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Original article

Dose-dependent associations of joint aerobic and muscle-strengthening exercise with obesity: A cross-sectional study of 280,605 adults

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Abstract

Background: Emerging epidemiological evidence suggests that compared to engaging in 1 activity mode alone, a combination of moderate-to-vigorous physical activity (MVPA: brisk walking/jogging, cycling) and muscle-strengthening exercise (MSE: push-ups/sit-ups, using weight machines) has more favorable associations with optimal weight status. However, few studies have examined the dose-dependent and joint associations of MVPA and MSE with obesity.

Methods: Based on cross-sectional analyses of the European Health Interview Survey Wave 2 (2013−2014), we examined prevalence ratios (PRs) of joint and stratified associations between MVPA (4 categories: (i) 0 min/week, (ii) 1−149 min/week, (iii) 150−299 min/week, and (iv) ≥300 min/week) and MSE (3 categories: (i) 0 day/week, (ii) 1 day/week, and (iii) ≥2 days/week) with body mass index-defined obesity (body mass index of ≥30.0 kg/m^2) using Poisson regression with robust error variance. PRs were examined unadjusted and adjusted for sociodemographic and lifestyle characteristics (e.g., sex, age, education, income, and smoking status).

Results: Data were available for 280,456 adults (≥18 years), of which 46,166 (15.5%) were obese. The interaction MVPA × MSE guideline adherence was statistically significant for obesity ($p \leq 0.05$). The joint MVPA−MSE analysis showed that compared to the reference group (i.e., no MVPA and no MSE), the PRs followed a dose-dependent pattern, with the lowest observed among those reporting ≥150 MVPA min/week and ≥1 MSE days/week (PR: 0.43; 95% confidence interval: 0.41−0.46). When stratified across each MVPA strata, the PRs were mostly lower among those engaging in MSE 1 day/week, as compared to those doing MSE ≥2 days/week.

Conclusion: There was evidence for a dose-dependent association between joint MVPA−MSE with a reduced prevalence of obesity. Public health strategies for the prevention and management of obesity should recommend both MVPA and MSE.

Keywords: Body mass index; Epidemiology; Public health; Resistance exercise

1. Introduction

Obesity prevention and management is a major 21st-century global public health challenge.[1,2] Across European countries, it is estimated that currently between 10% and 30% of adults are obese,[3] with the prevalence increasing steadily over the past decade. Being obese increases the risk of multiple common noncommunicable diseases, including coronary heart disease, stroke, diabetes, hypertension, depression, osteoarthritis, and some cancers (i.e., endometrial, breast).[4] Furthermore, obesity is attributable to around 12% of all deaths and 6% of health costs across European countries.[5]

Regular physical activity is a key modifiable lifestyle behavior for the prevention and management of obesity.[6,7] The 2010 World Health Organization's "Global Recommendations on Physical Activity for Health" recommend both aerobic moderate-to-vigorous physical activity (MVPA: brisk walking, cycling, or jogging) for ≥150 min/week as well as muscle-strengthening exercise (MSE: use of weight machines, push-ups, sit-ups) ≥2 times/week for optimal health and wellbeing in adults, which includes maintaining a healthy weight.[8] At present, most research on the relationship between physical activity and obesity is from studies examining the benefits of

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aerobic MVPA.[6,7] A recent synthesis of 33 longitudinal studies identified strong evidence linking greater volumes of aerobic MVPA to the prevention and minimization of excessive weight gain/obesity and to the maintenance of a healthy weight.[7] It is currently recommended that an adult should achieve between 150 and 250 MVPA min/week to prevent weight gain and between 225 and 420 MVPA min/week to lose weight.[7]

Emerging epidemiological evidence suggests that MSE may also be beneficial for obesity prevention/management. In a U.S. longitudinal study of 10,500 healthy men, less waist circumference increase was observed over a 12-year follow-up period among men who met the MVPA guideline (≥150 min/week) and engaged in the highest level of MSE (≥25 min/day).[9] More recently we showed that among a representative sample of 1.7 million U.S. adults, meeting both guidelines was associated with a lower prevalence of body mass index (BMI)-defined obesity than was meeting either the MVPA or MSE guideline alone.[10] However, this study used MVPA−MSE cut points based on guideline adherence (≥150 MVPA min/week; MSE ≥ 2 days/week) without addressing dose-dependent associations.[10]

Based on the existing evidence, it is possible that a combination of MVPA and MSE may be the most optimal physical activity-related strategy for maintaining a healthy weight. However, to our knowledge, no research has comprehensively assessed the dose-dependent associations between joint MVPA and MSE with obesity among a population-representative sample of adults. Establishing dose-dependent associations between physical activity and obesity is important to inform future approaches to prevent/manage this ubiquitous and detrimental health condition. This study aimed to examine the dose-dependent associations of joint MVPA and MSE with prevalent obesity among a large sample of adults.

2. Methods

2.1. Sample

Data were drawn from the European Health Interview Survey (EHIS Wave 2), which was conducted between 2013 and 2014. The EHIS Wave 2 was commissioned by the European Union with the aim of measuring the health status and health determinants of European Union citizens aged ≥17 years.[11] Details about the EHIS Wave 2 are available elsewhere.[11] Ethical approval for the study was provided by the European commission (https://eurlex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2013:047:0020:0048:EN:PDF). Briefly, a multistage sampling technique was applied to recruit nationally representative samples from participating European Union countries. Data were collected via a combination of face-to-face, computer-assisted telephone, and computer-assisted web-based interviews. A total of 316,333 participants initially responded. With the exception of 5 countries (Denmark, Germany, Luxembourg, Austria, and Finland) the response rate was >50%, with the highest rate at >90% in Cyprus and Portugal.

2.2. Exposure variables: Aerobic and MSE

Self-reported physical activity levels were assessed using the European Health Interview Survey Physical Activity Questionnaire (EHIS-PAQ).[12] The development, design and psychometric testing of this instrument have been described elsewhere.[12] The EHIS-PAQ has been shown to be a reliable and valid physical activity assessment tool for use in public health surveillance.[12]

2.2.1. Self-reported aerobic MVPA

Consistent with standardized protocols,[12] and in consideration of the aerobic MVPA (hereafter MVPA) guideline, we included aerobic physical activity accrued within the domains of (i) recreation (e.g., jogging, brisk walking, bicycling, and swimming) and (ii) transportation (e.g., brisk walking/cycling). For these 2 domains, respondents were asked to consider bouted physical activity that lasted for ≥10 min during a "typical week". In each domain, respondents were asked to report the number of days per week and total time spent (h/min). MVPA was then calculated by summing the reported time in the 2 domains to provide a weekly aerobic MVPA estimate. A validation study showed that when assessing moderate-to-vigorous aerobic recreational and transport-related physical activity, the EHIS-PAQ items have "good" test−retest reliability (intraclass correlation coefficient = 0.72−0.73) and acceptable concurrent validity (Spearman's rank-order correlation = 0.36−0.43), using accelerometry as the standard.[12]

2.2.2. Self-reported MSE

To assess participation in MSE, respondents were asked, "In a typical week, on how many days do you carry out physical activities specifically designed to strengthen your muscles such as doing resistance training or strength exercises?" Respondents were prompted to disregard aerobic physical activity/exercise and only consider MSE-related activities, such as resistance training, strength exercises (using weights, elastic band, own body weight, *etc.*), knee bends (squats), and push-ups (press-ups). The EHIS-PAQ MSE item has shown to have "fair" test−retest reliability (intraclass correlation coefficient = 0.55),[12] and a comparable item has shown evidence of concurrent validity (using MSE ≥2 times/week threshold against all-cause mortality).[13]

2.2.3. Joint aerobic and muscle-strengthening physical activity classifications

To examine the dose-dependent and joint associations of MVPA and MSE with obesity, we categorized physical activity levels according to the World Health Organization's physical activity guidelines.[8] Weekly MVPA was categorized into 4 groups: (i) 0 min/week (no MVPA), (ii) 1−149 min/week (insufficient MVPA), (iii) 150−299 min/week (active−lower recommendation), and (iv) ≥300 min/week (active−upper recommendation). Based on the current global recommendations on physical activity for health,[8] weekly MSE was categorized into 3 groups: (i) 0 day/week, (ii) 1 day/week, and (iii)

≥2 days/week. Based on the above MVPA−MSE classifications, 12 mutually exclusive physical activity groups were created by combining each of the 4 MVPA classifications with each of the 3 MSE classifications.

2.3. Outcome variable: Obesity

BMI-defined obesity (hereafter obesity) was calculated from self-reported height (m) and weight (kg) using the formula: BMI = kg/m^2. A previous study has shown a strong correlation ($r = 0.95$) between self-reported height/weight-calculated BMI and objectively measured height/weight-calculated BMI.[14] Using a standardized BMI cut point,[15] obesity was defined as a BMI of ≥30.0 kg/m^2.

2.4. Covariates

Covariates were selected based on their documented association with MVPA and MSE[16−18] and obesity.[2] They included sociodemographic (sex, age, education, income, occupational status, degree of urbanization, and physical effort of working tasks) and lifestyle (self-rated health, limitations due to health problems for ≥6 months, and smoking status) characteristics, all of which were assessed using standardized survey items.[11] In addition, since the EHIS Wave 2 was conducted across 28 countries, country was included as a covariate.

2.5. Statistical analysis

Analyses were conducted using the Complex Samples module of SPSS (Version 23.0; IBM Corp., Armonk, NY, USA). To improve population representativeness, each EHIS Wave 2 respondent was provided with an individual weighting factor to correct for non-response and under/over-sampling of specific population groups.[11] All data were presented in Table 1, which provides an overview of the EHIS Wave 2 sample sociodemographic/lifestyle factors and physical activity levels, were weighted at the population level.

To examine the associations of MVPA and MSE (exposure variables) with obesity (dependent variable: BMI ≥ 30.0 kg/m^2), we used unweighted data to run a series of generalized linear Poisson regression models with robust error variance to calculate the prevalence ratios (PRs). First, to test the main associations of MVPA and MSE with obesity, 2 separate regression models were conducted: (i) MVPA (reference = 0 min/week of MVPA) and (ii) MSE (reference = 0 day/week). Second, after testing the MVPA × MSE interaction using logistic regression, we ran stratified analyses across each MVPA stratum (4 separate models) to

Table 1.
Sample characteristics, weighted[a] percentages, and 95% confidence intervals (95%CIs). Sociodemographic, lifestyle-related factors, physical activity levels, and body mass index[b] ($n = 280{,}605$).

	n[c]	Weighted[a] % (95%CI)
Characteristics		
Female	153,530	52.1 (51.9−52.4)
18−34 years	57,379	25.2 (24.9−25.5)
Tertiary education (bachelor level or higher)	53,113	20.9 (20.6−21.1)
Highest quintile of income	53,039	21.3 (21.0−21.5)
Employed full time or part time	136,380	53.0 (52.7−53.3)
Live in densely populated area	97,345	37.3 (37.0−37.5)
Mostly sit or stand at work	128,067	51.7 (51.4−51.9)
Very good self-rated health	60,851	23.0 (22.8−23.2)
Not limited due to health problems for ≥6 months	192,620	73.3 (73.0−73.5)
Current non-smoker	212,954	75.5 (75.3−75.7)
Aerobic MVPA: guideline adherence classification groups		
0 min/week (inactive)	142,0147	49.0 (48.8−49.3)
1−149 min/week (insufficiently active)	39,710	14.6 (14.4−14.8)
150−299 min/week (active−lower recommendation)	10,782	4.2 (4.1−4.3)
≥300 min/week (active−upper recommendation)	110,818	32.2 (31.9−32.4)
Muscle-strengthening exercise:[d] guideline adherence classification groups		
0 day/week	220,074	76.5 (76.3−76.8)
1 day/week	14,978	6.2 (6.0−6.3)
≥2 days/week	45,353	17.3 (17.1−17.5)
Body mass index (kg/m^2):[b] defined weight groups		
<18.5 (underweight)	9845	3.8 (3.7−3.8)
18.5−24.9 (healthy weight)	120,638	45.5 (45.3−45.8)
25.0−29.9 (overweight)	101,202	35.0 (34.7−35.2)
≥30.0 (obese)	46,221	15.7 (15.5−15.9)

[a] Weighted using final individual weights specified in the European Health Interview Survey (EHIS Wave 2) methodological manual.[11]
[b] BMI calculated from self-reported height and weight.
[c] Numbers different because of missing responses. Missing cases as follows; n (percentage of final analytical sample): education $n = 1250$ (0.4%); income $n = 17{,}091$ (6.1%); employment $n = 1429$ (0.5%); degree of urbanicity $n = 294$ (0.1%); physical effort during working tasks $n = 28{,}990$ (10.3%); self-rated health $n = 2678$ (1.0%); functional limitations $n = 2574$ (0.9%); smoking status $n = 1678$ (0.6%); BMI $n = 2699$ (0.9%) .
[d] Muscle-strengthening exercise defined as physical activities specifically designed to strengthen muscles, such as doing resistance training or strength exercises (using weights, elastic band, own body weight, *etc.*), push-ups (press-ups), and knee bends (squats).
Abbreviations: BMI = body mass index; MVPA = moderate-to-vigorous physical activity.

describe how MSE within each MVPA stratum was associated with obesity. Third, to examine the joint associations between MVPA−MSE with obesity, we ran a regression model utilizing the 12 MVPA−MSE classifications (reference = "least active", 0 min/week of MVPA and MSE 0 day/week) and obesity. All regression models were run both unadjusted and adjusted for all covariates described above. Before conducting our analytical models, we tested for multicollinearity among potential covariates using tests for χ^2 test of association and the variance inflation factor, with a variance inflation factor of ≥2 indicating multicollinearity. No covariates were shown to be significantly associated. Moreover, all models were checked for nonnormality, heteroscedasticity, and nonlinearity. A review of scatterplots showed no indication of under- or over-distribution.

We performed several sensitivity analyses to enable a more robust interpretation of the results. First, given that obesity[19] and MVPA−MSE[20] have been shown to differ by sex and age, we conducted sex (males *vs.* females) and age (18−64 years *vs.* ≥65 years) stratified analyses on the joint, dose-dependent associations. Since smoking can impact both obesity[21] and physical activity,[20] we also stratified the sample by smoking status (current non-smoker *vs.* current smoker). Since functional limitations and self-rated health are likely to affect physical activity participation, to minimize the risk of reverse causation we stratified the sample by reporting of limitations due to health problems ≥6 months ("yes" *vs.* "no") and by self-rated health ("very good/good" *vs.* "bad/very bad"). Last, given that physical activity during working tasks may impact overall physical activity levels and obesity, we stratified the sample by mostly sit or stand at work ("yes" *vs.* "no").

3. Results

A total of 280,605 participants were included in the analysis, after excluding those aged 15−17 years (n = 9453), and those who did not respond to the physical activity questions (n = 26,275, 8.3% original sample) (Fig. 1). The characteristics of the analytical sample are shown in Table 1 (Supplementary Table 1 for a full sample description). Just over half were female and employed, 25.2% were aged 18−34 years, and

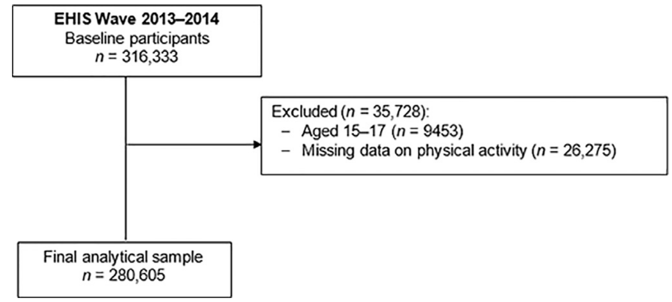

Fig. 1. European Health Interview Survey (EHIS Wave 2) participant flow diagram.

20.9% had tertiary education. Sample sizes from EHIS Wave 2-participating countries ranged from 3774 (Iceland) to 24,016 (Germany). (Supplementary Table 2 for the sample size for individual countries). For physical activity, 32.2% reported ≥300 MVPA min/week, and 17.3% reported MSE ≥2 days/week. For BMI, 45.5% had a BMI between 18.5−24.9 kg/m^2 ("healthy weight"), and 15.7% had a BMI ≥ 30.0 kg/m^2 ("obese").

3.1. Main associations of MVPA and MSE with obesity

The unadjusted PRs and adjusted PRs (APRs) for obesity in the main association models are shown in Table 2. For MVPA, compared to those doing none, those classified as insufficiently active, active-lower recommendation and active-upper recommendation were 18%, 25%, and 40% less likely to be classified as obese, respectively. For MSE, compared to those doing none, lower APRs for obesity were observed for those doing MSE 1 day/week (APR: 0.57; 95%CI: 0.54−0.59) and ≥2 days/week (APR: 0.55; 95%CI: 0.54−0.57). The MVPA × MSE group interaction was statistically significant for obesity (odds ratio: 0.81; 95%CI: 0.75−0.88; $p < 0.001$).

3.2. Stratified associations of MVPA and MSE with obesity

Fig. 2 shows the stratified associations of MSE with obesity across each MVPA stratum (data shown in Supplementary

Table 2.
Associations of aerobic moderate-to-vigorous physical activity and muscle-strengthening exercise with body mass index-derived obesity.[a]

	Unadjusted prevalence ratio[b] (95%CI)	Adjusted prevalence ratio[c] (95%CI)
Moderate-to-vigorous physical activity (min/week)		
0 (inactive)	1 (reference)	1 (reference)
1−149 (insufficiently active)	0.81 (0.78−0.84)	0.82 (0.78−0.85)
150−299 (active−lower recommendation)	0.72 (0.69−0.76)	0.75 (0.72−0.79)
≥300 (active−upper recommendation)	0.57 (0.56−0.58)	0.60 (0.59−0.61)
Muscle-strengthening exercise (day/week)		
0	1 (reference)	1 (reference)
1	0.55 (0.53−0.55)	0.57 (0.54−0.59)
≥2	0.54 (0.52−0.55)	0.55 (0.54−0.57)

[a] Obesity classified as body mass index of ≥30.0 kg/m^2.
[b] Prevalence ratio calculated using Poisson regression with a robust error variance.
[c] Adjusted for sex, age, education, income, occupational status, degree of urbanization, physical effort during working tasks, country, self-rated health, limitations due to health problems for ≥6 months, smoking, and muscle-strengthening exercise.
Abbreviation: 95%CI = 95% confidence interval.

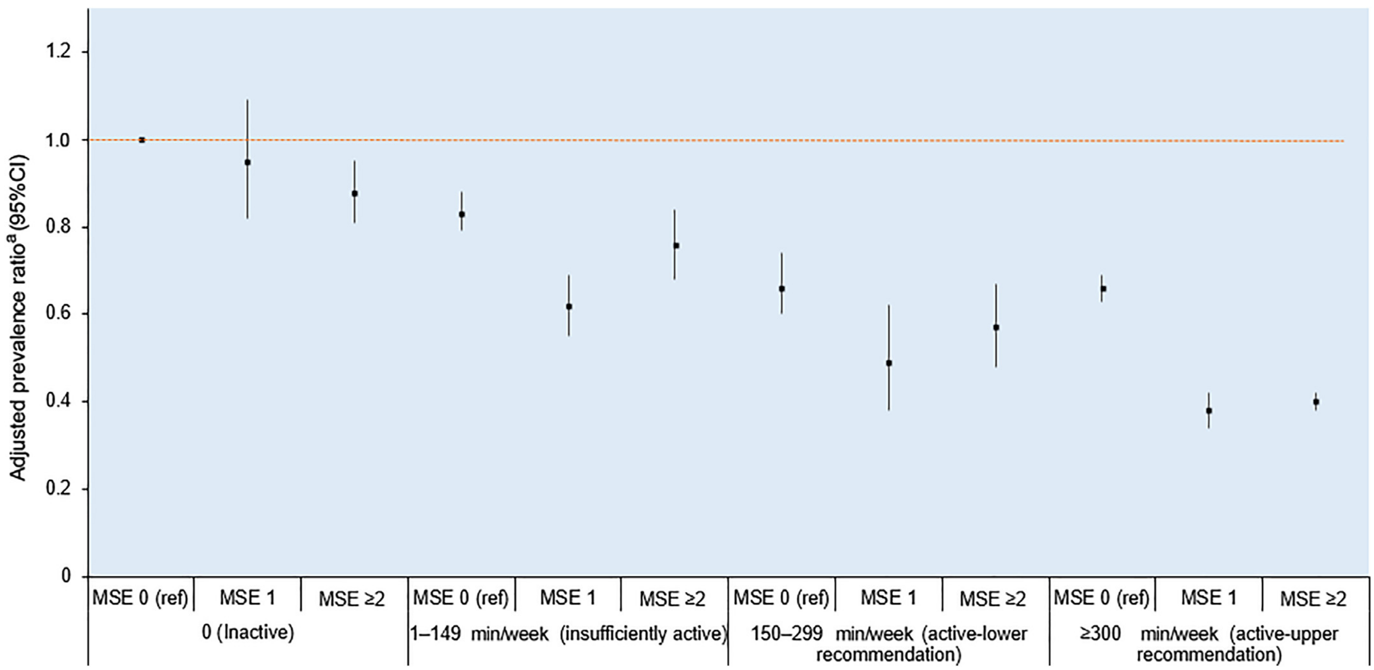

Fig. 2. The stratified association between aerobic MVPA and MSE and body mass index-derived obesity. Obesity classified as body mass index of ≥30.0 kg/m^2. [a] Prevalence ratio calculated using a Poisson regression model with a robust error variance and adjusted sex, age, education, income, occupational status, degree of urbanization, country, physical effort during working tasks, self-rated health, limitations owing to health problems for ≥6 months, and smoking (raw data shown in Supplementary Table 3). 95%CI = 95% confidence interval; MSE = muscle-strengthening exercise; MVPA = moderate-to-vigorous physical activity; ref = 0 min/week .

Table 3). Overall, the APRs for obesity were lowest among the sufficiently active MVPA groups ($p < 0.05$). Except for the most active MVPA group (≥300 min/week), the APRs for obesity were lower among those doing MSE 1 day/week, compared to those doing ≥2 days/week.

3.3. Joint and dose-dependent associations of MVPA and MSE with obesity

Fig. 3 shows the joint and dose-dependent associations of MVPA−MSE with obesity in the adjusted model (data shown

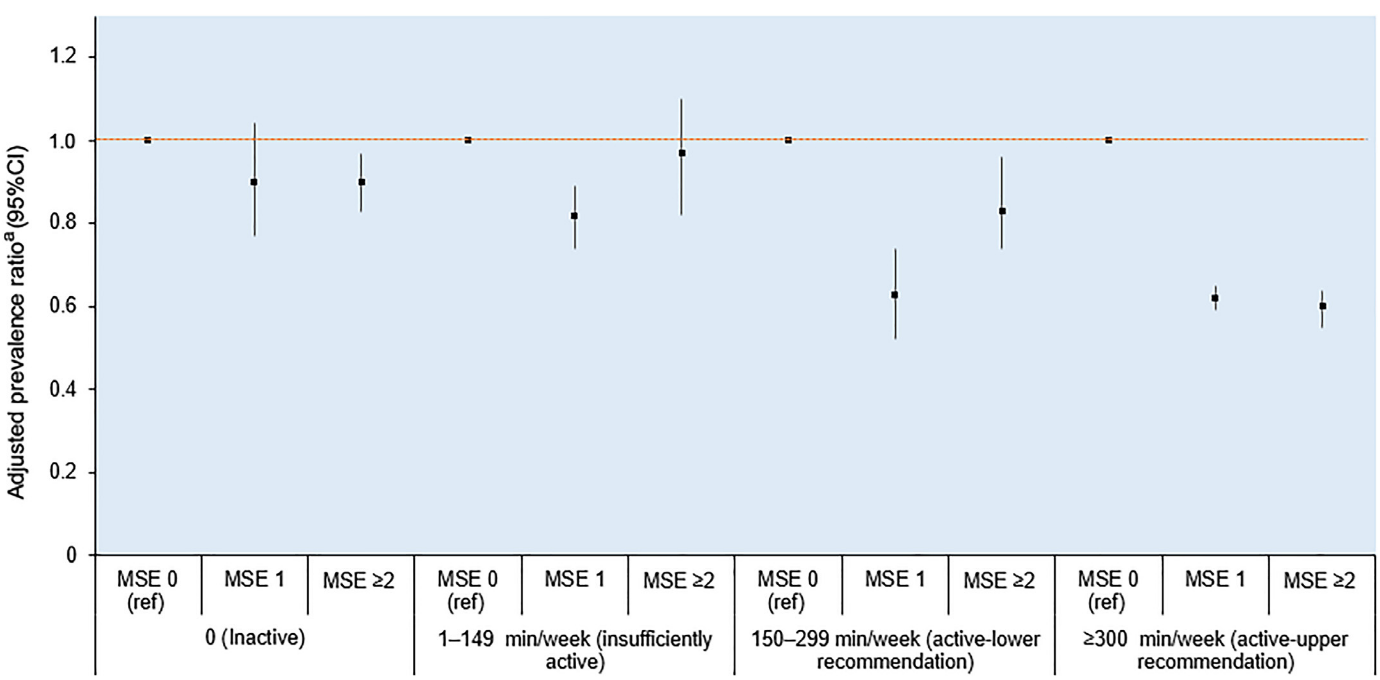

Fig. 3. The joint associations between aerobic MVPA and MSE and body mass index-derived obesity. Obesity classified as body mass index of ≥30.0 kg/m^2. [a] Prevalence ratio calculated using a Poisson regression model with a robust error variance and adjusted sex, age, education, income, occupational status, degree of urbanization, country, physical effort during working tasks, self-rated health, limitations due to health problems for ≥6 months, and smoking (raw data shown in Supplementary Table 4). 95%CI = 95% confidence interval; MSE = muscle-strengthening exercise; MVPA = moderate-to-vigorous physical activity; ref = 0 min/week.

in Supplementary Table 4). When compared to the least active group, and apart from those reporting no MVPA and MSE 1 day/week, all other joint MVPA−MSE groups had lower APRs for obesity ($p < 0.05$ for all comparisons). In particular, across the groups who met the MVPA recommendation in combination with MSE at least once a week, the APRs for obesity were lower compared to those who did not meet the MVPA and MSE recommendation.

3.4. Sensitivity analyses

Analyses stratified for sex, age, smoking habits, and health-related variables are shown in Supplementary Table 5. In brief, similar associations between joint MVPA−MSE and obesity were observed among males (APR range: 0.46−0.88) *vs.* females (APR range: 0.32−0.95), as well as younger (18−64 years old) (APR range: 0.45−0.90) *vs.* older adults (≥65 years old) (APR range: 0.0.56−1.03). When compared to daily smokers (APR range: 0.55−0.84; $p < 0.05$), the association between MVPA−MSE categories and obesity were stronger among non-smokers (APR range: 0.46−0.88; $p < 0.05$). Compared to those who reported being limited by functional limitations (APR range: 0.46−0.88; $p < 0.05$), the association between MVPA−MSE categories and obesity was consistently stronger among those who reported no functional limitations (APR range: 0.59−0.93; $p < 0.05$). Compared to those reporting "very good/good" self-rated health, among those reporting "very bad/bad" health, a lower APR for obesity was observed only for those with the highest joint MVPA−MSE level (APR = 0.81; 95%CI: 0.70−0.93*;* $p < 0.05$). Finally, compared to those reporting mostly sitting or standing at work (APR range: 0.29−0.98), similar APRs were observed among those who did not commonly sit or stand for working tasks (APR range: 0.42−0.91).

4. Discussion

This study is the first to describe the dose-dependent associations of combinations of MVPA and MSE with obesity prevalence among a large representative sample of European adults. The key finding was that lower levels of MVPA and MSE were associated with a higher prevalence of obesity, with associations more pronounced among those not meeting the MVPA recommendation. Further, across all MVPA levels, the absence of MSE resulted in an additional increase in obesity prevalence.

Currently, most of the research on physical activity and obesity among adults is based on studies of MVPA (e.g., walking, cycling, or jogging).[22,23] The current study provides a unique insight into the role of MSE (e.g., use of weight machines, push-ups, and sit-ups) and its potential additive role to MVPA in the maintenance of a healthy weight. While recognizing the limitations of the cross-sectional nature of these data, the current study suggests that a physical activity routine that involves a combination of MVPA and MSE is likely to be important for maintaining a healthy weight.

The main findings presented here are consistent with a large U.S. cohort study of predominantly high socioeconomic status Caucasian males,[9] which showed that participants with high levels of both MVPA and MSE had the most favorable changes in waist circumference over a follow-up period of 12-years.[17] Our findings suggest that these favorable associations between joint MVPA−MSE and adiposity are likely to be generalizable to females, those with different levels of education/income. Additionally, the current study further supports findings from our recent U.S. study using crude cut points for MVPA (0−149 min/week *vs.* ≥150 min/week) and MSE (0−1 day/week *vs.* ≥ 2 days/week).[10] However, the MVPA and MSE groups utilized in the current study enabled a more detailed exploration into dose-dependent associations between joint MVPA−MSE and obesity by encompassing a broader range of MVPA−MSE thresholds (MVPA: 0 min/week, 1−149 min/week, 150−299 min/week, ≥300 min/week; MSE: 0 day/week, 1 day/week, ≥2 days/week).

A further key finding was, that irrespective of the MVPA level, the lack of MSE was associated with higher obesity prevalence. Within the context of the present study, we can only speculate on the physiological mechanisms for this finding. However, a recent meta-analysis of clinical exercise interventions showed that, compared to MVPA,[24] MSE was associated with a significantly increased resting metabolic rate, a well-established protective factor against obesity.[25,26] Furthermore, systematic reviews of clinical studies have established that, compared to doing 1 type of activity alone, combining MVPA and MSE has more favorable associations with key markers of cardiometabolic health, such as insulin sensitivity[27] and blood lipid biomarkers (i.e., low-density lipoprotein cholesterol/high-density lipoprotein cholesterol, triglycerides).[28] Somewhat surprising was that when stratified across MVPA strata, there was a tendency for an increase in APRs for obesity among those reporting MSE 2 days/week, compared to those reporting MSE 1 day/week. A potential explanation for this finding may be that there is an established dose-response relationship between MSE volume and increased skeletal muscle mass.[29] Hence, it is possible that the slight increase in APRs for obesity among the current sample reporting higher MSE levels may be somewhat explained by an increase in skeletal muscle mass, as opposed to an increase in adipose tissue. Furthermore, it has been documented that BMI may not be the best measure for adiposity because it cannot distinguish between fat mass and fat-free mass.[30] Therefore, using BMI as a marker for adiposity may result in misclassifying those with high muscle mass to the "obese" category. Alternately, it might also be possible that MSE 1 day/week may be sufficient to reduce the likelihood of obesity, and levels beyond this offer no further reduction on risk of adiposity. Irrespective of the cause of the apparent non-dose-dependent associations between weekly frequency of MSE and obesity prevalence, it should be reinforced that across all MVPA levels, the addition of MSE, even for 1 session a week, was associated with a lower prevalence of obesity compared to no MSE. Given the cross-sectional nature of this study, we are cautious in assuming causality from the key findings. However, it was noteworthy that when stratified by self-rated health and functional limitations, the associations between MVPA−MSE and obesity were more favorable among the healthy subgroups, hence suggesting some potential for a causal association.

Current findings and other similar epidemiological studies suggest that the combination of MVPA and MSE is likely to have a role in obesity prevention and management. However, compared to MVPA, MSE has received less attention in physical activity promotion.[31,32] It is noteworthy that 75.8% of the current sample reported no MSE, in contrast to 47.9% who reported no MVPA through recreation and transport. Importantly, MSE may be an alternative for those that are not able to perform aerobic MVPA due to co-morbidities, such as functional limitations or chronic obstructive pulmonary disease[33,34] or for those who face environmental barriers.[35,36]

A key strength of the current study was the large representative sample of adults, which allows for exploration of finer categories of MVPA and MSE combinations. A further strength was the use of previously validated physical activity survey items and standardized collection/reduction procedures. Adjustment for a range of potential confounders as well as a comprehensive sensitivity analysis have contributed to the robustness of our findings. A key limitation, on the other hand, was the cross-sectional study design because it limits causal inference. That is, it is possible that those who are obese are less likely to engage in MVPA and MSE because of their excessive weight. In the current study, we used MVPA−MSE cut points that are consistent with global physical activity recommendations.[8] However, it could be the case that further reducing MVPA−MSE data beyond these established cut points may provide a more nuanced association between physical activity and obesity. A further limitation is the use of self-reported assessments of physical activity, height and weight, which may have resulted in recall and social disability bias. For example, in the current study, a large proportion reported MVPA ≥300 min/week, which suggest that the EHIS-PAQ may have resulted in overestimates of engagement in this physical activity-related behavior. As noted, BMI may be limited as an indicator of adiposity and is likely to misclassify those with high muscle mass into a higher BMI category.[30] The non-reporting of dietary intake, alcohol consumption, medication use, sleep duration, sedentary time, and light-intensity physical activity was also a further limitation. Finally, the response rate (∼50%) was modest in some countries,[37] and 8.3% of the original sample did not provide data on the physical activity items.

5. Conclusion

Among a large representative sample of European adults, lower levels of joint MVPA−MSE were associated with a higher obesity prevalence. Among those doing any MVPA, MSE 1 day/week may be enough to lower the likelihood of obesity in adults. While these preliminary cross-sectional findings need to be replicated by prospective cohort studies, our data suggest that a physical activity routine that includes a combination of MVPA and MSE is likely to be the most beneficial for the maintenance of a healthy weight.

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Authors' contributions

JAB did the analysis and drafted the manuscript; KDC and DD assisted with the analysis. All authors have read and approved the final version of the manuscript, and agree with the order of the presentation of the authors.

Competing interests

The authors declare that they have no competing interests.

Supplementary materials

Supplementary materials associated with this article can be found, in the online version, at doi:10.1016/j.jshs.2021.01.002.

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