveillance System (BRFSS) + National Physical Activity Survey	The NHIS used examples of strengthening activities (e.g., lifting weights, calisthenics). The BRFSS used examples of activities for strengthening (e.g., lifting weights, pull-ups, push-ups, sit-ups). The NPAS terms were identical to the BRFSS study	Ham, Macera, Jones, Ainsworth, and Turczyn (2004)
	PEAK-25 Cohort Self-administered questionnaire (Questionnaire)	The subjects were asked to grade their own overall activity level; to describe the types of exercise they performed; to estimate the amount of time spent on each specific activity; and to specify seasonal variations in their activity.	Callréus, McGuigan, Ringsberg, and Åkesson (2012)

Year	Surveillance system/survey	Question/s contained within each included article [additional notes]	Ref
2000	Behavioral Risk Factor Surveillance System	"During the past month, did you participate in any physical activities or exercises such as running, calisthenics, golf, gardening, or walking for exercise?" Those who answered affirmatively then were asked to provide information about the type, frequency, and duration of up to two activities.	Ford et al. (2003)
		What type of physical activity or exercise did you spend the most time doing during the past month? and What other type of physical activity gave you the next most exercise during the past month?, providing their two most common activities.	Sciamanna et al. (2017)
	Nurses' Health Study + Nurses' Health Study II	each participant reported her average weekly amount of resistance exercise, lower intensity exercise (yoga, stretching, toning), and aerobic physical activities.	Grnøtved et al. (2014)
	VITamins And Lifestyle study (Questionnaire)	Respondents were instructed to only report activities carried out regularly, defined as at least once per week for at least 1 y in the previous 10y. Participants reported the number of years in the last 10 that they did each activity, along with the days per week and the minutes per day.	Littman, Kristal, and White (2005)

Year	Surveillance system/survey	Question/s contained within each included article [additional notes]	Ref
2001	Exercise, Recreation and Sport Survey	participation in leisure-time physical activity, defined as; 'any physical activity done for exercise, recreation or sport in the past 12 months'. Respondents were asked to exclude 'any physical activity associated with work, household or garden chores'. Those who indicated participation were asked to list the types of leisuretime physical activity undertaken, whether each activity was organised or non-organised, and the number of times they participated in each activity during the previous 12 months. From 2005 onwards, participants were also asked about the frequency and average session duration in the past two weeks.	Bennie, Pedišić, van Uffelen, Charity, et al. (2016)
		participants were asked about any physical activity done for exercise, recreation or sport in the past 12 months.	Merom, Cosgrove, Venugopal, and Bauman (2012)
	National Health Interview Survey	"How often do you do physical activities specifically designed to strengthen your muscles, such as lifting weights or doing calisthenics?"	Kruger, Yore, and Kohl (2007)

Year	Surveillance system/survey	Question/s contained within each included article [additional notes]	Ref
2002	Modified CHAMPS questionnaire	The participants were first asked whether they had done each of these activities in a typical week during the last month (yes/no). Those who answered no were referred to the next item. Those who answered yes then responded to the frequency question "how many times a week?" and the duration question "how many hours a week?" with six response options (<1, 1–2, 3–4, 5–6, 7–8, and ≥9 hr).	Zizzi et al. (2006)
	National Health Interview Survey	"How often do you do physical activities specifically designed to STRENGTHEN your muscles such as lifting weights or doing calisthenics? (Include all such activities even if you mentioned them before.) [Asked of all adults.]"	Adams and Schoenborn (2006)
	National Physical Activity and Weight Loss Survey	Respondents were asked whether they participated in any activities designed to increase muscle strength or tone in a usual week, and if so, how many days per week did they participate in such resistance-type activities	Ciccolo, Gabriel, Macera, and Ainsworth (2010)
		"In a usual week, do you do any activities designed to increase muscle strength or tone, such as lifting weights, pull-ups, push-ups, or sit-ups?" Those who said yes were asked, "How many days per week do you do these activities?"	Kruger, Yore, Ainsworth, and Macera (2008)

Year	Surveillance system/survey	Question/s contained within each included article [additional notes]	Ref
2003	American Time Use Survey	Respondents were asked to sequentially describe each activity and its duration for the 24-h period beginning at 4:00 a.m. Follow-up questions assessed where and with whom each activity occurred. Each interview lasted approximately 15 to 20 min	Dunton, Berrigan, Ballard-Barbash, Graubard, and Atienza (2009)
	Go for the Gold employee wellness program (the Wellsource Concise Assessment Plus Personal Wellness Profile)	Engaging in strength exercising (sit-ups, pushups, or use weight training equipment) How many times per week do you do strength building exercises such as situps, pushups, or use weight training equipment?	Byrne et al. (2016)
	National Health and Nutrition Examination Survey	i) 'Over the past 30 days, did you do any physical activities specifically designed to strengthen your muscles such as lifting weights, push-ups or sit-ups?' (response option: yes or no), and (ii) among those answering yes to this first question, they were asked, 'Over the past 30 days, how many times did you do these activities designed to strengthen your muscles such as lifting weights, push-ups, or sit-ups?'	Buckner, Loenneke, and Loprinzi (2017) Loprinzi, Addoh, and Mann (2017)

Year	Surveillance system/survey	Question/s contained within each included article [additional notes]	Ref
		(1) "Over the past 30 days, did you do any physical activities specifically designed to strengthen your muscles such as lifting weights, push-ups or sit-ups?" and, if so, (2) "Over the past 30 days, how many times did you do these activities designed to strengthen your muscles such as lifting weights, push-ups or sit-ups?"	Dankel, Loenneke, and Loprinzi (2015) Dankel, Loenneke, and Loprinzi (2016b)
		(1) "Over the past 30 days, did you do any physical activities specifically designed to strengthen your muscles such as lifting weight, push-ups or sit-ups?" and if yes (2) "Over the past 30 days, how many times did you do these activities designed to strengthen your muscles such as lifting weights, push-ups or sit-ups?"	Dankel, Loenneke, and Loprinzi (2016c)
		(1) ''Over the past 30 days, did you do any physical activities specifically designed to strengthen your muscles such as lifting weight, push-ups, or sit-ups?'', (2) ''Over the past 30 days, how many times did you do these activities designed to strengthen your muscles such as lifting weights, pushups, or sit-ups?'	Dankel, Loenneke, and Loprinzi (2017b)
		~ [Strengthening ≥2 times/week 1 time/week None]	Evenson, Wen, and Herring (2016)

Year	Surveillance system/survey	Question/s contained within each included article [additional notes]	Ref
		~ [All PA 3) Type of PA: number of sessions per month cardio strengthening Flexibility Total MeT-minutes cardio strengthening Flexibility]	Fan, Ham, Muppidi, and Mokdad (2009)
		The PA questionnaire data consisted of participants' responses to whether or not they participated in leisure-time MVPA and activities in other PA domains (e,g,, transportation related or domestic PA), and if yes, what were the type, frequency, and duration of the specific activities participants performed in the past 30 d	Gao and Zhu (2011)
		Participants were asked two questions related to engagement in MSA: (1) 'Over the past 30 days, did you do any physical activities specifically designed to strengthen your muscles such as lifting weights, push-ups or sit-ups?' (response option: yes or no), and (2) among those answering yes to this first question, they were asked, 'Over the past 30 days, how many times did you do these activities designed to strengthen your muscles such as lifting weights, pushups, or sit-ups?'	Loprinzi (2016b); Loprinzi, Loenneke, and Abe (2015)
	National Health Interview Survey	respondents were asked to report the frequency of ''physical activities specifically designed to strengthen your muscles such as lifting weights or doing calisthenics.''	Chevan (2008)

Year	Surveillance system/survey	Question/s contained within each included article [additional notes]	Ref
2004	Australian Diabetes, Obesity and Lifestyle study	‘‘How many times have you done any activities designed to increase muscle strength or tone, such as lifting weights, pull-ups, push-ups, or sit-ups?’’ In a separate question, ST duration was evaluated by asking, ‘‘What do you estimate was the total time that you spent in these activities in the last week?’’	Minges et al. (2013)
	Education and Research Towards Health Study (Questionnaire)	Questions about activities that are less frequently performed (traditional activities, leisure activities, and occupational activities) were asked in the manner of the Taylor questionnaire; participants chose from a list of individual activities and specified the length of time and frequency at which they were performed, for all activities, participants were asked to include only those lasting more than 10 minutes at a time, specify the days per week (or per month as applicable) of the activity, and specify the average time spent on each activity.	Redwood et al. (2009)
	Health risk survey	Using survey items similar to those included in national surveillance systems,... Students also self-reported the number of days in the past week in which they engaged in stretching and/or strengthening exercises.	Nelson, Lust, Story, and Ehlinger (2008)

Year	Surveillance system/survey	Question/s contained within each included article [additional notes]	Ref
	HealthStyles Survey	Respondents were also asked to report all physical activities/sports they engage in from a list of 18 specific activities: "Which of the following physical activities/sports do you participate in regularly?" These items included ..., lifting weights	Kruger, Blanck, and Gillespie (2006)
2005	Aerobics Center Longitudinal Study	Participants were asked to provide yes/no answers to 4 separate questions: (1) “Are you currently involved in a muscle-strengthening programme?” (2) Can you specify the muscle-strengthening activity as “Callisthenics”, “Free Weights”, “Weight Training Machines” or “Other”? (3) “Are you currently involved in exercises to maintain or improve your joint flexibility?” (4) Can you specify the flexibility activity as “Stretching”, “Callisthenic”, “Exercise Class”, “Yoga” or “Other”?	Sandler et al. (2014)
	Concord Health and Aging in Men Project (PASE)	Participants reported the frequency and time spent in the past 7 days … in muscle strengthening exercise.	Hsu et al. (2018)
	National Health and Nutrition Examination Survey	Participants were also asked if they participated in specific physical activities (not in the workplace) in the previous 30 days including ..., and muscle strengthening activities.	Czwornog and Austin (2015)

Year	Surveillance system/survey	Question/s contained within each included article [additional notes]	Ref
		Participants were also asked if they participated in specific physical activities (not in the workplace) in the previous 30 days including ... muscle strengthening activities. If they answered yes, they were asked about the frequency and the average duration of time they engaged in those activities	Jensen-Otsu and Austin (2015)
		1) "Over the past 30 days, did you do any physical activities specifically designed to strengthen your muscles such as lifting weights, push-ups or sit-ups?" (response option: yes or no), and 2) among those answering yes to this first question, they were asked, "Over the past 30 days, how many times did you do these activities designed to strengthen your muscles such as lifting weights, push-ups, or sit-ups?"	Loprinzi and Loenneke (2015)
	National Health Interview Survey	Respondents were asked to report the frequency they engaged in strength training (per day, week, month, or year).	Kruger et al. (2009)
		AHB.130 How often do you do LEISURE-TIME physical activities specifically designed to STRENGTHEN your muscles such as lifting weights or doing calisthenics? (Include all such activities even if you mentioned them before.) [Asked of all adults.]	Schoenborn and Adams (2010)

Year	Surveillance system/survey	Question/s contained within each included article [additional notes]	Ref
2006	Central Queensland Social Survey	'In the last week, did you do any gym-based resistance training'?	Humphries, Duncan, and Mummery (2008)
	Exercise, Recreation and Sport Survey	Respondents were asked if they participated in any physical activity for exercise, recreation and sport during the last 12 months, excluding activities that were part of work or household and garden chores. Those who indicated participation were asked to list up to 10 specific activities that were coded by the interviewer against a list of 166 activities (including two "other" options). Respondents reported the number of sessions they engaged in each activity over the previous 12 months. For the three activities with the highest frequency of participation over the previous 12 months, respondents also reported the number of sessions and average minutes per session of each activity during the previous 2 weeks.	Mealing, Bowles, Merom, and Bauman (2011)
	Japan Epidemiology Collaboration on Occupational Health Study	Participants were asked if they regularly engaged in any physical activity during leisure time including muscle strength training,	Kuwahara et al. (2015)

Year	Surveillance system/survey	Question/s contained within each included article [additional notes]	Ref
	SSF National Sports-Life Survey	Questions 1 and 2 of the questionnaire were utilized for the engagement of strength training.	Harada, Oka, Ota, Shibata, and Nakamura (2008)
2007	Canadian Community Health Survey (CHMS household questionnaire)	Respondents aged 12 or older were asked if they had engaged in any of the following activities in the previous three months: …, home exercises, … weight-training, …or any other. For each activity reported, respondents were asked the frequency in the past three months, and the average duration of each session: 1 to 15 minutes, 16 to 30 minutes, 31 to 60 minutes, or more than one hour.	Garriguet and Colley (2014)
	College Student Health Survey	In the past 7 days, how many hours did you spend doing the following activities? (C) Exercises to strengthen or tone your muscles	Vankim, Ehlinger, Lust, Story, and Laska (2010)
	General Student Health Survey [United Kingdom]	"On how many of the past 7 days did you do exercises to strengthen or tone muscles (push-ups, sit-ups, or weight lifting)?"	El Ansari et al. (2011)
	Korea National Health and Nutrition Examination Survey	how many days per week the individual spends on strengthening or stretching activity	Yeom, Jung, and Choi (2011)

Year	Surveillance system/survey	Question/s contained within each included article [additional notes]	Ref
	Millennium Cohort Study	"In a typical week, how much time do you spend participating in strength training or work that strengthens your muscles (such as lifting/pushing/pulling/weights)?”	de la Motte et al. (2019)
2008	General Student Health Survey [Libya]	“On how many of the past 7 days did you do exercises to strengthen or tone your muscles, such as push-ups, sit-ups, or weight lifting?” Participants answered 0–7 days	El Ansari, Khalil, Crone, and Stock (2014)
	Health Professionals Follow-up Study	Participants were asked to report the average time spent per week in the previous year in each … Calisthenics ..., weightlifting/ weight machine...	Mekary et al. (2015)
	National College Health Assessment [United States]	On how many of the past 7 days did you do 8 to 10 strength training exercises (such as resistance training weight machines) for 8 to 12 repetitions each?	Wald, Muennig, O'Connell, and Garber (2014)
	Korea National Health and Nutrition Examination Survey	~ [after adjustment for factors known to affect osteoporosis, such as age, gender, BMI, serum 25(OH) vitamin D level, menstruation status, hormone supplement use, menopausal status, and the number of days per week of muscular strength exercise.]	Hong, Kim, and Lee (2013)
		Participants also recorded the frequency of resistance exercises such as push-ups, sit-ups, or training using dumbbells, weights, or a horizontal bar in the past week.	Kim, Lee, Kye, Chung, and Kim (2015)

Year	Surveillance system/survey	Question/s contained within each included article [additional notes]	Ref
	National Health Interview Survey	‘How often do you do leisure-time muscle-strengthening activities (‘‘such as lifting weights or doing calisthenics’’)	Blackwell and Clarke (2016)
		AHB.130 How often do you do LEISURE-TIME physical activities specifically designed to STRENGTHEN your muscles such as lifting weights or doing calisthenics? (Include all such activities even if you mentioned them before.) [Asked of all sample adults.]	Schoenborn, Adams, and Peregoy (2013)
2009	COMMUNIty-wide CAmpaign To promote Exercise study (Questionnaire)	Respondents were asked about the weekly number of days performed was asked for muscle-strengthening activity.	Kamada et al. (2018)
		The weekly number of days engaged in muscle-strengthening activity was assessed by asking “Do you usually do activities to maintain and/or improve muscles and/or muscle strength (e.g., sit-ups, squats, knee extensions)?”	Kamada et al. (2013)
	HealthStyles Survey	Respondents were asked about muscle-strengthening participation (yes/no), frequency (days per week), inclusion of muscle group(s) (i.e., shoulders, arms, back, chest, abdomen, legs, and hips), and type and location of muscle strengthening activities performed during a usual week in the past month.	Loustalot, Carlson, Kruger, Buchner, and Fulton (2013)
	New South Wales Fall Prevention telephone survey (Questionnaire)	Participants were asked if in the past week they did “strength or resistance training such as lifting weights or push ups”.	Merom, Pye, et al. (2012)

Year	Surveillance system/survey	Question/s contained within each included article [additional notes]	Ref
2010	Central Queensland Social Survey (Based on the Active Australia Survey)	'Have you ever consistently, at least two times per week for at least six months, performed strength-based training to build or maintain muscle?' If yes, participants were asked to report how long ago they strength trained, with one of the category choices being, 'I currently strength train'.	Dalbo et al. (2015)
	Exercise, Recreation and Sport Survey	Interviewers asked respondents if they had participated in any LTPA for exercise, recreation or sport in the last 12 months (as opposed to PA associated with employment, housework or garden chores). If the response was 'yes', respondents were then asked to report what activities they had participated in during this time period (up to a maximum of 10 activities). Respondents were also asked how many times (sessions or episodes) they had participated in each of their nominated types of activity during the previous 12 months.	Eime et al. (2015)
	General Social Survey	gather information regarding daily time-use by asking participants to estimate the number of minutes spent engaging in various leisure and work-related activities during a designated day of the week.	Panten, Stone, and Baker (2017)
	Social Survey (Social Survey Questionnaire)	"Physical exercise to strengthen muscles is exercise intended to strengthen and build muscles, for example gymnastics, bodybuilding, and weightlifting. In the last three months, did you engage in exercise to strengthen muscles?	Zach and Lissitsa (2016)

Year	Surveillance system/survey	Question/s contained within each included article [additional notes]	Ref
2011	Behavioral Risk Factor Surveillance System	Respondents’ PA levels were determined using six items on the BRFSS that assessed ... the frequency of engaging in muscle strengthening exercises	Kamil-Rosenberg, Greaney, Hochman, and Garber (2019)
		2) the frequency of physical activities or exercises to strengthen their muscles (excluding aerobic activities but including yoga, sit-ups, push-ups, and exercises using weights or elastic bands).	Mu, Cohen, and Mukamal (2014)
		They also reported, during the past month, … (2) the frequency of physical activities or exercises to strengthen their muscles	Mu, Cohen, and Mukamal (2015)
		‘During the past month, how many times per week or per month did you do physical activities or exercises to STRENGTHEN your muscles? Do NOT count aerobic activities like walking, running, or bicycling. Count activities using your own body weight like yoga, situps or push-ups and those using weight machines, free weights, or elastic bands.’	Pabayo, Fuller, Lee, Horino, and Kawachi (2018) Vezina, Der Ananian, Greenberg, and Kurka (2014)

Year	Surveillance system/survey	Question/s contained within each included article [additional notes]	Ref
	Health Information National Trends Survey	"In a typical week, outside of your job or work around the house, how many days do you do leisure-time physical activities specifically designed to strengthen your muscles such as lifting weights or circuit training (do not include cardio exercise such as walking, biking, or swimming)?"	Robertson, Song, Taylor, Durand, and Basen-Engquist (2018)
	National Health Interview Survey + Behavioral Risk Factor Surveillance System + National Health and Nutrition Examination Activity Survey (NHANES)	NHANES only assessed muscle strengthening behaviors in 1999–2006, thus we did not report on these values due to the lack of recent data points. NHIS questionnaires included strength training from 1998 to 2013, BRFSS assessed strength training in 2011 and 2013.	Keadle, McKinnon, Graubard, and Troiano (2016)
	National Health Interview Survey	"How often do you do leisure-time physical activities specifically designed to strengthen your muscles such as lifting weights or doing calisthenics?" Participant responses included both the number of times ST was performed and the unit of time (i.e. "per week,""per month")	Kraschnewski et al. (2014)
		"How often do you do leisuretime physical activities specifically designed to strengthen your muscles such as lifting weights or doing calisthenics?"	Sciamanna et al. (2014)

Year	Surveillance system/survey	Question/s contained within each included article [additional notes]	Ref
	National Nutrition and Physical Activity Survey	"Including any activities already mentioned, in the last week did you do any strength or toning activities?". If they answered positively, they were further asked: "How many times did you do any strength or toning activities in the last week?".	Bennie, Pedišić, van Uffelen, Gale, et al. (2016)
		"In the last week, did you do any strength or toning activities? (For example; lifting weights, pull-ups, push-ups, or sit-ups)". If they answered 'yes' they were then asked, "How many times did you do any strength or toning activities in the last week?" and "What was the total time that you spent doing strength or toning activities in the last week?"	Freeston et al. (2017)
	New York City Neighborhood and Mental Health in the Elderly Study II, longitudinal study (Physical Activity Scale for the Elderly (PASE))	All subjects who were followed up successfully were asked at each wave about past-week physical activity using 16 items derived from the Physical Activity Scale for the Elderly (PASE) (26–28)	Mooney et al. (2018)
		PASE asks subjects to recall past-week engagement in ... muscle-strengthening	Mooney et al. (2015)

Year	Surveillance system/survey	Question/s contained within each included article [additional notes]	Ref
	Not disclosed (Questionnaire)	~ [Strength training was defined as all exercises that serve to enhance muscular strength and endurance, with regular strength training defined as 2 days or more per week. Respondents were categorized into two groups: those who engaged in regular strength-training behavior and those who did not. In addition, for those who reported regular training, the location (facility or home) was requested.] [Japan]	Harada, Shibata, Ishii, Liao, and Oka (2014)
		Respondents were asked to report how many days they participated in each type of activity during a typical week [Japan]	Harada, Shibata, Oka, and Nakamura (2015)
2012	Canadian Longitudinal Study on Aging (CLSA - modified Physical Activity Scale for Elderly (PASE))	participants were asked how often they engaged in exercises specifically to increase muscle strength and endurance	Copeland, Good, and Dogra (2019) Dogra et al. (2018)
	COMMUNIty-wide CAmpaign To promote Exercise study (Questionnaire)	The weekly number of days performed was asked for muscle-strengthening activity.	Masamitsu et al. (2015)
	National Health Interview Survey	How often do you do leisure-time activities specifically designed to strengthen your muscles such as lifting weights or doing calisthenics?	Wu et al. (2016)

Year	Surveillance system/survey	Question/s contained within each included article [additional notes]	Ref
	Scottish Health Survey	Respondents were asked to report the frequency (in the 28 days prior to interview) and average duration of any sport and exercise activities that they undertook. "During the past four weeks, was the effort of (name of activity) usually enough to make your muscles feel some tension, shake or feel warm?"	Strain, Fitzsimons, Kelly, and Mutrie (2016)
		For certain activities an additional question was asked to identify whether the activity could be classed as muscle strengthening. IF WhtAct, WhtAcB or OactQ = cycling, workout at a gym, aerobics, any other type of dancing, running/jogging, football/rugby, badminton/tennis, squash, exercises, ten pin bowling, yoga/pilates, aquarobics/aquafit, martial arts/Tai Chi, basketball, netball, lawn bowls, golf, hill walking/rambling, cricket, hockey, curling, ice skating, shinty, surf/body boarding, volleyball THEN [cyclemus to Vollmus] During the past four weeks, was the effort of (name of activity) usually enough to make your muscles feel some tension, shake or feel warm? 1 Yes 2 No IF WhtAct = Exercises (e.g. press-ups, sit-ups) AND (Age>=65) THEN [ExMov]2 Did these exercises involve you standing up and moving about? 1 Yes 2 No	Strain (2018)

Year	Surveillance system/survey	Question/s contained within each included article [additional notes]	Ref
2013	7 Day recall	Do you do exercise as a part of your daily routine?	Ahmad et al. (2015)
	Behavioral Risk Factor Surveillance System	All individuals who indicated any activity in the past month also were asked whether in the past month they had engaged in physical activity, such as yoga, sit-ups, push-ups, and using weight machines, free weights, and elastic bands, to strengthen their muscles, and how many times per week or month they engaged in those activities.	Desmond, Jackson, and Hunter (2015)
		Meeting the muscle strengthening recommendations was assessed by asking participants "what type of physical activity or exercise did you spend the most time doing during the past month?" …followed up by "how many times per week or per month did you take part in this activity during the past month?" and followed up by "and when you took part in this activity, for how many minutes or hours did you usually keep at it?"	Scarola (2016)

Year	Surveillance system/survey	Question/s contained within each included article [additional notes]	Ref
	Finnish Regional Health and Well-being Study	(a) "think about the past year (12 months)"; (b) "consider all regular weekly physical activity which lasts at least 10 minutes/session"; and (c) "select all alternatives that correspond to their physical activity habits". The frequency (days/week) and duration (hours and minutes/ week) of the following four physical activity- related behaviors were assessed: (iii) "Neuromuscular training (for example keep-fit circuit training or muscular strength training in a gym, and including exercises for the main muscle groups with 8-12 repetitions)"	Bennie et al. (2017)
	National College Health Assessment [Canada]	Participation in strength training activity was also assessed, using the question: In the past seven days, how many days did you exercise to strengthen muscles doing eight to ten repetitions?	Scarapicchia, Sabiston, and Faulkner (2015)
2014	Korea National Health and Nutrition Examination Survey	'Over the past 7 days, did you do any physical activities specifically designed to strengthen your muscles such as lifting weights, push-ups, or situps?'. Those who reported 'yes' were asked to report their MSE frequency (times/week). Based on the Korean guidelines	Bennie et al. (2018b)

Year	Surveillance system/survey	Question/s contained within each included article [additional notes]	Ref
		Based on the Global Physical activity questionnaire. And the frequency of participating in MSE (1 item) were also self-reported.	E. Y. Lee, Carson, Jeon, Spence, and Tremblay (2019)
		Subjects who performed resistance exercise were defined as those who performed exercises such as push-ups, crunches, or chin-ups for 1 day or more in the past week	Oh, Kim, Lee, Jung, and Lee (2017); Oh, Son, et al. (2017)
	National Health Interview Survey	~	Tarasenko, Chen, and Schoenberg (2017)
	Surveillance System of Risk Factors and Protection for Chronic Noncommunicable Diseases	"have you practiced any kind of physical exercise or sport during the last three months? Yes/No/Which?" "on the day you exercise or practice a sport, how long does this activity last?"	de Lima, Lima, and do Carmo Luiz (2017)

Year	Surveillance system/survey	Question/s contained within each included article [additional notes]	Ref
2015	Behavioral Risk Factor Surveillance System	"During the past month, how many times per week or per month did you do physical activities or exercises to strengthen your muscles?". "Do not count aerobic activities like walking, running, or bicycling. Count activities using your own body weight like yoga, sit-ups or push-ups and those using weight machines, free weights, or elastic bands"	Bennie et al. (2018a) Bennie, De Cocker, Teychenne, Brown, and Biddle (2019); Bennie, Teychenne, De Cocker, and Biddle (2019)
		~	Churilla et al. (2018)
	Korean Survey on Citizens' Sports Participation (2015 Survey on Citizens' Sports Participation)	"How often do you participate in structured/ nonstructured physical activity?"	Curtin, Lee, Yun, and Spence (2018)
	Longevity check-up 7+ (lifestyle interview/questionnaire)	~ [Information and data: - habitual physical activity]	Landi et al. (2018)
	National Health Interview Survey	Respondents reporting participation in leisure time physical activities specifically designed to strengthen their muscles (e.g., lifting weights, doing calisthenics) two or more times weekly were classified as meeting the muscle strengthening guideline.	Murphy et al. (2017)

Year	Surveillance system/survey	Question/s contained within each included article [additional notes]	Ref
		Morbidity and Mortality Weekly Report [looking at the actual questionnaire :-AHB.130_01.000: Strength activity freq: # of units	Xu, Dahlhamer, Zammitti, Wheaton, and Croft (2018)
Unclear	Active Australia survey	Respondents who reported any activity were asked to list their three main types of physical activities (unprompted) and how often they had engaged in each of 14 specific recreational physical activities over the previous 12 months (never, once every 6 months, once a month, once every 2 weeks, once a week and more than once a week).	Brown et al. (2013)

Year	Surveillance system/survey	Question/s contained within each included article [additional notes]	Ref
	Central Queensland Social Survey	"Do you currently perform any strength based training to build or maintain muscle? This could include activities such as training at home or the gym using barbells, dumbbells, hand weights or weight machines." "How many days each week do you perform strength based training activities?" "When you perform the activities to build or maintain muscle, how many different exercises do you perform?" "On average how many repetitions do you perform in each set?" and "Thinking about the weight that you lift during your muscle strengthening sessions, we would like you to categorise the intensity of this weight on a scale of 1–10, where 1 means that it is no effort at all, 5 is moderate effort and 10 is the weight you can only lift once."	Humphries, Stanton, Scanlan, and Duncan (2018)
	New York County Health Census (derived from Paffenbarger et al.'s16 original physical activity questionnaire)	"At least once a week, do you engage in any regular activity like brisk walking, jogging, bicycling, etc. long enough to work up a sweat? (No, Yes) If yes, how many times a week? __ Activity."	Eaton, Nafziger, Strogatz, and Pearson (1994)
	Structured questionnaire	Frequency and duration (i.e., quantity) of participation in strength training and 20 other physical activities, such as jogging, rowing, stair stepping, or swimming, were assessed with the quantitative ~ history method)	Tucker and Silvester (1996)

Year	Surveillance system/survey	Question/s contained within each included article [additional notes]	Ref
	Taiwanese version of the International Physical Activity Questionnaire-long version (IPAQ-LV)	Those who reported engagement in MS activities were asked whether they had done any MS activities in the previous week other than MVPA. If they answered affirmatively, they were further asked: "How many times did you do MS activities last week?"	Lin, Park, Hsueh, Sun, and Liao (2018)

~ [ ] Where the specific muscle-strengthening exercise questions were not explicitly detailed within the included articles we have included additional text, located within each respective manuscript, to indicate how the exercise was measured.

PA: Physical activity

LTPA: Leisure time physical activity

APPENDIX B: STUDY 2

Supplementary Table 1: Characteristics of participants included in the analysis [a]

Total sample of 2012 and 2016 Health Survey for England (n = 16,301)	
Total	**% (n)**
Sex	
Male	44.4 (7,232)
Female	55.6 (9,069)
Age (years)	
16-54	57.7 (9,402)
≥55	42.3 (6,899)
Education	
Graduate /degree	25.2 (4,093)
Higher education (below degree)	10.2 (1,651)
A or O level [b]	31.6 (5,131)
Other grade	3.8 (610)
Foreign/other	1.4 (234)
No qualification	22.1 (3,592)
Student (full-time)	5.8 (937)
Income Tertiles	
Highest	35.0 (4,420)
Middle	32.5 (4,106)
Lowest	32.5 (4,106)
Body Mass Index (kg/m^2)	
Underweight (<18.5)	1.6 (218)
Normal (≥18.5-<25)	34.6 (4,631)
Overweight (25– <30)	36.9 (4,940)
Obese (≥30)	26.8 (3,588)
Smoking status	
Never smoked	50.2 (8,120)

Ex-occasional smoker	5.1 (820)
Ex-regular smoker	26.7 (4,314)
Current smoker	18.1 (2,920)
Alcohol	
None (0)	17.8 (2,884)
Weekly	52.8 (8,530)
Monthly/Yearly	29.4 (4,749)
Cardiovascular medication	
Yes	18.6 (1,960)
No	81.4 (8,559)
Longstanding illness	
Yes	26.1 (4,256)
No	73.9 (12,033)
Aerobic-MVPA level (minutes/week)	
0minutes/week ‘inactive’	24.3 (3,912)
1-149 minutes/week ‘insufficiently active’	16.3 (2,635)
≥ 150 minutes/week ‘active’	59.4 (9,574)
Sedentary behavior (min/ day)	
Low (<480 minutes/day)	87.1 (14,142)
High (≥480 minutes/day)	12.9 (2,087)
Chronic conditions (yes)	
Diabetes	7.8 (1,273)
Heart condition	12.3 (2,006)
Respiratory condition	7.9 (1,285)
Musculoskeletal condition	18.2 (2,959)
Anxiety/depression (2012 only)	20.2 (1,493)
Number of Chronic conditions	
0	57.7 (4,254)
1	26.3 (1,937)
≥2	16.1 (1,188)

[a] Numbers vary slightly because of missing data for some characteristic variables

Missing data equated to: 0.3% education (53), household income 22.5% (3,669), BMI 17.9% (2,924), alcohol consumption 0.8% (138), smoking status 0.8% (127), cardiovascular medication 35.5% (5,782), longstanding illness 0.1% (12), aerobic-MVPA 1.1% (180), sedentary behaviour 0.4% (72), diabetes 0.1% (12), heart condition 0.0% (8), respiratory condition 0.0% (8), musculoskeletal 0.0% (8) and anxiety/depression 54.7% (8,911).

[b] A or O level – ‘A Level’ is a pre-university qualification that is equivalent to 13 years of study. ‘O’ level typically represents a total of 11 years of study and signifies the completion of compulsory secondary education.

Appendix-A. Health Survey for England exercise show card E6

CARD E6

1 Swimming

2 Cycling

3 Workout at a gym/Exercise bike/Weight training

4 Aerobics/Keep fit/Gymnastics/ Dance for fitness

5 Any other type of dancing

6 Running/Jogging

7 Football/Rugby

8 Badminton/tennis

9 Squash

10 Exercises (e.g. press-up, sit-ups)

ActPhy/WhtAct

Appendix-B. Health Survey for England exercise show card E7

CARD E7

1 Strength work out at the gym using machines or free weights

2 Exercise Bike

3 Spinning Classes

4 Stepping machine, rowing machine or cross trainer

5 Treadmill running

WorkOut

Appendix-C

Analysis of the relationship between muscle-strengthening exercise (duration/session and volume/week) between five chronic conditions and having one or two or more chronic conditions relative to two specific modes of muscle-strengthening exercise, and with the two models combined (PRs; APRs; 95%CI) significance is indicated by *.

Diabetes				
Duration/session				
Own-bodyweight exercises	Model A[a]	Model B[b]	Model C[c]	Model D[d]
0 minutes	1 (reference)	1 (reference)	1 (reference)	1 (reference)
10-20 minutes	0.35 (0.25-0.47) *	0.37 (0.26-0.51) *	0.39 (0.25-0.58) *	0.40 (0.25-0.59) *
21-59 minutes	0.37 (0.22-0.58) *	0.35 (0.19-0.58) *	0.36 (0.16-0.67) *	0.36 (0.17-0.68) *
60+ minutes	0.27 (0.11-0.52) *	0.29 (0.12-0.60) *	0.25 (0.06-0.65) *	0.26 (0.06-0.66) *
Gym-based-strength exercises				
0 minutes	1 (reference)	1 (reference)	1 (reference)	1 (reference)
10-20 minutes	0.46 (0.30-0.68) *	0.47 (0.28-0.73) *	0.54 (0.30-0.90) *	0.55 (0.30-0.92) *
21-59 minutes	0.32 (0.19-0.52) *	0.30 (0.16-0.52) *	0.31 (0.13-0.61) *	0.31 (0.13-0.61) *
60+ minutes	0.28 (0.13-0.50) *	0.38 (0.18-0.69) *	0.48 (0.10 0.98)	0.49 (0.19-0.99)
Total-MSE				
0 minutes	1 (reference)	1 (reference)	1 (reference)	1 (reference)
10-20 minutes	0.39 (0.28-0.52) *	0.42 (0.29-0.57) *	0.46 (0.30-0.67) *	0.47 (0.30-0.68) *
21-59 minutes	0.35 (0.24-0.50) *	0.33 (0.21-0.49) *	0.38 (0.22-0.61) *	0.39 (0.23-0.62) *
60+ minutes	0.25 (0.15-0.39) *	0.32 (0.19-0.50) *	0.31 (0.15-0.56) *	0.31 (0.15-0.57) *
Volume/week (frequency x duration)				
Own-bodyweight exercises [e]				

None	1 (reference)	1 (reference)	1 (reference)	1 (reference)
Low < mean	0.33 (0.25-0.44) *	0.33 (0.24-0.46) *	0.36 (0.23-0.52) *	0.36 (0.24-0.53) *
High ≥ mean	0.37 (0.22-0.56) *	0.40 (0.23-0.65) *	0.39 (0.18-0.70) *	0.39 (0.19-0.71) *
Gym-based-strength exercises [e]				
None	1 (reference)	1 (reference)	1 (reference)	1 (reference)
Low < mean	0.40 (0.28-0.55) *	0.40 (0.26-0.57) *	0.45 (0.28-0.70) *	0.46 (0.28-0.70) *
High ≥ mean	0.30 (0.16-0.50) *	0.37 (0.19-0.64) *	0.42 (0.18-0.81) *	0.42 (0.18-0.82) *
Total-MSE [e]				
None	1 (reference)	1 (reference)	1 (reference)	1 (reference)
Low < mean	0.34 (0.26-0.43) *	0.35 (0.26-0.45) *	0.39 (0.27-0.54) *	0.40 (0.28-0.55) *
High ≥ mean	0.35 (0.23-0.50) *	0.41 (0.26-0.61) *	0.43 (0.24-0.70) *	0.43 (0.24-0.71) *

Anxiety/Depression (only for 2012)				
Duration/session				
Own-bodyweight exercises	Model A[a]	Model B[b]	Model C[c]	Model D[d]
0 minutes	1 (reference)	1 (reference)	1 (reference)	1 (reference)
10-20 minutes	0.63 (0.51-0.78) *	0.59 (0.46-0.75) *	0.49 (0.35-0.67) *	0.50 (0.36-0.68) *
21-59 minutes	0.69 (0.48-0.96) *	0.68 (0.45-0.97) *	0.72 (0.45-1.08)	0.73 (0.46-1.10)
60+ minutes	0.44 (0.24-0.72) *	0.35 (0.17-0.63) *	0.33 (0.12-0.71) *	0.34 (0.12-0.73) *
Gym-based-strength exercises				
0 minutes	1 (reference)	1 (reference)	1 (reference)	1 (reference)
10-20 minutes	0.61 (0.43-0.83) *	0.58 (0.39-0.82) *	0.46 (0.27-0.74) *	0.47 (0.28-0.75) *
21-59 minutes	0.53 (0.36-0.75) *	0.50 (0.32-0.74) *	0.39 (0.21-0.66) *	0.39 (0.21-0.66) *
60+ minutes	0.50 (0.29-0.79) *	0.50 (0.27-0.82) *	0.65 (0.33-1.15)	0.68 (0.34-1.20)

Total-MSE				
0 minutes	1 (reference)	1 (reference)	1 (reference)	1 (reference)
10-20 minutes	0.68 (0.55-0.84) *	0.64 (0.50-0.81) *	0.57 (0.41-0.76) *	0.57 (0.41-0.77) *
21-59 minutes	0.56 (0.42-0.73) *	0.56 (0.41-0.74) *	0.48 (0.32-0.69) *	0.49 (0.32-0.70) *
60+ minutes	0.46 (0.32-0.64) *	0.42 (0.27-0.61) *	0.45 (0.27-0.70) *	0.46 (0.27-0.72) *
Volume/week (frequency x duration)				
Own-bodyweight exercises [e]				
None	1 (reference)	1 (reference)	1 (reference)	1 (reference)
Low < mean	0.62 (0.51-0.75) *	0.59 (0.47-0.73) *	0.50 (0.37-0.66) *	0.51 (0.37-0.67) *
High ≥ mean	0.60 (0.42-0.84) *	0.54 (0.35-0.79) *	0.62 (0.37-0.95) *	0.62 (0.38-0.96) *
Gym-based-strength exercises [e]				
None	1 (reference)	1 (reference)	1 (reference)	1 (reference)
Low < mean	0.54 (0.41-0.70) *	0.52 (0.38-0.68) *	0.38 (0.24-0.56) *	0.38 (0.24-0.57) *
High ≥ mean	0.61 (0.40-0.88) *	0.58 (0.36-0.88) *	0.73 (0.43-1.16)	0.76 (0.44-1.20)
Total-MSE [e]				
None	1 (reference)	1 (reference)	1 (reference)	1 (reference)
Low < mean	0.59 (0.49-0.71) *	0.57 (0.47-0.70) *	0.47 (0.35-0.61) *	0.48 (0.36-0.62) *
High ≥ mean	0.59 (0.43-0.77) *	0.53 (0.37-0.72) *	0.64 (0.42-0.92) *	0.65 (0.43-0.93) *

Heart Condition				
Duration/session				
Own-bodyweight exercises	Model A[a]	Model B[b]	Model C[c]	Model D[d]
0 minutes	1 (reference)	1 (reference)	1 (reference)	1 (reference)

10-20 minutes	0.54 (0.44-0.66) *	0.54 (0.43-0.68) *	0.54 (0.40-0.70) *	0.54 (0.40-0.71) *
21-59 minutes	0.46 (0.31-0.63) *	0.47 (0.31-0.68) *	0.41 (0.24-0.66) *	0.42 (0.24-0.67) *
60+ minutes	0.47 (0.29-0.72) *	0.47 (0.27-0.76) *	0.41 (0.19-0.76) *	0.37 (0.16-0.71) *
Gym-based-strength exercises				
0 minutes	1 (reference)	1 (reference)	1 (reference)	1 (reference)
10-20 minutes	0.48 (0.34-0.65) *	0.51 (0.35-0.71) *	0.57 (0.37-0.84) *	0.58 (0.37-0.86) *
21-59 minutes	0.33 (0.21-0.48) *	0.33 (0.20-0.50) *	0.32 (0.17-0.54) *	0.32 (0.17-0.54) *
60+ minutes	0.20 (0.10-0.35) *	0.16 (0.06-0.33) *	0.19 (0.06-0.44) *	0.19 (0.06-0.45) *
Total-MSE				
0 minutes	1 (reference)	1 (reference)	1 (reference)	1 (reference)
10-20 minutes	0.60 (0.49-0.73) *	0.60 (0.47-0.74) *	0.58 (0.43-0.76) *	0.58 (0.43-0.76) *
21-59 minutes	0.37 (0.28-0.49) *	0.38 (0.27-0.52) *	0.39 (0.26-0.56) *	0.40 (0.27-0.57) *
60+ minutes	0.33 (0.23-0.45) *	0.32 (0.21-0.46) *	0.29 (0.16-0.47) *	0.27 (0.15-0.45) *
Volume/week (frequency x duration)				
Own-bodyweight exercises [e]				
None	1 (reference)	1 (reference)	1 (reference)	1 (reference)
Low < mean	0.48 (0.39-0.58) *	0.47 (0.38-0.59) *	0.44 (0.33-0.58) *	0.45 (0.33-0.59) *
High ≥ mean	0.61 (0.45-0.81) *	0.64 (0.46-0.88) *	0.63 (0.41-0.92) *	0.62 (0.39-0.91) *
Gym-based-strength exercises [e]				
None	1 (reference)	1 (reference)	1 (reference)	1 (reference)
Low < mean	0.42 (0.32-0.54) *	0.42 (0.30-0.55) *	0.47 (0.32-0.65) *	0.48 (0.33-0.66) *
High ≥ mean	0.21 (0.11-0.34) *	0.23 (0.12-0.40) *	0.21 (0.08-0.43) *	0.22 (0.09-0.44) *
Total-MSE [e]				
None	1 (reference)	1 (reference)	1 (reference)	1 (reference)

Low < mean	0.51 (0.43-0.60) *	0.50 (0.41-0.60) *	0.50 (0.39-0.63) *	0.50 (0.39-0.63) *
High ≥ mean	0.32 (0.23-0.44) *	0.36 (0.24-0.50) *	0.31 (0.19-0.49) *	0.30 (0.18-0.48) *

Respiratory Condition				
Duration/session				
Own-bodyweight exercises	Model A[a]	Model B[b]	Model C[c]	Model D[d]
0 minutes	1 (reference)	1 (reference)	1 (reference)	1 (reference)
10-20 minutes	0.57 (0.44-0.73) *	0.56 (0.42-0.73) *	0.58 (0.41-0.79) *	0.58 (0.40-0.79) *
21-59 minutes	0.72 (0.50-1.01)	0.82 (0.56-1.17)	0.87 (0.55-1.31)	0.85 (0.52-1.28)
60+ minutes	0.67 (0.40-1.04)	0.67 (0.38-1.09)	0.61 (0.28-1.15)	0.55 (0.24-1.08)
Gym-based-strength exercises				
0 minutes	1 (reference)	1 (reference)	1 (reference)	1 (reference)
10-20 minutes	0.58 (0.39-0.83) *	0.52 (0.33-0.78) *	0.59 (0.34-0.94) *	0.53 (0.30-0.87) *
21-59 minutes	0.50 (0.32-0.74) *	0.50 (0.31-0.76) *	0.48 (0.25-0.80) *	0.44 (0.23-0.76) *
60+ minutes	0.50 (0.29-0.79) *	0.52 (0.29-0.87) *	0.50 (0.21-0.97)	0.51 (0.22-0.99)
Total-MSE				
0 minutes	1 (reference)	1 (reference)	1 (reference)	1 (reference)
10-20 minutes	0.67 (0.52-0.84) *	0.65 (0.49-0.84) *	0.68 (0.48-0.92) *	0.67 (0.48-0.92) *
21-59 minutes	0.49 (0.35-0.66) *	0.50 (0.35-0.69) *	0.49 (0.31-0.73) *	0.47 (0.30-0.71) *
60+ minutes	0.62 (0.45-0.84) *	0.65 (0.45-0.90) *	0.63 (0.39-0.96) *	0.58 (0.35-0.90) *
Volume/week (frequency x duration)				
Own-bodyweight exercises [e]				
None	1 (reference)	1 (reference)	1 (reference)	1 (reference)
Low < mean	0.60 (0.47-0.74) *	0.58 (0.44-0.73) *	0.58 (0.42-0.78) *	0.57 (0.41-0.77) *

High ≥ mean	0.69 (0.48-0.96) *	0.82 (0.56-1.15)	0.87 (0.55-1.30)	0.85 (0.53-1.28)
Gym-based-strength exercises [e]				
None	1 (reference)	1 (reference)	1 (reference)	1 (reference)
Low < mean	0.56 (0.41-0.74) *	0.50 (0.35-0.69) *	0.53 (0.35-0.77) *	0.50 (0.32-0.73) *
High ≥ mean	0.48 (0.29-0.73) *	0.54 (0.32-0.85) *	0.53 (0.26-0.94) *	0.49 (0.23-0.89) *
Total-MSE [e]				
None	1 (reference)	1 (reference)	1 (reference)	1 (reference)
Low < mean	0.50 (0.32-0.73) *	0.63 (0.50-0.77) *	0.62 (0.47-0.80) *	0.61 (0.46-0.79) *
High ≥ mean	0.49 (0.23-0.89) *	0.53 (0.36-0.75) *	0.56 (0.35-0.85) *	0.52 (0.31-0.80) *

Musculoskeletal Condition				
Duration/session				
Own-bodyweight exercises	Model A[a]	Model B[b]	Model C[c]	Model D[d]
0 minutes	1 (reference)	1 (reference)	1 (reference)	1 (reference)
10-20 minutes	0.54 (0.46-0.64) *	0.50 (0.41-0.61) *	0.53 (0.41-0.66) *	0.53 (0.42-0.67) *
21-59 minutes	0.56 (0.42-0.71) *	0.54 (0.40-0.72) *	0.63 (0.43-0.87) *	0.63 (0.44-0.88) *
60+ minutes	0.75 (0.55-0.99) *	0.68 (0.47-0.95) *	0.77 (0.49-1.14)	0.72 (0.45-1.09)
Gym-based-strength exercises				
0 minutes	1 (reference)	1 (reference)	1 (reference)	1 (reference)
10-20 minutes	0.46 (0.34-0.59) *	0.51 (0.37-0.67) *	0.46 (0.30-0.65) *	0.46 (0.31-0.67) *
21-59 minutes	0.34 (0.24-0.47) *	0.34 (0.23-0.48) *	0.38 (0.24-0.57) *	0.36 (0.23-0.55) *
60+ minutes	0.31 (0.20-0.45) *	0.32 (0.20-0.50) *	0.32 (0.16-0.57) *	0.33 (0.16-0.58) *
Total-MSE				
0 minutes	1 (reference)	1 (reference)	1 (reference)	1 (reference)

10-20 minutes	0.63 (0.53-0.73) *	0.59 (0.49-0.71) *	0.61 (0.48-0.76) *	0.61 (0.48-0.76) *
21-59 minutes	0.45 (0.36-0.55) *	0.45 (0.35-0.57) *	0.54 (0.40-0.70) *	0.53 (0.40-0.70) *
60+ minutes	0.48 (0.38-0.60) *	0.47 (0.36-0.61) *	0.48 (0.33-0.66) *	0.45 (0.31-0.64) *
Volume/week (frequency x duration)				
Own-bodyweight exercises [e]				
None	1 (reference)	1 (reference)	1 (reference)	1 (reference)
Low < mean	0.54 (0.46-0.63) *	0.51 (0.42-0.61) *	0.54 (0.43-0.66) *	0.53 (0.43-0.66) *
High ≥ mean	0.67 (0.53-0.84) *	0.62 (0.47-0.81) *	0.73 (0.52-0.98) *	0.72 (0.51-0.97) *
Gym-based-strength exercises [e]				
None	1 (reference)	1 (reference)	1 (reference)	1 (reference)
Low < mean	0.43 (0.35-0.53) *	0.47 (0.37-0.58) *	0.44 (0.33-0.59) *	0.44 (0.32-0.58) *
High ≥ mean	0.26 (0.17-0.38) *	0.26 (0.16-0.40) *	0.29 (0.16-0.49) *	0.30 (0.16-0.50) *
Total-MSE [e]				
None	1 (reference)	1 (reference)	1 (reference)	1 (reference)
Low < mean	0.57 (0.50-0.65) *	0.55 (0.48-0.64) *	0.58 (0.49-0.70) *	0.58 (0.48-0.70) *
High ≥ mean	0.43 (0.33-0.54) *	0.41 (0.31-0.53) *	0.46 (0.33-0.63) *	0.46 (0.32-0.63) *

Chronic Conditions		
Duration/session		
Own-bodyweight exercises	Model D[d] 1 condition	Model D[d] ≥2 conditions
0 minutes	1 (reference)	1 (reference)
10-20 minutes	0.70 (0.55-0.87) *	0.29 (0.18-0.44) *
21-59 minutes	0.84 (0.59-1.16)	0.30 (0.13-0.58) *

60+ minutes	0.66 (0.38-1.07)	0.16 (0.03-0.48) *	
Gym-based-strength exercises			
0 minutes	1 (reference)	1 (reference)	
10-20 minutes	0.63 (0.44-0.88) *	0.17 (0.06-0.36) *	
21-59 minutes	0.62 (0.42-0.88) *	0.07 (0.01-0.23) *	
60+ minutes	0.66 (0.38-1.05)	0.16 (0.03-0.48) *	
Total-MSE			
0 minutes	1 (reference)	1 (reference)	
10-20 minutes	0.73 (0.58-0.92) *	0.34 (0.22-0.51) *	
21-59 minutes	0.62 (0.46-0.82) *	0.21 (0.10-0.36) *	
60+ minutes	0.70 (0.50-0.95) *	0.09 (0.02-0.24) *	
Volume/week (frequency x duration)			
Own-bodyweight exercises [e]			
None	1 (reference)	1 (reference)	
Low < mean	0.68 (0.55-0.83) *	0.25 (0.16-0.38) *	
High ≥ mean	0.89 (0.63-1.21)	0.35 (0.16-0.65) *	
Gym-based-strength exercises [e]			
None	1 (reference)	1 (reference)	
Low < mean	0.56 (0.41-0.73) *	0.13 (0.06-0.26) *	
High ≥ mean	0.84 (0.57-1.20)	0.12 (0.02-0.36) *	
Total-MSE [e]			
None	1 (reference)	1 (reference)	
Low < mean	0.67 (0.55-0.80) *	0.26 (0.17-0.37) *	
High ≥ mean	0.76 (0.56-1.01) *	0.20 (0.08-0.38) *	

MSE = muscle-strengthening exercise, PRs = prevalence ratios, APRs = adjusted prevalence ratios, CI = confidence interval

Total-MSE = own-bodyweight exercise + gym-based-strength

* Result is significant i.e., <0.05

[a] Unadjusted model (Model A)

[b] Model B - adjusted for sociodemographic factors (sex, age groups in 10 years brackets, education, income tertiles)

[c] Model C - adjusted for sociodemographic factors (sex, age groups in 10 years brackets, education, income tertiles) and Lifestyle factors (BMI, weekly alcohol consumption, smoking status, blood pressure medication, longstanding illness)

[d] Model D adjusted for sociodemographic factors (sex, age groups in 10 years brackets, education, income tertiles) and Lifestyle factors (BMI, weekly alcohol consumption, smoking status, blood pressure medication, longstanding illness) and weekly aerobic-MVPA and weekly sedentary time

[e] mean value: own bodyweight 76.1 min/week, gym-based strength 99.4 min/week, total-MSE 107.6 min/week [low = below the mean, high = above the mean]

Appendix-D

Analysis of the relationship between muscle-strengthening exercise (duration/session) between five chronic conditions and having one or two or more chronic conditions relative to two specific modes of muscle-strengthening exercise, and with the two models combined (APRs; 95%CI).

Model D [d]	**Diabetes**	**Heart Condition**	**Respiratory Condition**	**Musculoskeletal Condition**	**Anxiety/ depression**	**1 Chronic Condition**	**≥2 Chronic Conditions**
Duration/session							
Own-bodyweight exercises							
0 minutes	1 (reference)	1 (reference)	1 (reference)	1 (reference)	1 (reference)	1 (reference)	1 (reference)
10-20 minutes	0.40 (0.25-0.59)*	0.54 (0.40-0.71)*	0.58 (0.40-0.79)*	0.53 (0.42-0.67)*	0.50 (0.36-0.68)*	0.70 (0.55-0.87)*	0.29 (0.18-0.44)*
21-59 minutes	0.36 (0.17-0.68)*	0.42 (0.24-0.67)*	0.85 (0.52-1.28)	0.63 (0.44-0.88)*	0.73 (0.46-1.10)	0.84 (0.59-1.16)	0.30 (0.13-0.58)*
60+ minutes	0.26 (0.06-0.66)*	0.37 (0.16-0.71)*	0.55 (0.24-1.08)	0.72 (0.45-1.09)	0.34 (0.12-0.73)*	0.66 (0.38-1.07)	0.16 (0.03-0.48)*
Gym-based-strength exercises							
0 minutes	1 (reference)	1 (reference)	1 (reference)	1 (reference)	1 (reference)	1 (reference)	1 (reference)
10-20 minutes	0.55 (0.30-0.92)*	0.58 (0.37-0.86)*	0.53 (0.30-0.87)*	0.46 (0.31-0.67)*	0.47 (0.28-0.75)*	0.63 (0.44-0.88)*	0.17 (0.06-0.36)*
21-59 minutes	0.31 (0.13-0.61)*	0.32 (0.17-0.54)*	0.44 (0.23-0.76)*	0.36 (0.23-0.55)*	0.39 (0.21-0.66)*	0.62 (0.42-0.88)*	0.07 (0.01-0.23)*
60+ minutes	0.49 (0.19-0.99)	0.19 (0.06-0.45)*	0.51 (0.22-0.99)	0.33 (0.16-0.58)*	0.68 (0.34-1.20)	0.66 (0.38-1.05)	0.16 (0.03-0.48)*
Total-MSE							
0 minutes	1 (reference)	1 (reference)	1 (reference)	1 (reference)	1 (reference)	1 (reference)	1 (reference)

10-20 minutes	0.47 (0.30-0.68)*	0.58 (0.43-0.76)*	0.67 (0.48-0.92)*	0.61 (0.48-0.76)*	0.57 (0.41-0.77)*	0.73 (0.58-0.92)*	0.34 (0.22-0.51)*
21-59 minutes	0.39 (0.23-0.62)*	0.40 (0.27-0.57)*	0.47 (0.30-0.71)*	0.53 (0.40-0.70)*	0.49 (0.32-0.70)*	0.62 (0.46-0.82)*	0.21 (0.10-0.36)*
60+ minutes	0.31 (0.15-0.57)*	0.27 (0.15-0.45)*	0.58 (0.35-0.90)*	0.45 (0.31-0.64)*	0.46 (0.27-0.72)*	0.70 (0.50-0.95)*	0.09 (0.02-0.24)*

MSE = muscle-strengthening exercise, PRs = prevalence ratios, APRs = adjusted prevalence ratios, CI = confidence interval

Total-MSE = own-bodyweight exercise + gym-based-strength

* Result is significant i.e., <0.05

[d] Model adjusted for sociodemographic factors (sex, age groups in 10 years brackets, education, income tertiles) and Lifestyle factors (BMI, weekly alcohol consumption, smoking status, blood pressure medication, longstanding illness) and weekly aerobic-MVPA and weekly sedentary time

Appendix-E

Analysis of the relationship between muscle-strengthening exercise (volume/week) between five chronic conditions and having one or two or more chronic conditions relative to two specific modes of muscle-strengthening exercise, and with the two models combined (APRs; 95%CI).

Model D [d]	**Diabetes**	**Heart Condition**	**Respiratory Condition**	**Musculoskeletal Condition**	**Anxiety/ depression**	**1 Chronic Condition**	**≥2 Chronic Conditions**
Volume/week (frequency x duration)							
Own-bodyweight exercises [e]							
None	1 (reference)	1 (reference)	1 (reference)	1 (reference)	1 (reference)	1 (reference)	1 (reference)
Low < mean	0.36 (0.24-0.53)*	0.45 (0.33-0.59)*	0.57 (0.41-0.77)*	0.53 (0.43-0.66)*	0.51 (0.37-0.67)*	0.68 (0.55-0.83)*	0.25 (0.16-0.38)*
High ≥ mean	0.39 (0.19-0.71)*	0.62 (0.39-0.91)*	0.85 (0.53-1.28)	0.72 (0.51-0.97)*	0.62 (0.38-0.96)*	0.89 (0.63-1.21)	0.35 (0.16-0.65)*
Gym-based-strength exercises [e]							
None	1 (reference)	1 (reference)	1 (reference)	1 (reference)	1 (reference)	1 (reference)	1 (reference)
Low < mean	0.46 (0.28-0.70)*	0.48 (0.33-0.66 *	0.50 (0.32-0.73)*	0.44 (0.32-0.58)*	0.38 (0.24-0.57)*	0.56 (0.41-0.73)*	0.13 (0.06-0.26)*
High ≥ mean	0.42 (0.18-0.82)*	0.22 (0.09-0.44)*	0.49 (0.23-0.89)*	0.30 (0.16-0.50)*	0.76 (0.44-1.20)	0.84 (0.57-1.20)	0.12 (0.02-0.36)*
Total-MSE [e]							
None	1 (reference)	1 (reference)	1 (reference)	1 (reference)	1 (reference)	1 (reference)	1 (reference)
Low < mean	0.40 (0.28-0.55)*	0.50 (0.39-0.63)*	0.61 (0.46-0.79)*	0.58 (0.48-0.70)*	0.48 (0.36-0.62)*	0.67 (0.55-0.80)*	0.26 (0.17-0.37)*
High ≥ mean	0.43 (0.24-0.71)*	0.30 (0.18-0.48)*	0.52 (0.31-0.80)*	0.46 (0.32-0.63)*	0.65 (0.43-0.93)*	0.76 (0.56-1.01)*	0.20 (0.08-0.38)*

MSE = muscle-strengthening exercise, PRs = prevalence ratios, APRs = adjusted prevalence ratios, CI = confidence interval

Total-MSE = own-bodyweight exercise + gym-based-strength

* Result is significant i.e., <0.05

[d] Model adjusted for sociodemographic factors (sex, age groups in 10 years brackets, education, income tertiles) and Lifestyle factors (BMI, weekly alcohol consumption, smoking status, blood pressure medication, longstanding illness) and weekly aerobic-MVPA and weekly sedentary time

[e] Mean value: own bodyweight 76.1min/week, gym-based strength 99.4 min/week, total-MSE 107.6 min/week [low = below the mean, high = above the mean]

Supplementary Table 1.1: Age stratified muscle-strengthening exercise behaviour characteristics (exposure variable) of participants included in the analysis

Total sample of 2012 and 2016 Health Survey for England (n = 16,301)			
Total	**Total % (n)**	**16-54 years % (n)**	**55+ years % (n)**
Muscle-strengthening exercise – Session duration			
Own-bodyweight (minutes/session)			
0 minutes	86.2 (14,057)	82.1 (7,721)	91.8 (6,336)
10-20 minutes	8.6 (1,406)	11.1 (1,035)	5.4 (371)
21-59 minutes	3.3 (533)	4.4 (415)	1.7 (118)
60+ minutes	1.9 (305)	2.5 (231)	1.1 (74)
Gym-based-strength (minutes/session)			
0 minutes	90.5 (14,752)	86.4 (8,126)	96.0 (6,626)
10-20 minutes	3.7 (603)	4.9 (459)	2.1 (144)
21-59 minutes	3.4 (558)	5.0 (473)	1.2 (85)
60+ minutes	2.4 (388)	3.7 (344)	0.6 (44)
Total-MSE (minutes/session)			
0 minutes	81.5 (13,285)	75.6 (7,105)	89.6 (6,180)
10-20 minutes	7.8 (1,278)	9.4 (886)	5.7 (392)

21-59 minutes	6.0 (982)	8.4 (789)	2.8 (193)
60+ minutes	4.6 (756)	6.6 (622)	1.9 (134)
Muscle-strengthening exercise – Weekly volume			
Own-bodyweight (minutes x frequency)			
None	86.2 (14,057)	82.1 (7,721)	91.8 (6,336)
Low < mean	10.3 (1,672)	13.5 (1,272)	5.8 (400)
High ≥ mean	3.5 (572)	4.4 (409)	2.4 (163)
Gym-based-strength (minutes x frequency)			
None	90.5 (14,757)	86.5 (8,129)	96.1 (6,627)
Low < mean	6.5 (1,062)	9.0 (842)	3.2 (220)
High ≥ mean	3.0 (482)	4.6 (430)	0.8 (52)
Total-MSE (minutes x frequency)			
None	81.5 (13,287)	75.6 (7,107)	89.6 (6,180)
Low < mean	13.4 (2,177)	17.1 (1,610)	8.2 (567)
High ≥ mean	5.1 (837)	7.3 (685)	2.2 (152)

MSE: muscle-strengthening exercise

Total-MSE = own-bodyweight exercise + gym-based-strength exercise

Mean values: own-bodyweight 76.1 min/week, gym-based-strength 99.4 min/week, total-MSE 107.6 min/week

Appendix-F– stratified by age

Analysis of the relationship between muscle-strengthening exercise (duration/session) between five chronic conditions and having one or two or more chronic conditions relative to two specific modes of muscle-strengthening exercise (total-MSE) combined (APRs; 95%CI).

Model D [d]	**Diabetes**	**Heart Condition**	**Respiratory Condition**	**Musculoskeletal Condition**	**Anxiety/ depression**	**1 Chronic Condition**	**≥2 Chronic Conditions**
Duration/session – total-MSE							
16-54 years							
0 minutes	1 (reference)	1 (reference)	1 (reference)	1 (reference)	1 (reference)	1 (reference)	1 (reference)
10-20 minutes	0.19 (0.05-0.49)*	0.61 (0.31-1.08)	0.77 (0.48-1.16)	0.51 (0.33-0.74)*	0.51 (0.33-0.74)*	0.71 (0.51-0.95)*	0.12 (0.03-0.32)*
21-59 minutes	0.47 (0.20-0.93)*	0.54 (0.26-1.00)	0.56 (0.32-0.92)*	0.44 (0.27-0.67)*	0.52 (0.33-0.77)*	0.66 (0.46-0.92)*	0.34 (0.14-0.66)*
60+ minutes	0.56 (0.22-1.16)	0.08 (0.00-0.37)*	0.57 (0.29-1.00)	0.49 (0.28-0.77)*	0.51 (0.30-0.81)*	0.67 (0.44-0.97)*	0.13 (0.02-0.41)*
55+ years							
0 minutes	1 (reference)	1 (reference)	1 (reference)	1 (reference)	1 (reference)	1 (reference)	1 (reference)
10-20 minutes	0.73 (0.46-1.10)	0.73 (0.53-1.00)*	0.66 (0.39-1.04)	0.82 (0.61-1.07)	0.70 (0.41-1.11)	0.90 (0.62-1.25)	0.66 (0.40-1.02)*
21-59 minutes	0.62 (0.30-1.13)	0.69 (0.41-1.06)	0.48 (0.19-0.99)	1.03 (0.71-1.44)	0.33 (0.10-0.78)*	0.70 (0.41-1.12)	0.19 (0.05-0.50)*
60+ minutes	0.33 (0.08-0.86)	0.73 (0.39-1.23)	0.90 (0.38-1.76)	0.77 (0.44-1.23)	0.16 (0.01-0.70)	1.15 (0.64-1.87)	0.16 (0.01-0.72)

MSE = muscle-strengthening exercise, APRs = adjusted prevalence ratios, CI = confidence interval

Total-MSE = own-bodyweight exercise + gym-based-strength exercise

* Result is significant i.e., <0.05

[d] Model adjusted for sociodemographic factors (sex, age groups in 10 years brackets, education, income tertiles) and Lifestyle factors (BMI, weekly alcohol consumption, smoking status, blood pressure medication, longstanding illness) and weekly aerobic-MVPA and weekly sedentary time

Appendix-G – stratified by age

Analysis of the relationship between muscle-strengthening exercise (volume/week) between five chronic conditions and having one or two or more chronic conditions relative to two specific modes of muscle-strengthening exercise (total-MSE) [e] combined (APRs; 95%CI).

Model D [d]	**Diabetes**	**Heart Condition**	**Respiratory Condition**	**Musculoskeletal Condition**	**Anxiety/ depression**	**1 Chronic Condition**	**≥2 Chronic Conditions**
Volume/week (frequency x duration)							
16-54 years							
None	1 (reference)	1 (reference)	1 (reference)	1 (reference)	1 (reference)	1 (reference)	1 (reference)
Low < mean	0.33 (0.16-0.61)*	0.60 (0.36-0.93)*	0.62 (0.42-0.88)*	0.51 (0.37-0.69)*	0.44 (0.31-0.60)*	0.67 (0.52-0.85)*	0.18 (0.08-0.35)*
High ≥ mean	0.51 (0.20-1.06)	0.08 (0.00-0.34)*	0.72 (0.41-1.16)	0.39 (0.22-0.64)*	0.70 (0.45-1.04)	0.72 (0.48-1.02)	0.25 (0.08-0.58)*
55+ years							
None	1 (reference)	1 (reference)	1 (reference)	1 (reference)	1 (reference)	1 (reference)	1 (reference)
Low < mean	0.61 (0.40-0.89)*	0.72 (0.54-0.93)*	0.74 (0.49-1.08)	0.86 (0.68-1.08)	0.55 (0.33-0.85)*	0.80 (0.59-1.07)	0.47 (0.29-0.72)*
High ≥ mean	0.72 (0.33-1.35)	0.74 (0.43-1.19)	0.31 (0.08-0.82)*	0.88 (0.55-1.31)	0.36 (0.09-0.93)	1.16 (0.70-1.79)	0.36 (0.09-0.93)

MSE = muscle-strengthening exercise, APRs = adjusted prevalence ratios, CI = confidence interval

Total-MSE = own-bodyweight exercise + gym-based-strength exercise

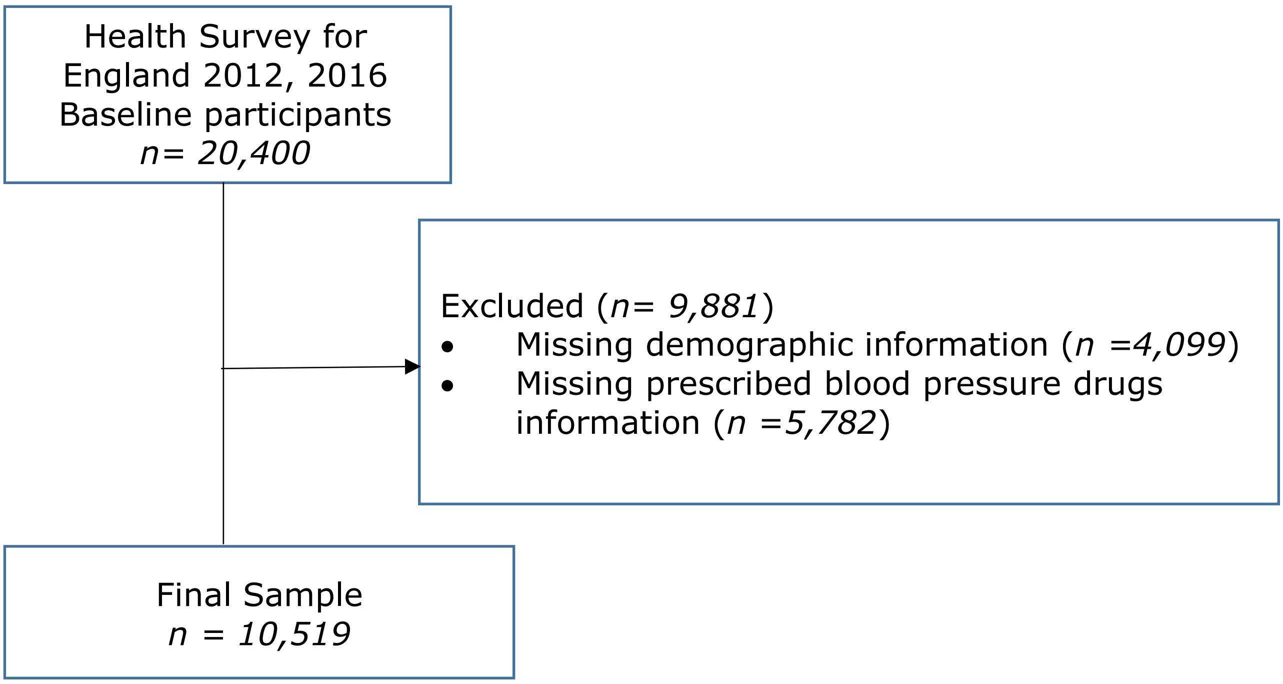
* Represents significance i.e., <0.05

[d] Model adjusted for sociodemographic factors (sex, age groups in 10 years brackets, education, income tertiles) and Lifestyle factors (BMI, weekly alcohol consumption, smoking status, blood pressure medication, longstanding illness) and weekly aerobic-MVPA and weekly sedentary time

[e] Mean value: own-bodyweight 76.1min/week, gym-based-strength 99.4 min/week, total-MSE 107.6 min/week [low = below the mean, high = above the mean]

APPENDIC C: STUDY 3

Supplemental Digital Content 1. Health Survey for England 2012 and 2016 participant flow diagram.



Supplemental Digital Content 2. Health Survey for England exercise show card E6

CARD E6

1 Swimming

2 Cycling

3 Workout at a gym/Exercise bike/Weight training

4 Aerobics/Keep fit/Gymnastics/ Dance for fitness

5 Any other type of dancing

6 Running/Jogging

7 Football/Rugby

8 Badminton/tennis

9 Squash

10 Exercises (e.g. press-up, sit-ups)

ActPhy/WhtAct

Supplemental Digital Content 3. Health Survey for England exercise show card E7

CARD E7

1 Strength work out at the gym using machines or free weights

2 Exercise Bike

3 Spinning Classes

4 Stepping machine, rowing machine or cross trainer

5 Treadmill running

WorkOut

Supplemental Digital Content 4. Analysis of the relationship between muscle-strengthening exercise (duration per session and volume per week) between hypertension according to two specific modes of muscle-strengthening exercise, and both modes combined (PRs; APRs; 95% CI).

Duration per session				
Own bodyweight exercises	Model A[a]	Model B[b]	Model C[c]	Model D[d]
0 minutes	1 (reference)	1 (reference)	1 (reference)	1 (reference)
10-20 minutes	0.80 (0.71-0.89)	0.80 (0.70-0.91)	0.78 (0.68-0.89)	0.78 (0.68-0.89)
21-59 minutes	0.78 (0.64-0.94)	0.78 (0.62-0.96)	0.76 (0.61-0.94)	0.75 (0.60-0.93)
60+ minutes	0.69 (0.52-0.89)	0.65 (0.48-0.87)	0.61 (0.43-0.83)	0.61 (0.43-0.83)
Gym-based strength exercises				
0 minutes	1 (reference)	1 (reference)	1 (reference)	1 (reference)
10-20 minutes	0.86 (0.72-1.01)	0.87 (0.72-1.04)	0.90 (0.74-1.08)	0.90 (0.74-1.08)
21-59 minutes	0.73 (0.60-0.89)	0.77 (0.62-0.94)	0.76 (0.61-0.93)	0.76 (0.61-0.93)
60+ minutes	0.70 (0.53-0.89)	0.65 (0.47-0.87)	0.66 (0.47-0.88)	0.66 (0.48-0.89)
All MSE				
0 minutes	1 (reference)	1 (reference)	1 (reference)	1 (reference)
10-20 minutes	0.83 (0.74-0.93)	0.85 (0.74-0.96)	0.83 (0.72-0.95)	0.83 (0.72-0.95)
21-59 minutes	0.77 (0.67-0.89)	0.78 (0.67-0.91)	0.78 (0.66-0.92)	0.78 (0.66-0.91)
60+ minutes	0.70 (0.59-0.83)	0.67 (0.55-0.82)	0.65 (0.52-0.79)	0.65 (0.52-0.79)
Volume per week (frequency x duration)				
Own bodyweight exercises [e]				
None	1 (reference)	1 (reference)	1 (reference)	1 (reference)
Low < mean	0.76 (0.68-0.84)	0.76 (0.67-0.85)	0.74 (0.65-0.84)	0.74 (0.64-0.84)
High ≥ mean	0.84 (0.70-1.00)	0.84 (0.69-1.01)	0.81 (0.65-0.98)	0.80 (0.65-0.98)
Gym-based strength exercises [e]				
None	1 (reference)	1 (reference)	1 (reference)	1 (reference)
Low < mean	0.82 (0.71-0.93)	0.82 (0.71-0.95)	0.84 (0.72-0.97)	0.84 (0.72-0.97)
High ≥ mean	0.69 (0.55-0.86)	0.71 (0.55-0.90)	0.70 (0.53-0.90)	0.70 (0.53-0.89)
All MSE [e]				
None	1 (reference)	1 (reference)	1 (reference)	1 (reference)
Low < mean	0.78 (0.71-0.86)	0.80 (0.72-0.89)	0.79 (0.70-0.88)	0.79 (0.70-0.88)
High ≥ mean	0.78 (0.66-0.90)	0.76 (0.63-0.91)	0.74 (0.61-0.89)	0.74 (0.61-0.88)

MSE = muscle-strengthening exercise, PRs = prevalence ratios, APRs = adjusted prevalence ratios, CI = confidence interval

[a] Unadjusted model (Model A)

[b] Model B - adjusted for sociodemographic factors (sex, age groups in 10 years brackets, education, income tertiles)

[c] Model C - adjusted for sociodemographic factors (sex, age groups in 10 years brackets, education, income tertiles) and lifestyle factors (BMI, weekly alcohol consumption, smoking status, blood pressure medication, longstanding illness)

[d] Model D adjusted for sociodemographic factors (sex, age groups in 10 years brackets, education, income tertiles) and lifestyle factors (BMI, weekly alcohol consumption, smoking status, blood pressure medication, longstanding illness) and weekly aerobic MVPA and weekly sedentary time

[e] mean value: own bodyweight 76.5 minutes/week, gym-based strength 96.3 minutes/week, all MSE 106.2 minutes/week [low = below the mean, high = above the mean]

Supplemental Digital Content 4.3 Analysis of the relationship between muscle-strengthening exercise (duration per session and volume per week) between hypertension (mean values for SBP and DBP) according to two specific modes of muscle-strengthening exercise, and both modes combined (SD).

Duration per session		
Own bodyweight exercises	Mean SBP mmHg (SD)	Mean DBP mmHg (SD)
0 minutes	126.99 (17.48)	73.21 (10.88)
10-20 minutes	123.55 (15.91)	71.41 (10.34)
21-59 minutes	123.57 (16.24)	71.46 (11.88)
60+ minutes	121.49 (13.43)	70.42 (9.99)
Gym-based strength exercises		
0 minutes	126.79 (17.49)	73.15 (10.79)
10-20 minutes	123.97 (15.40)	72.56 (11.28)
21-59 minutes	123.34 (14.83)	71.07 (11.32)
60+ minutes	121.80 (13.41)	67.54 (10.91)
All MSE		
0 minutes	127.19 (17.57)	73.31 (10.83)
10-20 minutes	123.86 (16.61)	72.09 (10.46)
21-59 minutes	123.41 (15.51)	71.89 (11.40)
60+ minutes	122.40 (13.82)	69.33 (10.81)
Volume per week (frequency x duration)		
Own bodyweight exercises [e]		
None	126.99 (17.48)	73.21 (10.88)
Low < mean	123.09 (15.71)	71.25 (10.47)
High ≥ mean	123.86 (15.63)	71.42 (11.25)
Gym-based strength exercises [e]		
None	126.79 (17.49)	73.15 (10.79)
Low < mean	123.57 (14.96)	72.05 (11.32)
High ≥ mean	122.53 (14.36)	68.17 (11.03)
All MSE [e]		
None	127.18 (17.57)	73.30 (10.83)
Low < mean	123.39 (15.80)	71.83 (10.69)
High ≥ mean	123.37 (15.24)	70.10 (11.38)

SBP = Systolic Blood Pressure

DBP = Diastolic Blood Pressure

MSE = muscle-strengthening exercise, SD = standard deviation

[e] mean value: own bodyweight 76.5 minutes/week, gym-based strength 96.3 minutes/week, all MSE 106.2 minutes/week [low = below the mean, high = above the mean]

Supplemental Digital Content 5. Adjusted Prevalence ratios (APR)[a] of hypertension[b] according to duration per session of all muscle-strengthening exercise (MSE) among Health Survey for England (2012-2016): stratified by sex, age, body mass index, smoking, long standing illness, and aerobic physical activity level.

	Hypertension[b]	
	Sex	
	Males	**Females**
All MSE	APR[c] (95% CI)	APR[c] (95% CI)
0 minutes	1 (reference)	1 (reference)
10-20 minutes	0.92 (0.76-1.09)	0.72 (0.58-0.88)
21-59 minutes	0.83 (0.68-1.02)	0.65 (0.49-0.84)
60+ minutes	0.64 (0.49-0.82)	0.58 (0.40-0.82)
	Age	
	16-54 years	**≥55 years**
All MSE	APR[d] (95% CI)	APR[d] (95% CI)
0 minutes	1 (reference)	1 (reference)
10-20 minutes	0.80 (0.65-0.98)	0.98 (0.82-1.17)
21-59 minutes	0.90 (0.72-1.10)	0.92 (0.70-1.19)
60+ minutes	0.77 (0.59-0.99)	0.76 (0.52-1.07)
	Body Mass Index (kg/m²)	
	≤ 24.99 (underweight/normal)	**≥25.0 (overweight/obese)**
All MSE	APR[e] (95% CI)	APR[e] (95% CI)
0 minutes	1 (reference)	1 (reference)
10-20 minutes	0.70 (0.53-0.91)	0.99 (0.84-1.15)
21-59 minutes	0.64 (0.45-0.88)	0.89 (0.74-1.07)
60+ minutes	0.63 (0.42-0.89)	0.73 (0.56-0.94)
	Smoking	
	Never smoked [i]	**Current smoker**
All MSE	APR[f] (95% CI)	APR[f] (95% CI)
0 minutes	1 (reference)	1 (reference)
10-20 minutes	0.84 (0.70-1.01)	0.57 (0.31-0.96)
21-59 minutes	0.82 (0.65-1.01)	0.72 (0.39-1.20)
60+ minutes	0.62 (0.46-0.82)	0.69 (0.33-1.27)
	Longstanding illness	
	No	**Yes**
All MSE	APR[g] (95% CI)	APR[g] (95% CI)
0 minutes	1 (reference)	1 (reference)

10-20 minutes	0.87 (0.74-1.01)	0.74 (0.51-1.03)
21-59 minutes	0.80 (0.67-0.96)	0.73 (0.48-1.08)
60+ minutes	0.61 (0.47-0.76)	1.05 (0.63-1.63)

	Aerobic physical activity level	
	Insufficiently active (0-149 MVPA minutes/week)	**Sufficiently active (≥150 MVPA minutes/week)**
All MSE	APR[h] (95% CI)	APR[h] (95% CI)
0 minutes	1 (reference)	1 (reference)
10-20 minutes	0.84 (0.60-1.14)	0.87 (0.74-1.01)
21-59 minutes	0.74 (0.36-1.35)	0.82 (0.69-0.97)
60+ minutes	0.66 (0.24-1.42)	0.68 (0.54-0.84)

[a] PR calculated using Poisson regression with a robust error variance.

[b] To be classified as having hypertension, a respondent had to have clinically assessed blood pressure of SBP ≥130mmHg or DBP ≥80mmHg.

[c] Adjusted for age, education, income, BMI, weekly alcohol consumption, smoking, prescription medication for blood pressure, longstanding illness, aerobic moderate-to-vigorous physical activity and weekly sedentary behaviour.

[d] Adjusted for sex, education, income, BMI, weekly alcohol consumption, smoking, prescription medication for blood pressure, longstanding illness, aerobic moderate-to-vigorous physical activity and weekly sedentary behaviour.

[e] Adjusted for sex, age, education, income, weekly alcohol consumption, smoking, prescription medication for blood pressure, longstanding illness, aerobic moderate-to-vigorous physical activity and weekly sedentary behaviour.

[f] Adjusted for sex, age, education, income, BMI, weekly alcohol consumption, prescription medication for blood pressure, longstanding illness, aerobic moderate-to-vigorous physical activity and weekly sedentary behaviour.

[g] Adjusted for sex, age, education, income, BMI, weekly alcohol consumption, smoking, prescription medication for blood pressure, aerobic moderate-to-vigorous physical activity and weekly sedentary behaviour.

[h] Adjusted for sex, age, education, income, BMI, weekly alcohol consumption, smoking, prescription medication for blood pressure, longstanding illness and weekly sedentary behaviour.

[i] excludes ex-smokers

Supplemental Digital Content 5.1 Adjusted Prevalence ratios (APR)[a] of hypertension[b] according to duration per session of all muscle-strengthening exercise (MSE) among Health Survey for England (2012-2016): stratified by sex, age, body mass index, smoking, long standing illness, and aerobic physical activity level.

	Hypertension[b]	
	European classification	
	Sex[c]	
	Males	**Females**
All MSE	APR[c] (95% CI)	APR[c] (95% CI)
0 minutes	1 (reference)	1 (reference)
10-20 minutes	0.91 (0.70-1.16)	0.67 (0.48-0.90)
21-59 minutes	0.55 (0.38-0.77)	0.60 (0.39-0.88)
60+ minutes	0.47 (0.30-0.70)	0.28 (0.12-0.54)
	Age[d]	
	16-54 years	**≥55 years**
All MSE	APR[d] (95% CI)	APR[d] (95% CI)
0 minutes	1 (reference)	1 (reference)
10-20 minutes	0.66 (0.44-0.94)	1.06 (0.83-1.33)
21-59 minutes	0.62 (0.40-0.91)	0.92 (0.63-1.29)
60+ minutes	0.54 (0.31-0.86)	0.59 (0.33-0.98)
	Body Mass Index (kg/m^2)[e]	
	≤ 24.99 (underweight/normal)	**≥25.0 (overweight/obese)**
All MSE	APR[e] (95% CI)	APR[e] (95% CI)
0 minutes	1 (reference)	1 (reference)
10-20 minutes	0.55 (0.34-0.82)	1.02 (0.81-1.27)
21-59 minutes	0.41 (0.21-0.71)	0.71 (0.52-0.94)
60+ minutes	0.42 (0.20-0.76)	0.48 (0.30-0.73)
	Smoking[f]	
	Never smoked [i]	**Current smoker**
All MSE	APR[f] (95% CI)	APR[f] (95% CI)
0 minutes	1 (reference)	1 (reference)
10-20 minutes	0.85 (0.65-1.10)	0.60 (0.25-1.18)
21-59 minutes	0.57 (0.38-0.82)	0.54 (0.19-1.17)
60+ minutes	0.41 (0.24-0.65)	0.30 (0.05-0.94)
	Longstanding illness[g]	
	No	**Yes**
All MSE	APR[g] (95% CI)	APR[g] (95% CI)

0 minutes	1 (reference)	1 (reference)
10-20 minutes	0.85 (0.68-1.05)	0.74 (0.45-1.16)
21-59 minutes	0.57 (0.41-0.76)	0.79 (0.44-1.29)
60+ minutes	0.37 (0.23-0.56)	0.86 (0.39-1.62)
	Aerobic physical activity level[h]	
	Insufficiently active (0-149 MVPA minutes/week)	**Sufficiently active (≥150 MVPA minutes/week)**
All MSE	APR[h] (95% CI)	APR[h] (95% CI)
0 minutes	1 (reference)	1 (reference)
10-20 minutes	0.96 (0.61-1.42)	0.84 (0.67-1.05)
21-59 minutes	0.31 (0.05-0.97)	0.68 (0.51-0.89)
60+ minutes	0.25 (0.01-1.10)	0.49 (0.33-0.70)

[a] APR calculated using Poisson regression with a robust error variance.

[b] To be classified as having hypertension, a respondent had to have clinically assessed blood pressure of SBP ≥140mmHg or DBP ≥90mmHg (Defined in 2018 ESC/ESH Guidelines for the management of arterial hypertension: The task force for the management of arterial hypertension of the European Society of Cardiology (ESC) and the European Society of Hypertension (ESH)).

[c] Adjusted for age, education, income, BMI, weekly alcohol consumption, smoking, prescription medication for blood pressure, longstanding illness, aerobic moderate-to-vigorous physical activity and weekly sedentary behaviour.

[d] Adjusted for sex, education, income, BMI, weekly alcohol consumption, smoking, prescription medication for blood pressure, longstanding illness, aerobic moderate-to-vigorous physical activity and weekly sedentary behaviour.

[e] Adjusted for sex, age, education, income, weekly alcohol consumption, smoking, prescription medication for blood pressure, longstanding illness, aerobic moderate-to-vigorous physical activity and weekly sedentary behaviour.

[f] Adjusted for sex, age, education, income, BMI, weekly alcohol consumption, prescription medication for blood pressure, longstanding illness, aerobic moderate-to-vigorous physical activity and weekly sedentary behaviour.

[g] Adjusted for sex, age, education, income, BMI, weekly alcohol consumption, smoking, prescription medication for blood pressure, aerobic moderate-to-vigorous physical activity and weekly sedentary behaviour.

[h] Adjusted for sex, age, education, income, BMI, weekly alcohol consumption, smoking, prescription medication for blood pressure, longstanding illness and weekly sedentary behaviour.

[i] excludes ex-smokers

Supplemental Digital Content 5.2 Adjusted Prevalence ratios (APR)[a] of hypertension[b] and hypertension[j] according to duration per session of all muscle-strengthening exercise (MSE) among Health Survey for England (2012-2016): stratified by sex, age, body mass index, smoking, long standing illness, and aerobic physical activity level.

	Sex			
	Males		**Females**	
	Hypertension[b]	**Hypertension[j]**	**Hypertension[b]**	**Hypertension[j]**
	US classification	**European classification**	**US classification**	**European classification**
All MSE	APR[c] (95% CI)	APR[c] (95% CI)	APR[c] (95% CI)	APR[c] (95% CI)
0 minutes	1 (reference)	1 (reference)	1 (reference)	1 (reference)
10-20 minutes	0.92 (0.76-1.09)	0.91 (0.70-1.16)	0.72 (0.58-0.88)	0.67 (0.48-0.90)
21-59 minutes	0.83 (0.68-1.02)	0.55 (0.38-0.77)	0.65 (0.49-0.84)	0.60 (0.39-0.88)
60+ minutes	0.64 (0.49-0.82)	0.47 (0.30-0.70)	0.58 (0.40-0.82)	0.28 (0.12-0.54)
	Age			
	16-54 years		**≥55 years**	
All MSE	APR[d] (95% CI)	APR[d] (95% CI)	APR[d] (95% CI)	APR[d] (95% CI)
0 minutes	1 (reference)	1 (reference)	1 (reference)	1 (reference)
10-20 minutes	0.80 (0.65-0.98)	0.66 (0.44-0.94)	0.98 (0.82-1.17)	1.06 (0.83-1.33)
21-59 minutes	0.90 (0.72-1.10)	0.62 (0.40-0.91)	0.92 (0.70-1.19)	0.92 (0.63-1.29)
60+ minutes	0.77 (0.59-0.99)	0.54 (0.31-0.86)	0.76 (0.52-1.07)	0.59 (0.33-0.98)
	Body Mass Index (kg/m^2)			
	≤ 24.99 (underweight/normal)		**≥25.0 (overweight/obese)**	
All MSE	APR[e] (95% CI)	APR[e] (95% CI)	APR[e] (95% CI)	APR[e] (95% CI)
0 minutes	1 (reference)	1 (reference)	1 (reference)	1 (reference)
10-20 minutes	0.70 (0.53-0.91)	0.55 (0.34-0.82)	0.99 (0.84-1.15)	1.02 (0.81-1.27)
21-59 minutes	0.64 (0.45-0.88)	0.41 (0.21-0.71)	0.89 (0.74-1.07)	0.71 (0.52-0.94)
60+ minutes	0.63 (0.42-0.89)	0.42 (0.20-0.76)	0.73 (0.56-0.94)	0.48 (0.30-0.73)
	Smoking			
	Never smoked [i]		**Current smoker**	
All MSE	APR[f] (95% CI)	APR[f] (95% CI)	APR[f] (95% CI)	APR[f] (95% CI)
0 minutes	1 (reference)	1 (reference)	1 (reference)	1 (reference)
10-20 minutes	0.84 (0.70-1.01)	0.85 (0.65-1.10)	0.57 (0.31-0.96)	0.60 (0.25-1.18)
21-59 minutes	0.82 (0.65-1.01)	0.57 (0.38-0.82)	0.72 (0.39-1.20)	0.54 (0.19-1.17)
60+ minutes	0.62 (0.46-0.82)	0.41 (0.24-0.65)	0.69 (0.33-1.27)	0.30 (0.05-0.94)
	Longstanding illness			
	No		**Yes**	

All MSE	APR[g] (95% CI)	APR[g] (95% CI)	APR[g] (95% CI)	APR[g] (95% CI)
0 minutes	1 (reference)	1 (reference)	1 (reference)	1 (reference)
10-20 minutes	0.87 (0.74-1.01)	0.85 (0.68-1.05)	0.74 (0.51-1.03)	0.74 (0.45-1.16)
21-59 minutes	0.80 (0.67-0.96)	0.57 (0.41-0.76)	0.73 (0.48-1.08)	0.79 (0.44-1.29)
60+ minutes	0.61 (0.47-0.76)	0.37 (0.23-0.56)	1.05 (0.63-1.63)	0.86 (0.39-1.62)
	Aerobic physical activity level			
	Insufficiently active (0-149 MVPA minutes/week)		**Sufficiently active (≥150 MVPA minutes/week)**	
All MSE	APR[h] (95% CI)	APR[h] (95% CI)	APR[h] (95% CI)	APR[h] (95% CI)
0 minutes	1 (reference)	1 (reference)	1 (reference)	1 (reference)
10-20 minutes	0.84 (0.60-1.14)	0.96 (0.61-1.42)	0.87 (0.74-1.01)	0.84 (0.67-1.05)
21-59 minutes	0.74 (0.36-1.35)	0.31 (0.05-0.97)	0.82 (0.69-0.97)	0.68 (0.51-0.89)
60+ minutes	0.66 (0.24-1.42)	0.25 (0.01-1.10)	0.68 (0.54-0.84)	0.49 (0.33-0.70)

[a] APR calculated using Poisson regression with a robust error variance.

[b] To be classified as having hypertension, a respondent had to have clinically assessed blood pressure of SBP ≥130mmHg or DBP ≥80mmHg (Defined in 2017 ACC/AHA/AAPA/ABC/ACPM/AGS/APhA/ASH/ASPC/NMA/PCNA guideline for the prevention, detection, evaluation, and management of high blood pressure in adults: A report of the American college of cardiology/American heart association task force on clinical practice guidelines).

[c] Adjusted for age, education, income, BMI, weekly alcohol consumption, smoking, prescription medication for blood pressure, longstanding illness, aerobic moderate-to-vigorous physical activity, and weekly sedentary behaviour.

[d] Adjusted for sex, education, income, BMI, weekly alcohol consumption, smoking, prescription medication for blood pressure, longstanding illness, aerobic moderate-to-vigorous physical activity, and weekly sedentary behaviour.

[e] Adjusted for sex, age, education, income, weekly alcohol consumption, smoking, prescription medication for blood pressure, longstanding illness, aerobic moderate-to-vigorous physical activity, and weekly sedentary behaviour.

[f] Adjusted for sex, age, education, income, BMI, weekly alcohol consumption, prescription medication for blood pressure, longstanding illness, aerobic moderate-to-vigorous physical activity, and weekly sedentary behaviour.

[g] Adjusted for sex, age, education, income, BMI, weekly alcohol consumption, smoking, prescription medication for blood pressure, aerobic moderate-to-vigorous physical activity, and weekly sedentary behaviour.

[h] Adjusted for sex, age, education, income, BMI, weekly alcohol consumption, smoking, prescription medication for blood pressure, longstanding illness, and weekly sedentary behaviour.

[i] excludes ex-smokers

[j] To be classified as having hypertension, a respondent had to have clinically assessed blood pressure of SBP ≥140mmHg or DBP ≥90mmHg (Defined in 2018 ESC/ESH Guidelines for the management of arterial hypertension: The task force for the management of arterial hypertension of the European Society of Cardiology (ESC) and the European Society of Hypertension (ESH)).

Supplemental Digital Content 6. Adjusted Prevalence ratios (APR)[a] of hypertension[b] according to volume per week (frequency x duration) of all muscle-strengthening exercise (MSE) among Health Survey for England (2012-2016): stratified by sex, age, body mass index, smoking, long standing illness, and aerobic physical activity level.

	Hypertension[b]	
	Sex	
	Males	**Females**
All MSE [j]	APR[c] (95% CI)	APR[c] (95% CI)
None	1 (reference)	1 (reference)
Low < mean	0.85 (0.74-0.99)	0.69 (0.58-0.82)
High ≥ mean	0.74 (0.59-0.92)	0.59 (0.40-0.83)
	Age	
	16-54 years	**≥55 years**
All MSE [j]	APR[d] (95% CI)	APR[d] (95% CI)
None	1 (reference)	1 (reference)
Low < mean	0.84 (0.72-0.99)	0.92 (0.78-1.07)
High ≥ mean	0.79 (0.61-1.01)	0.97 (0.72-1.27)
	Body Mass Index (kg/m^2)	
	≤ 24.99 (underweight/normal)	**≥25.0 (overweight/obese)**
All MSE [j]	APR[e] (95% CI)	APR[e] (95% CI)
None	1 (reference)	1 (reference)
Low < mean	0.63 (0.50-0.79)	0.94 (0.82-1.06)
High ≥ mean	0.76 (0.54-1.04)	0.80 (0.63-0.99)
	Smoking	
	Never smoked [i]	**Current smoker**
All MSE [j]	APR[f] (95% CI)	APR[f] (95% CI)
None	1 (reference)	1 (reference)
Low < mean	0.78 (0.67-0.91)	0.72 (0.47-1.05)
High ≥ mean	0.79 (0.61-1.01)	0.51 (0.24-0.93)
	Longstanding illness	
	No	**Yes**
All MSE [j]	APR[g] (95% CI)	APR[g] (95% CI)
None	1 (reference)	1 (reference)
Low < mean	0.81 (0.71-0.91)	0.76 (0.57-0.99)
High ≥ mean	0.72 (0.59-0.89)	0.92 (0.56-1.40)
	Aerobic physical activity level	
	Insufficiently active	**Sufficiently active**

	(0-149 MVPA minutes/week)	(≥150 MVPA minutes/week)
All MSE [j]	APR[h] (95% CI)	APR[h] (95% CI)
None	1 (reference)	1 (reference)
Low < mean	0.78 (0.57-1.03)	0.82 (0.73-0.93)
High ≥ mean	1.10 (0.39-2.37)	0.76 (0.62-0.92)

[a] PR calculated using Poisson regression with a robust error variance.

[b] To be classified as having hypertension, a respondent had to have clinically assessed blood pressure of SBP ≥130mmHg or DBP ≥80mmHg.

[c] Adjusted for age, education, income, BMI, weekly alcohol consumption, smoking, prescription medication for blood pressure, longstanding illness, aerobic moderate-to-vigorous physical activity and weekly sedentary behaviour.

[d] Adjusted for sex, education, income, BMI, weekly alcohol consumption, smoking, prescription medication for blood pressure, longstanding illness, aerobic moderate-to-vigorous physical activity and weekly sedentary behaviour.

[e] Adjusted for sex, age, education, income, weekly alcohol consumption, smoking, prescription medication for blood pressure, longstanding illness, aerobic moderate-to-vigorous physical activity and weekly sedentary behaviour.

[f] Adjusted for sex, age, education, income, BMI, weekly alcohol consumption, prescription medication for blood pressure, longstanding illness, aerobic moderate-to-vigorous physical activity and weekly sedentary behaviour.

[g] Adjusted for sex, age, education, income, BMI, weekly alcohol consumption, smoking, prescription medication for blood pressure, aerobic moderate-to-vigorous physical activity and weekly sedentary behaviour.

[h] Adjusted for sex, age, education, income, BMI, weekly alcohol consumption, smoking, prescription medication for blood pressure, longstanding illness and weekly sedentary behaviour.

[i] excludes ex-smokers

[j] Mean value 106.2 minutes/week

Supplemental Digital Content 6.1 Adjusted Prevalence ratios (APR)[a] of hypertension[b] according to volume per week (frequency x duration) of all muscle-strengthening exercise (MSE) among Health Survey for England (2012-2016): stratified by sex, age, body mass index, smoking, long standing illness, and aerobic physical activity level.

	Hypertension[b]	
	European classification	
	Sex[c]	
	Males	**Females**
All MSE [j]	APR[c] (95% CI)	APR[c] (95% CI)
None	1 (reference)	1 (reference)
Low < mean	0.72 (0.57-0.89)	0.59 (0.45-0.76)
High ≥ mean	0.59 (0.40-0.82)	0.49 (0.26-0.82)
	Age[d]	
	16-54 years	**≥55 years**
All MSE [j]	APR[d] (95% CI)	APR[d] (95% CI)
None	1 (reference)	1 (reference)
Low < mean	0.61 (0.45-0.81)	0.95 (0.77-1.17)
High ≥ mean	0.63 (0.39-0.96)	0.91 (0.60-1.32)
	Body Mass Index (kg/m^2)[e]	
	≤ 24.99 (underweight/normal)	**≥25.0 (overweight/obese)**
All MSE [j]	APR[e] (95% CI)	APR[e] (95% CI)
None	1 (reference)	1 (reference)
Low < mean	0.44 (0.30-0.64)	0.84 (0.69-1.01)
High ≥ mean	0.56 (0.30-0.94)	0.67 (0.46-0.94)
	Smoking[f]	
	Never smoked [i]	**Current smoker**
All MSE [j]	APR[f] (95% CI)	APR[f] (95% CI)
None	1 (reference)	1 (reference)
Low < mean	0.65 (0.51-0.82)	0.59 (0.30-1.04)
High ≥ mean	0.69 (0.46-0.99)	0.33 (0.08-0.87)
	Longstanding illness[g]	
	No	**Yes**
All MSE [j]	APR[g] (95% CI)	APR[g] (95% CI)
None	1 (reference)	1 (reference)
Low < mean	0.68 (0.56-0.82)	0.73 (0.49-1.04)
High ≥ mean	0.55 (0.38-0.76)	0.98 (0.50-1.69)
	Aerobic physical activity level[h]	

	Insufficiently active (0-149 MVPA minutes/week)	Sufficiently active (≥150 MVPA minutes/week)
All MSE [j]	APR[h] (95% CI)	APR[h] (95% CI)
None	1 (reference)	1 (reference)
Low < mean	0.72 (0.46-1.06)	0.73 (0.60-0.88)
High ≥ mean	1.25 (0.31-3.25)	0.64 (0.46-0.86)

[a] APR calculated using Poisson regression with a robust error variance.

[b] To be classified as having hypertension, a respondent had to have clinically assessed blood pressure of SBP ≥140mmHg or DBP ≥90mmHg (Defined in 2018 ESC/ESH Guidelines for the management of arterial hypertension: The task force for the management of arterial hypertension of the European Society of Cardiology (ESC) and the European Society of Hypertension (ESH)).

[c] Adjusted for age, education, income, BMI, weekly alcohol consumption, smoking, prescription medication for blood pressure, longstanding illness, aerobic moderate-to-vigorous physical activity and weekly sedentary behaviour.

[d] Adjusted for sex, education, income, BMI, weekly alcohol consumption, smoking, prescription medication for blood pressure, longstanding illness, aerobic moderate-to-vigorous physical activity and weekly sedentary behaviour.

[e] Adjusted for sex, age, education, income, weekly alcohol consumption, smoking, prescription medication for blood pressure, longstanding illness, aerobic moderate-to-vigorous physical activity and weekly sedentary behaviour.

[f] Adjusted for sex, age, education, income, BMI, weekly alcohol consumption, prescription medication for blood pressure, longstanding illness, aerobic moderate-to-vigorous physical activity and weekly sedentary behaviour.

[g] Adjusted for sex, age, education, income, BMI, weekly alcohol consumption, smoking, prescription medication for blood pressure, aerobic moderate-to-vigorous physical activity and weekly sedentary behaviour.

[h] Adjusted for sex, age, education, income, BMI, weekly alcohol consumption, smoking, prescription medication for blood pressure, longstanding illness and weekly sedentary behaviour.

[i] excludes ex-smokers

[j] Mean value 106.2 minutes/week

Supplemental Digital Content 6.2 Adjusted Prevalence ratios (APR)[a] of hypertension[b] and hypertension[k] according to volume per week (frequency x duration) of all muscle-strengthening exercise (MSE) among Health Survey for England (2012-2016): stratified by sex, age, body mass index, smoking, long standing illness, and aerobic physical activity level.

	Sex			
	Males		**Females**	
	Hypertension[b]	**Hypertension[k]**	**Hypertension[b]**	**Hypertension[k]**
	US classification	**European Classification**	**US classification**	**European Classification**
All MSE [j]	APR[c] (95% CI)	APR[c] (95% CI)	APR[c] (95% CI)	APR[c] (95% CI)
None	1 (reference)	1 (reference)	1 (reference)	1 (reference)
Low < mean	0.85 (0.74-0.99)	0.72 (0.57-0.89)	0.69 (0.58-0.82)	0.59 (0.45-0.76)
High ≥ mean	0.74 (0.59-0.92)	0.59 (0.40-0.82)	0.59 (0.40-0.83)	0.49 (0.26-0.82)
	Age			
	16-54 years		**≥55 years**	
All MSE [j]	APR[d] (95% CI)	APR[d] (95% CI)	APR[d] (95% CI)	APR[d] (95% CI)
None	1 (reference)	1 (reference)	1 (reference)	1 (reference)
Low < mean	0.84 (0.72-0.99)	0.61 (0.45-0.81)	0.92 (0.78-1.07)	0.95 (0.77-1.17)
High ≥ mean	0.79 (0.61-1.01)	0.63 (0.39-0.96)	0.97 (0.72-1.27)	0.91 (0.60-1.32)
	Body Mass Index (kg/m^2)			
	≤ 24.99 (underweight/normal)		**≥25.0 (overweight/obese)**	
All MSE [j]	APR[e] (95% CI)	APR[e] (95% CI)	APR[e] (95% CI)	APR[e] (95% CI)
None	1 (reference)	1 (reference)	1 (reference)	1 (reference)
Low < mean	0.63 (0.50-0.79)	0.44 (0.30-0.64)	0.94 (0.82-1.06)	0.84 (0.69-1.01)
High ≥ mean	0.76 (0.54-1.04)	0.56 (0.30-0.94)	0.80 (0.63-0.99)	0.67 (0.46-0.94)
	Smoking			
	Never smoked [i]		**Current smoker**	
All MSE [j]	APR[f] (95% CI)	APR[f] (95% CI)	APR[f] (95% CI)	APR[f] (95% CI)
None	1 (reference)	1 (reference)	1 (reference)	1 (reference)
Low < mean	0.78 (0.67-0.91)	0.65 (0.51-0.82)	0.72 (0.47-1.05)	0.59 (0.30-1.04)
High ≥ mean	0.79 (0.61-1.01)	0.69 (0.46-0.99)	0.51 (0.24-0.93)	0.33 (0.08-0.87)
	Longstanding illness			
	No		**Yes**	
All MSE [j]	APR[g] (95% CI)	APR[g] (95% CI)	APR[g] (95% CI)	APR[g] (95% CI)
None	1 (reference)	1 (reference)	1 (reference)	1 (reference)
Low < mean	0.81 (0.71-0.91)	0.68 (0.56-0.82)	0.76 (0.57-0.99)	0.73 (0.49-1.04)
High ≥ mean	0.72 (0.59-0.89)	0.55 (0.38-0.76)	0.92 (0.56-1.40)	0.98 (0.50-1.69)

	Aerobic physical activity level			
	Insufficiently active (0-149 MVPA minutes/week)		**Sufficiently active (≥150 MVPA minutes/week)**	
All MSE [j]	APR[h] (95% CI)	APR[h] (95% CI)	APR[h] (95% CI)	APR[h] (95% CI)
None	1 (reference)	1 (reference)	1 (reference)	1 (reference)
Low < mean	0.78 (0.57-1.03)	0.72 (0.46-1.06)	0.82 (0.73-0.93)	0.73 (0.60-0.88)
High ≥ mean	1.10 (0.39-2.37)	1.25 (0.31-3.25)	0.76 (0.62-0.92)	0.64 (0.46-0.86)

[a] APR calculated using Poisson regression with a robust error variance.

[b] To be classified as having hypertension, a respondent had to have clinically assessed blood pressure of SBP ≥130mmHg or DBP ≥80mmHg (Defined in 2017 ACC/AHA/AAPA/ABC/ACPM/AGS/APhA/ASH/ASPC/NMA/PCNA guideline for the prevention, detection, evaluation, and management of high blood pressure in adults: A report of the American college of cardiology/American heart association task force on clinical practice guidelines).

[c] Adjusted for age, education, income, BMI, weekly alcohol consumption, smoking, prescription medication for blood pressure, longstanding illness, aerobic moderate-to-vigorous physical activity, and weekly sedentary behaviour.

[d] Adjusted for sex, education, income, BMI, weekly alcohol consumption, smoking, prescription medication for blood pressure, longstanding illness, aerobic moderate-to-vigorous physical activity, and weekly sedentary behaviour.

[e] Adjusted for sex, age, education, income, weekly alcohol consumption, smoking, prescription medication for blood pressure, longstanding illness, aerobic moderate-to-vigorous physical activity, and weekly sedentary behaviour.

[f] Adjusted for sex, age, education, income, BMI, weekly alcohol consumption, prescription medication for blood pressure, longstanding illness, aerobic moderate-to-vigorous physical activity, and weekly sedentary behaviour.

[g] Adjusted for sex, age, education, income, BMI, weekly alcohol consumption, smoking, prescription medication for blood pressure, aerobic moderate-to-vigorous physical activity, and weekly sedentary behaviour.

[h] Adjusted for sex, age, education, income, BMI, weekly alcohol consumption, smoking, prescription medication for blood pressure, longstanding illness, and weekly sedentary behaviour.

[i] excludes ex-smokers

[j] Mean value 106.2 minutes/week

[k] To be classified as having hypertension, a respondent had to have clinically assessed blood pressure of SBP ≥140mmHg or DBP ≥90mmHg (Defined in 2018 ESC/ESH Guidelines for the management of arterial hypertension: The task force for the management of arterial hypertension of the European Society of Cardiology (ESC) and the European Society of Hypertension (ESH)).

APPENDIX D: STUDY 4

Supplemental Digital Content 1

Preamble:
The next questions are about your participation in muscle-strengthening exercise

The questions within this section relate to the physical activities that you perform during your leisure-time only. When we say leisure time we mean your free time and the activities that you perform that are NOT done as part of your work/job, transportation (moving to a different location), or as a part of household activities (chores).

The types of muscle-strengthening exercise modes that we are interested in include;

- Use of weight machines (typically in a gym or fitness centre)
- Bodyweight exercises (including push-ups, sit-ups)
- Resistance exercises (using resistance bands or free weights like dumbbells)
- Holistic exercises (including Yoga, Tai-Chi and Pilates)

There are no right or wrong responses to the following questions, we are interested in your open and honest feedback.

1. Do you usually do muscle-strengthening exercise?

The types of muscle-strengthening exercises include;

Using of weight machines to do e.g. leg press, chest press, lat pulldown (typically in a gym or fitness centre) Body weight exercises (including push-ups, sit-ups) Resistance exercises (using resistance bands or free weights like dumbbells) Holistic exercises (including Yoga, Tai-Chi and Pilates)

Yes ☐

No ☐

2. How many days, in a usual week, do you do muscle-strengthening exercise?

The types of muscle-strengthening exercises include;

Using of weight machines to do e.g. leg press, chest press, lat pulldown (typically in a gym or fitness centre environment) Body weight exercises (including push-ups, sit-ups) Resistance exercises (using resistance bands or free weight like dumbbells) Holistic exercises (including Yoga, Tai-Chi and Pilates)

none ☐

1 day in a usual week ☐

2 days in a usual week ☐

3 days in a usual week ☐

4 days in a usual week ☐

5 days in a usual week ☐

6 days in a usual week ☐

7 days in a usual week ☐

3.

In a usual week please indicate a) <u>how often</u> you do, and b) <u>how long you spend</u>, doing each of the following types of muscle-strengthening exercise.

Number of DAYS in a usual week.

	0 days	1 day	2 days	3 days	4 days	5 days	6 days	7 days
Use weight machines (e.g. leg press, chest press, lat pulldown)	☐	☐	☐	☐	☐	☐	☐	☐
Body weight exercises (e.g. push-ups, sit-ups)	☐	☐	☐	☐	☐	☐	☐	☐
Use resistance bands or free weights (e.g. dumbbells)	☐	☐	☐	☐	☐	☐	☐	☐
Holistic exercises (including Yoga, Tai-chi and Pilates)	☐	☐	☐	☐	☐	☐	☐	☐

4.

In a usual week please indicate a) <u>how often</u> you do, and b) <u>how long you spend</u>, doing each of the following types of muscle-strengthening exercise.

Minutes spent in a usual session.

	0 minutes	less than 10 minutes	10 - 20 minutes	21 - 30 minutes	31 - 40 minutes	41 - 50 minutes	51 - 60 minutes	more than 60 minutes
Use weight machines (e.g. leg press, chest press, lat pulldown)	☐	☐	☐	☐	☐	☐	☐	☐
Body weight exercises (e.g. push-ups, sit-ups)	☐	☐	☐	☐	☐	☐	☐	☐
Use resistance bands or free weights (e.g. dumbbells)	☐	☐	☐	☐	☐	☐	☐	☐
Holistic exercises (including Yoga, Tai-	☐	☐	☐	☐	☐	☐	☐	☐

5.

In a usual week please indicate which muscle groups you use when you do each of the following types of muscle-strengthening exercises.

If you <u>do not do</u> the muscle-strengthening exercise, please select NO.

Using WEIGHT MACHINES in a usual session.

	No	Yes
Legs (e.g. squats, lunges, bridges)	☐	☐
Hips (e.g. side leg raises, bridges)	☐	☐
Back (e.g. lat pulldown, bent-over row)	☐	☐
Abdomen (e.g. crunches, sit-ups)	☐	☐
Chest (e.g. bench press, push-ups)	☐	☐
Shoulders (e.g. lat raise, overhead press)	☐	☐
Arms (e.g. bicep curl, tricep dips)	☐	☐

6.

In a usual week please indicate which muscle groups you use when you do each of the following types of muscle-strengthening exercises.

If you <u>do not do</u> the muscle-strengthening exercise, please select NO.

Doing BODY WEIGHT exercises (e.g. push-ups, sit-ups) in a usual session.

	No	Yes
Legs (e.g. squats, lunges, bridges)	☐	☐
Hips (e.g. side leg raises, bridges)	☐	☐
Back (e.g. lat pulldown, bent-over row)	☐	☐
Abdomen (e.g. crunches, sit-ups)	☐	☐
Chest (e.g. bench press, push-ups)	☐	☐
Shoulders (e.g. lat raise, overhead press)	☐	☐
Arms (e.g. bicep curl, tricep dips)	☐	☐

7.

In a usual week please indicate which muscle groups you use when you do each of the following types of muscle-strengthening exercises.

If you <u>do not do</u> the muscle-strengthening exercise, please select NO.

Using RESISTANCE BANDS or FREE WEIGHTS (e.g. dumbbells) in a usual session.

	No	Yes
Legs (e.g. squats, lunges, bridges)	☐	☐
Hips (e.g. side leg raises, bridges)	☐	☐
Back (e.g. lat pulldown, bent-over row)	☐	☐
Abdomen (e.g. crunches, sit-ups)	☐	☐
Chest (e.g. bench press, push-ups)	☐	☐
Shoulders (e.g. lat raise, overhead press)	☐	☐
Arms (e.g. bicep curl, tricep dips)	☐	☐

8.

In a usual week please indicate which muscle groups you use when you do each of the following types of muscle-strengthening exercises.

If you <u>do not do</u> the muscle-strengthening exercise, please select NO.

Doing HOLISTIC EXERCISES (including Yoga, Tai-chi and Pilates) in a usual session.

	No	Yes
Legs (e.g. squats, lunges, bridges)	☐	☐
Hips (e.g. side leg raises, bridges)	☐	☐
Back (e.g. lat pulldown, bent-over row)	☐	☐
Abdomen (e.g. crunches, sit-ups)	☐	☐
Chest (e.g. bench press, push-ups)	☐	☐
Shoulders (e.g. lat raise, overhead press)	☐	☐
Arms (e.g. bicep curl, tricep dips)	☐	☐

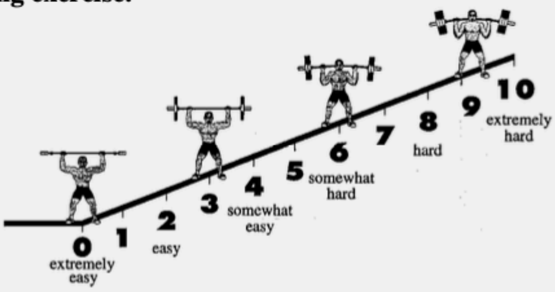
9.

For each of the following types of muscle-strengthening exercises, please say

How hard (level of intensity) you usually exercise

How hard you feel you are exercising can also be called intensity or rating of perceived effort. The level of intensity is often assessed on a 0 to 10 scale with 0 representing "extremely easy" and 10 representing "extremely hard".

Using the picture below as a guide on a scale of 0-10 please indicate how hard you feel you exercise when you are doing muscle-strengthening exercise.



(Robertson et al., 2003)

Level of INTENSITY in a usual session.

	Not applicable	0 Extremely easy	1	2 Easy	3	4 Somewhat easy	5	6 Somewhat hard	7	8 Hard	9	10 Extremely hard
Use weight machines (e.g. leg press, chest press, lat pulldown)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Body weight exercises (e.g. push-ups, sit-ups)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Use resistance bands or free weights (e.g. dumbbells)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Holistic exercises (including Yoga, Tai-chi and Pilates)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

Supplemental Digital Content 2

Supplemental Digital Content 2

Muscle-strengthening Exercise Questionnaire Short Form (MSEQ-Short)

Your participation in muscle-strengthening exercise

The next set of questions are about your participation in **muscle-strengthening exercise,** sometimes called weight or resistance training.

When thinking about muscle-strengthening exercise, we are only interested in exercises that you do during your leisure or free time, and NOT done as part of your work/job, or as a part of household activities (chores).

The types of muscle-strengthening exercise we are interested in include:

- **Using weight machines** - typically in a gym or fitness centre
- **Bodyweight exercises** - including push-ups or sit-ups
- **Resistance exercises** – using free weights like dumbbells or using resistance bands
- **Holistic exercises** - including Yoga, Tai-Chi or Pilates

1. Do you **do muscle-strengthening exercise** in a **usual week?**

   ☐ **Yes**

   ☐ **No** → **Skip to next module**

2. How **many days,** in a **usual week,** do you do muscle-strengthening exercise?

   _______ **days per week**

3. **On the day(s)** that you **do muscle-strengthening exercise**, please indicate **how long** you spend doing this activity?

   _______ **minutes per day**

4. On a scale from 0 to 10**,** how **hard do you feel** you are **working when doing muscle-strengthening exercise** with '0' being 'extremely easy' and '10' being 'extremely hard'

   _______ **intensity of session**

5. What **types of muscle-strengthening exercise do you usually do**?

Weight machines (Lat pulldown, bench press, leg press)	Yes or No _______
Resistance exercises (resistance bands/dumbbells)	Yes or No _______
Bodyweight exercises (push-ups, sit-ups)	Yes or No _______
Holistic exercises (Yoga, Tai-Chi and Pilates)	Yes or No_______

6. When you do muscle-strengthening exercise, **do you usually do exercise that target or use the** following **muscle groups or parts of your body?**

Legs (e.g. squats, lunge, leg press)	Yes or No _______
Hips (e.g. bridges, lateral banded walk)	Yes or No _______
Back (e.g. lat pulldown, dumbbell row)	Yes or No _______
Abdomen (e.g. sit-ups, planking)	Yes or No _______
Chest (e.g. bench press, push-ups)	Yes or No _______
Shoulders (e.g. shoulder/overhead press)	Yes or No _______
Arms (e.g. bicep curl, tricep dips)	Yes or No _______

This is the end of the survey, thank you for participating.

Muscle-strengthening Exercise Questionnaire Long Form (MSEQ-Long)

Your participation in muscle-strengthening exercise

The next set of questions are about your participation in **muscle-strengthening exercise,** sometimes called weight or resistance training.

When thinking about muscle-strengthening exercise, we are only interested in exercises that you do during your leisure or free time, and NOT done as part of your work/job, or as a part of household activities (chores).

The types of muscle-strengthening exercise we are interested in include:

- **Using weight machines** - typically in a gym or fitness centre
- **Bodyweight exercises** - including push-ups or sit-ups
- **Resistance exercises** – using free weights like dumbbells or using resistance bands
- **Holistic exercises** - including Yoga, Tai-Chi or Pilates

1. Do you **do muscle-strengthening exercise** in a **usual week?**

☐ **Yes**

☐ **No** → **Skip to next module**

WEIGHT MACHINES

1. When you do muscle-strengthening exercise, **do you use weight machines (Lat pulldown, bench press, leg press)**?

   ☐ **Yes**

   ☐ **No** → **Skip to question 6**

2. How **many days,** in a **usual week,** do you use weight machines?

   _______ **days per week**

3. In a usual week, **on the day(s)** that you use **weight machines**, please indicate **how long** you spend doing this activity per session?

   _______ **minutes per day**

4. On a scale from 0 to 10, how **hard you feel when using weight machines** with ‘0’ being ‘extremely easy’ and ‘10’ being ‘extremely hard’

   _______ **intensity of session**

5. When you use weight machines, **do you usually do exercise that target or use the following muscle groups or parts of your body?**

Legs (leg press, leg extension)	Yes or No _______
Hips (machine hip/glute raises)	Yes or No _______
Back (Lat pulldown, seated row)	Yes or No _______
Abdomen (crunches, sit-ups)	Yes or No _______
Chest (bench press)	Yes or No _______
Shoulders (machine shoulder press)	Yes or No _______
Arms (bicep curl, tricep push down)	Yes or No _______

BODYWEIGHT EXERCISES

6. When you do muscle-strengthening exercise, do you do **bodyweight exercises** (including push-ups, sit-ups, planking)

☐ **Yes**

☐ **No** ⟶ **Skip to question 11**

7. How **many days,** in a **usual week,** do you use bodyweight exercises?

_______ **days per week**

8. In a usual week, **on the day(s)** that you do **bodyweight exercises**, please indicate **how long** you spend doing this activity per session?

_______ **minutes per day**

9. On a scale from 0 to 10**,** how **hard you feel when doing bodyweight exercises** with **'**0' being 'extremely easy' and '10' being 'extremely hard'

_______ **intensity of session**

10. When you do bodyweight exercises, **do you usually do exercise that target or use the following muscle groups or parts of your body?**

Legs (squats, lunges)	Yes or No _______
Hips (glute raises, lateral banded walk)	Yes or No _______
Back (pull-ups, back extension)	Yes or No _______
Abdomen (crunches, planking)	Yes or No _______
Chest (pull ups)	Yes or No _______
Shoulders (push ups)	Yes or No _______
Arms (dips, chair dips)	Yes or No _______

RESISTANCE EXERCISES

11. When you do muscle-strengthening exercise, do you do **resistance exercises, such as using resistance bands or free weights like dumbbells**?

☐ **Yes**

☐ **No** ⟶ **Skip to question 16**

12. How **many days,** in a **usual week,** do you do resistance exercises, such as using resistance bands or free weights like dumbbells?

_______ **days per week**

13. In a usual week, **on the day(s)** that you do **resistance exercises**, please indicate **how long** you spend doing this activity per session?

_______ **minutes per day**

14. On a scale from 0 to 10**,** how **hard you feel** **when doing** **resistance exercises** with **'**0' being 'extremely easy' and '10' being 'extremely hard'?

_______ **intensity of session**

15. When you doing resistance exercises, **do you usually do exercise that target or use the following muscle groups or parts of your body?**

Legs (squats/lunges with dumbbells)	Yes or No _______
Hips (side lying leg raise with resistance band)	Yes or No _______
Back (dumbbell row)	Yes or No _______
Abdomen (weighted crunches, sit-ups)	Yes or No _______
Chest (dumbbell bench press)	Yes or No _______
Shoulders (dumbbell shoulder press)	Yes or No _______
Arms (bicep curl, tricep push down)	Yes or No _______

HOLISTIC EXERCISES

16. When you do muscle-strengthening exercise, do you do **Holistic exercises (including Yoga, Tai-Chi and Pilates)?**

☐ **Yes**

☐ **No** → **Skip to next module**

17. How **many days,** in a **usual week,** do you holistic exercises?

_______ **days per week**

18. In a usual week, **on the day(s)** that you do **holistic exercises**, please indicate **how long** you spend doing this activity per session?

_______ **minutes per day**

19. On a scale from 0 to 10**,** how **hard you feel** **when doing** **holistic exercises** with **'**0' being 'extremely easy' and '10' being 'extremely hard'?

_______ **intensity of session**

20. When you do holistic exercises**, do you usually do exercise that target or use the following muscle groups or parts of your body?**

Legs (squats/lunges)	Yes or No _______
Hips (bridges, single/double leg stretch)	Yes or No _______
Back (superman)	Yes or No _______
Abdomen (knee-to-elbow crunches, leg raises)	Yes or No _______
Chest (push-ups)	Yes or No _______
Shoulders (Plank, side plank)	Yes or No _______
Arms (Bird/dog)	Yes or No _______

This is the end of the questionnaire, thank you for participating.

Supplemental Digital Content 3.

About you

The first set of questions will provide us with some basic information about you.

1. What was your age at your last birthday?

Please enter only whole numbers.

☐☐☐

2. What was your sex at birth?

- Female ☐
- Male ☐

3. Which country do you usually live in?

- Afghanistan ☐
- Albania ☐
- Algeria ☐
- Andorra ☐
- Angola ☐
- Antigua and Barbuda ☐
- Argentina ☐
- Armenia ☐
- Australia ☐
- Austria ☐
- Azerbaijan ☐
- Bahamas ☐
- Bahrain ☐
- Bangladesh ☐
- Barbados ☐
- Belarus ☐
- Belgium ☐
- Belize ☐
- Benin ☐

Bhutan ☐

Bolivia ☐

Bosnia and Herzegovina ☐

Botswana ☐

Brazil ☐

Brunei ☐

Bulgaria ☐

Burkina Faso ☐

Burundi ☐

Côte d'Ivoire ☐

Cabo Verde ☐

Cambodia ☐

Cameroon ☐

Canada ☐

Central African Republic ☐

Chad ☐

Chile ☐

China ☐

Colombia ☐

Comoros ☐

Congo (Congo-Brazzaville) ☐

Costa Rica ☐

Croatia ☐

Cuba ☐

Cyprus ☐

Czechia (Czech Republic) ☐

Democratic Republic of the Congo ☐

Denmark ☐

Djibouti ☐

Dominica
Dominican Republic
Ecuador
Egypt
El Salvador
Equatorial Guinea
Eritrea
Estonia
Eswatini (fmr. "Swaziland")
Ethiopia
Fiji
Finland
France
Gabon
Gambia
Georgia
Germany
Ghana
Greece
Grenada
Guatemala
Guinea
Guinea-Bissau
Guyana
Haiti
Holy See
Honduras
Hungary
Iceland

India

Indonesia

Iran

Iraq

Ireland

Israel

Italy

Jamaica

Japan

Jordan

Kazakhstan

Kenya

Kiribati

Kuwait

Kyrgyzstan

Laos

Latvia

Lebanon

Lesotho

Liberia

Libya

Liechtenstein

Lithuania

Luxembourg

Madagascar

Malawi

Malaysia

Maldives

Mali

Malta ☐

Marshall Islands ☐

Mauritania ☐

Mauritius ☐

Mexico ☐

Micronesia ☐

Moldova ☐

Monaco ☐

Mongolia ☐

Montenegro ☐

Morocco ☐

Mozambique ☐

Myanmar (formerly Burma) ☐

Namibia ☐

Nauru ☐

Nepal ☐

Netherlands ☐

New Zealand ☐

Nicaragua ☐

Niger ☐

Nigeria ☐

North Korea ☐

North Macedonia ☐

Norway ☐

Oman ☐

Pakistan ☐

Palau ☐

Palestine State ☐

Panama ☐

Papua New Guinea ☐

Paraguay ☐

Peru ☐

Philippines ☐

Poland ☐

Portugal ☐

Qatar ☐

Romania ☐

Russia ☐

Rwanda ☐

Saint Kitts and Nevis ☐

Saint Lucia ☐

Saint Vincent and the Grenadines ☐

Samoa ☐

San Marino ☐

Sao Tome and Principe ☐

Saudi Arabia ☐

Senegal ☐

Serbia ☐

Seychelles ☐

Sierra Leone ☐

Singapore ☐

Slovakia ☐

Slovenia ☐

Solomon Islands ☐

Somalia ☐

South Africa ☐

South Korea ☐

South Sudan ☐

▼

Spain

Sri Lanka

Sudan

Suriname

Sweden

Switzerland

Syria

Tajikistan

Tanzania

Thailand

Timor-Leste

Togo

Tonga

Trinidad and Tobago

Tunisia

Turkey

Turkmenistan

Tuvalu

Uganda

Ukraine

United Arab Emirates

United Kingdom

United States of America

Uruguay

Uzbekistan

Vanuatu

Venezuela

Vietnam

Yemen

Zambia ☐

Zimbabwe ☐

4. What best describes the region you live in?

Urban - capital cities or metropolitan centres with a population of >100,000 ☐

Regional - large rural centres with a population between 5,000-99,000 ☐

Remote - remote centres with a population of <5,000 ☐

5. Which of the following descriptions best applies to your usual 'work' situation?

Going to school or university full-time ☐

In paid employment or self-employed ☐

Doing unpaid work for a business that you own, or that a relative owns ☐

Permanently unable to work because of long-term sickness or disability ☐

Retired from paid work ☐

Looking after home or family ☐

Other ☐

Other

6. What is your highest level of education completed?

Never attended school ☐

Primary school ☐

Some high school ☐

Year 12 or equivalent ☐

Technical or trade school certificate/apprenticeship ☐

University or tertiary qualification (Undergraduate) ☐

University or tertiary qualification (Postgraduate/Masters/Doctorate) ☐

Other ☐

Other

7. **What is your marital status?**

- Married ☐
- Defacto ☐
- Separated / Divorced ☐
- Widowed ☐
- Never married ☐

The next questions are about your own health behaviours.

In this section, we ask questions about your health and health behaviours to get an idea of your health and lifestyle.

8. **About how tall are you, without shoes, in centimetres (cm) or feet (ft) and inches (in)?**

in centimetres (cm)

Comment

in feet (ft) and inches (in)

Comment

9. **About how much do you weigh, without shoes and heavy clothes, in kilograms (kg) or pounds (lb) and ounces (oz)?**

in kilograms (kg)

Comment

in pounds (lb) and ounces (oz)

Comment

10. **How would you rate your general health?**

- Excellent ☐
- Very good ☐
- Good ☐
- Fair ☐
- Poor ☐

Table. Supplemental Digital Content 3: Interclass correlations coefficient (ICC), Spearman's rank correlation (ρ), Kappa statistics (κ), and 95% confidence interval (95% CI) for test-retest reliability [a], and concurrent validity [b] of the Muscle-Strengthening Exercise Questionnaire (MSEQ)-Short items.

	Test-retest reliability [a]				Concurrent validity [b]	
MSEQ-Short items (All types of MSE combined)	**ICC (95%CI)**	**ρ (95% CI)**	**κ (95% CI)**	**% Agreement**	**ICC (95%CI)**	**ρ (95% CI)**
Days per week (usual week)	0.58 (0.40-0.73)	0.91 (0.85-0.95)	–	–	0.56 (0.37-0.71)	0.58 (0.35-0.76)
Duration (minutes/per day)	0.69 (0.55-0.80)	0.89 (0.78-0.95)	–	–	0.46 (0.24-0.64)	0.73 (0.59-0.83)
Level of intensity [c]	0.51 (0.31-0.68)	0.82 (0.66-0.92)	–	–	0.18 (-0.06-0.42)	0.45 (0.18-0.67)
Muscle groups targeted						
Legs	–	–	0.41 (0.22-0.58)	79.6	–	–
Hips	–	–	0.51 (0.34-0.66)	79.6	–	–
Back	–	–	0.45 (0.26-0.63)	81.5	–	–
Abdomen	–	–	0.35 (0.17-0.52)	77.8	–	–
Chest	–	–	0.41 (0.22-0.59)	77.8	–	–
Shoulders	–	–	0.44 (0.24-0.60)	83.3	–	–
Arms	–	–	0.47 (0.29-0.64)	77.8	–	–

[a] Test and retest of MSEQ was conducted a maximum of 14 days apart.

[b] To assess the concurrent validity, respondents completed the MSE 7-day log for 7 consecutive days a maximum of 14 days after the first administration.

[c] To assess level of intensity, using the previously validated OMNI-Resistance Exercise Scale (Robertson et al., 2003), respondents was asked to report for each type of muscle-strengthening exercise “on a scale of 0-10 please indicate how hard you feel you exercise when you are doing … with 0 representing “extremely easy” and 10 representing “extremely hard”.

[d] To assess muscle groups used, respondents were asked when they undertake muscle-strengthening exercise, do they do exercise that target the following muscle groups legs, hips, back, abdomen, chest, shoulders, and arms.

[e] Weight machines defined as using weight machines such as leg press, chest press, lat pulldown.

[f] Body weight exercises defined as doing push-ups, sit-ups.

[g] Resistance exercises defined as using resistance bands or free weights like dumbbells.

[h] Holistic exercises defined as doing Yoga, Tai-Chi and Pilates.

– results not applicable for this variable.

Table. Supplemental Digital Content 4: Interclass correlations coefficient (ICC), Spearman's rank correlation (ρ), Kappa statistics (κ), and 95% confidence interval (95% CI) for test-retest reliability [a], and concurrent validity [b] of the Muscle-Strengthening Exercise Questionnaire (MSEQ)-Long items.

	Test-retest reliability [a]				Concurrent validity [b]	
MSEQ-Long items (4 types of MSE assessed separately)	**ICC (95%CI)**	**ρ (95% CI)**	**κ (95% CI)**	**% Agreement**	**ICC (95%CI)**	**ρ (95% CI)**
Days per week (usual week)						
Use weight machines [e]	0.85 (0.74-0.91)	0.79 (0.60-0.94)	–	–	0.69 (0.16-0.86)	0.76 (0.59-0.89)
Body weight exercises [f]	0.93 (0.88-0.96)	0.86 (0.73-0.93)	–	–	0.74 (0.56-0.85)	0.59 (0.36-0.76)
Use resistance bands or free weights [g]	0.95 (0.92-0.97)	0.87 (0.73-0.95)	–	–	0.72 (0.35-0.86)	0.64 (0.38-0.84)
Holistic exercises [h]	0.95 (0.91-0.97)	0.83 (0.65-0.95)	–	–	0.78 (0.45-0.89)	0.77 (0.60-0.89)
Duration (minutes/per day)						
Use weight machines [e]	0.90 (0.82-0.94)	0.82 (0.67-0.93)	–	–	0.60 (0.18-0.79)	0.73 (0.56-0.87)
Body weight exercises [f]	0.88 (0.79-0.93)	0.77 (0.60-0.87)	–	–	0.39 (-0.04-0.64)	0.34 (0.08-0.56)

Use resistance bands or free weights [g]	0.89 (0.82-0.94)	0.79 (0.62-0.90)	–	–	0.78 (0.37-0.90)	0.74 (0.55-0.86)
Holistic exercises [h]	0.96 (0.94-0.98)	0.88 (0.74-0.96)	–	–	0.70 (0.38-0.84)	0.73 (0.54-0.87)
Level of intensity [c]						
Use weight machines [e]	0.90 (0.83-0.94)	0.82 (0.66-0.95)	–	–	0.73 (0.38-0.87)	0.71 (0.52-0.85)
Body weight exercises [f]	0.93 (0.89-0.96)	0.78 (0.61-0.90)	–	–	0.35 (-0.07-0.61)	0.30 (0.03-0.55)
Use resistance bands or free weights [g]	0.93 (0.88-0.96)	0.76 (0.59-0.88)	–	–	0.78 (0.21-0.91)	0.68 (0.52-0.82)
Holistic exercises [h]	0.89 (0.82-0.94)	0.81 (0.63-0.94)	–	–	0.69 (0.43-0.83)	0.63 (0.41-0.78)
Muscle groups used [d]						
Use weight machines [e]						
Legs	–	–	0.70 (0.49-0.88)	85.2	–	–
Hips	–	–	0.61 (0.34-0.85)	87.0	–	–
Back	–	–	0.74 (0.54-0.89)	87.0	–	–
Abdomen	–	–	0.33 (-0.01-0.65)	81.5	–	–
Chest	–	–	0.78 (0.59-0.93)	88.9	–	–
Shoulders	–	–	0.85 (0.67-0.96)	92.6	–	–

Arms	–	–	0.81 (0.63-0.96)	90.7	–	–
Body weight exercises [f]						
Legs	–	–	0.51 (0.19-0.79)	85.2	–	–
Hips	–	–	0.83 (0.65-0.96)	92.6	–	–
Back	–	–	0.40 (0.14-0.64)	72.7	–	–
Abdomen	–	–	0.71 (0.41-0.93)	90.7	–	–
Chest	–	–	0.54 (0.23-0.80)	85.2	–	–
Shoulders	–	–	0.53 (0.26-0.74)	77.8	–	–
Arms	–	–	0.57 (0.33-0.79)	79.6	–	–
Use resistance bands or free weights [g]						
Legs	–	–	0.55 (0.23-0.81)	87.0	–	–
Hips	–	–	0.66 (0.45-0.85)	83.3	–	–
Back	–	–	0.49 (0.16-0.74)	81.5	–	–
Abdomen	–	–	0.44 (0.19-0.67)	72.2	–	–
Chest	–	–	0.33 (0.02-0.60)	75.9	–	–
Shoulders	–	–	0.84 (0.55-1.00)	96.3	–	–
Arms	–	–	0.63 (0.22-0.92)	92.6	–	–
Holistic exercises [h]						
Legs	–	–	0.58 (0.34-0.79)	79.6	–	–

Hips	–	–	0.61 (0.38-0.81)	81.5	–	–
Back	–	–	0.74 (0.50-0.91)	88.9	–	–
Abdomen	–	–	0.66 (0.45-0.85)	83.3	–	–
Chest	–	–	0.69 (0.44-0.88)	87.0	–	–
Shoulders	–	–	0.57 (0.34-0.78)	81.5	–	–
Arms	–	–	0.76 (0.53-0.94)	90.7	–	–

[a] Test and retest of MSEQ was conducted a maximum of 14 days apart.

[b] To assess the concurrent validity, respondents completed the MSE 7-day log for 7 consecutive days a maximum of 14 days after the first administration.

[c] To assess level of intensity, using the previously validated OMNI-Resistance Exercise Scale (Robertson et al., 2003), respondents was asked to report for each type of muscle-strengthening exercise "on a scale of 0-10 please indicate how hard you feel you exercise when you are doing … with 0 representing "extremely easy" and 10 representing "extremely hard".

[d] To assess muscle groups used, respondents were asked when they undertake muscle-strengthening exercise, do they do exercise that target the following muscle groups legs, hips, back, abdomen, chest, shoulders, and arms.

[e] Weight machines defined as using weight machines such as leg press, chest press, lat pulldown.

[f] Body weight exercises defined as doing push-ups, sit-ups.

[g] Resistance exercises defined as using resistance bands or free weights like dumbbells.

[h] Holistic exercises defined as doing Yoga, Tai-Chi and Pilates.

– results not applicable for this variable.

APPENDIX E: STUDY 5

Electronic Supplementary Material 1

Preamble:

Factors influencing leisure-time muscle-strengthening exercise.

We are now interested in understanding the '*type of things*' that may motivate you to do muscle-strengthening exercise, and also the '*type of things*' that may be barriers to you doing (or doing more) muscle-strengthening exercise.

1. Please indicate how to what extent you agree or disagree with the following questions.

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
I do muscle-strengthening exercise to improve my health and well-being	☐	☐	☐	☐	☐
I do muscle-strengthening exercise to improve my appearance	☐	☐	☐	☐	☐
I do muscle-strengthening exercise to be with others	☐	☐	☐	☐	☐
I do muscle-strengthening exercise to improve existing skills	☐	☐	☐	☐	☐
I do muscle-strengthening exercise because I enjoy this activity	☐	☐	☐	☐	☐

2. How true are the following statements for you?

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
I don't have enough time to do muscle-strengthening exercise	☐	☐	☐	☐	☐
I need expensive equipment to do muscle-strengthening exercise	☐	☐	☐	☐	☐
I feel I don't have enough knowledge about muscle-strengthening exercise to do it	☐	☐	☐	☐	☐
I do not have enough energy to do muscle-strengthening exercise	☐	☐	☐	☐	☐
Doing muscle-strengthening exercise is a low priority for me	☐	☐	☐	☐	☐

3. How true are the following statements for you?

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
I am scared that I will injure myself doing muscle-strengthening exercise	☐	☐	☐	☐	☐
I would not enjoy doing muscle-strengthening exercise	☐	☐	☐	☐	☐
I am not healthy enough to do muscle-strengthening exercise	☐	☐	☐	☐	☐
I do not feel comfortable doing muscle-strengthening exercise in a gym/fitness centre	☐	☐	☐	☐	☐

Support for doing muscle-strengthening exercise during leisure-time.

These questions are about "*what sort of things*" may help or support or facilitate you to do (or do more) muscle-strengthening exercise activities during your leisure-time.

4. How useful would the following be in helping you to do muscle-strengthening exercise?

	Not at all useful to me	Somewhat useful to me	Very useful to me	I already have this
If I had access to equipment at home	☐	☐	☐	☐
If I had access to facilities (e.g. gym or fitness centre)	☐	☐	☐	☐
If I had access to outdoor equipment (e.g. equipment in a community park)	☐	☐	☐	☐
If I had access to fitness trainers to help me	☐	☐	☐	☐
If I had access to facilities where I work	☐	☐	☐	☐
If I had access to a subsidised gym membership	☐	☐	☐	☐
If I had access to educational materials (e.g. leaflets or brochures)	☐	☐	☐	☐
If I had access to multi-media/smartphone applications	☐	☐	☐	☐
If I had access to an online or virtual trainer	☐	☐	☐	☐
If I had a workout partner	☐	☐	☐	☐

Muscle-strengthening exercise confidence

This section of questions refers to your perception of your confidence in undertaking muscle-strengthening exercise.

5. Please indicate how likely you agree or disagree with the following questions.

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
I have the physical capacity to complete muscle-strengthening exercises	☐	☐	☐	☐	☐
I can complete muscle-strengthening exercises without the help of someone else (e.g. friend, trainer)	☐	☐	☐	☐	☐
If I don't have access to a gym I can still do muscle-strengthening exercise (e.g. body weight exercises)	☐	☐	☐	☐	☐
I have the skill and technique to complete muscle-strengthening exercises safely	☐	☐	☐	☐	☐

Electronic Supplementary Material 2. Proportion of sample [excluded i.e. n=26] plus full sample classified into three categories according to the number of muscle-strengthening exercise related guidelines met overall and by sociodemographic and behavioural characteristics [a].

Characteristic [a]	Main Study (Total sample)	This Study (Total sample)	Excluded	Number of muscle-strengthening exercise related constructs (meeting none, one, two or three guidelines)			
	% (n=461)	% (n=435)	% (n=26)	<2 x a week % (n=101)	≥2 x a week % (n=334)	≥2 x a week AND ≥5 muscle-groups % (n=309)	≥2 x a week AND ≥5 muscle-groups AND moderate-intensity % (n=290)
Sex							
Female	61.0 (281)	60.5 (263)	61.5 (16)	73.3 (74)	56.6 (189)	57.6 (178)	57.2 (166)
Male	39.0 (180)	39.5 (172)	38.5 (10)	26.7 (27)	43.4 (145)	42.4 (131)	42.8 (124)
Age (years)	Mean age 40.4 ± 14.4 years	Mean age 40.1 ± 14.1 years	Mean age 46.0 ± 17.1 years				

18-34	42.7 (197)	43.4 (189)	30.8 (8)	30.7 (31)	47.3 (158)	49.2 (152)	51.0 (148)
35-54	37.1 (171)	37.9 (165)	26.9 (7)	46.5 (47)	35.3 (118)	34.6 (107)	33.8 (98)
55-74	20.2 (93)	18.6 (81)	42.3 (11)	22.8 (23)	17.4 (58)	16.2 (50)	15.2 (44)
Country							
Australia	52.9 (244)	53.1 (231)	50.0 (13)	50.5 (51)	53.9 (180)	54.0 (167)	53.8 (156)
Other	47.1 (217)	46.9 (204)	50.0 (13)	46.5 (50)	46.1(154)	46.0 (142)	46.2 (134)
Region							
Urban	62.7 (289)	63.0 (274)	57.7 (15)	55.4 (56)	65.3 (218)	65.7 (203)	66.2 (192)
Regional/remote	37.3 (172)	37.0 (161)	42.3 (11)	44.6 (45)	34.7 (116)	34.3 (106)	33.8 (98)
Education							
Primary school/ Some high school	3.7 (17)	4.2 (18)	0.0 (0)	5.9 (6)	3. (12)	3.9 (12)	3.9 (11)
Year 12 or equivalent	11.2 (51)	10.7 (46)	11.5 (3)	15.8 (16)	9.1 (30)	9.9 (30)	9.8 (28)

Higher education (below degree)/ University qualification	85.1 (388)	85.1 (366)	88.5 (23)	78.2 (79)	87.2 (287)	86.2 (262)	86.3 (246)
Marital status							
Married	43.2 (199)	42.5 (185)	50.0 (13)	51.5 (52)	39.8 (133)	37.9 (117)	36.6 (106)
Not married (Defacto/separated/divorced/widowed)	22.1 (102)	22.3 (97)	23.1 (6)	19.8 (20)	37.1 (124)	39.2 (121)	41.0 (119)
Never married	34.7 (160)	35.2 (153)	26.9 (7)	28.7 (29)	23.1 (77)	23.0 (71)	22.4 (65)
Work situation							
School/University (full-time)	16.3 (75)	16.3 (71)	11.5 (3)	11.9 (12)	17.7 (59)	18.8 (58)	19.0 (55)
Paid employment/self-employed/unpaid work	68.1 (314)	69.2 (301)	53.8 (14)	70.3 (71)	68.9 (230)	69.3 (214)	70.7 (205)
Not working/other	15.6 (72)	14.5 (63)	34.6 (9)	17.8 (18)	13.5 (45)	12.0 (37)	10.3 (30)
Self-rated health							
Excellent	23.6 (109)	22.8 (99)	38.5 (10)	9.9 (10)	26.6 (89)	26.2 (81)	27.6 (80)

Very good	43.2 (199)	45.1 (196)	19.2 (5)	32.7 (33)	48.8 (163)	49.5 (153)	48.6 (141)
Good	23.9 (110)	22.8 (99)	34.6 (9)	34.7 (35)	19.2 (64)	19.7 (61)	20.0 (58)
Fair/poor	9.3 (43)	9.4 (41)	7.7 (2)	22.8 (23)	5.4 (18)	4.5 (14)	3.8 (11)
Body Mass Index classification							
Underweight or normal weight	49.7 (229)	49.9 (217)	53.8 (14)	44.4 (44)	52.1. (173)	52.4 (161)	53.1 (153)
Overweight	33.2 (153)	32.4 (141)	38.5 (10)	32.3 (32)	32.8 (109)	32.9 (101)	33.0 (95)
Obese	16.3 (75)	16.8 (73)	7.7 (2)	23.2 (23)	15.1 (50)	14.7 (45)	13.9 (40)
Smoking status							
Never smoked	74.4 (343)	75.6 (339)	57.7 (15)	68.3 (69)	77.8 (260)	77.7 (240)	78.6 (228)
Smoker (current or former)	25.6 (118)	24.4 (106)	42.3 (11)	31.7 (32)	22.2 (74)	22.3 (69)	21.4 (62)
Alcohol							
Non-drinker	38.6 (178)	38.4 (167)	42.3 (11)	58.4 (59)	37.4 (125)	37.2 (115)	36.6 (106)

Drinker	61.4 (283)	61.6 (268)	57.7 (15)	41.6 (42)	62.6 (209)	62.8 (194)	63.4 (184)
Frequency of muscle-strengthening exercise (days/week)							
0	20.2 (93)	20.4 (89)	3.8 (1)	88.1 (89)			
1	2.6 (12)	2.8 (12)	0.0 (0)	11.9 (12)			
2	14.1 (65)	14.0 (61)	23.1 (6)		18.3 (61)	16.5 (51)	15.9 (46)
3	23.4 (108)	23.0 (100)	30.8 (8)		29.9 (100)	29.4 (91)	29.7 (86)
4	16.5 (76)	16.8 (73)	11.5 (3)		21.9 (73)	22.1 (70)	23.4 (68)
5	12.6 (58)	12.6 (55)	15.4 (4)		16.5 (55)	17.5 (54)	17.2 (50)
6	7.6 (35)	7.4 (32)	11.5 (3)		9.6 (32)	10.0 (31)	10.3 (30)
7	3.0 (14)	3.0 (13)	3.8 (1)		3.9 (13)	3.9 (12)	3.4 (10)

Note.

[a] Numbers vary slightly because of missing data for some characteristic variables. Missing data equated to; education (1.1% n=5), calculated BMI (0.9% n=4)

Preamble:
The next questions are about your participation in muscle-strengthening exercise

The questions within this section relate to the physical activities that you perform during your leisure-time only. When we say leisure-time we mean your free-time and the activities that you perform that are NOT done as part of your work/job, transportation (moving to a different location), or as a part of household activities (chores).

The types of muscle-strengthening exercise modes that we are interested in include;

- Use of weight machines (typically in a gym or fitness centre)
- Bodyweight exercises (including push-ups, sit-ups)
- Resistance exercises (using resistance bands or free weights like dumbbells)
- Holistic exercises (including Yoga, Tai-Chi and Pilates)

Electronic Supplementary Material 4. Male vs female: Single-factor adjusted[a] odds ratios (OR) split by sex, and their 95% confidence intervals (95% CI) for being classified as meeting the muscle-strengthening exercise guideline according to individual behavioural factors – for the total sample (n=435).

	Dependent variable **Odds of being classified as meeting the muscle-strengthening guidelines (≥ 2 times/week)** **Single-factor models** **AOR[a] (95% CI)**			
	Male	***p*-value**	**Female**	***p*-value**
Perceptions				
I don't have enough time to do muscle-strengthening exercise	0.18 (0.05-0.63)	0.007	0.44 (0.21-0.91)	0.027
I need expensive equipment to do muscle-strengthening exercise	1.63 (0.42-6.23)	0.478	0.93 (0.40-2.18)	0.868
I feel I don't have enough knowledge about muscle-strengthening exercise to do it	0.18 (0.05-0.60)	0.005	0.15 (0.06-0.34)	<0.000
I do not have enough energy to do muscle-strengthening exercise	0.25 (0.08-0.78)	0.016	0.13 (0.06-0.27)	<0.000
Doing muscle-strengthening exercise is a low priority for me	0.04 (0.01-0.13)	<0.000	0.09 (0.04-0.22)	<0.000
Belief factors				

I am scared that I will injure myself doing muscle-strengthening exercise	0.35 (0.09-1.36)	0.128	0.58 (0.25-1.35)	0.209
I would not enjoy doing muscle-strengthening exercise	0.02 (0.00-0.10)	<0.000	0.03 (0.01-0.12)	<0.000
I am not healthy enough to do muscle-strengthening exercise	0.14 (0.02-1.22)	0.075	1.31 (0.38-4.49)	0.665
I do not feel comfortable doing muscle-strengthening exercise in a gym/fitness centre	0.14 (0.04-0.46)	0.001	0.34 (0.17-0.68)	0.002
Confidence/Belief factors				
I have the physical capacity to complete muscle-strengthening exercises	5.80 (1.41-23.90)	0.015	2.27 (0.64-8.00)	0.204
I can complete muscle-strengthening exercises without the help of someone else (e.g. friend, trainer)	6.82 (2.21-21.03)	0.001	2.62 (1.24-5.54)	0.011
If I don't have access to a gym I can still do muscle-strengthening exercise (e.g. body weight exercises)	1.40 (0.42-4.73)	0.583	2.84 (1.30-6.18)	0.009
I have the skill and technique to complete muscle-strengthening exercises safely	14.70 (4.66-46.36)	<0.000	4.43 (2.09-9.40)	<0.000

Note.

Missing data: Confidence 0.5% (n=2)

[a] Adjusted for: age, work situation, education, self-rated health, body mass index (BMI).

Electronic Supplementary Material 5. Male vs female: Multiple factor adjusted[a] odds ratios (OR) split by sex, and their 95% confidence intervals (95% CI) for being classified as meeting the muscle-strengthening exercise guideline according to individual behavioural factors – for the total sample (n=435).

	Dependent variable Odds of being classified as meeting the muscle-strengthening guidelines (≥ 2 times/week)			
	Multiple-factor model AOR[a] (95% CI)			
	Male	***p*-value**	**Female**	***p*-value**
Perceptions				
I don't have enough time to do muscle-strengthening exercise	0.09 (0.02-0.55)	0.009	0.46 (0.17-1.23)	0.121
I need expensive equipment to do muscle-strengthening exercise				
I feel I don't have enough knowledge about muscle-strengthening exercise to do it	6.19 (0.59-65.47)	0.130	0.41 (0.13-1.32)	0.135
I do not have enough energy to do muscle-strengthening exercise	4.06 (0.29-57.51)	0.300	0.17 (0.06-0.44)	<0.000
Doing muscle-strengthening exercise is a low priority for me	0.18 (0.02-1.55)	0.118	0.20 (0.06-0.66)	0.008

Belief factors				
I am scared that I will injure myself doing muscle-strengthening exercise				
I would not enjoy doing muscle-strengthening exercise	0.05 (0.00-0.49)	0.010	0.05 (0.01-0.30)	0.001
I am not healthy enough to do muscle-strengthening exercise				
I do not feel comfortable doing muscle-strengthening exercise in a gym/fitness centre	0.72 (0.07-7.30)	0.778	1.34 (0.48-3.73)	0.581
Confidence/Belief factors				
I have the physical capacity to complete muscle-strengthening exercises				
I can complete muscle-strengthening exercises without the help of someone else (e.g. friend, trainer)	1.42 (0.21-9.89)	0.720	1.27 (0.41-3.99)	0.380
If I don't have access to a gym I can still do muscle-strengthening exercise (e.g. body weight exercises)				
I have the skill and technique to complete muscle-strengthening exercises safely	11.93 (1.57-90.58)	0.017	2.91 (0.95-8.88)	0.061

Note.

Missing data: Confidence 0.5% (n=2)

[a] Adjusted for: age, work situation, education, self-rated health, body mass index (BMI).

Electronic Supplementary Material 6. Test-retest reliability of the Muscle-Strengthening Exercise Questionnaire (MSEQ) behavioural statements assessing participation in muscle-strengthening exercise.

	Test-retest reliability	
	Interclass correlations coefficient (95% CI[a])	**Spearman's Rho (95 % CI[a])**
Perceptions		
I don't have enough time to do muscle-strengthening exercise	0.75 (0.62-0.84)	0.61 (0.43-0.76)
I need expensive equipment to do muscle-strengthening exercise	0.81 (0.70-0.87)	0.59 (0.41-0.73)
I feel I don't have enough knowledge about muscle-strengthening exercise to do it	0.84 (0.76-0.90)	0.73 (0.58-0.84)
I do not have enough energy to do muscle-strengthening exercise	0.88 (0.82-0.92)	0.75 (0.63-0.86)
Doing muscle-strengthening exercise is a low priority for me	0.89 (0.82-0.93)	0.82 (0.74-0.89)
Belief factors		
I am scared that I will injure myself doing muscle-strengthening exercise	0.88 (0.81-0.92)	0.77 (0.67-0.85)
I would not enjoy doing muscle-strengthening exercise	0.93 (0.89-0.95)	0.85 (0.77-0.91)
I am not healthy enough to do muscle-strengthening exercise	0.80 (0.70-0.87)	0.67 (0.51-0.81)
I do not feel comfortable doing muscle-strengthening exercise in a gym/fitness centre	0.88 (0.81-0.92)	0.76 (0.62-0.87)

Confidence/Belief factors		
I have the physical capacity to complete muscle-strengthening exercises	0.80 (0.69-0.87)	0.58 (0.39-0.76)
I can complete muscle-strengthening exercises without the help of someone else (e.g. friend, trainer)	0.87 (0.80-0.91)	0.77 (0.64-0.88)
If I don’t have access to a gym I can still do muscle-strengthening exercise (e.g. body weight exercises)	0.69 (0.53-0.80)	0.59 (0.40-0.76)
I have the skill and technique to complete muscle-strengthening exercises safely	0.83 (0.74-0.89)	0.67 (0.51-0.81)

Note.

[a] 95% confidence intervals (95% CI)

Electronic Supplementary Material 7. Sociodemographic characteristics [a] of participants classified as either 'meeting' or 'not meeting' the respective components of the muscle-strengthening exercise guidelines included in the analysis.

	Not Meeting [b] % (n)	Meeting 1[b] % (n)	*p*-value [e]	Meeting 2[c] % (n)	*p*-value [e]	Meeting 3[d] % (n)	*p*-value [e]
Total sample (n=435)	**23.2 (101)**	**76.8 (334)**		**71.0 (309)**		**66.7 (290)**	
Sex							
Female	73.3 (74)	56.6 (189)	0.003 *	57.6 (178)	0.057	57.2 (166)	0.052
Male	26.7 (27)	43.4 (145)		42.4 (131)		42.8 (124)	
Age (years)							
18-34	30.7 (31)	47.3 (158)		49.2 (152)		51.0 (148)	
35-54	46.5 (47)	35.3 (118)	0.013 *	34.6 (107)	0.001 *	33.8 (98)	<0.000 *
55-74	22.8 (23)	17.4 (58)		16.2 (50)		15.2 (44)	
Country							
Australia	50.5 (51)	53.9 (180)	0.549	54.0 (167)	0.538	53.8 (156)	0.684
Other	46.5 (50)	46.1 (154)		46.0 (142)		46.2 (134)	

Region							
Urban	55.4 (56)	65.3 (218)	0.073	65.7 (203)	0.067	66.2 (192)	0.049 *
Regional/remote	44.6 (45)	34.7 (116)		34.3 (106)		33.8 (98)	
Education							
Higher education (below degree)/University qualification	78.2 (79)	87.2 (287)	0.083	86.2 (262)	0.623	86.3 (246)	0.619
Year 12 or equivalent	15.8 (16)	9.1 (30)		9.9 (30)		9.8 (28)	
Primary school/ Some high school	5.9 (6)	3.6 (12)		3.9 (12)		3.9 (11)	
Marital status							
Married	51.5 (52)	39.8 (133)	0.110	37.9 (117)	0.005 *	36.6 (106)	<0.000 *
Not married (Defacto/separated/ divorced/widowed)	19.8 (20)	23.1 (77)		23.0 (71)		22.4 (65)	

Never married	28.7 (29)	37.1 (124)		39.2 (121)		41.0 (119)	
Work situation							
Paid employment/self-employed/unpaid work	70.3 (71)	68.9 (230)	0.269	69.3 (214)	0.014 *	70.7 (205)	0.001*
School/University (full-time)	11.9 (12)	17.7 (59)		18.8 (58)		19.0 (55)	
Not working/other	17.8 (18)	13.5 (45)		12.0 (37)		10.3 (30)	
Self-rated health							
Excellent	9.9 (10)	26.6 (89)		26.2 (81)		27.6 (80)	
Very good	32.7 (33)	48.8 (163)	<0.000 *	49.5 (153)	<0.000 *	48.6 (141)	<0.000 *
Good	34.7 (35)	19.2 (64)		19.7 (61)		20.0 (58)	
Fair/poor	22.8 (23)	5.4 (18)		4.5 (14)		3.8 (11)	
Body Mass Index classification							

Underweight or normal weight	44.4 (44)	52.1. (173)	0.142	52.4 (161)	0.122	53.1 (153)	0.047 *
Overweight	32.3 (32)	32.8 (109)		32.9 (101)		33.0 (95)	
Obese	23.2 (23)	15.1 (50)		14.7 (45)		13.9 (40)	
Smoking status							
Never smoked	68.3 (69)	77.8 (260)	0.051	77.7 (240)	0.121	78.6 (228)	0.040 *
Smoker (current or former)	31.7 (32)	22.2 (74)		22.3 (69)		21.4 (62)	
Alcohol							
Drinker	58.4 (59)	62.6 (209)	0.451	37.2 (115)	0.430	36.6 (106)	0.265
Non drinker	41.6 (42)	37.4 (125)		62.8 (194)		63.4 (184)	

Note.

[a] Numbers vary slightly because of missing data for some characteristic variables. Missing data equated to; education (1.1% n=5), calculated BMI (0.9% n=4)

[b] Frequency guideline of ≥2 times/week

[c] Frequency guideline of ≥2 x a week plus muscle groups targeted (≥5 muscle-groups)

[d] Frequency guideline of ≥2 x a week plus muscle groups targeted (≥5 muscle-groups) plus intensity (rating of perceived exertion ≥6)

[e] Pearson Chi-square test of independence

* Indicates significance i.e. <0.05

Electronic Supplementary Material 8. Percentage agreement of behavioural correlates of participants classified as either 'meeting' or 'not meeting' the muscle-strengthening exercise guideline of ≥2 time/ week included in the analysis.

	Total Sample % agreement	Not Meeting % (n)	Meeting % (n)	*p*-value [c]
Perceptions				
I don't have enough time to do muscle-strengthening exercise				
Agree[a]	14.5	28.7 (29)	10.2 (34)	<0.001*
Disagree[b]	85.5	71.3 (72)	89.8 (300)	
I need expensive equipment to do muscle-strengthening exercise				
Agree[a]	14.5	12.9 (13)	15.0 (50)	0.599
Disagree[b]	85.5	87.1 (88)	85.0 (284)	
I feel I don't have enough knowledge about muscle-strengthening exercise to do it				
Agree[a]	13.1	36.6 (37)	6.0 (20)	<0.001*
Disagree[b]	86.9	63.4 (64)	94.0 (314)	
I do not have enough energy to do muscle-strengthening exercise				
Agree[a]	17.7	47.5 (48)	8.7 (29)	<0.001*
Disagree[b]	82.3	52.5 (53)	91.3 (305)	
Doing muscle-strengthening exercise is a low priority for me				

Agree[a]	13.3	41.6 (42)	4.8 (16)	<0.001*
Disagree[b]	86.7	58.4 (59)	95.2 (318)	
Belief factors				
I am scared that I will injure myself doing muscle-strengthening exercise				
Agree[a]	11.3	22.8 (23)	7.8 (26)	<0.001*
Disagree[b]	88.7	77.2 (78)	92.2 (308)	
I would not enjoy doing muscle-strengthening exercise				
Agree[a]	9.9	35.6 (36)	2.1 (7)	<0.001*
Disagree[b]	90.1	64.4 (65)	97.9 (327)	
I am not healthy enough to do muscle-strengthening exercise				
Agree[a]	4.1	8.9 (9)	2.7 (9)	0.006*
Disagree[b]	95.9	91.1 (92)	97.3 (325)	
I do not feel comfortable doing muscle-strengthening exercise in a gym/fitness centre				
Agree[a]	17.7	39.6 (40)	11.1 (37)	<0.001*
Disagree[b]	82.3	60.4 (61)	88.9 (297)	
Confidence/Belief factors				
I have the physical capacity to complete muscle-strengthening exercises				
Agree[a]	93.8	83.2 (84)	97.0 (322)	<0.001*
Disagree[b]	6.2	16.8 (17)	3.0 (10)	
I can complete muscle-strengthening exercises without the help of someone else (e.g. friend, trainer)				

Agree[a]	82.7	60.4 (61)	89.5 (297)	<0.001*
Disagree[b]	17.3	39.6 (40)	10.5 (35)	
If I don't have access to a gym I can still do muscle-strengthening exercise (e.g. body weight exercises)				
Agree[a]	84.5	74.3 (75)	87.7 (291)	0.001*
Disagree[b]	15.5	25.7 (26)	12.3 (41)	
I have the skill and technique to complete muscle-strengthening exercises safely				
Agree[a]	83.4	54.5 (55)	92.2 (306)	<0.001*
Disagree[b]	16.6	45.5 (46)	7.8 (26)	

Note.

Missing data: Confidence 0.5% (n=2)

[a] Agree – strongly agree/agree

[b] Disagree – neutral/disagree/strongly disagree

[c] Pearson Chi-square test of independence

* Indicates significance i.e., <0.05

Electronic Supplementary Material 9. Muscle-strengthening exercise behaviour influencing factors (outcome variable) of participants included in the analysis (adjusted).

Factors Statements about participation in muscle-strengthening exercise	Dependent variable Odds of being classified as meeting the muscle-strengthening guidelines					
	Single-factor models AOR[a] (95% CI)		**Single-factor models AOR[a] (95% CI)**		**Single-factor models AOR[a] (95% CI)**	
	(≥ 2 times/week)		**(≥ 2 times/week + muscle groups)**		**(≥ 2 times/week + muscle groups + Moderate Intensity)**	
Perceptions		***p*-value**		***p*-value**		***p*-value**
I don't have enough time to do muscle-strengthening exercise	0.35 (0.19-0.65)	0.001	0.29 (0.16-0.53)	<0.000	0.36 (0.20-0.65)	0.001
I need expensive equipment to do muscle-strengthening exercise	1.14 (0.56-2.30)	0.719	0.86 (0.46-1.60)	0.627	1.12 (0.60-2.09)	0.717
I feel I don't have enough knowledge about muscle-strengthening exercise to do it	0.16 (0.08-0.31)	<0.000	0.20 (0.10-0.38)	<0.000	0.19 (0.10-0.38)	<0.000

I do not have enough energy to do muscle-strengthening exercise	0.15 (0.08-0.28)	<0.000	0.15 (0.08-0.27)	<0.000	0.18 (0.10-0.33)	<0.000
Doing muscle-strengthening exercise is a low priority for me	0.07 (0.03-0.14)	<0.000	0.08 (0.04-0.17)	<0.000	0.08 (0.04-0.18)	<0.000
Belief factors						
I am scared that I will injure myself doing muscle-strengthening exercise	0.45 (0.22-0.90)	0.024	0.44 (0.22-0.87)	0.018	0.52 (0.26-1.04)	0.065
I would not enjoy doing muscle-strengthening exercise	0.03 (0.01-0.08)	<0.000	0.02 (0.01-0.08)	<0.000	0.03 (0.01-0.10)	<0.000
I am not healthy enough to do muscle-strengthening exercise	0.74 (0.26-2.12)	0.580	0.54 (0.19-1.54)	0.246	0.39 (0.13-1.22)	0.106
I do not feel comfortable doing muscle-strengthening exercise in a gym/fitness centre	0.26 (0.15-0.46)	<0.000	0.26 (0.15-0.46)	<0.000	0.26 (0.14-0.46)	<0.000
Confidence/Belief factors						
I have the physical capacity to complete muscle-strengthening exercises	3.42 (1.32-8.90)	0.012	2.86 (1.13-7.21)	0.026	3.35 (1.25-8.99)	0.016
I can complete muscle-strengthening exercises without the	3.44 (1.89-6.28)	<0.000	3.15 (1.77-5.61)	<0.000	4.41 (2.42-8.02)	<0.000

help of someone else (e.g. friend, trainer)						
If I don’t have access to a gym I can still do muscle-strengthening exercise (e.g. body weight exercises)	2.00 (1.07-3.72)	0.029	2.11(1.18-3.77)	0.012	2.00 (1.12-3.59)	0.020
I have the skill and technique to complete muscle-strengthening exercises safely	6.56 (3.56-12.10)	<0.000	5.92 (3.25-10.78)	<0.000	6.67 (3.55-12.53)	<0.000

Note.

Missing data: Confidence 0.5% (n=2)

[a] Adjusted for: sex, age, work situation, education, self-rated health, body mass index (BMI).

Electronic Supplementary Material 10. Muscle-strengthening exercise behaviour influencing factors (outcome variable) of participants included in the analysis (adjusted).

Factors	**Dependent variable**					
	Odds of being classified as meeting the muscle-strengthening guidelines					
Statements about participation in muscle-strengthening exercise	**Multiple-factor model AOR[a] (95% CI)**		**Multiple-factor model AOR[a] (95% CI)**		**Multiple-factor model AOR[a] (95% CI)**	
	(≥ 2 times/week)		**(≥ 2 times/week + muscle groups)**		**(≥ 2 times/week + muscle groups + Moderate Intensity)**	
Perceptions		***p*-value**		***p*-value**		***p*-value**
I don't have enough time to do muscle-strengthening exercise	0.38 (0.17-0.86)	0.020	0.31 (0.15-0.64)	0.002	0.38 (0.19-0.78)	0.008
I need expensive equipment to do muscle-strengthening exercise						
I feel I don't have enough knowledge about muscle-strengthening exercise to do it	0.70 (0.26-1.84)	0.467	0.92 (0.36-2.36)	0.862	1.06 (0.41-2.74)	0.904
I do not have enough energy to do muscle-strengthening exercise	0.26 (0.12-0.59)	0.001	0.27 (0.13-0.59)	0.001	0.36 (0.17-0.77)	0.009

Doing muscle-strengthening exercise is a low priority for me	0.25 (0.10-0.64)	0.004	0.31 (0.12-0.79)	0.014	0.31 (0.12-0.79)	0.015
Belief factors						
I am scared that I will injure myself doing muscle-strengthening exercise	1.81 (0.61-5.42)	0.287	1.46 (0.52-4.10)	0.475		
I would not enjoy doing muscle-strengthening exercise	0.07 (0.02-0.23)	<0.000	0.06 (0.01-0.23)	<0.000	0.08 (0.02-0.33)	<0.000
I am not healthy enough to do muscle-strengthening exercise						
I do not feel comfortable doing muscle-strengthening exercise in a gym/fitness centre	1.13 (0.47-2.69)	0.789	0.89 (0.39-2.00)	0.772	0.77 (0.35-1.68)	0.507
Confidence/Belief factors						
I have the physical capacity to complete muscle-strengthening exercises	1.05 (0.28-3.95)	0.946	0.77 (0.22-2.72)	0.684	0.76 (0.21-2.75)	0.679
I can complete muscle-strengthening exercises without the help of someone else (e.g. friend, trainer)	1.44 (0.56-3.67)	0.448	1.26 (0.52-3.02)	0.611	2.10 (0.92-4.83)	0.080

If I don’t have access to a gym I can still do muscle-strengthening exercise (e.g. body weight exercises)	1.05 (0.41-2.67)	0.919	1.32 (0.59-2.99)	0.499	1.04 (0.47-2.33)	0.918
I have the skill and technique to complete muscle-strengthening exercises safely	3.75 (1.44-9.81)	0.007	3.75 (1.51-9.31)	0.004	3.56 (1.45-8.72)	0.006

Note.

Missing data: Confidence 0.5% (n=2)

[a] Adjusted for: sex, age, work situation, education, self-rated health, body mass index (BMI).

Electronic Supplementary Material 11. Muscle-strengthening exercise behaviour influencing factors (outcome variable) of participants included in the analysis (unadjusted).

Factors Statements about participation in muscle-strengthening exercise	Dependent variable Odds of being classified as meeting the muscle-strengthening guidelines (≥ 2 times/week) Single-factor models OR (95% CI)		Multiple-factor model OR (95% CI)	
Perceptions		***p*-value**		***p*-value**
I don't have enough time to do muscle-strengthening exercise	0.28 (0.16-0.49)	<0.000	0.24 (0.11-0.53)	<0.000
I need expensive equipment to do muscle-strengthening exercise	1.19 (0.62-2.30)	0.600		
I feel I don't have enough knowledge about muscle-strengthening exercise to do it	0.11 (0.06-0.20)	<0.000	0.51 (0.20-1.32)	0.167
I do not have enough energy to do muscle-strengthening exercise	0.10 (0.06-0.18)	<0.000	0.17 (0.08-0.36)	<0.000
Doing muscle-strengthening exercise is a low priority for me	0.07 (0.04-0.13)	<0.000	0.24 (0.09-0.61)	0.003
Belief factors				

I am scared that I will injure myself doing muscle-strengthening exercise	0.29 (0.15-0.53)	<0.000	1.34 (0.48-3.76)	0.573
I would not enjoy doing muscle-strengthening exercise	0.04 (0.02-0.09)	<0.000	0.08 (0.03-0.26)	<0.000
I am not healthy enough to do muscle-strengthening exercise	0.28 (0.11-0.73)	<0.009	18.54 (3.51-97.96)	0.001
I do not feel comfortable doing muscle-strengthening exercise in a gym/fitness centre	0.19 (0.11-0.32)	<0.000	1.00 (0.42-2.37)	0.993
Confidence/Belief factors				
I have the physical capacity to complete muscle-strengthening exercises	6.52 (2.88-14.75)	<0.000	1.34 (0.38-4.69)	0.648
I can complete muscle-strengthening exercises without the help of someone else (e.g. friend, trainer)	5.56 (3.27-9.46)	<0.000	1.41 (0.55-3.59)	0.474
If I don’t have access to a gym I can still do muscle-strengthening exercise (e.g. body weight exercises)	2.46 (1.42-4.28)	0.001	1.07 (0.45-2.55)	0.882
I have the skill and technique to complete muscle-strengthening exercises safely	9.84 (5.62-17.23)	<0.000	5.45 (2.14-13.92)	<0.000

Note.

Missing data: Confidence 0.5% (n=2).

Electronic Supplementary Material 12. Muscle-strengthening exercise behaviour influencing factors (outcome variable) of participants included in the analysis (unadjusted).

Factors **Statements about participation in muscle-strengthening exercise**	**Dependent variable** **Odds of being classified as meeting the muscle-strengthening guidelines**					
	Single-factor models OR (95% CI)		**Single-factor models OR (95% CI)**		**Single-factor models OR (95% CI)**	
	(≥ 2 times/week)		**(≥ 2 times/week + muscle groups)**		**(≥ 2 times/week + muscle groups + Moderate Intensity)**	
Perceptions		***p*-value**		***p*-value**		***p*-value**
I don't have enough time to do muscle-strengthening exercise	0.28 (0.16-0.49)	<0.000	0.26 (0.15-0.45)	<0.000	0.31 (0.18-0.54)	<0.000
I need expensive equipment to do muscle-strengthening exercise	1.19 (0.62-2.30)	0.600	0.94 (0.52-1.68)	0.821	1.19 (0.66-2.12)	0.564

I feel I don't have enough knowledge about muscle-strengthening exercise to do it	0.11 (0.06-0.20)	<0.000	0.14 (0.08-0.25)	<0.000	0.13 (0.07-0.25)	<0.000
I do not have enough energy to do muscle-strengthening exercise	0.10 (0.06-0.18)	<0.000	0.12 (0.07-0.20)	<0.000	0.13 (0.08-0.23)	<0.000
Doing muscle-strengthening exercise is a low priority for me	0.07 (0.04-0.13)	<0.000	0.07 (0.04-0.14)	<0.000	0.07 (0.04-0.15)	<0.000
Belief factors						
I am scared that I will injure myself doing muscle-strengthening exercise	0.29 (0.15-0.53)	<0.000	0.31 (0.17-0.57)	<0.000	0.36 (0.20-0.66)	0.001
I would not enjoy doing muscle-strengthening exercise	0.04 (0.02-0.09)	<0.000	0.03 (0.01-0.08)	<0.000	0.04 (0.01-0.11)	<0.000
I am not healthy enough to do muscle-strengthening exercise	0.28 (0.11-0.73)	0.009	0.24 (0.09-0.64)	0.004	0.18 (0.06-0.51)	0.001
I do not feel comfortable doing muscle-strengthening exercise in a gym/fitness centre	0.19 (0.11-0.32)	<0.000	0.21 (0.12-0.35)	<0.000	0.21 (0.12-0.35)	<0.000

Confidence/Belief factors						
I have the <u>physical capacity</u> to complete muscle-strengthening exercises	6.52 (2.88-14.75)	<0.000	5.59 (2.44-12.82)	<0.000	6.50 (2.68-15.76)	<0.000
I can complete muscle-strengthening exercises <u>without the help</u> of someone else (e.g. friend, trainer)	5.56 (3.27-9.46)	<0.000	4.85 (2.88-8.18)	<0.000	6.54 (3.79-11.27)	<0.000
If I <u>don't have access</u> to a gym I can still do muscle-strengthening exercise (e.g. body weight exercises)	2.46 (1.42-4.28)	0.001	2.49 (1.46-4.25)	0.001	2.40 (1.41-4.07)	0.001
I have the <u>skill and technique</u> to complete muscle-strengthening exercises safely	9.84 (5.62-17.23)	<0.000	8.67 (4.94-15.21)	<0.000	9.89 (5.46-17.91)	<0.000

Note.

Missing data: Confidence 0.5% (n=2).

Electronic Supplementary Material 13. Single-factor and multiple factor adjusted[a] odds ratios (OR) and their 95% confidence intervals (95% CI) for being classified as meeting the muscle-strengthening exercise guideline (frequency + muscle groups targeted) according to individual behavioural factors – for the total sample (n=435).

	Dependent variable Odds of being classified as meeting the muscle-strengthening guidelines (≥ 2 times/week) + muscle groups)			
	Single-factor models AOR[a] (95% CI)		**Multiple-factor model AOR[a] (95% CI)**	
		***p*-value**		***p*-value**
Perceptions				
I don't have enough time to do muscle-strengthening exercise	0.29 (0.16-0.53)	<0.000	0.31 (0.15-0.64)	0.002
I need expensive equipment to do muscle-strengthening exercise	0.86 (0.46-1.60)	0.627		
I feel I don't have enough knowledge about muscle-strengthening exercise to do it	0.20 (0.10-0.38)	<0.000	0.92 (0.36-2.36)	0.862
I do not have enough energy to do muscle-strengthening exercise	0.15 (0.08-0.27)	<0.000	0.27 (0.13-0.59)	0.001

Doing muscle-strengthening exercise is a low priority for me	0.08 (0.04-0.17)	<0.000	0.31 (0.12-0.79)	0.014
Belief factors				
I am scared that I will injure myself doing muscle-strengthening exercise	0.44 (0.22-0.87)	0.018	1.46 (0.52-4.10)	0.475
I would not enjoy doing muscle-strengthening exercise	0.02 (0.01-0.08)	<0.000	0.06 (0.01-0.23)	<0.000
I am not healthy enough to do muscle-strengthening exercise	0.54 (0.19-1.54)	0.246		
I do not feel comfortable doing muscle-strengthening exercise in a gym/fitness centre	0.26 (0.15-0.46)	<0.000	0.89 (0.39-2.00)	0.772
Confidence/Belief factors				
I have the physical capacity to complete muscle-strengthening exercises	2.86 (1.13-7.21)	0.026	0.77 (0.22-2.72)	0.684
I can complete muscle-strengthening exercises without the help of someone else (e.g. friend, trainer)	3.15 (1.77-5.61)	<0.000	1.26 (0.52-3.02)	0.611
If I don’t have access to a gym I can still do muscle-strengthening exercise (e.g. body weight exercises)	2.11 (1.18-3.77)	0.012	1.32 (0.59-2.99)	0.499
I have the skill and technique to complete muscle-strengthening exercises safely	5.92 (3.25-10.78)	<0.000	3.75 (1.51-9.31)	0.004

Note.

Missing data: Confidence 0.5% (n=2)

[a] Adjusted for: sex, age, work situation, education, self-rated health, body mass index (BMI).

Electronic Supplementary Material 14. Muscle-strengthening exercise behaviour influencing factors (outcome variable) of participants included in the analysis (unadjusted).

Factors	**Dependent variable**			
	Odds of being classified as meeting the muscle-strengthening guidelines (≥ 2 times/week + muscle groups)			
Statements about participation in muscle-strengthening exercise	**Single-factor models OR (95% CI)**		**Multiple-factor model OR (95% CI)**	
Perceptions		***p*-value**		***p*-value**
I don't have enough <u>time</u> to do muscle-strengthening exercise	0.26 (0.15-0.45)	<0.000	0.26 (0.13-0.51)	<0.000
I need <u>expensive equipment</u> to do muscle-strengthening exercise	0.94 (0.52-1.68)	0.821		
I feel I don't have enough <u>knowledge</u> about muscle-strengthening exercise to do it	0.14 (0.08-0.25)	<0.000	0.71 (0.28-1.80)	0.476
I do not have enough <u>energy</u> to do muscle-strengthening exercise	0.12 (0.07-0.20)	<0.000	0.20 (0.10-0.43)	<0.000
Doing muscle-strengthening exercise is a <u>low priority</u> for me	0.07 (0.04-0.14)	<0.000	0.26 (0.10-0.65)	0.004

Belief factors				
I am scared that I will injure myself doing muscle-strengthening exercise	0.31 (0.17-0.57)	<0.000	1.34 (0.51-3.52)	0.548
I would not enjoy doing muscle-strengthening exercise	0.03 (0.01-0.08)	<0.000	0.08 (0.02-0.27)	<0.000
I am not healthy enough to do muscle-strengthening exercise	0.24 (0.09-0.64)	0.004	12.38 (2.43-63.03)	0.002
I do not feel comfortable doing muscle-strengthening exercise in a gym/fitness centre	0.21 (0.12-0.35)	<0.000	0.92 (0.41-2.05)	0.830
Confidence/Belief factors				
I have the physical capacity to complete muscle-strengthening exercises	5.59 (2.44-12.82)	<0.000	1.06 (0.31-3.56)	0.930
I can complete muscle-strengthening exercises without the help of someone else (e.g. friend, trainer)	4.85 (2.88-8.18)	<0.000	1.38 (0.58-3.29)	0.463
If I don’t have access to a gym I can still do muscle-strengthening exercise (e.g. body weight exercises)	2.49 (1.46-4.25)	0.001	1.28 (0.58-2.81)	0.539
I have the skill and technique to complete muscle-strengthening exercises safely	8.67 (4.94-15.21)	<0.000	4.97 (2.06-11.98)	<0.000

Note.

Missing data: Confidence 0.5% (n=2).

Electronic Supplementary Material 15. Single-factor and multiple factor adjusted[a] odds ratios (OR) and their 95% confidence intervals (95% CI) for being classified as meeting the muscle-strengthening exercise guideline (frequency + muscle groups targeted + intensity) according to individual behavioural factors – for the total sample (n=435).

	Dependent variable **Odds of being classified as meeting the muscle-strengthening guidelines (≥ 2 times/week) + muscle groups + Moderate Intensity)**			
	Single-factor models AOR[a] (95% CI)		**Multiple-factor model AOR[a] (95% CI)**	
		***p*-value**		***p*-value**
Perceptions				
I don't have enough time to do muscle-strengthening exercise	0.36 (0.20-0.65)	0.001	0.38 (0.19-0.78)	0.008
I need expensive equipment to do muscle-strengthening exercise	1.12 (0.60-2.09)	0.717		
I feel I don't have enough knowledge about muscle-strengthening exercise to do it	0.19 (0.10-0.38)	<0.000	1.06 (0.41-2.74)	0.904
I do not have enough energy to do muscle-strengthening exercise	0.18 (0.10-0.33)	<0.000	0.36 (0.17-0.77)	0.009

Doing muscle-strengthening exercise is a low priority for me	0.08 (0.04-0.18)	<0.000	0.31 (0.12-0.79)	0.015
Belief factors				
I am scared that I will injure myself doing muscle-strengthening exercise	0.52 (0.26-1.04)	0.065		
I would not enjoy doing muscle-strengthening exercise	0.03 (0.01-0.10)	<0.000	0.08 (0.02-0.33)	<0.000
I am not healthy enough to do muscle-strengthening exercise	0.39 (0.13-1.22)	0.106		
I do not feel comfortable doing muscle-strengthening exercise in a gym/fitness centre	0.26 (0.14-0.46)	<0.000	0.77 (0.35-1.68)	0.507
Confidence/Belief factors				
I have the physical capacity to complete muscle-strengthening exercises	3.35 (1.25-8.99)	0.016	0.76 (0.21-2.75)	0.679
I can complete muscle-strengthening exercises without the help of someone else (e.g. friend, trainer)	4.41 (2.42-8.02)	<0.000	2.10 (0.92-4.83)	0.080
If I don't have access to a gym I can still do muscle-strengthening exercise (e.g. body weight exercises)	2.00 (1.12-3.59)	0.020	1.04 (0.47-2.33)	0.918
I have the skill and technique to complete muscle-strengthening exercises safely	6.67 (3.55-12.53)	<0.000	3.56 (1.45-8.72)	0.006

Note.

Missing data: Confidence 0.5% (n=2)

[a] Adjusted for: sex, age, work situation, education, self-rated health, body mass index (BMI).

Electronic Supplementary Material 16. Muscle-strengthening exercise behaviour influencing factors (outcome variable) of participants included in the analysis (unadjusted).

Factors	**Dependent variable**			
	Odds of being classified as meeting the muscle-strengthening guidelines (≥ 2 times/week + muscle groups + Moderate Intensity)			
Statements about participation in muscle-strengthening exercise	**Single-factor models OR (95% CI)**		**Multiple-factor model OR (95% CI)**	
Perceptions		***p*-value**		***p*-value**
I don't have enough time to do muscle-strengthening exercise	0.31 (0.18-0.54)	<0.000	0.36 (0.18-0.71)	0.003
I need expensive equipment to do muscle-strengthening exercise	1.19 (0.66-2.12)	0.564		
I feel I don't have enough knowledge about muscle-strengthening exercise to do it	0.13 (0.07-0.25)	<0.000	0.81 (0.32-2.05)	0.660
I do not have enough energy to do muscle-strengthening exercise	0.13 (0.08-0.23)	<0.000	0.28 (0.13-0.58)	0.001
Doing muscle-strengthening exercise is a low priority for me	0.07 (0.04-0.15)	<0.000	0.25 (0.10-0.63)	0.003
Belief factors				

I am <u>scared that I will injure</u> myself doing muscle-strengthening exercise	0.36 (0.20-0.66)	0.001	1.91 (0.73-5.00)	0.187
I would <u>not enjoy</u> doing muscle-strengthening exercise	0.04 (0.01-0.11)	<0.000	0.12 (0.04-0.43)	0.001
I am <u>not healthy enough</u> to do muscle-strengthening exercise	0.18 (0.06-0.51)	0.001	4.53 (0.99-20.64)	0.051
I do <u>not feel comfortable</u> doing muscle-strengthening exercise in a gym/fitness centre	0.21 (0.12-0.35)	<0.000	0.75 (0.35-1.61)	0.464
Confidence/Belief factors				
I have the <u>physical capacity</u> to complete muscle-strengthening exercises	6.50 (2.68-15.76)	<0.000	1.01 (0.29-3.50)	0.989
I can complete muscle-strengthening exercises <u>without the help</u> of someone else (e.g. friend, trainer)	6.54 (3.79-11.27)	<0.000	2.70 (1.22-5.94)	0.014
If I <u>don't have access</u> to a gym I can still do muscle-strengthening exercise (e.g. body weight exercises)	2.40 (1.41-4.07)	0.001	1.01 (0.47-2.17)	0.986
I have the <u>skill and technique</u> to complete muscle-strengthening exercises safely	9.89 (5.46-17.91)	<0.000	4.55 (1.93-10.75)	0.001

Note.

Missing data: Confidence 0.5% (n=2).

APPENDIX F: FULL SEARCH STRATEGY (STUDY 1)

Date	Search Strategy	Database	Number of results	Field	Notes
18.6.19	TI ((("strength training" or "resistance training" Or “muscle strengthening exercise” Or “muscle strengthening activity” Or “muscle strengthening activities” OR "weight training" Or "weight lifting" Or "muscle strengthening" Or "muscular strengthening" or "muscle training" Or "muscle toning" or "weight bearing training" Or "weight bearing strengthening" or toning or exercise or “resistance band” or “anaerobic” or “muscular conditioning” or “muscle strength” Or “elastic band exercise” OR “Weight-Bearing Exercise Program” OR “Weight-Lifting Exercise Program” OR “Weight-Lifting Strengthening Program” Or “resistance bands” Or “weight machines” OR “free weights” OR “handheld weights”) AND (“Public health surveillance” OR “Public health” OR surveillance OR Population OR Prevalence OR Correlate? OR Assess* OR Measure* OR “physical activity epidemiology” OR adherence OR Guideline?) AND Adult?)) OR AB ((("strength training" or "resistance training" Or “muscle strengthening exercise” Or “muscle strengthening activity” Or “muscle strengthening activities” OR "weight training" Or "weight lifting" Or "muscle strengthening" Or "muscular strengthening" or "muscle training" Or "muscle toning" or "weight bearing training" Or "weight bearing strengthening" or toning or exercise or “resistance band” or “anaerobic” or “muscular conditioning” or “muscle strength” Or “elastic band exercise” OR “Weight-Bearing Exercise Program” OR “Weight-Lifting Exercise Program” OR “Weight-Lifting Strengthening Program” Or “resistance bands” Or “weight machines” OR “free weights” OR “handheld weights”) AND (“Public health surveillance” OR “Public health” OR surveillance OR Population OR Prevalence OR Correlate? OR Assess* OR Measure* OR “physical activity epidemiology” OR adherence OR Guideline?) AND Adult?))	CINAHL	7,759	Title, Abstract	limited to English language
18.6.19	TI ((("strength training" or "resistance training" Or “muscle strengthening exercise” Or “muscle strengthening activity” Or “muscle strengthening activities” OR "weight training" Or "weight lifting" Or "muscle strengthening" Or "muscular strengthening" or "muscle training" Or "muscle toning" or "weight bearing training" Or "weight bearing strengthening" or toning or exercise or “resistance band” or “anaerobic” or “muscular conditioning” or “muscle strength” Or “elastic band exercise” OR “Weight-Bearing Exercise Program” OR “Weight-Lifting Exercise Program” OR “Weight-Lifting Strengthening Program” Or “resistance bands” Or “weight machines” OR “free weights” OR “handheld weights”) AND (“Public health surveillance” OR “Public health” OR surveillance OR Population OR Prevalence OR Correlate? OR Assess* OR Measure* OR “physical activity epidemiology” OR adherence OR Guideline?) AND Adult?)) OR AB ((("strength training" or "resistance training" Or “muscle strengthening exercise” Or “muscle strengthening activity” Or “muscle strengthening activities” OR "weight training" Or "weight lifting" Or "muscle strengthening" Or "muscular strengthening" or "muscle training" Or "muscle toning" or "weight bearing training" Or "weight bearing strengthening" or toning or exercise or “resistance band” or “anaerobic” or “muscular conditioning” or “muscle strength” Or “elastic band exercise” OR “Weight-Bearing Exercise Program” OR “Weight-Lifting Exercise Program” OR “Weight-Lifting Strengthening Program” Or “resistance bands” Or “weight machines” OR “free weights” OR “handheld weights”) AND (“Public health surveillance” OR “Public health” OR surveillance OR Population OR Prevalence OR Correlate? OR Assess* OR Measure* OR “physical activity epidemiology” OR adherence OR Guideline?) AND Adult?)) OR KW ((("strength training" or "resistance training" Or “muscle strengthening exercise” Or “muscle strengthening activity” Or “muscle strengthening activities” OR "weight training" Or "weight lifting" Or "muscle strengthening" Or "muscular strengthening" or "muscle training" Or "muscle toning" or "weight bearing training" Or "weight bearing strengthening" or toning or exercise or “resistance band” or “anaerobic” or “muscular conditioning” or “muscle strength” Or “elastic band exercise” OR “Weight-Bearing Exercise Program” OR “Weight-Lifting Exercise Program” OR “Weight-Lifting Strengthening Program” Or “resistance bands” Or “weight machines” OR “free weights” OR “handheld weights”) AND (“Public health surveillance” OR “Public health” OR surveillance OR Population OR Prevalence OR Correlate? OR Assess* OR Measure* OR “physical activity epidemiology” OR adherence OR Guideline?) AND Adult?))	EBSCOhost academic search ultimate	8,430	Title, Abstract	limited to English language

Date	Search Strategy	Database	Number of results	Field	Notes
18.6.19	TI ((("strength training" or "resistance training" Or “muscle strengthening exercise” Or “muscle strengthening activity” Or “muscle strengthening activities” OR "weight training" Or "weight lifting" Or "muscle strengthening" Or "muscular strengthening" or "muscle training" Or "muscle toning" or "weight bearing training" Or "weight bearing strengthening" or toning or exercise or “resistance band” or “anaerobic” or “muscular conditioning” or “muscle strength” Or “elastic band exercise” OR “Weight-Bearing Exercise Program” OR “Weight-Lifting Exercise Program” OR “Weight-Lifting Strengthening Program” Or “resistance bands” Or “weight machines” OR “free weights” OR “handheld weights”) AND (“Public health surveillance” OR “Public health” OR surveillance OR Population OR Prevalence OR Correlate? OR Assess* OR Measure* OR “physical activity epidemiology” OR adherence OR Guideline?) AND Adult?)) OR AB ((("strength training" or "resistance training" Or “muscle strengthening exercise” Or “muscle strengthening activity” Or “muscle strengthening activities” OR "weight training" Or "weight lifting" Or "muscle strengthening" Or "muscular strengthening" or "muscle training" Or "muscle toning" or "weight bearing training" Or "weight bearing strengthening" or toning or exercise or “resistance band” or “anaerobic” or “muscular conditioning” or “muscle strength” Or “elastic band exercise” OR “Weight-Bearing Exercise Program” OR “Weight-Lifting Exercise Program” OR “Weight-Lifting Strengthening Program” Or “resistance bands” Or “weight machines” OR “free weights” OR “handheld weights”) AND (“Public health surveillance” OR “Public health” OR surveillance OR Population OR Prevalence OR Correlate? OR Assess* OR Measure* OR “physical activity epidemiology” OR adherence OR Guideline?) AND Adult?)) OR KW ((("strength training" or "resistance training" Or “muscle strengthening exercise” Or “muscle strengthening activity” Or “muscle strengthening activities” OR "weight training" Or "weight lifting" Or "muscle strengthening" Or "muscular strengthening" or "muscle training" Or "muscle toning" or "weight bearing training" Or "weight bearing strengthening" or toning or exercise or “resistance band” or “anaerobic” or “muscular conditioning” or “muscle strength” Or “elastic band exercise” OR “Weight-Bearing Exercise Program” OR “Weight-Lifting Exercise Program” OR “Weight-Lifting Strengthening Program” Or “resistance bands” Or “weight machines” OR “free weights” OR “handheld weights”) AND (“Public health surveillance” OR “Public health” OR surveillance OR Population OR Prevalence OR Correlate? OR Assess* OR Measure* OR “physical activity epidemiology” OR adherence OR Guideline?) AND Adult?))	PsycINFO	4,425	Title, Abstract, Keyword	limited to English language
18.6.19	TITLE-ABS-KEY ((("strength training" OR "resistance training" OR "muscle strengthening exercise" OR "muscle strengthening activity" OR "muscle strengthening activities" OR "weight training" OR "weight lifting" OR "muscle strengthening" OR "muscular strengthening" OR "muscle training" OR "muscle toning" OR "weight bearing training" OR "weight bearing strengthening" OR toning OR exercise OR "resistance band" OR "anaerobic" OR "muscular conditioning" OR "muscle strength" OR "elastic band exercise" OR "Weight-Bearing Exercise Program" OR "Weight-Lifting Exercise Program" OR "Weight-Lifting Strengthening Program" OR calisthenics OR "resistance bands" OR "weight machines" OR "free weights" OR "handheld weights") AND ("Public health surveillance" OR "Public health" OR surveillance OR population OR prevalence OR correlate? OR assess* OR measure* OR "physical activity epidemiology" OR adherence OR guideline?) AND adult?)) AND (LIMIT-TO (LANGUAGE , "English"))	Scopus	25,871	Title, Abstract, Keyword	limited to English language

Date	Search Strategy	Database	Number of results	Field	Notes
18.6.19	TI ((("strength training" or "resistance training" Or "muscle strengthening exercise" Or "muscle strengthening activity" Or "muscle strengthening activities" OR "weight training" Or "weight lifting" Or "muscle strengthening" Or "muscular strengthening" or "muscle training" Or "muscle toning" or "weight bearing training" Or "weight bearing strengthening" or toning or exercise or "resistance band" or "anaerobic" or "muscular conditioning" or "muscle strength" Or elastic band exercise" OR "Weight-Bearing Exercise Program" OR "Weight-Lifting Exercise Program" OR "Weight-Lifting Strengthening Program" Or "resistance bands" Or "weight machines" OR "free weights" OR "handheld weights") AND ("Public health surveillance" OR "Public health" OR surveillance OR Population OR Prevalence OR Correlate? OR Assess* OR Measure* OR "physical activity epidemiology" OR adherence OR Guideline?) AND Adult?)) OR AB ((("strength training" or "resistance training" Or "muscle strengthening exercise" Or "muscle strengthening activity" Or "muscle strengthening activities" OR "weight training" Or "weight lifting" Or "muscle strengthening" Or "muscular strengthening" or "muscle training" Or "muscle toning" or "weight bearing training" Or "weight bearing strengthening" or toning or exercise or "resistance band" or "anaerobic" or "muscular conditioning" or "muscle strength" Or "elastic band exercise" OR "Weight-Bearing Exercise Program" OR "Weight-Lifting Exercise Program" OR "Weight-Lifting Strengthening Program" Or "resistance bands" Or "weight machines" OR "free weights" OR "handheld weights") AND ("Public health surveillance" OR "Public health" OR surveillance OR Population OR Prevalence OR Correlate? OR Assess* OR Measure* OR "physical activity epidemiology" OR adherence OR Guideline?) AND Adult?)) OR KW ((("strength training" or "resistance training" Or "muscle strengthening exercise" Or "muscle strengthening activity" Or "muscle strengthening activities" OR "weight training" Or "weight lifting" Or "muscle strengthening" Or "muscular strengthening" or "muscle training" Or "muscle toning" or "weight bearing training" Or "weight bearing strengthening" or toning or exercise or "resistance band" or "anaerobic" or "muscular conditioning" or "muscle strength" Or "elastic band exercise" OR "Weight-Bearing Exercise Program" OR "Weight-Lifting Exercise Program" OR "Weight-Lifting Strengthening Program" Or "resistance bands" Or "weight machines" OR "free weights" OR "handheld weights") AND ("Public health surveillance" OR "Public health" OR surveillance OR Population OR Prevalence OR Correlate? OR Assess* OR Measure* OR "physical activity epidemiology" OR adherence OR Guideline?) AND Adult?))	Sportdiscus	3,941	Title, Abstract, Keyword	limited to English language
18.6.19	ab((("strength training" or "resistance training" Or "muscle strengthening exercise" Or "muscle strengthening activity" Or "muscle strengthening activities" OR "weight training" Or "weight lifting" Or "muscle strengthening" Or "muscular strengthening" or "muscle training" Or "muscle toning" or "weight bearing training" Or "weight bearing strengthening" or toning or exercise or "resistance band" or "anaerobic" or "muscular conditioning" or "muscle strength" Or "elastic band exercise" OR "Weight-Bearing Exercise Program" OR "Weight-Lifting Exercise Program" OR "Weight-Lifting Strengthening Program" Or Calisthenics Or "resistance bands" Or "weight machines" OR "free weights" OR "handheld weights") AND ("Public health surveillance" OR "Public health" OR surveillance OR Population OR Prevalence OR Correlate? OR Assess* OR Measure* OR "physical activity epidemiology" OR adherence OR Guideline?) AND Adult?)) OR ti((("strength training" or "resistance training" Or "muscle strengthening exercise" Or "muscle strengthening activity" Or "muscle strengthening activities" OR "weight training" Or "weight lifting" Or "muscle strengthening" Or "muscular strengthening" or "muscle training" Or "muscle toning" or "weight bearing training" Or "weight bearing strengthening" or toning or exercise or "resistance band" or "anaerobic" or "muscular conditioning" or "muscle strength" Or "elastic band exercise" OR "Weight-Bearing Exercise Program" OR "Weight-Lifting Exercise Program" OR "Weight-Lifting Strengthening Program" Or Calisthenics Or "resistance bands" Or "weight machines" OR "free weights" OR "handheld weights") AND ("Public health surveillance" OR "Public health" OR surveillance OR Population OR Prevalence OR Correlate? OR Assess* OR Measure* OR "physical activity epidemiology" OR adherence OR Guideline?) AND Adult?)) OR diskw((("strength training" or "resistance training" Or "muscle strengthening exercise" Or "muscle strengthening activity" Or "muscle strengthening activities" OR "weight training" Or "weight lifting" Or "muscle strengthening" Or "muscular strengthening" or "muscle training" Or "muscle toning" or "weight bearing training" Or "weight bearing strengthening" or toning or exercise or "resistance band" or "anaerobic" or "muscular conditioning" or "muscle strength" Or "elastic band exercise" OR "Weight-Bearing Exercise Program" OR "Weight-Lifting Exercise Program" OR "Weight-Lifting Strengthening Program" Or Calisthenics Or "resistance bands" Or "weight machines" OR "free weights" OR "handheld weights") AND ("Public health surveillance" OR "Public health" OR surveillance OR Population OR Prevalence OR Correlate? OR Assess* OR Measure* OR "physical activity epidemiology" OR adherence OR Guideline?) AND Adult?))	Proquest	2,824	Title, Abstract, Keyword	limited to English language

Date	Search Strategy	Database	Number of results	Field	Notes
19.6.19	((("strength training" or "resistance training" Or “muscle strengthening exercise” Or “muscle strengthening activity” Or “muscle strengthening activities” OR "weight training" Or "weight lifting" Or "muscle strengthening" Or "muscular strengthening" or "muscle training" Or "muscle toning" or "weight bearing training" Or "weight bearing strengthening" or toning or exercise or “resistance band” or “anaerobic” or “muscular conditioning” or “muscle strength” Or “elastic band exercise” OR “Weight-Bearing Exercise Program” OR “Weight-Lifting Exercise Program” OR “Weight-Lifting Strengthening Program” Or Calisthenics Or “resistance bands” Or “weight machines” OR “free weights” OR “handheld weights”) AND (“Public health surveillance” OR “Public health” OR surveillance OR Population OR Prevalence OR Correlate? OR Assess* OR Measure* OR “physical activity epidemiology” OR adherence OR Guideline?) AND Adult?)) OR ti((("strength training" or "resistance training" Or “muscle strengthening exercise” Or “muscle strengthening activity” Or “muscle strengthening activities” OR "weight training" Or "weight lifting" Or "muscle strengthening" Or "muscular strengthening" or "muscle training" Or "muscle toning" or "weight bearing training" Or "weight bearing strengthening" or toning or exercise or “resistance band” or “anaerobic” or “muscular conditioning” or “muscle strength” Or “elastic band exercise” OR “Weight-Bearing Exercise Program” OR “Weight-Lifting Exercise Program” OR “Weight-Lifting Strengthening Program” Or Calisthenics Or “resistance bands” Or “weight machines” OR “free weights” OR “handheld weights”) AND (“Public health surveillance” OR “Public health” OR surveillance OR Population OR Prevalence OR Correlate? OR Assess* OR Measure* OR “physical activity epidemiology” OR adherence OR Guideline?) AND Adult?)) OR diskw((("strength training" or "resistance training" Or “muscle strengthening exercise” Or “muscle strengthening activity” Or “muscle strengthening activities” OR "weight training" Or "weight lifting" Or "muscle strengthening" Or "muscular strengthening" or "muscle training" Or "muscle toning" or "weight bearing training" Or "weight bearing strengthening" or toning or exercise or “resistance band” or “anaerobic” or “muscular conditioning” or “muscle strength” Or “elastic band exercise” OR “Weight-Bearing Exercise Program” OR “Weight-Lifting Exercise Program” OR “Weight-Lifting Strengthening Program” Or Calisthenics Or “resistance bands” Or “weight machines” OR “free weights” OR “handheld weights”) AND (“Public health surveillance” OR “Public health” OR surveillance OR Population OR Prevalence OR Correlate? OR Assess* OR Measure* OR “physical activity epidemiology” OR adherence OR Guideline?) AND Adult?))	Web of Science	33,422	TOPIC (Title, Abstract, Author Keywords)	limited to English language
	Total		**86,672**		

APPENDIX G: ONLINE SURVEY QUESTIONNAIRE (STUDY 4 AND STUDY 5)

Muscle-strengthening exercise: Assessing participation and influences

UNIVERSITY OF SOUTHERN QUEENSLAND AUSTRALIA | Research

Human Research Ethics Approval Number - H20REA233

Welcome to the research study!

Description

This project is being undertaken as part of a Doctor of Philosophy. The purpose of this project is to explore the participation characteristics of, and the possible influences on participation in, muscle-strengthening exercise conducted during leisure-time among English speaking free-living adults' aged 18 years and older, living in Australia or internationally. The research team requests your assistance because your participation in this research will help us to make a meaningful contribution to the existing body of knowledge on leisure-time muscle-strengthening exercise as a component of physical activity.

Participation

Your participation will involve the completion of an online questionnaire that will take approximately 20 minutes of your time. Questions will include (a) some basic information about you, (b) your health behaviours, (c) your participation in muscle-strengthening exercise, (d) factors influencing your participation (or non-participation) in muscle-strengthening exercise, (e) factors that may support muscle-strengthening exercise participation, (f) your confidence to participate in muscle-strengthening exercise, and (g) your participation in aerobic physical activities. You will also be invited to participate in additional survey activities; however, we will contact you later about this.

Your participation in this project is entirely voluntary. If you do not wish to take part, you are not obliged to. If you decide to take part and later change your mind, you are free to withdraw from the project at any stage. You may also request that any data collected about you be withdrawn and confidentially destroyed, however, you will be unable to withdraw data collected about yourself after the data has been analysed. If you do wish to withdraw from this project or withdraw data collected about you, please contact the Research Team (contact details at the bottom of this form). Your decision whether you take part, do not take part, or to take part and then withdraw, will in no way impact your current or future relationship with the University of Southern Queensland.

Expected Benefits

It is expected that this project will not directly benefit you. However, it may benefit the future assessment of leisure-time muscle-strengthening exercise and physical activity in large population public health surveillance.

Risks

In participating in the questionnaire, there are minimal risks such as thinking about your personal health and health behaviours. Sometimes thinking about the sorts of issues raised in the questionnaire can create some uncomfortable or distressing feelings. If you need to talk to someone about this immediately, please contact Beyond Blue at https://www.beyondblue.org.au/get-support/get-immediate-support or on 1300 22 4636. You may also wish to consider consulting your General Practitioner (GP) for additional support.

Privacy and Confidentiality

All comments and responses will be treated confidentially unless required by law. The names of individual persons are not required in any of the responses; however, you will be asked to provide your contact details if you indicate that you would be willing to participate in additional survey activities as part of this project. The results of the study will be published in a journal, although only non-identifiable data will be reported. Participant data will be made available for future research purposes, for similar projects, however, it too will be non-identifiable. Electronic data will be stored on two password-protected computers that only the researchers may access. Participants may request a summary report by contacting the primary researcher at jane.shakespear-druery@usq.edu.au. Any data collected as a part of this project will be stored securely as per the University of Southern Queensland's Research Data Management policy.

Questions or Further Information about the Project

Please refer to the Research Team contact details to have any questions answered or to request further information about this project.

Research Team Contact Details

Principal Investigator Details	Supervisor Details
Mrs. Jane Shakespear-Druery	Dr. Jason Bennie

[redacted]

Supervisor Details	Supervisor Details
Dr. Katrien De Cocker	Professor Stuart Biddle

[redacted]

Concerns or Complaints Regarding the Conduct of the Project

If you have any concerns or complaints about the ethical conduct of the project, you may contact the University of Southern Queensland Manager of Research Integrity and Ethics on +61 7 4631 1839 or email researchintegrity@usq.edu.au. The Manager of Research Integrity and Ethics is not connected with the research project and can facilitate a resolution to your concern in an unbiased manner.

Thank you for taking the time to help with this research project.

Kindly note that the survey will display best on a laptop or desktop computer. Some features may be less compatible for use on a mobile device.

Statement of Consent

By clicking the **next** button below, you are indicating that you:

- Have read and understood the information regarding this project.
- Have had any questions answered to your satisfaction.
- Understand that if you have any additional questions you can contact the research team.
- Are over 18 years of age.
- Understand that any data collected may be used in future research activities related to this field.
- Agree to participate in the project.

There are 35 questions in this survey.

Section 1: About you

The first set of questions will provide us with some basic information about you.

What was your **age** at your last birthday? *

Your answer must be between 18 and 110

Please write your answer here:

Please enter only whole numbers.

What was your **sex** at birth? *

Please choose **only one** of the following:

- Female
- Male

Which **country** do you **usually** live in? *

Please choose **only one** of the following:

- ◯ Afghanistan
- ◯ Albania
- ◯ Algeria
- ◯ Andorra
- ◯ Angola
- ◯ Antigua and Barbuda
- ◯ Argentina
- ◯ Armenia
- ◯ Australia
- ◯ Austria
- ◯ Azerbaijan
- ◯ Bahamas
- ◯ Bahrain
- ◯ Bangladesh
- ◯ Barbados
- ◯ Belarus
- ◯ Belgium
- ◯ Belize
- ◯ Benin
- ◯ Bhutan
- ◯ Bolivia
- ◯ Bosnia and Herzegovina
- ◯ Botswana
- ◯ Brazil
- ◯ Brunei
- ◯ Bulgaria
- ◯ Burkina Faso
- ◯ Burundi
- ◯ Côte d'Ivoire
- ◯ Cabo Verde
- ◯ Cambodia
- ◯ Cameroon

- Canada
- Central African Republic
- Chad
- Chile
- China
- Colombia
- Comoros
- Congo (Congo-Brazzaville)
- Costa Rica
- Croatia
- Cuba
- Cyprus
- Czechia (Czech Republic)
- Democratic Republic of the Congo
- Denmark
- Djibouti
- Dominica
- Dominican Republic
- Ecuador
- Egypt
- El Salvador
- Equatorial Guinea
- Eritrea
- Estonia
- Eswatini (fmr. "Swaziland")
- Ethiopia
- Fiji
- Finland
- France
- Gabon
- Gambia
- Georgia
- Germany
- Ghana
- Greece

- Grenada
- Guatemala
- Guinea
- Guinea-Bissau
- Guyana
- Haiti
- Holy See
- Honduras
- Hungary
- Iceland
- India
- Indonesia
- Iran
- Iraq
- Ireland
- Israel
- Italy
- Jamaica
- Japan
- Jordan
- Kazakhstan
- Kenya
- Kiribati
- Kuwait
- Kyrgyzstan
- Laos
- Latvia
- Lebanon
- Lesotho
- Liberia
- Libya
- Liechtenstein
- Lithuania
- Luxembourg
- Madagascar

- ◯ Malawi
- ◯ Malaysia
- ◯ Maldives
- ◯ Mali
- ◯ Malta
- ◯ Marshall Islands
- ◯ Mauritania
- ◯ Mauritius
- ◯ Mexico
- ◯ Micronesia
- ◯ Moldova
- ◯ Monaco
- ◯ Mongolia
- ◯ Montenegro
- ◯ Morocco
- ◯ Mozambique
- ◯ Myanmar (formerly Burma)
- ◯ Namibia
- ◯ Nauru
- ◯ Nepal
- ◯ Netherlands
- ◯ New Zealand
- ◯ Nicaragua
- ◯ Niger
- ◯ Nigeria
- ◯ North Korea
- ◯ North Macedonia
- ◯ Norway
- ◯ Oman
- ◯ Pakistan
- ◯ Palau
- ◯ Palestine State
- ◯ Panama
- ◯ Papua New Guinea
- ◯ Paraguay

- Peru
- Philippines
- Poland
- Portugal
- Qatar
- Romania
- Russia
- Rwanda
- Saint Kitts and Nevis
- Saint Lucia
- Saint Vincent and the Grenadines
- Samoa
- San Marino
- Sao Tome and Principe
- Saudi Arabia
- Senegal
- Serbia
- Seychelles
- Sierra Leone
- Singapore
- Slovakia
- Slovenia
- Solomon Islands
- Somalia
- South Africa
- South Korea
- South Sudan
- Spain
- Sri Lanka
- Sudan
- Suriname
- Sweden
- Switzerland
- Syria
- Tajikistan

- ◯ Tanzania
- ◯ Thailand
- ◯ Timor-Leste
- ◯ Togo
- ◯ Tonga
- ◯ Trinidad and Tobago
- ◯ Tunisia
- ◯ Turkey
- ◯ Turkmenistan
- ◯ Tuvalu
- ◯ Uganda
- ◯ Ukraine
- ◯ United Arab Emirates
- ◯ United Kingdom
- ◯ United States of America
- ◯ Uruguay
- ◯ Uzbekistan
- ◯ Vanuatu
- ◯ Venezuela
- ◯ Vietnam
- ◯ Yemen
- ◯ Zambia
- ◯ Zimbabwe

Which **state or territory** do you **usually** live in? *

Only answer this question if the following conditions are met:
Answer was 'Australia' at question '4 [Q03]' (Which country do you usually live in?)

Please choose **only one** of the following:

- ◯ Western Australia
- ◯ Northern Territory
- ◯ South Australia
- ◯ Queensland
- ◯ New South Wales
- ◯ Australian Capital Territory
- ◯ Victoria
- ◯ Tasmania

What **best** describes the **region** you live in? *

Please choose **only one** of the following:

- ◯ Urban - capital cities or metropolitan centres with a population of >100,000
- ◯ Regional - large rural centres with a population between 5,000-99,000
- ◯ Remote - remote centres with a population of <5,000

Which of the following descriptions best applies to your **usual 'work'** situation?

*

Please choose **only one** of the following:

- ◯ Going to school or university full-time
- ◯ In paid employment or self-employed
- ◯ Doing unpaid work for a business that you own, or that a relative owns
- ◯ Permanently unable to work because of long-term sickness or disability
- ◯ Retired from paid work
- ◯ Looking after home or family
- ◯ Other ______

How many **hours** do you **work during a usual week**? *

Only answer this question if the following conditions are met:
Answer was ' In paid employment or self-employed ' *or* ' Doing unpaid work for a business that you own, or that a relative owns' at question '7 [Q06]' (Which of the following descriptions best applies to your usual 'work' situation?)

❗ Your answer must be between 1 and 168
Please write your answer here:

______

What is your **total yearly income** before tax? *

Only answer this question if the following conditions are met:
Answer was 'Australia' at question '4 [Q03]' (Which country do you usually live in?)

Please choose **only one** of the following:

- ◯ Under $20,000
- ◯ $20,000 - $50,000
- ◯ $50,000 - $80,000
- ◯ $80,000 - $100,000
- ◯ More than $100,000
- ◯ I'd prefer not to say

What is your highest level of education completed? *

Please choose **only one** of the following:

- ◯ Never attended school
- ◯ Primary school
- ◯ Some high school
- ◯ Year 12 or equivalent
- ◯ Technical or trade school certificate/apprenticeship
- ◯ University or tertiary qualification (Undergraduate)
- ◯ University or tertiary qualification (Postgraduate/Masters/Doctorate)
- ◯ Other ____________________

What is your marital status? *

Please choose **only one** of the following:

- ◯ Married
- ◯ Defacto
- ◯ Separated / Divorced
- ◯ Widowed
- ◯ Never married

Section 2: The next questions are about your own health behaviours.

In this section, we ask questions about your health and health behaviours to get an idea of your health and lifestyle.

About how **tall** are you, without shoes, in centimetres (cm) **or** feet (ft) and inches (in)? *

❶ Comment only when you choose an answer.
❶ Please select one answer
Please choose all that apply and provide a comment:

☐ in centimetres (cm)

☐ in feet (ft) and inches (in)

About how much do you **weigh**, without shoes and heavy clothes, in kilograms (kg) **or** pounds (lb) and ounces (oz)? *

❶ Comment only when you choose an answer.
❶ Please select one answer
Please choose all that apply and provide a comment:

☐ in kilograms (kg)

☐ in pounds (lb) and ounces (oz)

In a **usual week,** how often do you usually drink alcohol (e.g., beer, wine, or spirits)? *

Please choose **only one** of the following:

- ◯ Once a week
- ◯ 3 times or fewer times a week
- ◯ 4 times or 5 times a week
- ◯ Every day
- ◯ I do not drink alcohol

What is your smoking status? *

❗ Choose one of the following answers
Please choose **only one** of the following:

- ◯ Current smoker (daily)
- ◯ Current smoker (some days)
- ◯ Former smoker
- ◯ Never smoked

How would you rate your **general health**? *

Please choose **only one** of the following:

- ◯ Excellent
- ◯ Very good
- ◯ Good
- ◯ Fair
- ◯ Poor

Section 3: The next questions are about your participation in muscle-strengthening exercise

The questions within this section relate to the physical activities that you perform during your **leisure-time** only. When we say leisure-time we mean your free-time and the activities that you perform that are NOT done as part of your work/job, transportation (moving to a different location), or as a part of household activities (chores).

The types of **muscle-strengthening exercise** modes that we are interested in include;

- Use of **weight machines** (typically in a gym or fitness centre)
- **Bodyweight** exercises (including push-ups, sit-ups)
- **Resistance** exercises (using resistance bands or free weights like dumbbells)
- **Holistic** exercises (including Yoga, Tai-Chi and Pilates)

There are no right or wrong responses to the following questions, we are interested in your open and honest feedback.

Do you **usually** do muscle-strengthening exercise? *

Please choose **only one** of the following:

◯ Yes

◯ No

The types of muscle-strengthening exercises include;

- Using of weight machines to do e.g. leg press, chest press, lat pulldown (typically in a gym or fitness centre)
- Body weight exercises (including push-ups, sit-ups)
- Resistance exercises (using resistance bands or free weights like dumbbells)
- Holistic exercises (including Yoga, Tai-Chi and Pilates)

Please answer the following question - I do **muscle-strengthening exercise** for:

*

Only answer this question if the following conditions are met:
Answer was 'Yes' at question '17 [Q16]' (Do you usually do muscle-strengthening exercise?)

Please choose **all** that apply:

☐ General fitness and health

☐ Strength-related sports (e.g. weight/power lifting)

☐ Appearance purposes (e.g. body-building/sculpting)

☐ Physical therapy (e.g. rehabilitation from injury)

☐ Conditioning for sports performance

☐ Other:

Please select **all** that apply.

How many **days**, in a **usual week**, do you do **muscle-strengthening exercise**? *

Only answer this question if the following conditions are met:
Answer was 'Yes' at question '17 [Q16]' (Do you usually do muscle-strengthening exercise?)

Please choose **only one** of the following:

- ◯ none
- ◯ 1 day in a usual week
- ◯ 2 days in a usual week
- ◯ 3 days in a usual week
- ◯ 4 days in a usual week
- ◯ 5 days in a usual week
- ◯ 6 days in a usual week
- ◯ 7 days in a usual week

The types of muscle-strengthening exercises include;

- Using of **weight machines** to do e.g. leg press, chest press, lat pulldown (typically in a gym or fitness centre environment)
- **Body weight** exercises (including push-ups, sit-ups)
- **Resistance** exercises (using resistance bands or free weight like dumbbells)
- **Holistic** exercises (including Yoga, Tai-Chi and Pilates)

How long have you been doing muscle-strengthening exercise each week? *

Only answer this question if the following conditions are met:
Answer was 'Yes' at question '17 [Q16]' (Do you usually do muscle-strengthening exercise?)

Please choose **only one** of the following:

- ◯ I have been doing muscle-strengthening exercise **irregularly** (e.g. I do it some weeks and not others)
- ◯ I have been doing muscle-strengthening exercise each week for **less than** 6 months
- ◯ I have been doing muscle-strengthening exercise each week for **6 months or more**

In a **usual** week please indicate a) how often you do, and b) how long you spend, doing each of the following types of **muscle-strengthening exercise**.

*

Only answer this question if the following conditions are met:
Answer was 'Yes' at question '17 [Q16]' (Do you usually do muscle-strengthening exercise?)

Please choose the appropriate response for each item:

	Number of DAYS in a usual week.								Minutes spent in a usual session.							
	0 days	1 day	2 days	3 days	4 days	5 days	6 days	7 days	0 minutes	less than 10 minutes	10 - 20 minutes	21 - 30 minutes	31 - 40 minutes	41 - 50 minutes	51 - 60 minutes	more than 60 minutes
Use weight machines (e.g. leg press, chest press, lat pulldown)	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯
Body weight exercises (e.g. push-ups, sit-ups)	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯
Use resistance bands or free weights (e.g. dumbbells)	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯
Holistic exercises (including Yoga, Tai-chi and Pilates)	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯

✓ Please choose...
0 days
1 day
2 days
3 days
4 days
5 days
6 days
7 days

✓ Please choose...
0 minutes
less than 10 minutes
10 - 20 minutes
21 - 30 minutes
31 - 40 minutes
41 - 50 minutes
51 - 60 minutes
more than 60 minutes

In a **usual** week please indicate how many **sets** and how many **repetitions** you do of each of the following types of **muscle-strengthening exercises**. *

Only answer this question if the following conditions are met:
Answer was 'Yes' at question '17 [Q16]' (Do you usually do muscle-strengthening exercise?)

Please choose the appropriate response for each item:

	Number of SETS in a usual session.											**Number of REPETITIONS in a usual session.**						
	none	**1 set**	**2 sets**	**3 sets**	**4 sets**	**5 sets**	**6 sets**	**7 sets**	**8 sets**	**9 sets**	**10 or more sets**	**None**	**1 to 3 repetitions**	**3 to 6 repetitions**	**6 to 10 repetitions**	**10 to 15 repetitions**	**15 to 25 repetitions**	**more than 25 repetitions**
Use weight machines (e.g. leg press, chest press, lat pulldown)	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
Body weight exercises (e.g. push-ups, sit-ups)	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
Use resistance bands or free weights (e.g. dumbbells)	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○

✓ Please choose...
none
1 set
2 sets
3 sets
4 sets
5 sets
6 sets
7 sets
8 sets
9 sets
10 or more sets

✓ Please choose...
None
1 to 3 repetitions
3 to 6 repetitions
6 to 10 repetitions
10 to 15 repetitions
15 to 25 repetitions
more than 25 repetitions

In a **usual** week please indicate which **muscle groups** you use when you do each of the following types of **muscle-strengthening exercises**.

If you <u>do not do</u> the muscle-strengthening exercise, please select **NO**.

*

Only answer this question if the following conditions are met:
Answer was 'Yes' at question '17 [Q16]' (Do you usually do muscle-strengthening exercise?)

Please choose the appropriate response for each item:

	Using WEIGHT MACHINES in a usual session.			Doing BODY WEIGHT exercises (e.g. push-ups, sit-ups) in a usual session.	
	No	Yes		No	Yes
Legs (e.g. squats, lunges, bridges)	○	○		○	○
Hips (e.g. side leg raises, bridges)	○	○		○	○
Back (e.g. lat pulldown, bent-over row)	○	○		○	○
Abdomen (e.g. crunches, sit-ups)	○	○		○	○
Chest (e.g. bench press, push-ups)	○	○		○	○
Shoulders (e.g. lat raise, overhead press)	○	○		○	○
Arms (e.g. bicep curl, tricep dips)	○	○		○	○

In a **usual** week please indicate which **muscle groups** you use when you do each of the following types of muscle-strengthening exercises.

If you do not do the muscle-strengthening exercise, please select **NO**.

*

Only answer this question if the following conditions are met:
Answer was 'Yes' at question '17 [Q16]' (Do you usually do muscle-strengthening exercise?)

Please choose the appropriate response for each item:

	Using RESISTANCE BANDS or FREE WEIGHTS (e.g. dumbbells) in a usual session.			Doing HOLISTIC EXERCISES (including Yoga, Tai-chi and Pilates) in a usual session.	
	No	**Yes**		**No**	**Yes**
Legs (e.g. squats, lunges, bridges)	○	○		○	○
Hips (e.g. side leg raises, bridges)	○	○		○	○
Back (e.g. lat pulldown, bent-over row)	○	○		○	○
Abdomen (e.g. crunches, sit-ups)	○	○		○	○
Chest (e.g. bench press, push-ups)	○	○		○	○
Shoulders (e.g. lat raise, overhead press)	○	○		○	○
Arms (e.g. bicep curl, tricep dips)	○	○		○	○

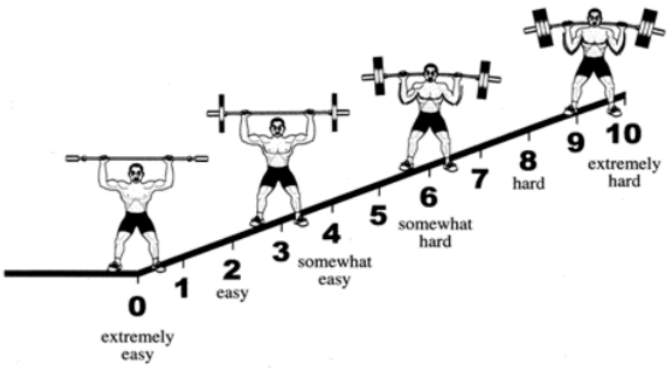
For each of the following types of **muscle-strengthening exercises**, please say

a) How hard (level of intensity) you **usually** exercise, and

b) Where you **usually** go (location) to do these exercises

How hard you feel you are exercising can also be called **intensity** or **rating of perceived effort**. The level of intensity is often assessed on a 0 to 10 scale with 0 representing “extremely easy” and 10 representing “extremely hard”.

Using the picture below as a guide on a scale of 0-10 please indicate how hard you feel you exercise when you are doing muscle-strengthening exercise.



(Robertson et al., 2003)

*

Only answer this question if the following conditions are met:
Answer was 'Yes' at question '17 [Q16]' (Do you usually do muscle-strengthening exercise?)

Please choose the appropriate response for each item:

	Level of INTENSITY in a usual session.													LOCATION in a usual session.					
	Not applicable	0 Extremely easy	1	2 Easy	3	4 Somewhat easy	5	6 Somewhat hard	7	8 Hard	9	10 Extremely hard		Not applicable	Public community health and fitness facility	Private community Health and fitness facility	University Health and fitness facility	At home	Outdoors (e.g. in a park)

	Level of INTENSITY in a usual session.												LOCATION in a usual session.					
	Not applicable	0 Extremely easy	1	2 Easy	3	4 Somewhat easy	5	6 Somewhat hard	7	8 Hard	9	10 Extremely hard	Not applicable	Public community health and fitness facility	Private community health and fitness facility	Worksite health and fitness facility	At home	Outdoors (e.g. in a park)
Use weight machines (e.g. leg press, chest press, lat pulldown)	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯
Body weight exercises (e.g. push-ups, sit-ups)	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯
Use resistance bands or free weights (e.g. dumbbells)	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯
Holistic exercises (including Yoga, Tai-chi and Pilates)	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯

✓ Please choose...
- Not applicable
- 0 Extremely easy
- 1
- 2 Easy
- 3
- 4 Somewhat easy
- 5
- 6 Somewhat hard
- 7
- 8 Hard
- 9
- 10 Extremely hard

✓ Please choose...
- Not applicable
- Public community health and fitness facility
- Private community health and fitness facility
- Worksite health and fitness facility
- At home
- Outdoors (e.g. in a park)

You have told us that you usually do muscle-strengthening exercise at a community or worksite health and fitness facility. Can you please let us know how far away the facility is from your usual residence? *

Only answer this question if the following conditions are met:
-------- Scenario 1 --------
Answer was 'Public community health and fitness facility' *or* 'Private community health and fitness facility' *or* 'Worksite health and fitness facility' at question '25 [Q24]' (For each of the following types of muscle-strengthening exercises, please say a) How hard (level of intensity) you usually exercise, and b) Where you usually go (location) to do these exercises How hard you feel you are exercising can also be called intensity or rating of perceived effort. The level of intensity is often assessed on a 0 to 10 scale with 0 representing "extremely easy" and 10 representing "extremely hard". Using the picture below as a guide on a scale of 0-10 please indicate how hard you feel you exercise when you are doing muscle-strengthening exercise. (Robertson et al., 2003) (**Holistic** exercises (including Yoga, Tai-chi and Pilates) Label LOCATION in a usual session.))
-------- or Scenario 2 --------
Answer was 'Worksite health and fitness facility' *or* 'Private community health and fitness facility' *or* 'Public community health and fitness facility' at question '25 [Q24]' (For each of the following types of muscle-strengthening exercises, please say a) How hard (level of intensity) you usually exercise, and b) Where you usually go (location) to do these exercises How hard you feel you are exercising can also be called intensity or rating of perceived effort. The level of intensity is often assessed on a 0 to 10 scale with 0 representing "extremely easy" and 10 representing "extremely hard". Using the picture below as a guide on a scale of 0-10 please indicate how hard you feel you exercise when you are doing muscle-strengthening exercise. (Robertson et al., 2003) (Use **resistance** bands or free weights (e.g. dumbbells) Label LOCATION in a usual session.))
-------- or Scenario 3 --------
Answer was 'Worksite health and fitness facility' *or* 'Private community health and fitness facility' *or* 'Public community health and fitness facility' at question '25 [Q24]' (For each of the following types of muscle-strengthening exercises, please say a) How hard (level of intensity) you usually exercise, and b) Where you usually go (location) to do these exercises How hard you feel you are exercising can also be called intensity or rating of perceived effort. The level of intensity is often assessed on a 0 to 10 scale with 0 representing "extremely easy" and 10 representing "extremely hard". Using the picture below as a guide on a scale of 0-10 please indicate how hard you feel you exercise when you are doing muscle-strengthening exercise. (Robertson et al., 2003) (**Body weight** exercises (e.g. push-ups, sit-ups) Label LOCATION in a usual session.))
-------- or Scenario 4 --------
Answer was 'Public community health and fitness facility' *or* 'Private community health and fitness facility' *or* 'Worksite health and fitness facility' at question '25 [Q24]' (For each of the following types of muscle-strengthening exercises, please say a) How hard (level of intensity) you usually exercise, and b) Where you usually go (location) to do these exercises How hard you feel you are exercising can also be called intensity or rating of perceived effort. The level of intensity is often assessed on a 0 to 10 scale with 0 representing "extremely easy" and 10 representing "extremely hard". Using the picture below as a guide on a scale of 0-10 please indicate how hard you feel you exercise when you are doing muscle-strengthening exercise. (Robertson et al., 2003) (Use **weight machines** (e.g. leg press, chest press, lat pulldown) Label LOCATION in a usual session.))

Please choose **only one** of the following:

- ◯ less than 5 km
- ◯ 5 - 9 km
- ◯ 10 - 14 km
- ◯ 15 - 20 km
- ◯ more than 20 km

Section 4: Factors influencing leisure-time muscle-strengthening exercise.

We are now interested in understanding the '*type of things*' that may motivate you to do muscle-strengthening exercise, and also the '*type of things*' that may be barriers to you doing (or doing more) muscle-strengthening exercise.

Please indicate how to what extent you agree or disagree with the following questions. *

Only answer this question if the following conditions are met:
Answer was 'Yes' at question '17 [Q16]' (Do you usually do muscle-strengthening exercise?)

Please choose the appropriate response for each item:

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
I do muscle-strengthening exercise to improve my health and well-being	○	○	○	○	○
I do muscle-strengthening exercise to improve my appearance	○	○	○	○	○
I do muscle-strengthening exercise to be with others	○	○	○	○	○
I do muscle-strengthening exercise to improve existing skills	○	○	○	○	○
I do muscle-strengthening exercise because I enjoy this activity	○	○	○	○	○

How true are the following statements for you? *

Please choose the appropriate response for each item:

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
I don't have enough time to do muscle-strengthening exercise	○	○	○	○	○
I need expensive equipment to do muscle-strengthening exercise	○	○	○	○	○
I feel I don't have enough knowledge about muscle-strengthening exercise to do it	○	○	○	○	○
I do not have enough energy to do muscle-strengthening exercise	○	○	○	○	○
Doing muscle-strengthening exercise is a low priority for me	○	○	○	○	○

How true are the following statements for you?

*

Please choose the appropriate response for each item:

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
I am <u>scared</u> that I will injure myself doing muscle-strengthening exercise	○	○	○	○	○
I would <u>not enjoy</u> doing muscle-strengthening exercise	○	○	○	○	○
I am <u>not healthy</u> enough to do muscle-strengthening exercise	○	○	○	○	○
I do <u>not feel comfortable</u> doing muscle-strengthening exercise in a gym/fitness centre	○	○	○	○	○

Section 5: Support for doing muscle-strengthening exercise during leisure-time.

These questions are about "*what sort of things*" may help or support or facilitate you to do (or do more) muscle-strengthening exercise activities during your leisure-time.

How useful would the following be in helping you to do muscle-strengthening exercise? *

Please choose the appropriate response for each item:

	Not at all useful to me	Somewhat useful to me	Very useful to me	I already have this
If I had access to equipment at home	○	○	○	○
If I had access to facilities (e.g. gym or fitness centre)	○	○	○	○
If I had access to outdoor equipment (e.g. equipment in a community park)	○	○	○	○
If I had access to fitness trainers to help me	○	○	○	○
If I had access to facilities where I work	○	○	○	○
If I had access to a subsidised gym membership	○	○	○	○
If I had access to educational materials (e.g. leaflets or brochures)	○	○	○	○
If I had access to multi-media/smartphone applications	○	○	○	○
If I had access to an online or virtual trainer	○	○	○	○
If I had a workout partner	○	○	○	○

Section 6: Muscle-strengthening exercise confidence

This section of questions refers to your perception of your confidence in undertaking muscle-strengthening exercise.

Please indicate how likely you agree or disagree with the following questions. *

Please choose the appropriate response for each item:

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
I have the physical capacity to complete muscle-strengthening exercises	○	○	○	○	○
I can complete muscle-strengthening exercises without the help of someone else (e.g. friend, trainer)	○	○	○	○	○
If I don't have access to a gym I can still do muscle-strengthening exercise (e.g. body weight exercises)	○	○	○	○	○
I have the skill and technique to complete muscle-strengthening exercises safely	○	○	○	○	○

Section 7: The next questions are about your participation in aerobic physical activities

The questions in this section are about any other physical activities (e.g., walking, jogging, cycling, gentle swimming, vigorous gardening) that you do in a **usual** week.

In a **usual** week please indicate how often you do, and how long you spend, doing each of the following types of aerobic physical activities. *

Please choose the appropriate response for each item:

	Number of DAYS in a usual week.								Minutes spent in a usual session.						
	0 days	1 day	2 days	3 days	4 days	5 days	6 days	7 days	None	10 - 30 minutes	31 - 60 minutes	61 - 90 minutes	91 - 120 minutes	121 - 150 minutes	more than 150 minutes
Walk continuously, for at least 10 minutes, for recreation, exercise, or to get or from places?	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
Doing vigorous gardening, heavy work around the house or yard, which makes you breathe harder or huff and puff?	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
<u>Excluding household chores, gardening, or yard work</u> - Doing any vigorous physical activity, which makes you breathe harder or puff and pant? (e.g., jogging, cycling, aerobics, competitive tennis)	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
Do other more moderate activities that have not already mentioned? (e.g., gentle swimming, social tennis, golf)	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○

✓ Please choose...
0 days
1 day
2 days
3 days
4 days
5 days
6 days
7 days

✓ Please choose...
None
10 - 30 minutes
31 - 60 minutes
61 - 90 minutes
91 - 120 minutes
121 - 150 minutes
more than 150 minutes

Section 8: The end of the survey

Thank you for taking the time to complete this survey. Your responses will provide us with valuable information that may be used to inform the future assessment of muscle-strengthening exercise both within Australia and internationally.

Is there anything else that you would like to say about **muscle-strengthening exercise**?

Please write your answer here:

The second part of our research is to establish the reliability and validity of the survey that you have just completed. In order to be able to do this, we are asking you if you would like to participate. There is no obligation for you to do this and your decision is purely voluntary.

If you would like to help us, please include your name **and** contact details (email and phone) below.

*

❶ Comment only when you choose an answer.

Please choose all that apply and provide a comment:

☐ My name is:

☐ My email address is:

☐ My best contact number is:

☐ I do not wish to take part in the second part of this research

Once we have gathered all the data, we will make available a summary of the results.

If you have any further comments or questions, please include them below.

Please write your answer here:

Thank you kindly for taking time to help with this research.

If you have indicated that you would like to help us in the second part of our research, **thank you!**

The second part of our research aims to establish the reliability and validity of the questionnaire that you have just completed (specifically in relation to the questions about muscle-strengthening exercise).

Next Steps

- In 7 to 10 days' time, you will receive an email/text message containing a link that will enable you to complete the follow-up phase of our research.

11.03.2021 – 16:17

Submit your survey.
Thank you for completing this survey.

APPENDIX H: ONLINE SURVEY QUESTIONNAIRE - RELIABILITY (STUDY 4 AND STUDY 5)

Muscle-strengthening exercise: Assessing participation and influences (Follow-up Testing)

Human Research Ethics Approval Number - H20REA233

Welcome to the research study follow-up testing!

Participation

Your participation will involve the completion of an online questionnaire that will take approximately 10 minutes of your time. Questions will include (a) some basic information about you, (b) your participation in muscle-strengthening exercise, (c) factors influencing your participation (or non-participation) in muscle-strengthening exercise, (d) factors that may support muscle-strengthening exercise participation, and (e) your confidence to participate in muscle-strengthening exercise.

Your continued participation in this project is entirely voluntary. If you do not wish to take part, you are not obliged to. If you decide to take part and later change your mind, you are free to withdraw from the project at any stage. You may also request that any data collected about you be withdrawn and confidentially destroyed, however, you will be unable to withdraw data collected about yourself after the data has been analysed. If you do wish to withdraw from this project or withdraw data collected about you, please contact the Research Team (contact details at the bottom of this form). Your decision whether you take part, do not take part, or to take part and then withdraw, will in no way impact your current or future relationship with the University of Southern Queensland.

Research Team Contact Details

Principal Investigator Details

Mrs. Jane Shakespear-Druery

Email: Jane.Shakespear-Druery@usq.edu.au

Telephone: +61 7 3470 4136

Concerns or Complaints Regarding the Conduct of the Project

If you have any concerns or complaints about the ethical conduct of the project, you may contact the University of Southern Queensland Manager of Research Integrity and Ethics on +61 7 4631 1839 or email researchintegrity@usq.edu.au. The Manager of Research Integrity and Ethics is not connected with the research project and can facilitate a resolution to your concern in an unbiased manner.

Thank you for taking the time to help with this research project.

Kindly note that the survey will display best on a laptop or desktop computer. Some features may be less compatible for use on a mobile device.

Statement of Consent

By clicking the **next** button below, you are indicating that you:

- Have read and understood the information regarding this project.
- Have had any questions answered to your satisfaction.
- Understand that if you have any additional questions you can contact the research team.
- Are over 18 years of age.
- Understand that any data collected may be used in future research activities related to this field.
- Agree to participate in the project.

There are 18 questions in this survey.

Section 1: About you

Please confirm the **Email address** that you told us when you completed our "**Muscle-strengthening exercise: Assessing participation and influences**" survey. *

Please write your answer here:

Section 2: The next questions are about your participation in muscle-strengthening exercise

The questions within this section relate to the physical activities that you perform during your **leisure-time** only. When we say leisure-time we mean your free-time and the activities that you perform that are NOT done as part of your work/job, transportation (moving to a different location), or as a part of household activities (chores).

The types of **muscle-strengthening exercise** modes that we are interested in include;

- Use of **weight machines** (typically in a gym or fitness centre)
- **Bodyweight** exercises (including push-ups, sit-ups)
- **Resistance** exercises (using resistance bands or free weights like dumbbells)
- **Holistic** exercises (including Yoga, Tai-Chi and Pilates)

There are no right or wrong responses to the following questions, we are interested in your open and honest feedback.

Do you **usually** do muscle-strengthening exercise? *

Please choose **only one** of the following:

- ◯ Yes
- ◯ No

The types of muscle-strengthening exercises include;

- Using of weight machines to do e.g. leg press, chest press, lat pulldown (typically in a gym or fitness centre)
- Body weight exercises (including push-ups, sit-ups)
- Resistance exercises (using resistance bands or free weights like dumbbells)
- Holistic exercises (including Yoga, Tai-Chi and Pilates)

Please answer the following question -
I do **muscle-strengthening exercise** for:
*

Only answer this question if the following conditions are met:
Answer was 'Yes' at question '3 [Q16]' (Do you usually do muscle-strengthening exercise?)

Please choose **all** that apply:

- ☐ General fitness and health
- ☐ Strength-related sports (e.g. weight/power lifting)
- ☐ Appearance purposes (e.g. body-building/sculpting)
- ☐ Physical therapy (e.g. rehabilitation from injury)
- ☐ Conditioning for sports performance
- ☐ Other:

Please select **all** that apply.

How many **days**, in a **usual week**, do you do **muscle-strengthening exercise**? *

Only answer this question if the following conditions are met:
Answer was 'Yes' at question '3 [Q16]' (Do you usually do muscle-strengthening exercise?)

Please choose **only one** of the following:

- ◯ none
- ◯ 1 day in a usual week
- ◯ 2 days in a usual week
- ◯ 3 days in a usual week
- ◯ 4 days in a usual week
- ◯ 5 days in a usual week
- ◯ 6 days in a usual week
- ◯ 7 days in a usual week

The types of muscle-strengthening exercises include;

- Using of **weight machines** to do e.g. leg press, chest press, lat pulldown (typically in a gym or fitness centre environment)
- **Body weight** exercises (including push-ups, sit-ups)
- **Resistance** exercises (using resistance bands or free weight like dumbbells)
- **Holistic** exercises (including Yoga, Tai-Chi and Pilates)

How long have you been doing muscle-strengthening exercise each week? *

Only answer this question if the following conditions are met:
Answer was 'Yes' at question '3 [Q16]' (Do you usually do muscle-strengthening exercise?)

Please choose **only one** of the following:

- ◯ I have been doing muscle-strengthening exercise **irregularly** (e.g. I do it some weeks and not others)
- ◯ I have been doing muscle-strengthening exercise each week for **less than** 6 months
- ◯ I have been doing muscle-strengthening exercise each week for **6 months or more**

In a **usual** week please indicate a) <u>how often</u> you do, and b) <u>how long you spend</u>, doing each of the following types of **muscle-strengthening exercise**. *

Only answer this question if the following conditions are met:
Answer was 'Yes' at question '3 [Q16]' (Do you usually do muscle-strengthening exercise?)

Please choose the appropriate response for each item:

	Number of DAYS in a usual week.									Minutes spent in a usual session.							
	0 days	1 day	2 days	3 days	4 days	5 days	6 days	7 days		0 minutes	less than 10 minutes	10 - 20 minutes	21 - 30 minutes	31 - 40 minutes	41 - 50 minutes	51 - 60 minutes	more than 60 minutes
Use weight machines (e.g. leg press, chest press, lat pulldown)	○	○	○	○	○	○	○	○		○	○	○	○	○	○	○	○
Body weight exercises (e.g. push-ups, sit-ups)	○	○	○	○	○	○	○	○		○	○	○	○	○	○	○	○
Use resistance bands or free weights (e.g. dumbbells)	○	○	○	○	○	○	○	○		○	○	○	○	○	○	○	○
Holistic exercises (including Yoga, Tai-chi and Pilates)	○	○	○	○	○	○	○	○		○	○	○	○	○	○	○	○

In a **usual** week please indicate how many **sets** and how many **repetitions** you do of each of the following types of **muscle-strengthening exercises**. *

Only answer this question if the following conditions are met:
Answer was 'Yes' at question '3 [Q16]' (Do you usually do muscle-strengthening exercise?)

Please choose the appropriate response for each item:

	Number of SETS in a usual session.												Number of REPETITIONS in a usual session.						
	none	1 set	2 sets	3 sets	4 sets	5 sets	6 sets	7 sets	8 sets	9 sets	10 or more sets		None	1 to 3 repetitions	3 to 6 repetitions	6 to 10 repetitions	10 to 15 repetitions	15 to 25 repetitions	more than 25 repetitions
Use weight machines (e.g. leg press, chest press, lat pulldown)	○	○	○	○	○	○	○	○	○	○	○		○	○	○	○	○	○	○
Body weight exercises (e.g. push-ups, sit-ups)	○	○	○	○	○	○	○	○	○	○	○		○	○	○	○	○	○	○
Use resistance bands or free weights (e.g. dumbbells)	○	○	○	○	○	○	○	○	○	○	○		○	○	○	○	○	○	○

In a **usual** week please indicate which **muscle groups** you use when you do each of the following types of **muscle-strengthening exercises**.

If you <u>do not do</u> the muscle-strengthening exercise, please select **NO**. *

Only answer this question if the following conditions are met:
Answer was 'Yes' at question '3 [Q16]' (Do you usually do muscle-strengthening exercise?)

Please choose the appropriate response for each item:

	Using WEIGHT MACHINES in a usual session.			Doing BODY WEIGHT exercises (e.g. push-ups, sit-ups) in a usual session.	
	No	Yes		No	Yes
Legs (e.g. squats, lunges, bridges)	○	○		○	○
Hips (e.g. side leg raises, bridges)	○	○		○	○
Back (e.g. lat pulldown, bent-over row)	○	○		○	○
Abdomen (e.g. crunches, sit-ups)	○	○		○	○
Chest (e.g. bench press, push-ups)	○	○		○	○
Shoulders (e.g. lat raise, overhead press)	○	○		○	○
Arms (e.g. bicep curl, tricep dips)	○	○		○	○

In a **usual** week please indicate which **muscle groups** you use when you do each of the following types of muscle-strengthening exercises.

If you <u>do not do</u> the muscle-strengthening exercise, please select **NO**. *

Only answer this question if the following conditions are met:
Answer was 'Yes' at question '3 [Q16]' (Do you usually do muscle-strengthening exercise?)

Please choose the appropriate response for each item:

	Using RESISTANCE BANDS or FREE WEIGHTS (e.g. dumbbells) in a usual session.			Doing HOLISTIC EXERCISES (including Yoga, Tai-chi and Pilates) in a usual session.	
	No	Yes		No	Yes
Legs (e.g. squats, lunges, bridges)	○	○		○	○
Hips (e.g. side leg raises, bridges)	○	○		○	○
Back (e.g. lat pulldown, bent-over row)	○	○		○	○
Abdomen (e.g. crunches, sit-ups)	○	○		○	○
Chest (e.g. bench press, push-ups)	○	○		○	○
Shoulders (e.g. lat raise, overhead press)	○	○		○	○
Arms (e.g. bicep curl, tricep dips)	○	○		○	○

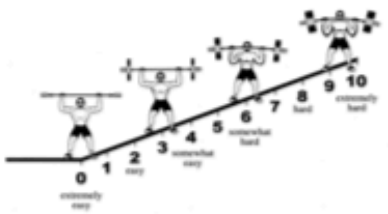
For each of the following types of **muscle-strengthening exercises**, please say

a) How hard (level of intensity) you **usually** exercise, and

b) Where you **usually** go (location) to do these exercises

How hard you feel you are exercising can also be called **intensity** or **rating of perceived effort**. The level of intensity is often assessed on a 0 to 10 scale with 0 representing "extremely easy" and 10 representing "extremely hard".

Using the picture below as a guide on a scale of 0-10 please indicate how hard you feel you exercise when you are doing muscle-strengthening exercise.



(Robertson et al., 2003)

*

Only answer this question if the following conditions are met:
Answer was 'Yes' at question '3 [Q16]' (Do you usually do muscle-strengthening exercise?)

Please choose the appropriate response for each item:

	Level of INTENSITY in a usual session.													LOCATION in a usual session.					
	Not applicable	0 Extremely easy	1	2 Easy	3	4 Somewhat easy	5	6 Somewhat hard	7	8 Hard	9	10 Extremely hard		Not applicable	Public community health and fitness facility	Private health and fitness facility	Worksite health and fitness facility	At home	Outdoor (e.g. in a park)
Use weight machines (e.g. leg press, chest press, lat pulldown)	○	○	○	○	○	○	○	○	○	○	○	○		○	○	○	○	○	○
Body weight exercises (e.g. push-ups, sit-ups)	○	○	○	○	○	○	○	○	○	○	○	○		○	○	○	○	○	○
Use resistance bands or free weights (e.g. dumbbells)	○	○	○	○	○	○	○	○	○	○	○	○		○	○	○	○	○	○
Holistic exercises (including Yoga, Tai-chi and Pilates)	○	○	○	○	○	○	○	○	○	○	○	○		○	○	○	○	○	○

You have told us that you usually do muscle-strengthening exercise at a community or worksite health and fitness facility. Can you please let us know how far away the facility is from your usual residence? *

Only answer this question if the following conditions are met:
-------- Scenario 1 --------
Answer was 'Public community health and fitness facility' *or* 'Private community health and fitness facility' *or* 'Worksite health and fitness facility' at question '11 [Q24]' (For each of the following types of muscle-strengthening exercises, please say a) How hard (level of intensity) you usually exercise, and b) Where you usually go (location) to do these exercises How hard you feel you are exercising can also be called intensity or rating of perceived effort. The level of intensity is often assessed on a 0 to 10 scale with 0 representing "extremely easy" and 10 representing "extremely hard". Using the picture below as a guide on a scale of 0-10 please indicate how hard you feel you exercise when you are doing muscle-strengthening exercise. (Robertson et al., 2003) (**Holistic** exercises (including Yoga, Tai-chi and Pilates) Label LOCATION in a usual session.))
-------- or Scenario 2 --------
Answer was 'Worksite health and fitness facility' *or* 'Private community health and fitness facility' *or* 'Public community health and fitness facility' at question '11 [Q24]' (For each of the following types of muscle-strengthening exercises, please say a) How hard (level of intensity) you usually exercise, and b) Where you usually go (location) to do these exercises How hard you feel you are exercising can also be called intensity or rating of perceived effort. The level of intensity is often assessed on a 0 to 10 scale with 0 representing "extremely easy" and 10 representing "extremely hard". Using the picture below as a guide on a scale of 0-10 please indicate how hard you feel you exercise when you are doing muscle-strengthening exercise. (Robertson et al., 2003) (Use **resistance** bands or free weights (e.g. dumbbells) Label LOCATION in a usual session.))
-------- or Scenario 3 --------
Answer was 'Worksite health and fitness facility' *or* 'Private community health and fitness facility' *or* 'Public community health and fitness facility' at question '11 [Q24]' (For each of the following types of muscle-strengthening exercises, please say a) How hard (level of intensity) you usually exercise, and b) Where you usually go (location) to do these exercises How hard you feel you are exercising can also be called intensity or rating of perceived effort. The level of intensity is often assessed on a 0 to 10 scale with 0 representing "extremely easy" and 10 representing "extremely hard". Using the picture below as a guide on a scale of 0-10 please indicate how hard you feel you exercise when you are doing muscle-strengthening exercise. (Robertson et al., 2003) (**Body weight** exercises (e.g. push-ups, sit-ups) Label LOCATION in a usual session.))
-------- or Scenario 4 --------
Answer was 'Public community health and fitness facility' *or* 'Private community health and fitness facility' *or* 'Worksite health and fitness facility' at question '11 [Q24]' (For each of the following types of muscle-strengthening exercises, please say a) How hard (level of intensity) you usually exercise, and b) Where you usually go (location) to do these exercises How hard you feel you are exercising can also be called intensity or rating of perceived effort. The level of intensity is often assessed on a 0 to 10 scale with 0 representing "extremely easy" and 10 representing "extremely hard". Using the picture below as a guide on a scale of 0-10 please indicate how hard you feel you exercise when you are doing muscle-strengthening exercise. (Robertson et al., 2003) (Use **weight machines** (e.g. leg press, chest press, lat pulldown) Label LOCATION in a usual session.))

Please choose **only one** of the following:

◯ less than 5 km
◯ 5 - 9 km
◯ 10 - 14 km
◯ 15 - 20 km
◯ more than 20 km

Section 3: Factors influencing leisure-time muscle-strengthening exercise.

We are now interested in understanding the '*type of things*' that may motivate you to do muscle-strengthening exercise, and also the '*type of things*' that may be barriers to you doing (or doing more) muscle-strengthening exercise.

Please indicate how to what extent you agree or disagree with the following questions. *

Only answer this question if the following conditions are met:
Answer was 'Yes' at question '3 [Q16]' (Do you usually do muscle-strengthening exercise?)

Please choose the appropriate response for each item:

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
I do muscle-strengthening exercise to improve my health and well-being	◯	◯	◯	◯	◯
I do muscle-strengthening exercise to improve my appearance	◯	◯	◯	◯	◯
I do muscle-strengthening exercise to be with others	◯	◯	◯	◯	◯
I do muscle-strengthening exercise to improve existing skills	◯	◯	◯	◯	◯
I do muscle-strengthening exercise because I enjoy this activity	◯	◯	◯	◯	◯

How true are the following statements for you? *

Please choose the appropriate response for each item:

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
I don't have enough time to do muscle-strengthening exercise	◯	◯	◯	◯	◯
I need expensive equipment to do muscle-strengthening exercise	◯	◯	◯	◯	◯
I feel I don't have enough knowledge about muscle-strengthening exercise to do it	◯	◯	◯	◯	◯
I do not have enough energy to do muscle-strengthening exercise	◯	◯	◯	◯	◯
Doing muscle-strengthening exercise is a low priority for me	◯	◯	◯	◯	◯

How true are the following statements for you?
*

Please choose the appropriate response for each item:

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
I am scared that I will injure myself doing muscle-strengthening exercise	○	○	○	○	○
I would not enjoy doing muscle-strengthening exercise	○	○	○	○	○
I am not healthy enough to do muscle-strengthening exercise	○	○	○	○	○
I do not feel comfortable doing muscle-strengthening exercise in a gym/fitness centre	○	○	○	○	○

Section 4: Support for doing muscle-strengthening exercise during leisure-time.

These questions are about "*what sort of things*" may help or support or facilitate you to do (or do more) muscle-strengthening exercise activities during your leisure-time.

How useful would the following be in helping you to do muscle-strengthening exercise? *

Please choose the appropriate response for each item:

	Not at all useful to me	Somewhat useful to me	Very useful to me	I already have this
If I had access to equipment at home	○	○	○	○
If I had access to facilities (e.g. gym or fitness centre)	○	○	○	○
If I had access to outdoor equipment (e.g. equipment in a community park)	○	○	○	○
If I had access to fitness trainers to help me	○	○	○	○
If I had access to facilities where I work	○	○	○	○
If I had access to a subsidised gym membership	○	○	○	○
If I had access to educational materials (e.g. leaflets or brochures)	○	○	○	○
If I had access to multi-media/smartphone applications	○	○	○	○
If I had access to an online or virtual trainer	○	○	○	○
If I had a workout partner	○	○	○	○

Section 5: Muscle-strengthening exercise confidence

This section of questions refers to your perception of your confidence in undertaking muscle-strengthening exercise.

Please indicate how likely you agree or disagree with the following questions. *

Please choose the appropriate response for each item:

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
I have the physical capacity to complete muscle-strengthening exercises	○	○	○	○	○
I can complete muscle-strengthening exercises without the help of someone else (e.g. friend, trainer)	○	○	○	○	○
If I don't have access to a gym I can still do muscle-strengthening exercise (e.g. body weight exercises)	○	○	○	○	○
I have the skill and technique to complete muscle-strengthening exercises safely	○	○	○	○	○

Section 6: The end of the survey

Thank you for taking the time to complete this follow-up testing survey. Your responses will provide us with valuable information that may be used to inform the future assessment of muscle-strengthening exercise both within Australia and internationally.

If you have any further comments or questions, please include them below.

Please write your answer here:

Thank you kindly for taking time to help with this research.

22.03.2021 – 08:20

Submit your survey.
Thank you for completing this survey.

APPENDIX I: ONLINE SURVEY QUESTIONNAIRE – VALIDITY (STUDY 4)

Muscle-strengthening exercise: Assessing participation and influences (Follow-up Testing - Day 1)

Human Research Ethics Approval Number - H20REA233

Welcome to the research study follow-up testing day 1!

Participation

Your participation will involve the completion of a modified version of the online questionnaire that you completed 7-10 days ago and should take less than 10 minutes of your time (each day for the next 7 days). Questions will include (a) some basic information about you, and (b) your participation in muscle-strengthening exercise.

Your continued participation in this project is entirely voluntary. If you do not wish to take part, you are not obliged to. If you decide to take part and later change your mind, you are free to withdraw from the project at any stage. You may also request that any data collected about you be withdrawn and confidentially destroyed, however, you will be unable to withdraw data collected about yourself after the data has been analysed. If you do wish to withdraw from this project or withdraw data collected about you, please contact the Research Team (contact details at the bottom of this form). Your decision whether you take part, do not take part, or to take part and then withdraw, will in no way impact your current or future relationship with the University of Southern Queensland.

Research Team Contact Details

Principal Investigator Details

Mrs. Jane Shakespear-Druery

Email: Jane.Shakespear-Druery@usq.edu.au

Telephone: +61 7 3470 4136

Concerns or Complaints Regarding the Conduct of the Project

If you have any concerns or complaints about the ethical conduct of the project, you may contact the University of Southern Queensland Manager of Research Integrity and Ethics on +61 7 4631 1839 or email researchintegrity@usq.edu.au. The Manager of Research Integrity and Ethics is not connected with the research project and can facilitate a resolution to your concern in an unbiased manner.

Thank you for taking the time to help with this research project.

Kindly note that the survey will display best on a laptop or desktop computer. Some features may be less compatible for use on a mobile device.

Statement of Consent

By clicking the **next** button below, you are indicating that you:

- Have read and understood the information regarding this project.
- Have had any questions answered to your satisfaction.
- Understand that if you have any additional questions you can contact the research team.
- Are over 18 years of age.
- Understand that any data collected may be used in future research activities related to this field.
- Agree to participate in the project.

There are 9 questions in this survey.

Section 1: About you

Please confirm the **Email address** that you told us when you completed our **"Muscle-strengthening exercise: Assessing participation and influences"** survey.

*

Please write your answer here:

Section 2: The next questions are about your participation in muscle-strengthening exercise

The questions within this section relate to the physical activities that you perform during your **leisure-time** only. When we say leisure-time we mean your free-time and the activities that you perform that are NOT done as part of your work/job, transportation (moving to a different location), or as a part of household activities (chores).

The types of **muscle-strengthening exercise** modes that we are interested in include;

- Use of **weight machines** (typically in a gym or fitness centre)
- **Bodyweight** exercises (including push-ups, sit-ups)
- **Resistance** exercises (using resistance bands or free weights like dumbbells)
- **Holistic** exercises (including Yoga, Tai-Chi and Pilates)

There are no right or wrong responses to the following questions, we are interested in your open and honest feedback.

Did you **do any** muscle-strengthening exercise today (DAY 1)? *

Please choose **only one** of the following:

○ Yes
○ No

The types of muscle-strengthening exercises include;

- Using of weight machines to do e.g. leg press, chest press, lat pulldown (typically in a gym or fitness centre)
- Body weight exercises (including push-ups, sit-ups)
- Resistance exercises (using resistance bands or free weights like dumbbells)
- Holistic exercises (including Yoga, Tai-Chi and Pilates)

Please indicate a) which you did (yes or no), and b) how long you spent, doing each of the following types of **muscle-strengthening exercise** on DAY 1.
*

Only answer this question if the following conditions are met:
Answer was 'Yes' at question '3 [Q16]' (Did you do any muscle-strengthening exercise today (DAY 1)?)

Please choose the appropriate response for each item:

	DAY 1.			**Minutes spent - DAY 1.**							
	Yes	**No**		**0 minutes**	**less than 10 minutes**	**10 - 20 minutes**	**21 - 30 minutes**	**31 - 40 minutes**	**41 - 50 minutes**	**51 - 60 minutes**	**more than 60 minutes**
Use weight machines (e.g. leg press, chest press, lat pulldown)	○	○		○	○	○	○	○	○	○	○
Body weight exercises (e.g. push-ups, sit-ups)	○	○		○	○	○	○	○	○	○	○
Use resistance bands or free weights (e.g. dumbbells)	○	○		○	○	○	○	○	○	○	○
Holistic exercises (including Yoga, Tai-chi and Pilates)	○	○		○	○	○	○	○	○	○	○

Please indicate how many **sets** and how many **repetitions** you did of each of the following types of **muscle-strengthening exercises** on **DAY 1**. *

Only answer this question if the following conditions are met:
Answer was 'Yes' at question '3 [Q16]' (Did you do any muscle-strengthening exercise today (DAY 1)?)

Please choose the appropriate response for each item:

	Number of SETS - DAY 1.												**Number of REPETITIONS - DAY 1.**						
	none	**1 set**	**2 sets**	**3 sets**	**4 sets**	**5 sets**	**6 sets**	**7 sets**	**8 sets**	**9 sets**	**10 or more sets**		**None**	**1 to 3 repetitions**	**3 to 6 repetitions**	**6 to 10 repetitions**	**10 to 15 repetitions**	**15 to 25 repetitions**	**more than 25 repetitions**
Use weight machines (e.g. leg press, chest press, lat pulldown)	○	○	○	○	○	○	○	○	○	○	○		○	○	○	○	○	○	○
Body weight exercises (e.g. push-ups, sit-ups)	○	○	○	○	○	○	○	○	○	○	○		○	○	○	○	○	○	○
Use resistance bands or free weights (e.g. dumbbells)	○	○	○	○	○	○	○	○	○	○	○		○	○	○	○	○	○	○

Please indicate which **muscle groups** you used on **DAY 1** when you did each of the following types of **muscle-strengthening exercises**.

If you do not do the muscle-strengthening exercise, please select **NO**.

*

Only answer this question if the following conditions are met:
Answer was 'Yes' at question '3 [Q16]' (Did you do any muscle-strengthening exercise today (DAY 1)?)

Please choose the appropriate response for each item:

	Using WEIGHT MACHINES - DAY 1.			Doing BODY WEIGHT exercises (e.g. push-ups, sit-ups) - DAY 1.	
	No	Yes		No	Yes
Legs (e.g. squats, lunges, bridges)	○	○		○	○
Hips (e.g. side leg raises, bridges)	○	○		○	○
Back (e.g. lat pulldown, bent-over row)	○	○		○	○
Abdomen (e.g. crunches, sit-ups)	○	○		○	○
Chest (e.g. bench press, push-ups)	○	○		○	○
Shoulders (e.g. lat raise, overhead press)	○	○		○	○
Arms (e.g. bicep curl, tricep dips)	○	○		○	○

Please indicate which **muscle groups** you used on DAY 1 when you did each of the following types of muscle-strengthening exercises.

If you do not do the muscle-strengthening exercise, please select **NO**.

*

Only answer this question if the following conditions are met:
Answer was 'Yes' at question '3 [Q16]' (Did you do any muscle-strengthening exercise today (DAY 1)?)

Please choose the appropriate response for each item:

	Using RESISTANCE BANDS or FREE WEIGHTS (e.g. dumbbells) - DAY 1.			Doing HOLISTIC EXERCISES (including Yoga, Tai-chi and Pilates) - DAY 1.	
	No	Yes		No	Yes
Legs (e.g. squats, lunges, bridges)	○	○		○	○
Hips (e.g. side leg raises, bridges)	○	○		○	○
Back (e.g. lat pulldown, bent-over row)	○	○		○	○
Abdomen (e.g. crunches, sit-ups)	○	○		○	○
Chest (e.g. bench press, push-ups)	○	○		○	○
Shoulders (e.g. lat raise, overhead press)	○	○		○	○
Arms (e.g. bicep curl, tricep dips)	○	○		○	○

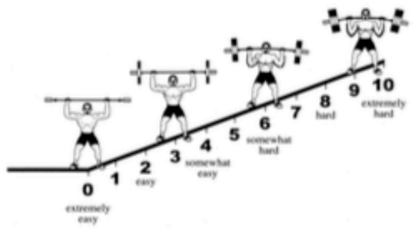
For each of the following types of **muscle-strengthening exercises**, please say

a) How hard (level of intensity) you **exercised**, and

b) Where you **went** (location) to do these exercises

How hard you feel you are exercising can also be called **intensity** or **rating of perceived effort**. The level of intensity is often assessed on a 0 to 10 scale with 0 representing "extremely easy" and 10 representing "extremely hard".

Using the picture below as a guide on a scale of 0-10 please indicate how hard you felt when you did your muscle-strengthening exercise on DAY 1.



(Robertson et al., 2003)

*

Only answer this question if the following conditions are met:
Answer was 'Yes' at question '3 [Q16]' (Did you do any muscle-strengthening exercise today (DAY 1)?)

Please choose the appropriate response for each item:

	Level of INTENSITY - DAY 1.												LOCATION - DAY 1.					
	Not applicable	0 Extremely easy	1	2 Easy	3	4 Somewhat easy	5	6 Somewhat hard	7	8 Hard	9	10 Extremely hard	Not applicable	Public community health and fitness facility	Private community health and fitness facility	Worksite health and fitness facility	At home	Outdoor (e.g. in a park)
Use weight machines (e.g. leg press, chest press, lat pulldown)																		
Body weight exercises (e.g. push-ups, sit-ups)																		
Use resistance bands or free weights (e.g. dumbbells)																		
Holistic exercises (including Yoga, Tai-chi and Pilates)																		

Section 3: The end of the survey

Thank you for taking the time to complete this follow-up testing survey (DAY 1). Your responses will provide us with valuable information that may be used to inform the future assessment of muscle-strengthening exercise both within Australia and internationally.

Tomorrow you will receive an invitation to complete DAY 2 of the follow-up testing research.

If you have any further comments or questions, please include them below.

Only answer this question if the following conditions are met:
Answer was 'No' at question '3 [Q16]' (Did you do any muscle-strengthening exercise today (DAY 1)?)

Please write your answer here:

Thank you kindly for taking time to help with this research.

22.03.2021 – 08:26

Submit your survey.
Thank you for completing this survey.

APPENDIX J: OTHER DOCUMENTS (STUDY 4)

Scoring protocol for the Muscle-Strengthening Exercise Questionnaire (MSEQ)

Jane Shakespear-Druery
Professor Katrien De Cocker
Professor Stuart J.H. Biddle
Associate Professor Jason A Bennie

Contact: Jane Shakespear-Druery - [redacted]

Table of Contents

Introduction

Muscle-strengthening exercise (MSE) is a physical activity that often includes the use of an individual's own bodyweight, free weights or weight machines. If MSE is undertaken regularly it can lead to increases in muscle strength, endurance, power, and mass [1].

Research into MSE lends support to the call for the regular undertaking of this exercise modality in the efforts to reduce the risks of mortality and morbidity associated with many chronic conditions, such as hypertension, disordered mental health, and some cancers [2]. Moreover, undertaking even small-to-moderate amounts of MSE has been shown to reduce these risks at the population level [3].

Despite this, there is currently lack of uniformity in the way that muscle-strengthening exercise behaviours are assessed within large population health surveillance [4]. Therefore the MSEQ was designed to provide a valid and reliable self-report instrument to assess adults' (≥18 years) muscle-strengthening exercise behaviours [5] which can then be used for comparison to the current physical activity guidelines. The instrument can be used in physical activity surveillance in a standalone capacity, or in conjunction with other large-scale physical activity assessment tools such as the International Physical Activity Questionnaire (IPAQ) [6] or the Global Physical Activity Questionnaire (GPAQ) [7].

The MSEQ was designed for both online and paper-based administration[1]. This document has been developed to assist researchers to interpret the results obtained when the online version of the MSEQ is administered.

Results from this questionnaire can help you compare the participant's self-reported results with national and international physical activity guidelines for muscle-strengthening exercise.

Additional online tools to assist with the 'automatic' scoring of this questionnaire, and the paper-based MSEQ-Short and MSEQ-Long are currently being developed. The following section will provide an overview on how to manually score the online version of the MSEQ.

[1] In conjunction with the development of the online MSEQ, two additional paper based versions of the questionnaire were also developed, the MSEQ-Short and MSEQ-Long [5]. The MSEQ-Short is a 6-item instrument, while the MSEQ-Long is an expanded 20-item instrument. As the MSEQ-Short and MSEQ-Long contain a mix of categorical and continuous variables, a separate scoring protocol will apply.

Scoring the Muscle-Strengthening Exercise Questionnaire (MSEQ) – Guideline Concordance

Background

Designed for use in large population-based studies, results from the MSEQ can be used to report on the degree of concordance with one or more components of the muscle-strengthening exercise guidelines. Currently international [8] and many national [1] guidelines for muscle-strengthening exercise consist of three core components.

These are:
- Frequency (≥2 days/week)
- Intensity (moderate or greater intensity); and
- Muscle groups (involving all the major muscle groups)

In the online version of the MSEQ, a combination of dichotomous and categorical variables were developed.

Muscle-strengthening exercise guideline concordance

Scoring **FULL** concordance using the MSEQ means that participants are highly sufficient with meeting the muscle-strengthening exercise guidelines. Scoring **MODEST** concordance using the MSEQ means that participants are moderately sufficient with meeting the muscle-strengthening exercise guidelines. Scoring **MINIMAL** concordance using the MSEQ means that participants are sufficient with meeting the muscle-strengthening exercise guidelines.

People who score **FULL** (3/3) on the MSEQ engage in a

- **Frequency** of 2 or more days using any combination of weight machines, bodyweight, resistance, or holistic exercises

AND

- Undertake any combination of the exercises at **moderate or greater intensity** (rating of perceived effort of '6 somewhat hard' or greater) [9]

AND

- Use all the **major muscle groups** (legs, hips, back, abdomen, chest, shoulders, arms) when doing any combination of weight machine, bodyweight, resistance, or holistic exercises.

People who score **MODEST** (2/3) on the MSEQ engage in a

- **Frequency** of 2 or more days using any combination of weight machines, bodyweight, resistance, or holistic exercises

AND

- Undertake any combination of the exercises at **moderate or greater intensity** (rating of perceived effort of '6 somewhat hard' or greater) [9]

OR

- Use all of the **major muscle groups** (legs, hips, back, abdomen, chest, shoulders, arms) when doing any combination of weight machine, bodyweight, resistance, or holistic exercises.

People who score **MINIMAL** (1/3) on the MSEQ engage in a

- **Frequency** of 2 or more days using any combination of weight machines, bodyweight, resistance, or holistic exercises

No Activity (Not Met)

People who do not meet the **MINIMAL** score on the MSEQ are not meeting any of the muscle-strengthening exercise guidelines i.e., insufficient (1 day/week) or none (0 days/week).

Guideline concordance	**Not Met (0/3)**	**Minimal (1/3)**	**Modest (2/3)**	**Full (3/3)**
Frequency	<2 days/week	≥ 2 days/week	≥ 2 days/week	≥ 2 days/week
Intensity	<RPE 6		≥ RPE 6 OR	≥ RPE 6
Muscle Groups	<7 muscle groups		all muscle groups	all muscle groups

Additional component included in the MSEQ – Duration

While the muscle-strengthening exercise guidelines do not currently include a recommendation for duration (per session), this information is important for future research with respect to the relationship between muscle-strengthening exercise and health. Understanding the optimal dose response relationship between muscle-strengthening exercise and health is important in the efforts to reduce the risks associated with chronic disease. Therefore, the MSEQ asks participants to indicate 'how long you spend' in minutes in a usual session, for each of the four types of included exercises. We have recently used an assessment of volume in published papers [3, 10].

A crude calculation of total weekly muscle-strengthening exercise can be performed using the results of the MSEQ.

Calculating the results – Volume (frequency x duration)

Given the categorical nature of the duration variable it is recommended that you apply the median value (see the table below)

Categorical variable	0 minutes	Less than 10 minutes	10-20 minutes	21-30 minutes	31-40 minutes	41-50 minutes	51-60 minutes	More than 60 minutes
Median value	0 minutes	5.5 minutes	15 minutes	25.5 minutes	35.5 minutes	45.5 minutes	55.5 minutes	60 minutes

The following examples will guide in calculating the weekly volume of reported muscle-strengthening exercise.

Participant response in the MSEQ – example 1

In a usual week please indicate a) how often you do, and b) how long you spend, doing each of the following types of muscle-strengthening exercise.

Number of DAYS in a usual week.

	0 days	1 day	2 days	3 days	4 days	5 days	6 days	7 days
Use weight machines (e.g. leg press, chest press, lat pulldown)	X							
Body weight exercises (e.g. push-ups, sit-ups)			X					
Use resistance bands or free weights (e.g. dumbbells)			X					
Holistic exercises (including Yoga, Tai-chi and Pilates)	X							

In a usual week please indicate a) how often you do, and b) how long you spend, doing each of the following types of muscle-strengthening exercise.

Minutes spent in a usual session.

	0 minutes	less than 10 minutes	10 - 20 minutes	21 - 30 minutes	31 - 40 minutes	41 - 50 minutes	51 - 60 minutes	more than 60 minutes
Use weight machines (e.g. leg press, chest press, lat pulldown)	X							
Body weight exercises (e.g. push-ups, sit-ups)						X		
Use resistance bands or free weights (e.g. dumbbells)						X		
Holistic exercises (including Yoga, Tai-chi and Pilates)	X							

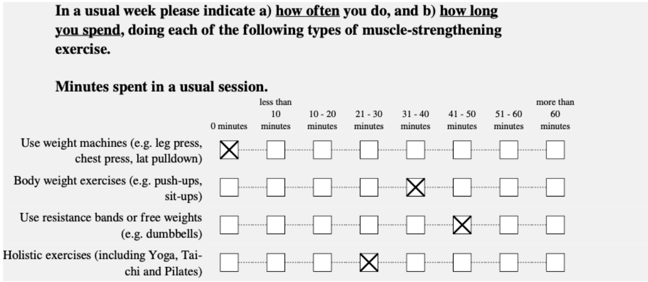
Muscle-strengthening exercise mode	Frequency (days)	Duration (median minutes)	Total volume (minutes per week)
Weight machines	0	0	0
Bodyweight	2	45.5	91
Resistance	2	45.5	91
Holistic	0	0	0
Total			182

Participant response in the MSEQ – example 2

In a usual week please indicate a) how often you do, and b) how long you spend, doing each of the following types of muscle-strengthening exercise.

Number of DAYS in a usual week.

	0 days	1 day	2 days	3 days	4 days	5 days	6 days	7 days
Use weight machines (e.g. leg press, chest press, lat pulldown)	X							
Body weight exercises (e.g. push-ups, sit-ups)		X						
Use resistance bands or free weights (e.g. dumbbells)				X				
Holistic exercises (including Yoga, Tai-chi and Pilates)		X						



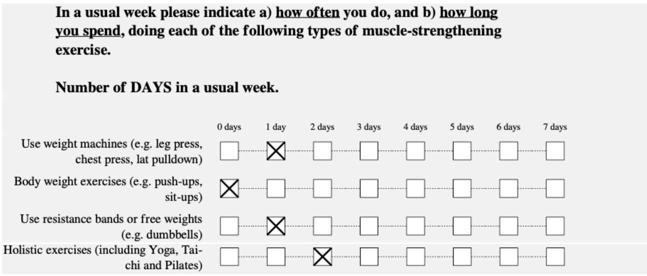
In a usual week please indicate a) <u>how often</u> you do, and b) <u>how long you spend</u>, doing each of the following types of muscle-strengthening exercise.

Minutes spent in a usual session.

	0 minutes	less than 10 minutes	10 - 20 minutes	21 - 30 minutes	31 - 40 minutes	41 - 50 minutes	51 - 60 minutes	more than 60 minutes
Use weight machines (e.g. leg press, chest press, lat pulldown)	X							
Body weight exercises (e.g. push-ups, sit-ups)					X			
Use resistance bands or free weights (e.g. dumbbells)						X		
Holistic exercises (including Yoga, Tai-chi and Pilates)				X				

Muscle-strengthening exercise mode	Frequency (days)	Duration (median minutes)	Total volume (minutes per week)
Weight machines	0	0	0
Bodyweight	1	35.5	35.5
Resistance	3	45.5	136.5
Holistic	1	25.5	25.5
Total			197.5

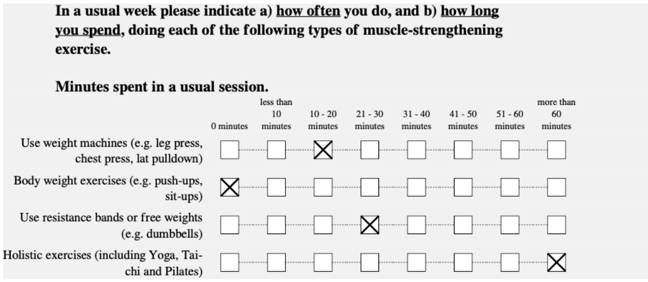
Participant response in the MSEQ – example 3



In a usual week please indicate a) <u>how often</u> you do, and b) <u>how long you spend</u>, doing each of the following types of muscle-strengthening exercise.

Number of DAYS in a usual week.

	0 days	1 day	2 days	3 days	4 days	5 days	6 days	7 days
Use weight machines (e.g. leg press, chest press, lat pulldown)		X						
Body weight exercises (e.g. push-ups, sit-ups)	X							
Use resistance bands or free weights (e.g. dumbbells)		X						
Holistic exercises (including Yoga, Tai-chi and Pilates)			X					



In a usual week please indicate a) <u>how often</u> you do, and b) <u>how long you spend</u>, doing each of the following types of muscle-strengthening exercise.

Minutes spent in a usual session.

	0 minutes	less than 10 minutes	10 - 20 minutes	21 - 30 minutes	31 - 40 minutes	41 - 50 minutes	51 - 60 minutes	more than 60 minutes
Use weight machines (e.g. leg press, chest press, lat pulldown)			X					
Body weight exercises (e.g. push-ups, sit-ups)	X							
Use resistance bands or free weights (e.g. dumbbells)				X				
Holistic exercises (including Yoga, Tai-chi and Pilates)								X

Muscle-strengthening exercise mode	Frequency (days)	Duration (median minutes)	Total volume (minutes per week)
Weight machines	1	15	15
Bodyweight	0	0	0
Resistance	1	25.5	25.5
Holistic	2	60	120
Total			160.5

References

1. U.S. Department of Health and Human Services, *Physical activity guidelines for Americans, 2nd edition*, U.S. Department of Health and Human Services, Editor. 2018: Washington, DC.

2. Bennie, J.A., J. Shakespear-Druery, and K. De Cocker, *Muscle-strengthening exercise epidemiology: A new frontier in chronic disease prevention.* Sports Medicine - Open, 2020. **6**(1): p. 1-8.

3. Shakespear-Druery, J., et al., *Associations between muscle-strengthening exercise and prevalent chronic health conditions in 16,301 adults: do session duration and weekly volume matter?* Journal of Science and Medicine in Sport, 2022. **25**(5): p. 407-418.

4. Shakespear-Druery, J., et al., *Assessment of muscle-strengthening exercise in public health surveillance for adults: A systematic review.* Preventive Medicine, 2021. **148**: p. 106566.

5. Shakespear-Druery, J., et al., *Muscle-Strengthening Exercise Questionnaire (MSEQ): An assessment of concurrent validity and test–retest reliability.* BMJ Open Sport & Exercise Medicine 2022. **8**(e001225): p. 1-10.

6. Craig, C.L., et al., *International physical activity questionnaire: 12-Country reliability and validity.* Medicine and Science in Sports and Exercise, 2003. **35**(8): p. 1381-1395.

7. Armstrong, T. and F. Bull, *Development of the World Health Organization Global Physical Activity Questionnaire (GPAQ).* Journal of Public Health, 2006. **14**(2): p. 66-70.

8. Bull, F.C., et al., *World Health Organization 2020 guidelines on physical activity and sedentary behaviour.* British Journal of Sports Medicine, 2020. **54**(24): p. 1451.

9. Robertson, R.J., et al., *Concurrent validation of the OMNI perceived exertion scale for resistance exercise.* Medicine & Science in Sports & Exercise, 2003. **35**(2): p. 333-341.

10. Shakespear-Druery, J., et al., *Associations between duration and volume of muscle-strengthening exercise and clinically assessed hypertension among 10519 UK adults: A cross-sectional study.* Journal of Hypertension, 2022. **40**(5): p. 947-955.