UNDERSTANDING MOVEMENT BEHAVIOURS IN SHIFT WORKERS: TOWARDS THE DEVELOPMENT OF A HEALTH PROMOTION PROGRAM FOR SHIFT WORKERS

A Thesis submitted by

Malebogo Monnaatsie (M.Ed.)

For the award of

Doctor of Philosophy

2023

ABSTRACT

Shift workers are prone to physical inactivity and high sedentary behaviour, which could lead to adverse health outcomes. Nonetheless, these behaviours are not well understood in shift workers. To address this gap, first, a meta-analysis was conducted following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses for Protocols (PRISMA) guidelines to summarize physical activity and sedentary behaviours in shift and non-shift workers. Results showed that shift and non-shift workers had similar physical activity patterns, but shift workers were less sedentary than non-shift workers. Only about 40% of shift workers met the physical activity guidelines. Additionally, previous studies mostly used retrospective self-report measures to assess behaviours. These results highlight the need to consider more objective measures to minimize recall biases, and the need to develop physical activity health promotion programs for shift workers. Second, a pilot study was conducted to test the applicability of a novel mobile Ecological Momentary Assessment (EMA) app with shift and non-shift workers (n=120). Participants downloaded an EMA app and answered 5 EMA surveys per day, for 7-10 days. Results indicate that EMA, tailored in real-time for shift workers, is a feasible and valid tool to assess physical activity and sedentary behaviour in this population. Finally, the feasibility and efficacy of a health promotion program during a 24-day shift cycle to improve habitual levels of physical activity was conducted. Shift workers in a mining company (n=51) were allocated to intervention or comparison groups. Efficacy outcome measures included moderate-to-vigorous physical activity (MVPA) steps and other movement-related outcomes (activPAL assessed), quality of sleep (PQSI), and quality of life (WHO-5). Participants in the intervention group participated in an action planning session and received messages to motivate change in physical activity and EMA surveys for self-reporting physical activity. The comparison group received feedback on their baseline assessments and generic health promotion material. The intervention resulted in changes in MVPA steps on all days (p=0.00), day shift (p=0.04), and non-workdays (p=0.00) in the intervention group, but not during night or evening shifts. Other outcomes remained unchanged. In addition to testing efficacy, a process evaluation with the intervention group (n=25) using the RE-AIM (reach, effectiveness, adoption, implementation, maintenance) framework was conducted. Online exit surveys, interviews, and the researcher log were used to assess the intervention feasibility. Based on the process evaluation findings, workers were positive and desired most intervention components. However, there is a need to address the identified barriers, including fatigue and better company management involvement. The thesis findings revealed the habitual movement-related behaviours in shift workers to provide the base to guide health promotion programs. The two empirical studies provided insights into using newer mobile technology to assess behaviours and promote physical activity for shift workers in their natural environment and in real time.

CERTIFICATION OF THESIS

I, Malebogo Monnaatsie, declare that the PhD Thesis entitled *Understanding movement behaviours in shift workers: towards the development of a health promotion program for shift workers* 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 Malebogo Monnaatsie except where otherwise acknowledged, with most 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: 23/03/2023

Endorsed by:

Tracy Kolbe-Alexander

Principal Supervisor

Stuart J. H. Biddle

Associate Supervisor

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

STATEMENT OF CONTRIBUTION

This thesis comprises of three main studies led by the candidate, Malebogo Monnaatsie. Study design, participant recruitment, data collection, data analysis and interpretation of results were led by the candidate. The candidate is the first author of all the published (chapter 3 and 6) and submitted (chapter 4 and 5) manuscripts.

Paper 1:

Monnaatsie, M., Biddle, S. J. H., Khan, S., & Kolbe-Alexander, T. L. (2021). Physical activity and sedentary behaviour in shift and non-shift workers: A systematic review and meta-analysis. *Preventive Medicine Reports*, *24*, 101597. doi.org/10.1016/j.pmedr.2021.101597

Malebogo Monnaatsie contributed 70% to to the concept development, analysis, drafting and revising the final submission. Collectively Stuart J.H. Biddle, Shahjahan Khan and Tracy Kolbe-Alexander contributed the 30 % to concept development, analysis, editing and providing important technical inputs.

Paper 2:

Monnaatsie, M., Biddle, S. J. H., Kolbe-Alexander T. (2023) The feasibility of a text-messaging intervention promoting physical activity in shift workers: a process evaluation. *International Journal* *of Environmental Research and Public Health*, *20*(4), 3260. doi.org/10.3390/ijerph20043260

Malebogo Monnaatsie contributed 70% to the concept development, analysis, drafting and revising the final submission. Collectively Stuart J.H. Biddle and Tracy Kolbe-Alexander contributed the other 30% to concept development, analysis, editing and providing important technical inputs.

Paper 3:

Monnaatsie, M., Biddle, S. J. H., Kolbe-Alexander T. (2022). Feasibility of ecological momentary assessment in measuring physical activity and sedentary behaviour in shift and non-shift workers. Submitted to *Measurement in Physical Education and Exercise Science.*

Malebogo Monnaatsie contributed 70% to the concept development, analysis, drafting and revising the final submission. Collectively Stuart J.H. Biddle and Tracy Kolbe-Alexander contributed the remainder. other 30% to concept development, analysis, editing and providing important technical

Paper 4:

Monnaatsie, M., Mielke, I. G., Biddle, S. J. H., Kolbe-Alexander T. (2023). Ecological Momentary Assessment of physical activity and sedentary behaviour in shift workers and non-shift workers: Validation Study. Submitted to *Journal of Sports Sciences*

Malebogo Monnaatsie contributed 70% to the concept development, analysis, drafting and revising the final submission. Collectively Stuart J.H. Biddle, Gregore Mielke and Tracy Kolbe-Alexander contributed the other 30% to concept development, analysis, editing and providing important technical

Additional outputs

Monnaatsie, M., Biddle, S. J. H., & Kolbe-Alexander, T.L (2021). Moving more, a shift in the right direction for shift workers. *Media report.* https://www.usq.edu.au/news/2021/11/moving-shift-workers

Conference presentations

- International Conference on Ambulatory Monitoring and Movement, June 2021. Virtual poster: The feasibility of an ecological momentary assessment to measure physical activity and sedentary behaviour in shift workers. *Monnaatsie,* M., Biddle, S., Schmidt, A., Willams, A., Rogers, A., & Kolbe-Alexander T. L.
- Centre for Health Research showcase event, Health Promotion, University of Southern Queensland, 2021. Video presentation: Physical activity and sedentary behaviour in shift and non-shift workers: A systematic review and meta-analysis. *Monnaatsie, M.,* Biddle, S. J. H., Khan, S., & Kolbe-Alexander, T. L.
- International Society of Behavioral Nutrition and Physical Activity, May 2022. Conference Symposium (online) presentation: The feasibility of an ecological momentary assessment to measure physical activity and sedentary behaviour in shift workers. *Monnaatsie, M.,* Biddle, S., & Kolbe-Alexander T. L.
- School of Health and Medical Sciences Student Research Symposium, University of Southern Queensland, July 2022. Online presentation: A mobile Ecological Momentary Assessment for measuring physical activity and sedentary behaviour in shift workers: A validation study. *Monnaatsie, M.,* Biddle, S J H., Mielke, G., & Kolbe-Alexander T. L.

ACKNOWLEDGEMENTS

Firstly, I would like to thank Professors, Tracy Kolbe-Alexander and Stuart Biddle for their support, advice, guidance, and patience. Thank you, Tracy, for giving me the opportunity. Your edits and attention to detail showed how much work you put into my work. Thanks to Stuart; your guidance and support gave me confidence throughout the PhD. I am grateful to have had two great supervisors. To Ineke, your constant check-ins were appreciated; thank you. To Shahjahan and Gregore, thank you for the guidance with statistics skills. To Prof Onyewadume, my master's supervisor, and mentor - I may not have been here without your guidance.

To my fellow PhD researchers whom I met at UniSQ, thanks for the friendship, advice, and support. Thanks to the friends I met in Australia during the PhD journey. A special mention to my housemate Dominic; thanks for listening to the endless PhD Stories. To family and friends in Botswana, thanks for being the support system. I also wish to acknowledge the support from my husband, Onkemetse Monnaatsie. Thanks for being my cheerleader. Thank you for holding the fort and caring for our daughter, Milan. To Milan, I hope this PhD inspires you.

A big thanks to all participants who volunteered their time to take part in this research. I would like to acknowledge Adam Schmidt, Amy

Willams, Anna Rogers, for their contributions with participant recruitment and data collection for study 2. This PhD would have not been possible without the financial support from the University of Botswana Staff Training Scholarship. Thank you to the University of Southern Queensland for the research funding support.

DEDICATION

To Mom, Sophie!

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABBREVIATIONS

ANOVA	Analysis of Variance
BCW	Behaviour Change Wheel
BMI	Body Mass Index
BRFSS	Behavioural Risk Factor Surveillance System
COM-B	Capability-Opportunity-Motivation Behaviour
CPM	Counts Per Minute
CVD	Cardiovascular disease
EMA	Ecological Momentary Assessment
FIFO	Fly-in-Fly-Out
GPAQ	Global Physical Activity Questionnaire
IARC	International Agency for Research on Cancer
IPAQ	International Physical Activity Questionnaires
IPAQ-SF	International Physical Activity Questionnaire-Short Form
LMICs	Low-and-Middle Income Countries
MRC	The Medical Research Council
MVPA	Moderate-to-Vigorous Intensity Physical Activity
NSW-S	Non-Shift Worker-Standard
NCDs	Non-Communicable Diseases
OR	Odds Ratio
PA	Physical activity
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-analysis
PSQI	Pittsburgh Sleep Quality Index
RE-AIM	Reach, Effectiveness, Adoption, Implementation, and Maintenance

SEMA	Smartphone Ecological Momentary Assessment
SB	Sedentary Behaviour
SPSS	Statistical Package for Social Sciences
STROBE	Strengthening the Reporting of Observational Studies in Epidemiology
SW-S	Shift Worker-Standard
SW-T	Shift Worker-Tailored
WHO	World Health Organisation
WHO-5	World Health Organisation-Five Well-Being Index
WHPP	Workplace Health Promotion Program
5As	Ask, Assess, Advise, Assist, and Arrange

CHAPTER 1: INTRODUCTION

1.1. Background

Shift work is prevalent in many industries, especially those requiring 24/7 work like healthcare, manufacturing, mining, hospitality, and retail (Messenger, 2018). However, shift work is associated with unhealthy behaviours, including physical inactivity and high sedentary time (Demou et al., 2018). Shift work is also related to misalignment of the circadian rhythms, disturbance in sleep, and disruption of family and social life (James et al., 2017). Physical inactivity, smoking, and high sedentary time are key risk factors for non-communicable diseases (NCDs) (Katzmarzyk et al., 2022). Therefore, the combination of unhealthy behaviours and disruption in circadian rhythms, in turn, leads to increases in disease risk and incidence (Rivera et al., 2020). Epidemiological evidence has shown that there is an increase in chronic diseases such as cardiovascular diseases, cancers, obesity, and diabetes in shift workers (Boivin et al., 2022). In addition, evidence has shown a strong link between working in shifts and mental health issues, such as anxiety, depression, and suicide (Khan et al., 2020). Consequently, unhealthy behaviours and disruptions may lead to long-term physical and mental health effects in the shift working population (Silva et al., 2020).

The disruption of circadian rhythms because of shift work, particularly the night shift, describes a state of desynchronization between circadian clocks and the environment (Boivin & Boudreau, 2014).

The circadian misalignment associated with working in shifts has then been implicated in the increased risk of metabolic syndrome (Gabriel & Zierath, 2019), type 2 diabetes (Mason et al., 2020), and cardiovascular diseases (Chellappa et al., 2019).

Lifestyle behaviours including smoking, unhealthy diets (Souza et al., 2019), physical inactivity (Cheng et al., 2020), sedentary behaviour (Hulsegge et al., 2017), lack and poor-quality sleep (Boivin & Boudreau, 2014) are hypothesised to contribute to higher disease risk in shift workers. Low-quality diet, characterised by inadequate intakes of fruit, vegetables, legumes, whole grains, nuts or seeds, fish, lean meat, poultry, and added sugars, and disturbances in sleep are frequently reported by shift workers (Redeker et al., 2019). Regular physical activity may be more challenging for shift workers due to limited time to participate in leisure-time activities and fatigue associated with some shift work (Boivin et al., 2022). Prevalence of sedentary behaviour may also be high in shift workers, especially those with driving occupations (79% of daily work time) or in call-centres (Varela-Mato et al., 2017).

Well-established evidence demonstrates that physical activity and a less sedentary lifestyle reduce the risk of non-communicable diseases and improve overall health and well-being (González et al., 2017). However, there have been mixed results related to the relationship between working shifts and movement-related behaviours (Cheng et al., 2020;

Nea et al., 2015). Some previous research demonstrates shift workers are more active compared to non-shift workers (Hulsegge et al., 2020; Loef et al., 2020), while some show that shift workers report less physical activity (Loprinzi, 2015; Mansouri et al., 2022), and no differences have been reported (Roskoden et al., 2017). For example, shift work was associated with increased levels of occupational physical activity (Ma et al., 2011). In another study, shift workers spent more time walking at work than non-shift workers, but there were no differences in other physical activity levels (Loef et al., 2016). There have also been mixed reports on the effect of shift work on sedentary behaviour, with both low (Loef et al., 2018; Loprinzi, 2015) and high sedentary time reported (Hulsegge et al., 2017). More evidence is needed to investigate whether shift workers are less active and more sedentary than non-shift workers.

Most studies investigating physical activity and sedentary behaviours were in high-income countries, for example, the USA, Australia, Netherlands, and Canada, with only a few from low- and middle-income countries (LIMC) (Monnaatsie et al., 2021). In addition, self-report measures were used more frequently than devices for the assessment of physical activity, which may result in recall and social desirability bias (Loef et al., 2017; Marqueze et al., 2014; Park & Suh, 2020). For example, questionnaires like IPAQ requires participants to report their behaviours over a predetermined time (e.g., over the past month), leading to some recall bias (Colley et al., 2018; von Haaren-Mack et al., 2020).

An increasing number of studies now use device-based measures of physical activity and sedentary behaviour (Lauren et al., 2020; Roskoden et al., 2017; Thompson et al., 2018). Similarly, devices can identify certain physical activity and sedentary behaviours, but not the context or domains of activity (Doherty et al., 2013). For example, the influence of work environments cannot be assessed with devices because they can fail to provide information about the location and type of behaviour or activity. Similarly, the types and domains of movement behaviours are not easily reported with devices (Nigg et al., 2020). Alternatives to retrospective self-report and device measures include using doubly labelled water and indirect calorimetry. The doubly-labelled water method which measures total energy expenditure is the gold standard for assessment of physical activity, based on measurement of energy expenditure (Speakman et al., 2021). However, the method places a large burden on participants and does not provide specific information on daily physical activity and sedentary behaviour (Ma et al., 2020; Westerterp, 2015).

There are other methods available to gather contextual information of physical activities and sedentary behaviours. Observational methods are a common approach for assessing movement-related behaviours and have been shown to be valid and reasonably reliable when trained observers rate the postures of large body parts (Mathiassen & Wahlström, 2013; Takala et al., 2010). However, observations are generally time-consuming and expensive. Observations may also modify the behaviour of the observed participant (observational bias) (Nyman et al., 2023). To overcome such limitations, ecological momentary assessment (EMA) offers an alternative and promising method to assess movement-related behaviours, with rich contextual longitudinal data in real-time (Dunton, 2017).

Using EMA with mobile phones highlights an opportunity to incorporate it in interventions to provide real-time and highly personalized support to increase health behaviour (Bentley et al., 2019). In addition, EMA can be suitable to demonstrate insights into health behaviours of shift workers catering to unique work rosters (Asare et al., 2023). Shift work results in adverse health effects; thus, developing appropriate interventions to improve workers' health should be a public health priority. To design effective interventions for shift workers, measurement tools that quantify specific physically active and sedentary behaviours within the relevant behavioral contexts are needed (Keadle et al., 2017). Most workplace physical activity and sedentary behaviour interventions do not target shift workers. As reported in one systematic review of physical activity-based interventions, a few have been implemented (Flahr et al., 2018).

1.2. Summary and aims

This PhD project, therefore, is aimed at increasing understanding of physical activity and sedentary behaviour in shift workers to inform health promotion programs to improve workers' health. The thesis consists of three main studies: a systematic review and meta-analysis and two primary empirical studies. The first study aimed to examine the levels of physical activity and sedentary behaviour in shift workers compared to non-shift workers to determine if shift workers are less active and more sedentary than non-shift workers. The second study aimed to determine the feasibility and validity of EMA with a mobile application as an alternative tool to consider in assessing physical activity and sedentary behaviour in shift workers. In the last study, a health promotion program's efficacy and process evaluation were examined to improve habitual levels of physical activity in shift workers.

CHAPTER 2: LITERATURE REVIEW

2.1. Chapter overview

This chapter presents an overview of the literature on shift work, health outcomes, and associated mechanisms in shift workers. Healthy behaviours, including physical activity and sedentary behaviour, are regarded as the leading risk factors for disease and all-cause mortality; thus they are possible risk factors that lead to adverse health outcomes in shift workers (Nea et al., 2015). These are explored in this section to discuss their influence on shift workers' health outcomes. Further, the physical activity and sedentary behaviour public health guidelines and the benefits of leading a healthy lifestyle will be reported. To report on the physical activity and sedentary behaviour determinants and measurement tools to assess these movement behaviours in the shift working population were also reviewed. Lastly, research on health promotion programs to improve physical health in the shift work population are presented.

2.2. What is shift work?

There are several definitions of shift work. One of the ~~more~~ common definitions is "any work outside the normal conventional work hours of 7:30-9:00am to 5:00-6:00pm" (Costa, 2003). Thus, any work in the early morning before 9am or after 5pm in the evening and night. Therefore, some studies would refer to shift work as non-standard work (i.e., work that falls outside the standard day/week) (Richbell et al., 2011).

The International Labour Organization (ILO) defines shift work as "a method of organization, of working time in which workers succeed one another at the workplace so that the establishment can operate longer than the hours of work of individual workers" (ILO, 1990). This means work hour arrangements involve two or more teams (shifts) that differ in terms of their work's starting and finishing times. Workplaces implement the work 'around the clock' to accommodate the demand of providing services or products 24 hours per day and seven days per week. Shift work is common in health care, emergency services, hospitality, transport, mining, and manufacturing (Åkerstedt, 1990). In this PhD thesis, shift work is defined as "work carried out at set times of the day or at night, outside the normal working day and where individuals may rotate between different work time patterns." In Botswana, where some of the PhD work was based, shift work is defined as work carried out 24/7, and the period of such work covers day, afternoon, and night shifts of eight hours each (Botswana Employment Act, 1982).

2.2.1 Shift schedules and patterns

Shift types or schedules can vary between countries and workplaces. Several types of shift work systems exist, including fixed shift systems, in which a particular group of workers always work the same shift; and rotating shift system, in which workers are assigned to work shifts that vary regularly over time and rotate around the clock; for example, from morning to afternoon/evening to night shift (Casjens et al., 2022). In Australia, the number of consecutive days on night shift should be optimally one or two but no more than three days. A clockwise shift rotation pattern is recommended, with simple and predictable scheduling templates used where possible (three day, three evening and three-night shifts, and three recuperative days off) (ACT, 2019). In Botswana, where shift work is prevalent in diamond mining companies, shift schedules are also in a clockwise shift rotation. However, workers have six-day shifts, six evening and six-night shifts of 8 hours, with two rest days in between the three shifts (Monnaatsie et al., 2023).

Shift work can also involve working time for all or part of the night, and the number of nights worked per week/month/year can vary considerably. Moreover, night work shifts can have varying start and finish times. For example, starting times can range from 8 pm, 9 pm, 10 pm, 11 pm or 12 pm, and finishing times from 4 am, 5 am, 6 am, or 6 am the following day (IARC, 2010).

2.2.2. Prevalence of shift work

The International Labour Organization and the European Foundation for the Improvement of Living and Working Conditions reported that between 10% and 30% of workers work night shifts at least once a month (Organization, 2019). Approximately 19 percent of Australian employees are shift workers, compared to 21% of Europeans and 25% of

Americans employed as shift workers (Brown et al., 2022; Lieberman et al., 2019; Australian Bureau of Statistics, 2019). Shift work is less prominent in Asia (12%) (Living & Conditions, 2019). In LMIC, about 15-30% of the workforce is involved in shift work (Merchaoui et al., 2017). In the case of Botswana, there is a paucity of research on the prevalence of shift work. However, there is evidence of shift work practices in the healthcare and mining industry (Koitsiwe & Adachi, 2017; Motlhatlhedi et al., 2020; Olashore et al., 2021; Weldegiorgis et al., 2023).

2.3. Health consequences of shift work

Working in shifts is associated with an increased risk for chronic diseases and premature mortality compared to non-shift workers and the general population (Boivin et al., 2022). In particular, working in shifts has been associated with an increased risk of NCDs (Gusmão et al., 2022; Rivera et al., 2020). The risk of NCDs, such as type 2 diabetes and cardiovascular diseases, is increased in people with metabolic syndrome (Leroith, 2012).

Several meta-analyses and systematic reviews have attempted to combine the various epidemiological studies that address the relationship between shift work and metabolic health, providing evidence for an association between shift work and metabolic syndrome (Dong et al., 2022; Khosravipour et al., 2021; Sooriyaarachchi et al., 2022). A meta-analysis of 12 studies concluded that compared to regular day workers, shift workers in the healthcare sector exhibited more than a two-fold increase in developing metabolic syndrome (Sooriyaarachchi et al., 2022). Similarly, the odds ratio for shift workers with metabolic syndrome was particularly high (OR = 30.55; CI 13.70–81.64) in comparison to non-shift workers (Arias et al., 2021). In a study of 1575 petrochemical workers, the risk of metabolic syndrome was higher in rotating shift workers than fixed day workers (Khosravipour et al., 2019). While the studies mentioned above showed the increased risk of metabolic syndrome in shift workers, there is insufficient evidence of some metabolic outcomes, including lipid metabolism and blood pressure (Proper et al., 2016). Proper and colleagues concluded that poor shift work measurement scores could have contributed to the results (Proper et al., 2016).

For over two decades, cardiovascular disease risk factors associated with shift work have been reported in the literature (Strohmaier et al., 2018). Working shifts increased the risk of cardiometabolic multimorbidity in a cohort of 36 969 UK workers (Yang et al., 2022). Similarly, a recent umbrella review estimated the risk of hypertension at 30% with rotating and night shift workers (Boini et al., 2022). Prolonged years of exposure to shift work is also related to a higher risk of cardiovascular disease (Abu Farha & Alefishat, 2018; Torquati et al., 2018; Wang et al., 2020). For example, there was a 7.1% increase in the risk of cardiovascular diseases for every additional five years of exposure to shift work (Torquati et al., 2018). The evidence on the duration of shift work and the risk of type 2 diabetes was also reported (Gao et al., 2020). The pooled odds ratio for five years of shift work was 1.07 (95% CI: 1.05–1.09), and for ten years of shift work, 1.11 (95% CI: 1.06–1.15) (Gao et al., 2020). This suggests that longitudinal studies are crucial when assessing disease risk in shift workers.

In addition, evidence from systematic reviews of cross-sectional studies shows that shift work was associated with an increased risk of diabetes (Anothaisintawee et al., 2016; Gao et al., 2020; Li et al., 2019; Pan et al., 2011; Shan et al., 2018). A pooled risk ratio of 1.40 (1.18, 1.66) (Anothaisintawee et al., 2016) and 1.10 (95% CI: 1.05, 1.14) was reported in shift workers compared with non-shift workers (Gao et al., 2020). In relation to gender, the association between shift work and type 2 diabetes appeared to be stronger among men than women (Gan et al., 2015). However, in another study, a strong and highly significant linear dose-response relationship between the duration of shift work and the risk of diabetes was higher in women than men (RR=1.07, 95% CI 1.04 to 1.09) (Li et al., 2019). When the type of shift was considered, rotating shifts were associated with an increased risk of type 2 diabetes compared to fixed shifts (Gan et al., 2015).

A large proportion of the research on shift work and cancer risk has mainly addressed breast cancer in women (Lin et al., 2015; Pronk et al., 2010; Schwarz et al., 2021). Shift work, particularly night shift work, is associated with increased breast (Cordina-Duverger et al., 2018; Sweeney et al., 2020; Wegrzyn et al., 2017) and prostate (Behrens et al., 2017) cancers. In June 2019, a working group convened by the International Agency for Research on Cancer (IARC) concluded that “night shift work” is probably carcinogenic to humans (Erren et al., 2019). While the epidemiological evidence is clear about shift work and breast cancer, the association between shift work and prostate cancer cannot be confirmed with the available current data.

Other cancers reported in the shift work population included colon cancer and colorectal cancer (Kolstad, 2008; Schernhammer et al., 2003). For example, a population-based cohort study involving male German reported an increased risk estimate for cancer of the distal colon in shift workers (IRR: 1.60, 95% CI: 0.53; 4.87) and in shift workers who did not perform night work (IRR: 3.93, 95% CI: 0.98; 15.70) (Wichert et al., 2020). However, in an Australian-based female case-control study involving shift workers, there was no evidence of an increased risk of colorectal cancer (Walasa et al., 2018). Evidence for an association between other forms of cancer and shift work is not particularly strong, with weak or conflicting data reported (Dun et al., 2020). Overall, evidence for the effect of shift work on cancer risk appears inconclusive. A point of consensus in the disparities seems to be the variability in study methodologies, with the definition of shift work and shift work exposure. The control for confounding factors, including shift work schedules and lifestyle behaviours is frequently unclear in the studies (Wichert et al., 2020).

Working in shifts has also been shown to affect workers' mental health (Sweeney et al., 2021; Torquati et al., 2019). Shift work has been associated with depressed mood and anxiety, substance use, impairments in cognition, lower quality of life, and even suicidal ideation (Brown et al., 2020; Kang et al., 2017). For instance, Australian paramedics working rotating shifts reported significantly higher levels of depression, anxiety, fatigue, and PTSD symptoms than the general population (Khan et al., 2020). Similarly, there was a significant increased risk of depression (OR = 1.13, 95% CI, 1.00–1.27) and poor self-rated health (OR = 1.13, 95% CI, 1.14–1.55) among shift workers compared to non-shift worker in Canada (Sweeney et al., 2021). Moreover, female shift workers were more likely to experience depressive symptoms than female non–shift workers (Sweeney et al., 2021; Torquati et al., 2019). Evidence, therefore, suggests that health promotion programs to improve mental health would be beneficial for shift workers.

Other adverse health outcomes associated with shift work include overweight and obesity (Liu et al., 2018; Peplonska et al., 2014; Smith et al., 2022), chronic fatigue (Courtney et al., 2010; Donnelly et al., 2019), and gastrointestinal symptoms and disorders (Smith et al., 2022). Night shift work, in particular, was associated with increased odds of becoming overweight (OR = 1.17; 95% CI, 0.97–1.41) or obese (OR = 1.27; 95% CI, 0.74–2.18) compared to those who only worked during the day (Sun et al., 2018). Another study indicated that permanent night shift workers had a greater risk of developing obesity than workers on rotating shift schedules (Sun et al., 2018).

Since a substantial proportion of the working population is involved in shift work, about 20% of the working population globally is at increased risk of developing various health problems (Kervezee et al., 2020). Literature on the effects of shift work on physical and mental health has been provided over the last few decades, leading to the publication of numerous systematic reviews. Although more evidence is still needed to analyse better the burden of shift work on the health and well-being of workers, we know enough to drive health promotion programs to prevent and promote better health.

2.4. Mechanisms affecting health in shift workers

The mechanisms related to shift work and poor health outcomes appear to be multifactorial (Hulsegge et al., 2017). Several mechanisms, such as circadian disruption, disturbed sleep, lifestyle behaviours, and psychosocial stress, have been suggested as possible reasons behind the health problems in shift workers (Cable et al., 2021). These factors disturb several physiological, socio-temporal, and behavioural processes that further contribute to and potentiate disease. Figure 2.1, adapted from Knutsson, shows the causal association of the factors that lead to long-term chronic diseases in shift workers (Knutsson, 2003).

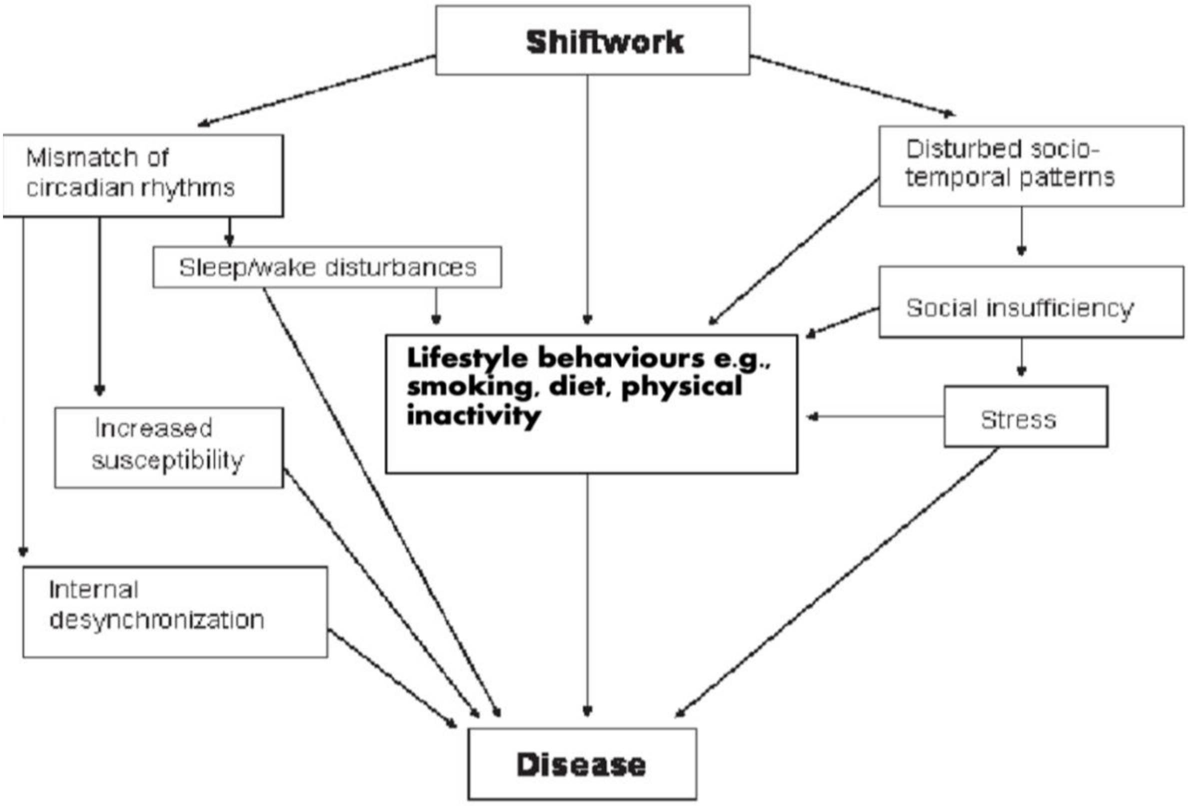


Figure 2.1 Mechanisms that result in diseases in shift workers (From Knutsson, 2003)

2.4.1. Circadian desynchronization

Substantial evidence has shown that shift work resulted in disturbances in sleep and low-quality sleep due to non-standard hours and rosters required of shift workers (Astiz et al., 2019; Boini et al., 2022). These disturbances result in circadian mismatch or misalignment, which describes a state of desynchronization between circadian clocks and the environment (James et al., 2017). Circadian disturbances have often been mentioned as a significant contributor to shift workers' adverse health outcomes and diseases (Kervezee et al., 2020). The findings give credence to the effect of circadian misalignment as a risk factor for cardio metabolic disturbances, independent of behavioural changes associated with night and shift work (Hemmer et al., 2021). The implications of circadian misalignment between the sleep/wake cycle and adverse health outcomes are perhaps obvious in shift workers. This PhD, however, primarily focuses on understanding movement behaviours and their association with shift work.

2.4.2 Lifestyle behaviours

Epidemiological studies highlight the strong link between sleep disturbances and unhealthy diets in shift workers compared to regular day workers. Sleep disturbances and altered meal timing due to shift work disturb the hormonal balance, disrupting the biological systems related to diet, weight, and metabolism (James et al., 2017). It is obvious that shift work results in disturbances to sleep and low-quality sleep due to non-standard hours and rosters required of shift workers (Astiz et al., 2019; Boini et al., 2022). Physical activity and high volumes of sedentary time are some of the possible health behaviours contributing to poor health outcomes in shift workers (Varela-Mato et al., 2017).

Evidence suggests that sleep deprivation, which is apparent in shift workers, can alter appetite, resulting in the consumption of high-energy food (Broussard & Van Cauter, 2016). In addition, sleep duration and quality are strongly related to the body's metabolic functioning (Crowther et al., 2021; Medic et al., 2017). Therefore, sleep disturbance due to shift work impacts workers' health, as it can predispose them to chronic diseases. Similarly, shift work has been shown to affect workers' diets. A sub-optimal diet has been identified as the leading risk factor for death and disability worldwide (GBD 2017 Diet, 2019). Higher energy intake has been reported in the shift work population, who are already at a high risk of diseases (Pepłońska et al., 2019). Meal timing, food choice, and variation of energy metabolism at night were hypothesised to be responsible for the increased rates of obesity observed in shift workers (Bonham et al., 2016).

A strong link between physical activity and health and the deleterious effects of inactivity led to the classification of physical inactivity as the fourth primary risk factor for NCDs (Guthold et al., 2018). There is a possible connection between the impact of shift work on regular physical activity due to several factors, including access to leisure facilities, availabilities of other work team or family members, conflicting domestic and family activities, and fatigue associated with shift work (Arlinghaus et al., 2019).

Like physical activity, shift workers are often involved in sedentary jobs, for example, drivers and call-centre workers (Varela-Mato et al., 2017). High sedentary behaviour is a risk factor for poor health (Gardner et al., 2016). Time spent in sedentary behaviour is associated with all-cause and cardiovascular disease mortality and several NCDs (Patterson et al., 2018). Sedentary behaviour as a possible predictor for developing metabolic syndrome was reported by night shift workers compared to daytime workers (Pietroiusti et al., 2010). Although occupation may influence sedentary behaviour, research on the impact of shift work on sedentary behaviour is limited.

2.5. Physical activity and sedentary behaviours in shift workers

2.5.1. Physical activity and public health guidelines

Physical activity refers to any body movement that results in energy expenditure, including exercise (planned and structured to improve or maintain physical fitness), occupational physical activity, sports, household, or other daily activities (Caspersen et al., 1985). The recent World Health Organisation (WHO) guidelines recommend that adults undertake 150-300 min of moderate-intensity aerobic physical activity or 75-150 min of vigorous-intensity aerobic physical activity (Bull et al., 2020). The guidelines further specified weekly thresholds, that MVPA bouts of any duration can contribute towards meeting the recommendations, and that any movement counts for many inactive people (Bull et al., 2020). These are also consistent with Australian guidelines for physical activity (Brown et al., 2012).

Despite the evidence on the benefits of physical activity, about one-quarter of adults worldwide do not meet the WHO recommendations based on self-report data (Guthold et al., 2018). In Australia, a smaller proportion (15%) of adults meet the physical activity guidelines (Bennie et al., 2019). In comparison, approximately 20% of Botswana adults are insufficiently active (Guthold et al., 2020). Physical activity guidelines can be met by being active in various domains, including active transport, leisure time, work, and household activities (Cusatis & Garbarski, 2019).

The recent WHO guidelines recommend general physical activity does not stipulate domain specifications (Coenen et al., 2018). However, evidence suggests that high levels of occupational physical activity may harm health (Holtermann et al., 2020). For example, in highly physically demanding jobs, such as construction and mining, manual work and prolonged occupational activity are carried out at lower intensities, which may not elicit substantial improvements in cardiorespiratory fitness (Coenen et al., 2018; Reed et al., 2018). The phenomenon has been referred to as the occupational physical activity paradox, which suggests that not all types of physical activities are necessarily good for health (Janssen et al., 2023). However, the evidence is inconclusive as some studies showed that high occupational physical activity has been shown to protect against chronic diseases (Martinez Gomez et al., 2022; Pearce et al., 2021). For example, blue collar shift workers are often involved in high levels of occupational physical activity that may result in adverse health outcomes, thus more investigation on domains of physical activity needed.

2.5.2. *Sedentary behaviour*

Sedentary behaviour is defined as any waking behaviour that is characterized by low energy expenditure (i.e., ≤ 1.5 metabolic equivalents) performed while in a seated, reclined or lying posture (e.g., reading, watching television) (Tremblay et al., 2017). Sedentary behaviour should be limited by breaking long periods of sitting and replacing it with some physical activity (Bull et al., 2020). Similar to the WHO guidelines, Australian guidelines advise adults to minimize time spent in prolonged sitting by breaking long periods of sitting as often as possible (Brown et al., 2012). With the recent WHO guidelines, the evidence on specific health benefits by type or domain of sedentary behaviour, or to determine the influence of frequency and duration of breaks in sedentary behaviour on health outcomes is still insufficient (Bull et al., 2020).

There is evidence that shows greater risk of cardio metabolic disease and mortality when sedentary time exceeds eight hours a day (Ekelund et al., 2016; Prince et al., 2016). Other studies have shown that adults spend on average 6–8 hours a day in sedentary behaviour, which can eventually lead to elevated levels of blood pressure and impaired cardiac autonomic modulation; both are risk factors for cardiovascular disease morbidity and mortality (Dempsey et al., 2018; Paterson et al., 2020). Further, there is new evidence on the interdependent relationship between sedentary behaviour and physical activity, suggesting that replacing sedentary time with any intensity of physical activity (including light intensity) has health benefits (Chastin et al., 2021).

Sedentary behaviour can occur across multiple domains and is influenced by various factors such as environmental, social, community/organisation, and culture (Owen et al., 2011). Understanding the physical and social context in which sedentary time takes place is crucial for workers. For example, in the transport domain, using a car or public transport rather than walking or riding a bike can result in high sedentary behaviour. Moreover, television viewing and use of screens are common in recreational settings (Prince et al., 2017).

Work environments can heavily influence physical activity and sedentary time (Prince et al., 2019). Occupations primarily involving screen use contribute extensively to prolonged sitting at work (Thorp et al., 2012). Workers spend approximately 8 hours at work and even more (up to 12 hours) for most shift workers (Ball et al., 2015). For instance, drivers spend large amounts of time sitting due to the nature of their work, while nurses can spend more time standing and walking at work (Coenen et al., 2018). Given the many hours adults spend at work, understanding the contribution of occupational sitting time to overall sedentary behaviour in shift workers is essential (Holmes et al., 2016).

Like insufficient physical activity, sedentary behaviour is related to other adverse health-related outcomes, which include cardiovascular disease mortality, diabetes, increased insulin resistance, high blood pressure, and obesity (Ekelund et al., 2016; Stamatakis et al., 2012). Recently, evidence on joint association of physical activity of any intensity and sedentary behaviour with all-cause mortality risk is growing, highlighting the need for combinations in quantifying the time spent in these behaviours (Chastin et al., 2021; Clarke & Janssen, 2021). While considerable research efforts have been directed at understanding the patterns of physical activity and sedentary behaviour in shift workers, the findings are mixed.

2.5.3. Prevalence of physical activity and sedentary behaviour in shift workers

Physical inactivity contributes to adverse health outcomes in shift workers (Atkinson, Fullick, Grindey & Maclaren, 2008). Loef et al. hypothesized that shift workers are less physically active than non-shift workers. However, they found no differences in leisure-time physical activity between shift workers and non-shift workers (Loef et al., 2017). Several other studies showed no differences in leisure-time physical activity between shift and non-shift workers (Chiang et al., 2022;

Hulsegge et al., 2017). A recent study showed no differences in overall physical activity in shift and non-shift workers using a novel physical activity–sleep index (Fenwick et al., 2022). Conversely, shift workers in the production industry engaged in less moderate-to-vigorous physical activity during leisure time (Hulsegge et al., 2021).

Some studies reported that shift workers are more active than non-shift workers, especially at work (Esquirol et al., 2009; Loef et al., 2019; Roskoden et al., 2017). For example, data from the NHANES survey showed that shift workers sustained more MVPA at work, but no differences in overall MVPA (Loprinzi, 2015). Similarly, hospital shift workers walked more (95% CI 0.1-2.2) and spent more time standing (95% CI 6.4–12.6) at work than non-shift workers (Loef et al., 2018). Shift-working nurses were also more physically active during work hours than non-shift workers (2.1 vs. 1.7 METs, $p<0.01$) (Roskoden et al., 2017).

On the contrary, low levels of occupational physical activity were reported in shift workers (Hulsegge et al., 2017). Like the results of Hulsegge and colleagues, 1300 shift workers in Ireland involved in various industries were less likely to spend more time at work physically active (Kelly et al., 2020). Further, the Irish middle-aged shift workers were 35% ($p=0.012$, OR=0.65, 95% CI 0.46 to 0.91) less likely to adhere to physical activity guidelines than the younger workers (Kelly et al., 2020).

While most of these studies showed that shift work did not negatively impact physical activity or differ from regular day workers, occupation-related physical activity seems higher than leisure-time physical activity.

Besides the type of physical activity (leisure time versus occupational), varying shift work patterns and characteristics might result in inconsistent conclusions. For example, non-fixed-rotating-shift nurses had relatively less physical activity than fixed-evening- or fixed-night-shift nurses (Chiang et al., 2022). In another study involving night and non-night work patterns, participants were less physically active during the night-shift session than in the non-night-shift session because of limited leisure activities (van de Langenberg et al., 2019). Similarly, gender seems to have an impact; too little physical activity was reported in women who work shifts.

Previous studies used cross-sectional data and did not study workers' physical activity over time (Monnaatsie et al., 2021). In a recent scoping review of longitudinal studies on shift workers' health behaviours, only three studies examined physical activity and concluded that shift workers might be physically inactive (Crowther et al., 2022). The results of a longitudinal study show that shift workers were increasingly becoming physically inactive over time (Cheng et al., 2020). In this study, the Finnish workers were asked to report hours of physical activity per week on average during leisure time or commuting within the past year

(Cheng et al., 2020). However, in another longitudinal study with a 6-year follow-up, no changes in physical activity were found (Buchvold et al., 2019).

The impact of shift work on sedentary behaviour also needs more conclusive evidence. The few studies that investigated shift workers' sedentary behaviours reported inconsistent results. Hulsegge et al. reported that shift workers spent more time in sedentary behaviours at work (Hulsegge et al., 2017), while Loef et al. have shown that shift workers are less sedentary at work (Loef et al., 2017). Like the results of Loef et al., shift workers engaged in less sedentary behaviour than non-shift workers (Loprinzi, 2015). Total and occupational sitting time differed between shift workers and non-shift workers (Vandelanotte et al., 2013). Other studies found no differences in sedentary behaviour between shift and day workers (Alves et al., 2017).

A key variable that explains sedentary behaviour is work tasks or work-related factors. For example, sitting time may be low in health services and construction and high in transport and office workers (Vandelanotte et al., 2013). In a review of occupational physical activity and sedentary behaviour correlates, white-collar occupation was found to be consistently and negatively associated with occupational sedentary behaviour due to the nature of the work in that industry (Smith et al., 2016). Working in a call centre has also been associated with higher levels of sedentary behaviour than other indoor occupations (Clark et al., 2022). Similarly, drivers sit for prolonged periods during driving and non-driving periods at work (Varela-Mato et al., 2016).

Shift types or work and non-workdays may also be associated with sitting patterns. A cross-sectional study investigating shift workers at two workplaces (airport versus manufacturing) in Australian employees showed that airport workers were more sedentary on day and night shifts than manufacturing workers (Kolbe-Alexander et al., 2019). Though speculative, a potential explanation might be that demographic factors, including age and gender, influence sedentary behaviours in shift workers. A sedentary lifestyle significantly increased with age in both shift and day workers (KivimÄki et al., 2001). Women who worked regular hours reported more sitting than shift or night workers (Clark et al., 2017). The discrepancy in the previous collective work is likely a result of different populations examined, different methods used to report and assess physical activity and sedentary behaviour, and the various work tasks and shift types. The previous findings do not provide strong evidence of an association between shift work and physical activity and sedentary behaviour.

2.5.4. Measurement of physical activity and sedentary behaviour in shift workers

Understanding the relationship between shift work and movement behaviours is important for managing the rising prevalence of disease burden in shift workers. Several studies in a variety of work industries have assessed the physical activity and sedentary behaviour levels of shift workers using self-report measures (Alves et al., 2017; Hulsegge et al., 2021; Vandelanotte et al., 2015). Self-report tools are mostly questionnaires, such as the Modifiable Activity Questionnaire (MAQ), Previous Week Modifiable Activity Questionnaire (PWMAQ), Recent Physical Activity Questionnaire (RPAQ), International Physical Activity Questionnaires (IPAQ), Workforce Sitting Questionnaire, Previous Day Physical Activity Recall (PDPAR) and 7-day Physical Activity Recall (PAR) (Sylvia et al., 2014).

Questionnaires continue to serve and contribute to physical activity and sedentary behaviour research (Nigg et al., 2020). Questionnaires are cost-effective and easy to use; however, they can be susceptible to various forms of bias (Sylvia et al., 2014). Biases in reporting can include systematic errors and difficulties recalling physical activity and sedentary behaviours by participants (Winckers et al., 2015) and social desirability by participants. Self-report measures can result in over-estimation of physical activity (Warren et al., 2010), underestimation of sedentary time

(Kastelic & Šarabon, 2019), and they provide less data on total and light physical activity (Ekelund et al., 2019).

The increased use of device-based measures in physical activity and sedentary behaviour is promising. Studies have investigated these behaviours in shift and non-shift workers using devices including ActiGraph (Loef et al., 2018; van de Langenberg et al., 2019), Actical accelerometers (Neil-Sztramko et al., 2016), and activPAL (Kolbe-Alexander et al., 2019). Accelerometer devices like ActivPAL and Actigraph have demonstrated exceptional validity and reliability in measuring both physical activity and sedentary behaviour (Chomistek et al., 2017; Edwardson et al., 2017). However, device-based tools like activPAL and Actigraph GT3x require technical expertise and cannot specify environmental context or behavioural specificity (Sylvia et al., 2014). Recently, a pilot work tested the feasibility of a novel sensor-based system that is reportedly easy to use and ensures the rapid collection of accurate surveillance of physical activity, sedentary behaviour, and sleep (SurPASS) (Crowley et al., 2022). However, the protocol is still limited in testing for social, cultural, and environmental contexts of the behaviours (Crowley et al., 2022).

For the shift work population, a measurement tool that is able to capture variations and environmental influences in physical activity and sedentary behaviour patterns would be useful to quantify these behaviours in shift workers. EMA is a real-time method that involves repeated brief surveys that assess current experiences in individuals' everyday environments. It provides context and type of activities, which can be beneficial in providing information on the influence of work shift schedules, thus providing valuable information in developing effective intervention strategies suitable for shift workers (Asare et al., 2022). This method allows for maximal ecological validity and minimal recall bias and, therefore, has the potential to assess within-person variability of behaviours (de Vries et al., 2021). Using EMA with accelerometers allows for time matching physical activity intensities and sedentary behaviours with self-report data (Knell et al., 2017). Despite the benefits of using EMA to assess behaviours, there is little evidence on its use with the shift work population.

Burke et al. defined EMA as a method that assesses participants' experiences, behaviours, and moods as they occur in their natural environment (Burke et al., 2017). This approach considers determinants of behaviour, such as the environment and occupation, which are important in influencing individuals' behaviours (Dunton, 2017). EMA techniques may be useful to overcome methodological limitations that comes with self-report and devise-based assessment of physical activity and sedentary behaviour (Knell et al., 2017). EMA has been used to measure physical activity and sedentary behaviour in adults (Maher et al., 2018).

2.6. Health promotion programs

Corrective and preventive action is needed for the vulnerable subpopulation (shift workers) of the global workforce. Findings suggest that interventions are needed to improve the physical and mental health of shift workers (Neil-Sztramko et al., 2014). In terms of sedentary behaviour, the evidence is lacking, and most of the available evidence shows that shift workers are less sedentary than non-shift workers (Monnaatsie et al., 2021). However, occupations that result in high sedentary time, like drivers and call-centre workers, will benefit from health promotion programs targeting reduced sitting time. It has been suggested that interventions for improving health should focus not only on prescribing MVPA but also include recommendations and strategies to reduce sitting time (Dunstan et al., 2021).

In recent years, there has been an increased number of health promotion intervention studies targeting shift and non-shift workers. A systematic review and meta-analysis of workplace interventions improved MVPA levels and related cardiometabolic health of working-age women in high-income and developing countries (Reed et al., 2017). Bort-Roig et al. conducted a mHealth workplace-based 'sit less, move more' intervention and found no changes in MVPA or sitting patterns were observed during worktime or non-work time on a workday (Bort-Roig et al., 2020). However, a review on mHealth interventions provided modest evidence that app-based interventions to improve physical activity and sedentary behaviours can be effective (Schoeppe et al., 2016).

Adults spend significant amounts of time of their waking hours in the workplace; thus the workplace can provide an important setting for implementing interventions to promote healthy lifestyle change (Genin et al., 2019). The workplace offers several advantages in that a substantial number of the working population can be reached (Buckingham et al., 2019). Moreover, workplace-based research is a key step for translating findings to real-world settings and interventions specifically targeted at improving lifestyle behaviours (Neil-Sztramko et al., 2014).

Several investigators have shown that workplace interventions are effective in increasing physical activity and reducing sedentary time (Chu et al., 2016; Reed et al., 2017). Workplace health promotion interventions have been shown to be effective in improving workers' health, wellbeing, and productivity if they are tailored to suit the organisational requirements (Demou et al., 2018). Buckingham et al. investigated mobile health interventions for promoting physical activity and reducing sedentary behaviour in the workplace. One systematic review reported diverse methods and approaches used for lifestyle workplace interventions (Buckingham et al., 2019). Text messaging-based cues had the potential to form physical activity habits at the workplace (Fournier et al., 2017).

The effectiveness of interventions may also be increased by applying principles from a wide range of theories incorporating all aspects that influence behaviours, including social, cultural, and economic factors (Davis et al., 2015). The Medical Research Council (MRC) guidance in the UK offers help in developing complex interventions by starting with understanding the problem and the need for intervention (O'Cathain et al., 2019). The MRC also involves key early tasks to develop a theoretical understanding of the likely process of behaviour change by drawing on existing evidence and theory (Craig et al., 2008) and deciding on behaviour change techniques to use (Croot et al., 2019). Several theories have been used in public health interventions, for example, the theory of planned behaviour (Ajzen, 2011) and social cognitive theory (Bandura, 2004). However, they do not account for other important determinants for behavioral intention and motivation, such as fear, threat, mood, or experience (Ong et al., 2022).

The Behaviour Change Wheel (BCW) (Michie et al., 2011) is an example of the protocol that can be used to change sitting behaviours and physical activity in shift workers. The BCW framework encompasses the components of capability, opportunity, and motivation to interact to generate behaviour - the 'COM-B' system. The framework has been used in intervention study designs focusing on targeted action mechanisms and integrating behaviour change theory (Munir et al., 2018).

In the COM-B model, capability is defined as the individual's psychological and physical capacity to engage in a behaviour. It includes having the necessary knowledge and skills. Motivation is defined as all those brain processes that energize and direct behaviour, not just goals and conscious decision-making. It involves habitual processes, emotional responding, as well as analytical decision-making. Opportunity includes all the factors that lie outside the individual that make the behaviour possible or prompt it (Michie et al., 2014). Figure 2.2 represents the potential influence between components in the COM-B system. For example, opportunity can influence motivation, as can capability; and performing a behaviour can alter capability, motivation, and opportunity.

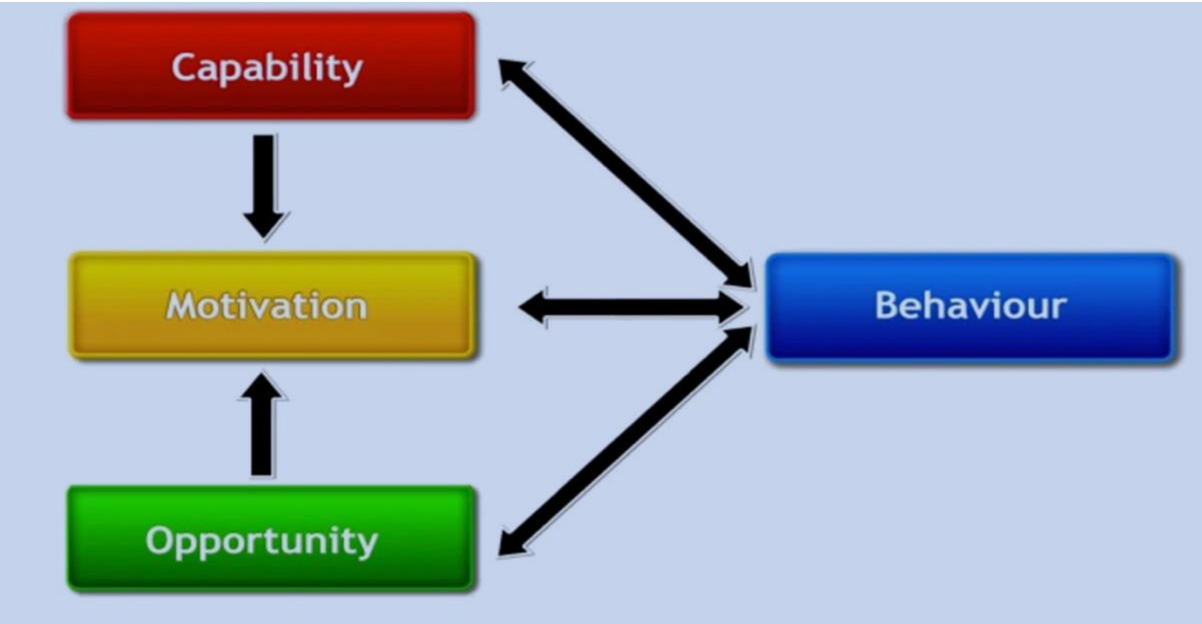


Figure 2.2 The COM-B system framework for understanding behaviour (from Michie et al., 2011)

A given intervention might change one or more components in the behaviour system and the causal links within to alter the effect of interventions (Michie et al., 2011), making the COM-B model likely to be effective in bringing about behaviour change in shift workers' lifestyle behaviours. The COM-B model has been applied successfully in a number of interventions in different contexts, such as sedentary behaviour (Biddle et al., 2020; Castro et al., 2021), physical activity (Webb et al., 2016; Willmott et al., 2021) and obesity prevention (Croker et al., 2020). For example, a recent workplace health promotion intervention targeting new graduate nurses reported an improvement in the health knowledge, and dietary and physical activity behaviours of some participants using the COM-B model (Brogan et al., 2022).

Some behaviour change techniques, including planning, specific goal setting, self-monitoring, and feedback on behaviours, are associated with effectiveness of interventions in increasing physical activity (Schroé et al., 2020). In addition to using theories and behaviour change techniques, the MRC also recommends process evaluations (Fletcher et al., 2016). Process evaluation focuses on building, testing, and refining middle-range theories regarding complex causal mechanisms and how these interact with individuals' agency and social context to produce outcomes (Moore et al., 2019).

Process evaluation is widely advocated for health promotion programs. In addition, the use of evaluation framework for intervention is crucial (Wallner et al., 2023). Process evaluations can provide an in-depth understanding of mechanisms of impact and context to understand how outcomes are interpreted (Johansson et al., 2022). This is done by analysing the implementation process and where context is important (Thøgersen-Ntoumani et al., 2019). Other evaluations, for example, the constructive evaluation is based on finding the information on how to improve the program, whereas the concluding evaluations gather information to assess the value of the program (Chen, 2014).

Applying a structured guide or plan is necessary to allow for comprehensive assessment like the RE-AIM framework. The RE-AIM is an acronym for the framework's five evaluation components: Reach, Effectiveness, Adoption, Implementation, and Maintenance. Reach refers to the absolute number, proportion, and representativeness of individuals participating in each intervention or program. Effectiveness is the impact of an intervention on important outcomes. Adoption is the absolute number, proportion, and representativeness of settings and intervention agents who initiate a program. Implementation refers to the intervention agents' fidelity to and adaptations of intervention and associated implementation strategies, including consistency of delivery as intended and the time and costs. Maintenance is the extent to which a program or policy becomes institutionalized or part of the routine organizational practices and policies (Glasgow et al., 1999). It helps better understand what works and what does not and under what conditions and evaluation of all interacting factors (Kwan et al., 2019). Through these components, the impact of interventions can be assessed at both individual and organizational levels (Sweet et al., 2014). The framework's operational components have been increasingly applied over the years. RE-AIM was applied in a workplace-based cluster randomised trial that showed how the intervention reduced neck pain in office workers (Welch et al., 2020).

2.6.1. Workplace health promotion programs for shift workers

The current prevalence of NCDs and mental health disorders in shift workers is concerning. Therefore, improving the associated health risk factors like physical activity is essential. In recent years, there has been an increased number of workplace interventions targeting physical activity and sedentary behaviour. The workplace provides an arena to promote physical activity and reduce sedentary behaviour. A systematic review of these behaviours in the workplace concluded that interventions might be most effective when targeted at white-collar workers, mainly because blue-collar work (including shift work) was associated with higher occupational physical activity and less sedentary time (Smith et al., 2016). Their findings suggest that for physically active occupations, physical activity interventions are not necessary. However, occupational physical activity is regarded as potentially hazardous and may not be beneficial for workers health (Coenen et al., 2020). An approach called the ‘Goldilocks Principle’ can thus be used to design health promoting work. The approach illustrates the need to design work with ‘just right’ amount of physical activity, standing and sitting. (Straker et al., 2018). In addition, health promotion at work has extensive reach, can positively influence workers’ health and wellbeing, and can result in improved productivity, decreased fatigue, and, consequently, reduced absenteeism (Prince et al., 2021).

Shifts in workplace culture are needed to improve shift workers’ physical activity levels, and subsequently cardiometabolic health. As the nature of work often results in fluctuating work hours, disturbances in circadian rhythm, and various health problems, interventions tailored to work patterns and occupational category may be useful to improve movement behaviours (Nea et al., 2015). Therefore, research must prioritise strategies to reduce the burden of shift work (Gupta et al., 2019).

A systematic review including seven studies on the impact of workplace interventions in improving healthy diet and physical activity in ‘around the clock’ (shift) workers showed moderate positive effects (Lassen et al., 2018). The review also highlights the need for more evidence on workplace intervention to promote physical activity and healthy behaviours in shift workers with individually tailored programmes. In a randomised control trial, Brunet et al. provided evidence for the potential of a web-based intervention to improve moderate-to-vigorous intensity physical activity among nurses (Brunet et al., 2021).

A structured health intervention for long distance truckers increased the mean daily steps, moderate-to-vigorous physical activity (6 mins/day, 95% CI: 0.3–11), and reduced time spent in sitting (Clemes et al., 2022). However, daily step counts remained constant across the 20-week intervention in a sample of 26 Australian drivers (Gilson et al., 2016). A four-week m-health pilot randomised study resulted in no changes in sleep quality in shift-workers (Oftedal et al., 2019). The results of a systematic review investigating group-based workplace interventions for shift workers demonstrated moderate evidence for effectiveness on weight and physical activity (Demou et al., 2018).

Other recent workplace interventions targeted at shift workers included a cluster randomized controlled trial design to examine the effectiveness of the mobile wellness program for nurses with rotating shifts (Ha et al., 2022); high-intensity exercise training over eight weeks targeted to improve cardiovascular disease risk factors among shift workers (Mamen et al., 2020) and a non-pharmacological fatigue countermeasure of short-wavelength light exposure and exercise (Barger et al., 2021). Additionally, most physical activity interventions have targeted nurses and healthcare workers (Brogan et al., 2022; Ha et al., 2022; Williams et al., 2018), drivers (Guest et al., 2022; Varela-Mato et al., 2018) and mainly in high-income countries (Gilson et al., 2019). This is particularly important, as 15-30% of the workforce involved in shift work is estimated to be in high-income countries, and a substantial number are found in the healthcare industry (Sweileh, 2022). Considering that work tasks and demands differ by industry and will influence workers' behaviours differently, developing interventions and programs suitable for different organisations is necessary. For example, drivers accumulate large volumes of sedentary behaviour than nurses (Guest et al., 2020). This presents research gaps in other industries like mining and manufacturing.

Similarly, due to rapid industrialization in developing countries, more research is needed on the shift in the work population in those countries. Like Sweileh's findings in their analysis of research on shift workers, the limited contribution of LMICs is primarily due to limited research resources rather than the absence of the problem (Sheileh, 2022). Thus, while the shift work population is lower in LMICs, the workers face the same problems.

2.7. Summary of literature review

While previous research has examined health behaviours in shift workers, little is known regarding the impact of mobile-based intervention considering the setting and timing of shift patterns in mining shift workers. There is a need to pilot real-time mobile technology and the influence of shift work patterns on physical activity. The findings highlight the need to target shift workers with workplace interventions that aim to improve their adherence to population physical activity guidelines. A study on the barriers and facilitators to a healthier lifestyle and the impact the working environment can have on shift workers found that the workplace environment was key in assisting shift workers to adopt and lead healthier lifestyles (Nea et al., 2017). In addition, the literature suggests that forming physical activity habits at the workplace might facilitate long-term maintenance of physical activity behaviours (Fournier et al., 2017).

Most studies investigating physical activity and sedentary behaviours were in first-world countries, for example, the USA, Australia, Netherlands, and Canada, and a few from LMICs (Monnaatsie et al., 2021). Physical activity research should continue to examine the mechanisms causing adverse health issues, the scope on feasibility and validity of physical activity and sedentary behaviours surveillance and innovative measures while improving the reach and translation to real-world settings, and the health promotion programs explicitly catering to the type of work.

2.8 Research gaps

Shift work is becoming increasingly prevalent. Epidemiological evidence showed that shift work is associated with negative health outcomes, and disease risk is apparent. Together with sleep and nutritional intake, physical and sedentary behaviours are important for a shift worker’s health. However, while the burden of diseases is increasing, evidence shows that fewer health promotion programs have targeted physical activity.

Evidence showed mixed findings when comparing physical activity and sedentary behaviours in shift workers. The links with physical activity, sedentary behaviour, and occupational psychosocial factors are worth being explored further. The inconsistency of the findings suggests the need for a comprehensive review to harmonise available data on physical activity and sedentary behaviours levels in shift and non-shift workers. Possible barriers to regular physical activity, including the type of shift and work factors, have been assessed. However, detailed information about how shift work influences physical activity and sedentary behaviour of workers is lacking. Thus, these factors need to be identified in large, controlled prospective studies to include and report the type of physical activity. Additionally, the findings show that few studies investigated sedentary behaviours in shift workers. Given the significant contribution of the workplace to sedentary behaviours in various shift work industries, more research is needed to investigate the sedentary behaviours of shift workers.

Quantifying physical activity and sedentary behaviour patterns that might fluctuate with varying work schedules may need a more feasible tool that measures behaviours in real time. To make sound decisions regarding shift workers' physical activity and sedentary behaviours, the highest quality evidence should be sought to develop and implement appropriate health interventions. Insights into physical activity levels and sedentary behaviours can offer opportunities for developing lifestyle interventions to improve shift workers' health.

The findings on the linear association between the duration of exposure to shift work and increased health risk were unclear in other studies. More longitudinal studies are needed to understand the association between adverse health outcomes and lifestyle behaviours. Occupational characteristics were associated with higher sitting, shorter sleep, and less activity, suggesting an important role for workplaces in promoting healthier behaviours (Clark et al., 2017). While there are some intervention studies conducted to improve shift workers' wellbeing, most studies are from high-income countries. There is a paucity of research on workplace health promotion in LMICs like Botswana and specifically in mining companies.

Three main studies (5 chapters) were conducted to address some of these gaps; therefore, this PhD aims:

Thesis objective	Study
To harmonise available data from previous studies on the levels of physical activity and sedentary behaviour in shift workers.	Physical activity and sedentary behaviour in shift and non-shift workers: A systematic review and meta-analysis
To determine the feasibility of a mobile EMA application to measure physical activity and sedentary behaviour in shift and non-shift workers.	Feasibility of ecological momentary assessment in measuring physical activity and sedentary behaviour in shift and non-shift workers
To examine the validity of EMA against accelerometer to assess physical activity and sitting time in shift and non-shift workers.	Ecological Momentary Assessment of physical activity and sedentary behaviour in shift workers and non-shift workers: Validation Study
To evaluate the workplace health promotion program that aimed to increase physical activity in shift workers.	The feasibility of a text-messaging intervention promoting physical activity in shift workers: a process evaluation
To determine the effectiveness of a health promotion intervention to improve workers' physical activity and well-being.	Efficacy of a text messaging intervention to improve physical activity in mining shift workers

CHAPTER 3: PAPER 1-PHYSICAL ACTIVITY AND SEDENTARY BEHAVIOR IN SHIFT AND NON-SHIFT WORKERS: A SYSTEMATIC REVIEW AND META-ANALYSIS

3.1 Introduction

Physical activity and sedentary behaviour can be used as treatment and prevention strategies to reduce the burden of disease in shift workers (Patnode et al., 2017). Current evidence shows mixed results when comparing the physical activity and sedentary behaviour in shift workers with those who work traditional daytime hours (Loef et al., 2018). It is important to harmonize the data available to help understand habitual levels of physical activity and sedentary behaviour in shift workers in various shift work industries. Therefore, the systematic review and meta-analysis in chapter 3 aimed to collate the evidence on habitual levels of physical activity and sedentary behaviours in shift workers compared to non-shift workers.

3.2 **Study 1:** Monnaatsie, M., Biddle, S. J. H., Khan, S., & Kolbe-Alexander, T. L. (2021). Physical activity and sedentary behaviour in shift and non-shift workers: A systematic review and meta-analysis. *Preventive Medicine Reports*, *24*, 101597. doi.org/10.1016/j.pmedr.2021.101597

Preventive Medicine Reports 24 (2021) 101597

Contents lists available at ScienceDirect

Preventive Medicine Reports

journal homepage: www.elsevier.com/locate/pmedr

Review article

Physical activity and sedentary behaviour in shift and non-shift workers: A systematic review and meta-analysis

Malebogo Monnaatsie [a,b,c,*], Stuart J.H. Biddle [b], Shahjahan Khan [d], Tracy Kolbe-Alexander [a,b,e,f]

[a] School of Health and Wellbeing, University of Southern Queensland, Ipswich, Queensland, Australia
[b] Physically Active Lifestyles (PALs) Research Group, Centre for Health Research, University of Southern Queensland, Springfield, Queensland, Australia
[c] Department of Sport Science, Faculty of Education, University of Botswana, Gaborone, Botswana
[d] School of Sciences and Centre for Health Research, University of Southern Queensland, Toowoomba, Queensland, Australia
[e] Division of Exercise Science and Sports Medicine, Department of Human Biology, Faculty of Health Sciences, University of Cape Town, South Africa
[f] School of Human Movement and Nutrition Sciences, The University of Queensland, Brisbane, Australia

ARTICLE INFO

Keywords:
Shift work
Moderate-to-vigorous physical activity
Sedentary behaviour
Self-report measures
Device-based measures

ABSTRACT

Research examining the prevalence, physical activity (PA) and sedentary behaviour (SB) in shift workers show mixed results. This systematic review and meta-analysis aimed to compare PA and SB in shift workers with non-shift workers following the PRISMA guidelines. Ebscohost megafile ultimate (CINHAL, E-journals, Academic search ultimate, health source consumer edition, SPORT Discus), PubMed, Scopus, Web of Science, and Science Direct databases were searched up to April 2021. Cross-sectional and baseline data from longitudinal studies reporting PA and SB in full time workers were eligible. Data on participants characteristics and time spent in PA and SB and/or prevalence of workers meeting PA guidelines were extracted and pooled with random effects model. The Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) 10-item checklist was adapted and used. A total of 49 studies met inclusion criteria and 21 studies included for meta-analysis. The prevalence of meeting physical activity guidelines (OR 0.84, 95% CI: 0.68, 1.03) and standardized mean difference (SMD) of time spent in moderate-to-vigorous physical activity (SMD −0.1, 95% CI: −0.4, 0.20) were similar in shift and non-shift workers. Time spent in sedentary behaviour was lower in shift workers than non-shift workers (SMD −0.2, 95% CI: 0.50, −0.001). While the differences in PA are not so evident between shift and non-shift workers, the prevalence of sufficient PA was low in both groups. These preliminary findings provide support for inclusion of physical activity and sedentary behaviour in health promotion interventions targeted at shift workers.

1. Introduction

Shift work is defined as work outside normal daytime working hours (7 a.m. and 6p.m.) (Caruso, 2014). Shift work can include evening shifts around (2 pm till 12 am), night shift (7 pm to 7 am) or rotating between day, evening and night shifts (Depner et al., 2014). Different industries may use different time schedules from the aforementioned ones. Shift work is common in industries that require 24/7 workforce and accounts for 20–25 % of occupations worldwide (Caruso, 2014; Presser, 2005). Approximately 15.6% Australians work shifts (Statistics, 2020), and about 20% of the workforce in Europe and U.S. work in shifts (Parent-Thirion et al., 2017; statistics USBol, 2018).

A rising number of shift workers in the workforce is a concern, as shift work is associated with a wide range of health problems (Kecklund and Axelsson, 2016). Shift workers are at increased risk of cardiovascular disease (Torquati et al., 2018), cancers (Hansen, 2017; Liu et al., 2018) and have higher prevalence of overweight and obesity than those who only work during the day (Antunes et al., 2010; Hulsegge et al., 2020). The risk of any cardiovascular disease (CVD) morbidity was 17% higher among shift workers than day workers (Torquati et al., 2018). There appears to be a dose–response relationship as the risk of CVD in shift workers increases by 7.1% for every additional five years of shift

* Corresponding author at: University of Southern Queensland, 37 Sinnathamby Blvd, Springfield Central QLD 4300, Queensland, Australia.
E-mail addresses: Malebogo.monnaatsie@usq.edu.au (M. Monnaatsie), stuart.biddle@usq.edu.au (S.J.H. Biddle), Shahjahan.Khan@usq.edu.au (S. Khan), tracy.kolbe-alexander@usq.edu.au (T. Kolbe-Alexander).

https://doi.org/10.1016/j.pmedr.2021.101597
Received 14 June 2021; Received in revised form 5 October 2021; Accepted 9 October 2021
Available online 12 October 2021

work (Torquati et al., 2018). Also, shift workers are more likely to have other adverse health outcomes, including poor mental health (Khan et al., 2018), and disturbed sleep (Kervezee et al., 2020).

Several physiological and behavioral mechanisms contribute to the negative health outcomes. Many shift workers experience circadian rhythm disruptions, due to the variations in sleep timing, meal timing and light exposure (James et al., 2017). The disruption of circadian rhythm tends to result in sleep deprivation, excessive sleepiness during wake hours, and insomnia symptoms. Therefore, the evidence supports that insufficient sleep maybe a mechanism of adverse health outcomes among shift workers (Kecklund and Axelsson, 2016). In addition to sleep disturbances and circadian misalignment adverse health outcomes in shift workers can also be attributed, in part, to habitual levels of physical activity and sedentary behaviour (Kervezee et al., 2020; Hulsegge et al., 2017).

The findings from previous research comparing physical activity and sedentary behaviour levels in shift workers have shown mixed results, which might be due to the measurement tools used. Several studies used self-report measures and observed no differences in overall physical activity levels between shift and non-shift worker (Loef et al., 2017; Vandelanotte et al., 2015). Self-report measurement remains a practical means for assessing lifestyle behaviours, even though it is widely recognized that participants tend to over-estimate their physical activity (Sylvia et al., 2014). As such, verifying their results with device-based measures is essential. Devices represent the best method for measuring physical activity and sedentary behaviour and is widely used in epidemiological studies (Welk et al., 2004). Loef et al. (Loef et al., 2018) found no differences between shift and non-shift workers' physical activity using device-based measures.

Shift workers were less physically active than non-shift workers (Ma et al., 2011; Loprinzi, 2015), supporting the hypothesis that leisure-time physical activity opportunities are generally decreased when working shifts (Kolbe-Alexander et al., 2019). For example, adults in the NHANES study asked to describe their work hours as regular evening, regular night shift, rotating shift or another schedule revealed that those working shifts were less physically active than those working regular hours (Loprinzi, 2015). On the other hand, previous research shows that shift workers are more active than non-shift workers (Hulsegge et al., 2020; Marqueze et al., 2013).

Shift work is common in most industries, for example health care, information technology, mining, police, security forces, transportation, construction and manufacturing (power plants, oil refinery, and steel industry) (Rydz et al., 2020). The discrepancy in physical activity is likely due to differences in shift schedules, job tasks and variations in definition of shift work, than as a result of differences in shift and non-shift workers. For instance, truck drivers and information technology shift workers are likely to spend more time sitting at work, thus they could spend more time active during leisure time to make up for more time spent sedentary at work. On the other hand, hospital workers may spend more time walking and standing at work, therefore they are likely to spend more time sitting during leisure time. Normal day workers mainly perform office-desk related jobs, spending more time seated. Truck drivers from Brazil who worked irregular shifts (25.8%), were more physically active (≥150 min) than non-shift workers (3.8%) (Marqueze et al., 2013). Compared to day workers, those working evening shifts engaged in less moderate to vigorous physical activity than night shift workers (Loprinzi, 2015); while those working in rotating shifts engaged in more light-intensity physical activity than non-shift workers (Marqueze et al., 2013). It can be concluded that work schedules distinctively influence physical activity in shift workers (Atkinson et al., 2008).

In addition to physical inactivity, substantial amount of evidence has linked time spent in sedentary behaviour with adverse health outcomes and all-cause mortality (Vincent et al., 2017; Ekelund et al., 2019). Sedentary behaviour is low energy sitting, reclining, or lying during waking hours (Tremblay et al., 2017). There is a paucity of research investigating sedentary behaviour in shift workers. Loprinzi (Loprinzi, 2015) showed that sedentary behaviour was lower in shift workers than non-shift workers in a sample of American adults. Conversely, Hulsegge et al (Hulsegge et al., 2017) reported that those working shifts spend more time in uninterrupted sedentary periods (7.2%, 95% CI 2.3,12.1) than non-shift workers (5.9%, 95% CI −10.1, −1.7). Notably, hospital shift workers spent less time sedentary at work than non-shift workers (Loef et al., 2018). In the same study, sedentary time appeared to be even less in nurses who worked shifts than those who only worked during the day (Loef et al., 2018). The two studies used different populations, with Loef et al (Loef et al., 2018) and colleagues studying hospital workers and various occupations sampled in Hulsegge's et al study (Hulsegge et al., 2017). Thus, the evidence suggests that most hospital workers, including nurses, spend more time standing and walking than office workers.

The inconsistency of the findings suggests the need for a comprehensive review comparing physical activity and sedentary behaviours in shift and non-shift workers. While public health physical activity and sedentary behaviour guidelines exist (Bull et al., 2020), it remains unclear how shift work affects achieving these targets. Previous reviews have looked at nurses' occupational physical activity levels (Chappel et al., 2017), physical activity interventions in shift workers (Flahr et al., 2018), with Lassen et al (Lassen et al., 2018) investigating interventions promoting healthier food and/or physical activity practices in those working shifts. Therefore, detailed information about whether shift work influences physical activity and sedentary behaviour of workers is lacking. The primary aim of this systematic review and meta-analysis, is to compare physical activity and sedentary behaviour levels in shift and non-shift workers. Outcomes of this review could inform development of health promotion interventions for shift workers. Insights into physical activity levels and sedentary behaviours can also inform policies on health and wellbeing in companies with shift work populations. If policy makers can better understand the prevalence of physical activity and sedentary behaviour in shift workers, they might support opportunities for health promotion in the workplace.

2. Methods

We conducted a systematic review and meta-analysis comparing physical activity and sedentary behaviour in shift and non-shift workers following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (Charrois, 2015). The protocol was registered with the PROSPERO database (CRD42020177839). A completed PRISMA checklist is presented in Fig. 1.

2.1. Search strategy

We searched the following databases: Ebscohost megafile ultimate (CINHAL, E-journals, Academic search ultimate, health source consumer edition, SPORT Discus), PubMed, Scopus, Web of Science, and Science Direct up to November 2020 and updated in April 2021. The search strategy was developed with the assistance of a research librarian using Population Intervention Comparison Outcome (PICO) strategy (Cumpston et al., 2020). The population was limited to shift workers, and comparators were non-shift workers or normal day workers. The outcomes included sedentary behaviour and physical activity. These are some of the following keywords: sedentary behaviour, sedentary behaviour, inactivity or exercise, shift work, non-shift worker, day work, with truncations used where appropriate. The full search strategy is available as an online supplementary Appendix A (Table A.1).

2.2. Selection criteria

For studies to be eligible, they had to meet the pre-determined inclusion criteria: 1) cross-sectional study or baseline data from longitudinal, intervention studies, or cohort studies, 2) reported time spent in

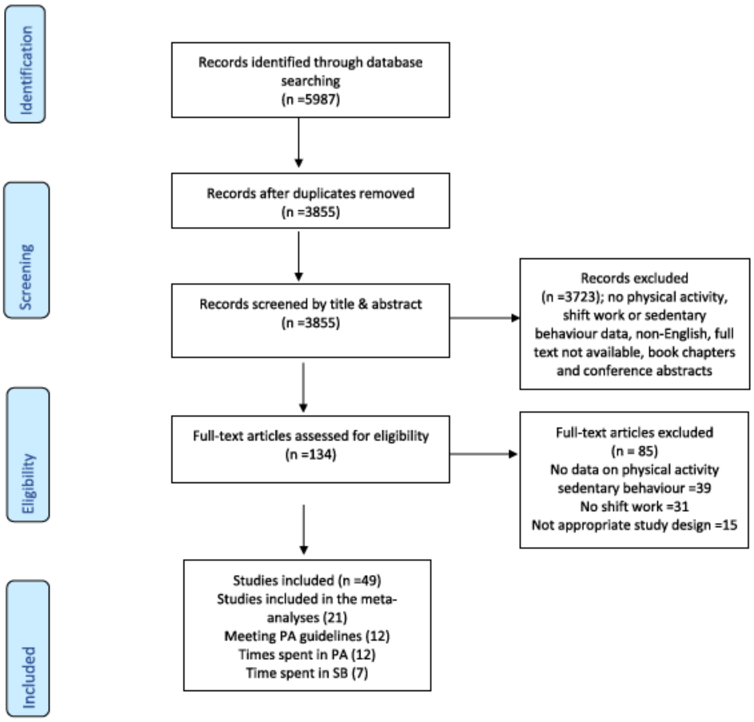


Fig. 1. PRISMA flow chart showing study screening process. PRISMA indicates Preferred Reporting Items for Systematic Reviews and Meta-analyses; PA, physical activity; SB, Sedentary behaviou.

(mean minutes/hours, percentages per day or week) physical activity and sedentary behaviour; and prevalence of workers meeting physical activity guidelines, at least 150–300 min of moderate-intensity aerobic physical activity, or at least 75–150 min of vigorous-intensity aerobic physical activity, as per the recent World Health Organisation guidelines (Bull et al., 2020); 3) include shift and non-shift workers. Book chapters, non-English articles, grey literature and conference proceedings were excluded. One author (MM) scanned the titles and abstracts to exclude 3723 articles from the 3,855 screened abstracts. Two authors (MM and TKA) then screened the 134 full texts articles to determine study eligibility. Any discrepancies were discussed between the two reviewers (MM and TKA) before a final decision on inclusion was made.

Data extraction

The two reviewers (MM and TKA) independently extracted data on author and publication year, study design, location and workplace, age, gender, type, and definition of shift work and any discrepancies were discussed between the two reviewers. Shift work included any arrangement of working hours other than the standard daylight hours (7/8 a.m.–5/6p.m.), while non-shift work includes normal work hours between 7/8 a.m.–5/6p.m. (Costa and Folkard, 2010). Data from selected studies were synthesised into a tabular format. Consistent with our study aim to compare physical activity and sedentary behaviour in shift and non-shift workers, we extracted physical activity and sedentary behaviour outcomes, including the prevalence of workers meeting physical activity guidelines and time spent in physical activity and sedentary behaviour. Point estimates and proportions for physical activity and sedentary behaviour were reported for most studies. Although some studies reported other Physical activity outcomes and sedentary behaviour outcomes other than prevalence of workers meeting physical activity guidelines and time spent in physical activity per day, and time spent in sedentary behaviour per day. Data were extracted according to the most reported outcomes in the studies to allow for synthesis and comparisons between shift and non-shift workers. To estimate the proportions of workers who meet physical activity guidelines, the mean prevalence and total sample of both shift and non-shift workers were extracted. Mean and standard deviations for time spent in physical activity and sedentary behaviour outcomes were selected for the meta-analysis. When not reported, standard deviations were calculated from standard of errors, 95% confidence intervals, or percentiles and means and sample size. If pertinent data were absent, we contacted authors on two separate occasions, and the necessary information was requested via e-mail. Nine authors were contacted, and only four responded, thus excluding the five studies without a response.

2.3. Quality assessment

The Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) quality assessment tool based on the checklist for reporting observational studies (von Elm et al., 2008) was adapted and has been previously used by Gilson et al (Gilson et al., 2019). The STROBE provides general reporting recommendations to improve the quality for descriptive observational studies and can be used for cross-sectional studies that were mainly included in our study (Vandenbroucke et al., 2007). The quality checklist (6–10 items) was scored for each of the following: sample population described and sample size sufficient, measurement tools appropriate, including devices, analyses and variables reported and results reported in the studies. Each item was marked as "yes" (1 point), and "no" or "unclear" (0 point) low or unclear response or "n/a" for an item not applicable in the study. A composite overall score for each study was then calculated for each study and based on items rated with affirmative answer $\geq$ 75% =Good, 50–75%=Fair, <50%=Poor (Torres-Castro et al., 2021).

2.4. Data analysis

Due to anticipated heterogeneity, random effects meta-analysis was used. Heterogeneity was measured by the I^2 statistic, with values above 75% considered as high (Higgins et al., 2003).

For the meta-analysis, first, we pooled data on each physical activity category (time estimates and proportions of workers meeting physical activity guidelines) in shift and non-shift workers. The odds ratio was used to estimate the effect size on the proportions of shift and non-shift workers who meet physical activity guidelines. A comparative meta-analysis of pooled percentages of time spent in physical activity per day between shift and non-shift workers was conducted, yielding Hedges' g effect size (Haidich, 2010). Next, a meta-analysis of pooled percentages of time spent in sedentary behaviour per day between shift and non-shift workers was also conducted. We conducted subgroup analyses to investigate differences between physical activity and sedentary behaviour assessment methods (i.e., self-reported vs. device-based measures). Further we conducted sensitivity analyses excluding outlier studies one by one. Analyses were performed using Comprehensive Meta-analysis version 3.3 (CMA; Biostat Inc., Eaglewood, USA).

3. Results

3.1. Study selection and included participants

The electronic database search identified 3,855 articles (excluding duplicates) and these were screened by title and abstract. One hundred and thirty-four full texts were reviewed by 2 reviewers and 85 were excluded, leaving a total of 49 articles meeting eligibility criteria (Fig. 1). Studies were excluded in languages other than English; with an inappropriate study design; when no physical activity, shift work or sedentary behaviour data presented; when full text not available; and book chapters and conference abstracts.

Studies were conducted in 18 countries between 2001 and 2021. Sample size ranged from 9 to 185,958 participants, with participants' age ranging between 18 and 81 years. Two-thirds of the studies (70%) included males and females, and 23% only had females. Thirty-six studies included both shift and non-shift workers. About 50% (n = 24) of studies included healthcare workers, with other industries included (e.g., drivers, police, manufacturers, chemical plant workers). The shift systems and schedules varied considerably, with shift work described as morning, evening/afternoon and night shifts, rotating, irregular, and fixed shifts. All study characteristics are available as online supplementary Appendix A (Tables A.2–A.5).

The measured point estimates outcomes reported physical activity in minutes per day, hours per week and MET-hours per week. The primary outcomes included sedentary behaviour in minutes per day or hours per week. Studies that were not included in the meta-analyses reported physical activity frequency (presented as scores 1 and 2; 1 = yes and 2 = no) or (with scores 1 = never, 2 = 2 times a week, 3–4 times a week and 4 = almost every day). Other three studies reported step counts recorded by pedometers. One study reported number of sweaty hours per day, while other 2 studies reported kilojoules. One study that was excluded reported prevalence of sedentary lifestyle as (yes and no for 1 h of fast walking per week).

3.2. Quality assessment

Out of the 10 score items, study score items ranged from 6 to 10, depending on the outcome assessed and measurement tools (self-report vs devices). From the all the studies (n = 49), 38 met 75% answer rating their quality as "good" and only 11 studies met the 50–75% rating indicating "fair" quality. The mean score across all the selected items was 89%. More than 90% of studies reported appropriate study design (item 1A) and 86% had a sufficient sample size (item 1B). The number of days assessed for device-based studies and those that have excluded insufficient wear time was rated 65%. All studies reported physical activity and/or sedentary behaviour (item 4D). The quality scoring for each study is available as online Supplementary Material (Table A.6).

3.3. Measurement of physical activity and sedentary behaviour

Physical activity self-report measures: The self-report instruments used to quantify physical activity included the International Physical Activity Questionnaire (IPAQ), IPAQ-short form, Baecke questionnaire, Multimedia Activity Recall for Children and Adults (MARCA), Active Australia questionnaire, 7-day Physical Activity Recall Questionnaire, and Positive Health Behaviour Scale (PHBS) and Behavioural risk Factor Surveillance system (BRFSS) (Table 1).

Physical activity device-based measures: Six studies reported time spent in physical activity derived from wearable devices. These included the ActiGraph GT3X and ActiGraph wGT3X-BT to assess light intensity and moderate-to-vigorous intensity physical activity. Moderate-to-vigorous physical activity was also calculated from a waist-worn Actical accelerometer in minutes per day (Tables 1 and 2).

Sedentary behaviour self-report measures: Two studies used self-report measures to assess sedentary behaviour including the Workforce Sitting Questionnaire and domain specific questionnaire, see Table 3.

Sedentary behaviour device-based measures: Five studies used devices including the Actigraph model 7164 and ActiGraph GT3X with sedentary behaviour recorded as counts per minute between 0 and 99. Mean daily sedentary minutes were calculated at an intensity less than 1.0 metabolic equivalents for data derived from Actical accelerometer (Table 3).

3.4. Physical activity outcomes

3.4.1. Prevalence of meeting guidelines

The proportions of shift workers and non-shift workers meeting *physical activity guidelines* were 41% and 46%, respectively. The mean range was 8% to 63.4% in shift workers who meet physical activity guidelines, whereas the range was 3% to 67.7% in non-shift workers.

3.4.2. Time spent in physical activity

The average mean *time spent* in physical activity was similar for shift workers and non-shift workers (17%). Physical activity reported according to domains showed that occupational related physical activity is the primary contributor of total physical activity in both shift workers and non-shift workers. Transport related physical activity accounted for only 0.5% of total physical activity in both groups. Time spent in physical activity per day was 13.2% and 14.2% in shift workers and non-shift workers respectively. The self-report data showed that those working in shifts spent 24.5% time in physical activity compared to 22.9% in regular day workers.

3.4.3. Time spent in sedentary behaviour

The mean *time spent* in sedentary behaviours was 2% higher in non-shift workers (39%) than shift workers (37%). Sedentary behaviour at work was similar in shift and non-shift workers and accounted for 4% of total sedentary behaviour per day. Both devices and self-report measures showed that those working regular shift spent more time in sedentary behaviour than non-shift workers.

Table 1
Prevalence of workers meeting physical activity guidelines.

Author, year	Occupation	Shift groups	Measurement tool	Meeting PA guidelines Shift workers (%)	Meeting PA guidelines Non-shift worker(%)
(Alves et al., 2017)	Poultry processing	early morning, day, night shift	IPAQ short	26.9	51.9
(Marqueze et al., 2013)	Truck drivers	Irregular, day shift	IPAQ	25.8	3.8
(da Silva et al., 2015)	Poultry processing	Day, night shift	Modified IPAQ	39.0	30.8
(Panczyk et al., 2018)	Nurses & midwives	shift and non-shift	(PHBS)	50.2	50.9
(Park and Suh, 2020)	Various industries	day and shift workers	IPAQ-SF	46.3	58.5
Chin et al., 2016 (Nam and Lee, 2016)	Nurses	Day, non-day	BRFSS (CDC,2013)	36.0	41.9
(Ma et al., 2011)	Police	Day, afternoon, midnight shift	Questionnaire	63.4	67.0
(Sugiura et al., 2020)	Health care support	Fixed daytime, shift worker	Questionnaire	54.6	66.4
(Hulsegge et al., 2020)	Industrial production	Morning, afternoon, night and non-shift	Questionnaire	58.0	56.0
(Hulsegge et al., 2021)	Manufacturing industries	Shift worker, non-shift worker	Questionnaire	58.0	58.0
(Neil-Sztramko et al., 2016) (	Various industries	Shift worker, day worker	Questionnaire	15.9	15.5
Loef et al., 2020)	Health care workers	Shift and non-shift workers	Actigraph GT3X	46.2	36.2

Legend: PA (physical activity), IPAQ (International Physical Activity Questionnaire), IPAQ-SF (International Physical Activity Questionnaire-Short Form), BRFSS Behavioural risk Factor Surveillance system, PHBS (Positive Health Behaviours Scale), Various industries: manufacturing, accommodation and food sector, chemical plants, firefighters, retail, Questionnaire: used when the type/name of questionnaire was not described.

Table 2
Time spent in moderate-to-vigorous physical activity in minutes per day in shift and non-shift workers.

Author, year	Occupation	Shift groups	Measurement tool	Time spent in PAShift workerMean (SD)	Time spent in PANon-shift workerMean (SD)
(Peplonska et al., 2014)	Nurses and midwives	Rotating night, day shifts	IPAQ	26.0 (11.0)	20.9 (9.9)
(Vandelanotte et al., 2015)	Various industries	Shift, non-shift, non-night shift	IPAQ	26.8 (9.7)	24.9 (9.4)
(Vlahoyiannis et al., 2021	Nurses	Morning, rotating shift worker	IPAQ	15.5 (15.7)	12.4 (13.5)
(Hulsegge et al., 2017)	Various industries	Day worker, night and non-night shift	Questionnaire	13.9 (9.0)	15.8 (7.3)
(Loef et al., 2017)	Various industries	Shift, non-shift workers	Questionnaire	21.3 (13.6)	18.8 (2.2)
(Tada et al., 2014)	Nurse	rotating	Questionnaire	25.2 (35.1)	24.7 (35.7)
(Clark et al., 2017)	Various industries	Shift/night and not shift/ night	Active Australia Questionnaire	12.5 (8.4)	11.5 (7.5)
(van de Langenberg et al., 2019)	Health care workers	nightshift worker, day worker	Actigraph GT3X	40.1 (35.2)	38.2 (26.8)
Lauren et al., 2020)	Nurses and medical staff	Day and night shift	Actigraph wGT3X-BT	12.8 (6.7)	14.3 (5.5)
(Loef et al., 2018)	Hospital shift workers	Shift, non-shift worker	Actigraph GT3X	11.7 (6.5)	12.5 (6.2)
(Loprinzi, 2015)	Various industries	Daytime, evening, night, rotating shift	Actigraph	25.8 (3.2)	28.5 (0.7)
(Neil-Sztramko et al., 2016)	Various industries	Shift worker, day worker	Actical accelerometer	10.1 (10.1)	10.2 (6.4)

Legend: PA (physical activity), IPAQ (International Physical Activity Questionnaire), SD (Standard Deviation), Various industries: manufacturing, accommodation and food sector, chemical plants, firefighters, retail, Questionnaire: used when the type/name of questionnaire was not reported.

3.5. *Meta-analyses*

Data were pooled from 12 studies for prevalence of shift and non-shift workers meeting physical activity guidelines. Estimates of time spent in the physical activity and sedentary behaviour meta-analysis included 12 and 7 studies, respectively.

3.5.1. *Prevalence of workers meeting physical activity guidelines*

Although shift workers were less likely to meet physical activities guidelines than non-shift workers, this difference was not statistically significant (OR 0.84, 95% CI:0.68, 1.03 (Fig. 2a). For the self-reported physical activity meta-analysis, the difference between shift and non-shift workers who meet physical activity guidelines was still not significant (OR 0.81, 95% CI: 0.67, 0.99) and heterogeneity was high ($I^2 =$ 96.3%) (Fig. 2b). There were insufficient data to pool results by device-based measures.

We did further analysis by removing one study (25) from all the studies included for meeting physical activity guidelines with a significant small effect size (OR 0.075). The overall effect size was increased from 0.84 to 0.87.

3.5.2. *Time spent in physical activity*

The difference in time spent in moderate-to-vigorous physical activity were not significant between shift and non-shift workers (SMD −0.1, 95% CI: −0.4, 0.20) (Fig. 3a). A separate analysis was conducted to compare time spent in moderate-to-vigorous physical activity in shift and non-shift workers by self-report measures. After removing one study (Loprinzi, 2015), with an unusually smaller effect size the heterogeneity was decreased substantially (from $I^2 = 98.8$ to $I^2 = 85.4$).

The results with self-report measures showed a non-significant difference between shift and non-shift workers (SMD 0.21, 95% CI: 0.00, 0.34) (Fig. 3b). Similar to overall results of time spent in moderate-to-

Table 3
Time spent in sedentary behaviour in minutes per day in shift and non-shift workers.

Author, year	Occupation	Shift groups	Measurement tool	Time spent in SBShift workerMean (SD)	Time spent in SBNon-shift workerMean (SD)
(Vandelanotte et al., 2013)	Various industries	Shift, non-shift, non-night shift	Workforce sitting questionnaire	36.1 (18.4)	37.2 (16.9)
(Clark et al., 2017)	Various industries	Regular hours, night work	Questionnaire	29.6 (16.6)	34.2 (16.3)
(Hulsegge et al., 2017)	Various industries	Day worker, night and non-night shift	Questionnaire	49.4 (18.2)	45.8 (16.4)
(Lauren et al., 2020)	Nurses and medical staff	Day and night shift	Actigraph wGT3X-BT	21.5 (9.0)	18.9 (5.2)
(Loef et al., 2018)	Hospital shift workers	Shift, non-shift worker	Actigraph GT3X	53.3 (12.0)	60.5 (16.5)
(Loprinzi, 2015)	Various industries	Daytime, evening, night, rotating shift	Accelerometer	31.8 (10.4)	35.0 (4.0)
(Neil-Sztramko et al., 2016)	Various industries	Shift worker, day worker	Actical accelerometer	39.5 (20.2)	40.0 (13.7)

Legend: SB (sedentary behaviour), IPAQ (International Physical Activity Questionnaire), SD (Standard Deviation), Various industries: manufacturing, accommodation and food sector, chemical plants, firefighters, retail, Questionnaire: used when the type/name of questionnaire was not reported.

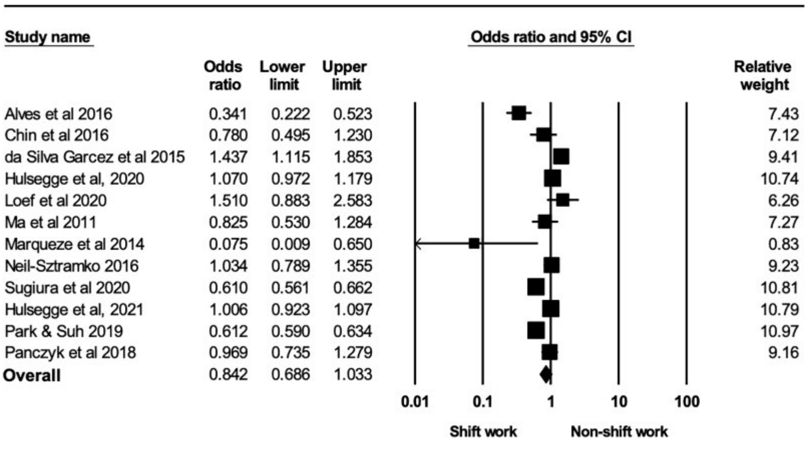


Fig. 2a. Forest plot of workers who meet physical activity guidelines (all studies).

vigorous physical activity analysis by device data shows non-significant differences (SMD −0.40, 95% CI: −1.16, 0.37) (Fig. 3c).

3.5.3. Time spent in sedentary behaviour

The meta-analysis results of the pooled data demonstrated that shift workers spend significantly less time in sedentary behaviour than non-shift workers (SMD −0.2, 95% CI: −0.50, −0.001) (Fig. 4a). A sufficient number of studies were available to compare the time spent in sedentary behaviour measured by devices. The difference between shift and non-shift workers was non-significant (SMD −0.23, 95% CI: −0.56, −0.09) (Fig. 4b). There were insufficient data to pool results by self-reported sedentary behaviour.

4. Discussion

This study aimed to compare physical activity and sedentary behaviour in shift and non-shift workers. Our findings show that habitual levels of physical activity were similar for shift and non-shift workers, and only 41% of shift workers meet physical activity guidelines. Similar to the shift work population, a significant number of adults are inactive. Globally, over a quarter of adults (27.5%) were reported to be insufficiently active (Guthold et al., 2018). For the shift worker, this puts an increased risk of developing diseases linked to inactivity as they are already identified as a risk group. Another major finding is that time spent in sedentary behaviour was significantly less in shift workers, although only a few studies were included.

Our findings demonstrated that compared to data using measurement devices, self-reported data showed that shift workers spent more time in physical activity than non-shift workers (SMD 0.21, 95% CI: 0.00, 0.34). Studies (Vandelanotte et al., 2015; Marqueze et al., 2013; Peplonska et al., 2014) included in our analysis used questionnaires where participants were asked to recall how often they had performed physical activity. It is possible that shift workers may have overreported their physical activity levels. Similar to most of our included studies, health workers (involved in shift work) reported higher physical activity compared with measures using the ActiGraph accelerometer (Zafiropoulos et al., 2019). Self-report measures can result in recall bias when compared to device-based measures (Sylvia et al., 2014). There is a need to use measurement tools that are feasible and capture the patterns of physical activity and sedentary behaviour in shift workers in real time.

It should be noted that our analyses included only overall physical activity in both shift and day workers. The similarity in shift workers and non-shift workers' physical activity levels could be a result of the type of activity reported. Even though not confirmed in our review, shift

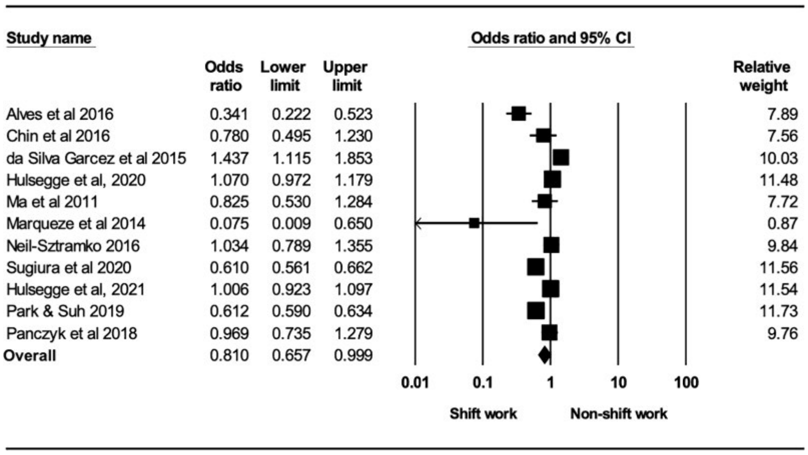


Fig. 2b. Forest plot of workers who meet physical activity guidelines (self-report).

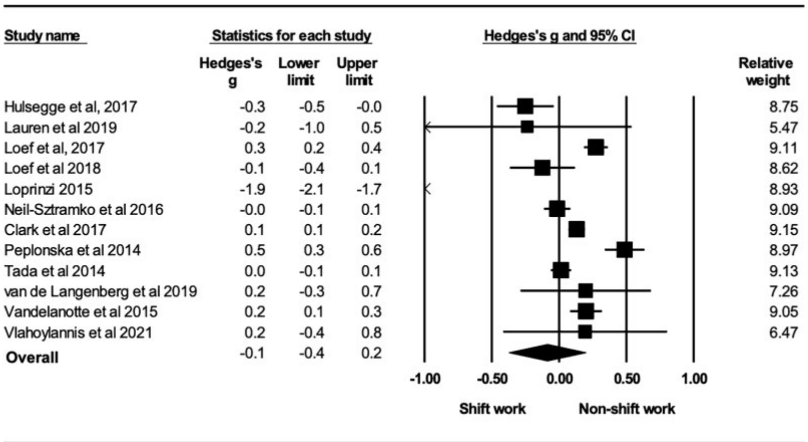


Fig. 3a. Forest plot of time spent in physical activity (all studies).

workers may have reported high occupational physical activity which is common in shift work occupations like health care and manufacturing. Normal day workers may have reported higher leisure time physical activity as their work times allow for more opportunities for physical activity and participation in sports. This might lead to total physical activity being similar in the two groups. For example, occupational activity was shown to contribute more than leisure-time physical activity to total daily energy expenditure in health care workers (Peplonska et al., 2014). Similarly, recent Australian data showed that shift workers were more likely to report low leisure-time physical activity than occupational physical activity (Vandelanotte et al., 2015). Thus, these factors need to be identified in large controlled prospective studies, to include and report the type of physical activity.

There is emerging and inconclusive evidence on the role of occupational physical activity on health outcomes (Cillekens et al., 2020). The 'physical activity paradox' states that increased physical activity in shift workers because of high occupational activity may not benefit workers' health (Gupta et al., 2020). For example, in one study investigating physical activity levels in shift workers, there were no significant associations between shift work and non-occupational physical activity (Loef et al., 2017). Thus, shift workers may still be at higher risk of diseases than day workers if most of their reported activities are from occupational physical activity. However, a recent study (Dalene et al.) using a large data set of Norwegian adults showed that occupational physical activity might reduce the risk of non-communicable diseases, suggesting that any physical activity, regardless of the domain, is beneficial to the health of workers.

Our findings suggest that those working shifts are less sedentary than those working normal day hours (SMD −0.2, 95% CI: −0.50, −0.001). Like our results, Loprinzi (Loprinzi, 2015) reported that rotating shift workers engaged in less sedentary behaviour than non-shift workers when assessed by an accelerometer. One of the most important factors in investigating sedentary behaviours is measurement tools. Out of the seven studies, five used devices, and our quality scoring show that 76%

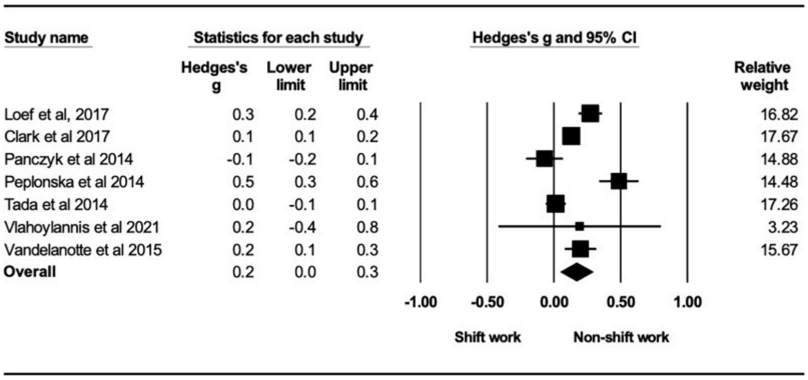


Fig. 3b. Forest plot of time spent in physical activity (self-report measures).

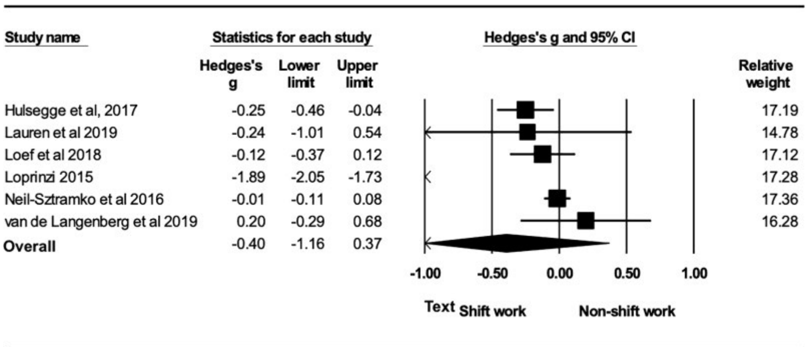


Fig. 3c. Forest plot of time spent in physical activity (devices).

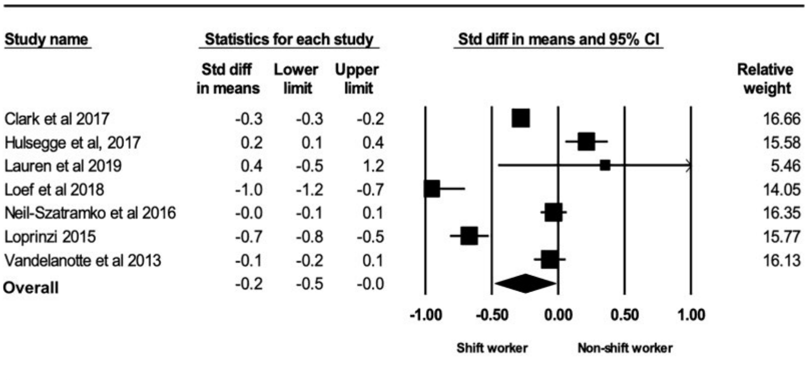


Fig. 4a. Forest plot of time spent in sedentary behaviour (all studies).

of the studies reported sedentary time that excludes sleeping time (Table 4). Thus, these results should be interpreted with caution as some of the time spent sedentary behaviour may be indistinguishable from sleep (Barone Gibbs and Kline, 2018).

In terms of workplace sectors, 50% of studies included in the review used health care professions, and mainly nurses, which might explain

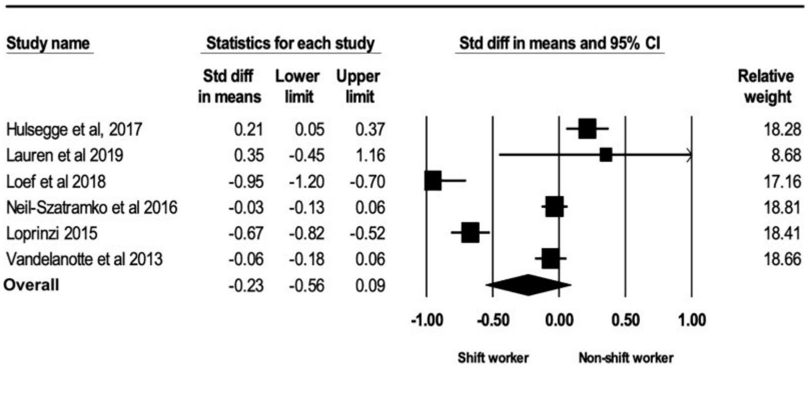


Fig. 4b. Forest plot of time spent in sedentary behaviour (devices).

Table 4
Quality assessment (10 items) and percentage scoring for each item.

Item	Criterion	Description	(%)
1A	Sample	Are the study design and population sufficiently described?	(90)
1B	Sample	Is sample size sufficient to give a good estimate of target behaviour(s) for the population?	(86)
2A	Measurement	are the number of days assessed sufficient (≥4) to give a good estimate of target behaviour(s) for the population? (device-based measures)	(65)
3A	Analyses	Is consideration given to excluding participants with insufficient wear time (for device-based measures)?	(65)
3B	Analyses	Are data analysed using inclonometry or pattern recognition algorithms, as opposed to accelerometer counts (for device-based measures)?	(82)
4A	Variables	Are data reported for specific shift work?	(93)
4C	Variables	Are daily times reported in absolute (hours or minutes/day) and relative (percentage) terms?	(83)
4D	Variables	Are sedentary/sitting and physical activity data reported?	(100)
4E	Variables	Does reported sedentary/sitting time exclude sleeping time?	(76)
5E	Results	Are results reported in sufficient detail regarding both central tendency and variability of the target behaviour(s)?	(77)

low sedentary time in shift workers. Other studies have investigated various occupations, including drivers, manufacturing workers, police, poultry workers, with different tasks and shift types. Further, it is not surprising that shift workers reported lower sedentary time than non-shift workers because most normal day workers are office jobs characterised by prolonged sitting periods. Shift workers in transportation and technology are still less likely to report high sitting time than those working in blue-collar and hospital settings where physically demanding occupations are less (Smith et al., 2016). Thus, it is better to compare sedentary behaviour levels in non-shift workers with shift workers in industries with sedentary tasks. The new WHO recommendations support breaking long periods of sitting at work and replace it with some physical activity (Dempsey et al., 2020). In industries where more time is spent in prolonged standing, in both shift and non-shift work, it would be advisable to alternate between sitting and standing to provide recovery and prevent fatigue (Waters and Dick, 2015).

Our review shows that few studies investigated sedentary behaviours in both shift and non-shift workers. Given the large contribution of the workplace to sedentary behaviours (Haslam et al., 2019), more research is needed to investigate the sedentary behaviours of shift workers. Prolonged sitting is prevalent in industries such as hotels, transport and communications involving shift work (Messenger, 2018). Reducing sedentary time may still be most effective when targeted at shift workers in customer service call centres, those using information technology, and drivers.

In the present review, shift work schedules were defined with different hours from the traditional regular working period from morning to afternoon and sometimes referred to irregular or fixed working hours. For example, Alves (Alves et al., 2017) and colleagues defined work schedules as the fixed morning, fixed day and evening shifts while Hulsegge et al (Hulsegge et al., 2017) defined the schedules as day, night and non-night shift work. It is likely that our results could have also been influenced by heterogeneity in study variables like shift schedules and types. The definitions of shift work schedules should be standardised across studies in future research.

Physical activity and sedentary behaviour are both complex and multidimensional behaviours. As such it was difficult to compare physical activity and sedentary behaviour in shift workers when reported by different types, measurement tools, schedules and different tasks performed at work. Adhering to consistent measurement tools to assess physical activity and sedentary behaviour could increase the comparability of results across studies. There is need to standardise definitions of shift work and shift schedules and to report all the various factors that influence physical activity and sedentary behaviour patterns in future studies.

4.1. Strengths and limitations

To date, there has not been a review on levels of physical activity in shift workers. Therefore, there are limitations in our ability to compare our results to those of prior research. Our systematic review and meta-analysis included studies with both device and self-report measures. We were also able to review studies from several countries and many industries involved in shift work. Therefore, it was possible to do comparisons by measurement tools as physical activity and sedentary behaviour outcomes were measured by both self-report and devices. The search strategy was thorough but included studies that were reported in English only, relevant publications in other languages may have been missed. Because few studies reported domain-based data, our results only reflect total physical activity and sedentary behaviour outcomes.

5. Concluding remarks

In conclusion, while physical activity levels do not differ between shift and non-shift workers and shift workers spending more time sitting, there is evidence that results might have been influenced by heterogeneity in the studies included. With workers spending most of their waking time at work, occupational factors can significantly influence physical activity and sedentary behaviours and may even be more complex in shift workers (Caruso, 2014). The rapid economic development in the world continues to increase the demand for shift work, resulting in many people working in shifts (Rajaratnam and Arendt, 2001). Intervention strategies are needed to ameliorate physical inactivity and health problems that are evident in shift workers. Furthermore, few workplace interventions have targeted shift workers (Flahr et al., 2018). Further research on the determinants of physical activity and sedentary behaviour in shift workers is needed.

CRediT authorship contribution statement

Malebogo Monnaatsie: Conceptualization, Methodology, Writing – original draft. **Stuart J.H. Biddle:** Methodology, Supervision. **Shahjahan Khan:** Formal analysis, Writing – review & editing. **Tracy Kolbe-Alexander:** Conceptualization, Methodology, Supervision.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

We thank Dr. Tricia Kelly, University of Southern Queensland research librarian, for her guidance in creating the search strategy used in this review.

Funding

This work is part of the lead author's PhD research project supported primarily by the University of Botswana staff scholarship and University of Southern Queensland.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.pmedr.2021.101597.

References

Caruso, C.C. 2014. Negative impacts of shiftwork and long work hours. Rehabil Nurs. 39 (1), 16-25. Epub 2013/06/20. doi: 10.1002/rnj.107. PubMed PMID: 23780784; PubMed Central PMCID: PMCPMC4629843.

Depner, C.M., Stothard, E.R., Wright, K.P., Jr. 2014. Metabolic consequences of sleep and circadian disorders. Curr Diab Rep. 14(7), 507. Epub 2014/05/13. doi: 10.1007/s11892-014-0507-z. PubMed PMID: 24816752; PubMed Central PMCID: PMCPMC4308960.

Presser, H.B. 2005. Working in a 24/7 economy: Challenges for American families: Russell Sage Foundation.

Statistics AB. Working arrangements. https://wwwabsgovau/statistics/labour/earnings-and-work-hours/working-arrangements/aug-2020.

Parent-Thirion, A., Biletta, I., Cabrita, J., Llave, O.V., Vermeylen, G., Wilczynska, A., et al. 2017. 6th European Working Conditions Survey: 2017 update: Publications Office of the European Union.

statistics USBol. Labor Force Statistics from the Current Population Survey. Work schedules (flexible and shift schedules). 2018.

Kecklund, G., Axelsson, J., 2016. Health consequences of shift work and insufficient sleep. BMJ. 355, i5210 https://doi.org/10.1136/bmj.i5210.

Torquati, L., Mielke, G.I., Brown, W.J., Kolbe-Alexander, T. 2018. Shift work and the risk of cardiovascular disease. A systematic review and meta-analysis including dose-response relationship. Scand. J. Work Environ. Health 44(3), 229-3Epub 2017/12/17. doi: 10.5271/sjweh.3700. PubMed PMID: 29247501.

Hansen, J. 2017. Night shift work and risk of breast cancer. Curr. Environ. Health Rep. 4 (3), 325-3Epub 2017/08/05. doi: 10.1007/s40572-017-0155-y. PubMed PMID: 28770538.

Liu, W., Zhou, Z., Dong, D., Sun, L., Zhang, G. 2018. Sex differences in the association between night shift work and the risk of cancers: a meta-analysis of 57 articles. Dis Markers 2018, 7925219. Epub 2019/01/02. doi: 10.1155/2018/7925219. PubMed PMID: 30598709; PubMed Central PMCID: PMCPMC6287141.

Antunes, L.C., Levandovski, R., Dantas, G., Caumo, W., Hidalgo, M.P. 2010. Obesity and shift work: chronobiological aspects. Nutr. Res. Rev. 23(1), 155-168. Epub 2010/02/04. doi: 10.1017/s0954422410000016. PubMed PMID: 20122305.

Hulsegge, G., van Mechelen, W., Paagman, H., Proper, K.I., Anema, J.R. 2020. The moderating role of lifestyle, age, and years working in shifts in the relationship between shift work and being overweight. Int. Arch. Occup. Environ. Health 93(6), 697-705. Epub 2020/02/11. doi: 10.1007/s00420-020-01519-4. PubMed PMID: 32040711; PubMed Central PMCID: PMCPMC7320962.

Khan, S., Duan, P., Yao, L., Hou, H. 2018. Shiftwork-mediated disruptions of circadian rhythms and sleep homeostasis cause serious health problems. Int. J. Genom. 2018, 8576890. Epub 2018/04/03. doi: 10.1155/2018/8576890. PubMed PMID: 29607311; PubMed Central PMCID: PMCPMC5828540.

Kervezee, L., Kosmadopoulos, A., Boivin, D.B. 2020. Metabolic and cardiovascular consequences of shift work: The role of circadian disruption and sleep disturbances. Eur. J. Neurosci. 51(1), 396-412. Epub 2018/10/26. doi: 10.1111/ejn.14216. PubMed PMID: 30357975.

James, S.M., Honn, K.A., Gaddameedhi, S., Van Dongen, H.P.A. 2017. Shift Work: disrupted circadian rhythms and sleep-implications for health and well-being. Curr. Sleep Med. Rep. 3(2), 104-112. Epub 2017/04/27. doi: 10.1007/s40675-017-0071-6. PubMed PMID: 29057204.

Hulsegge, G., Gupta, N., Holtermann, A., Jørgensen, M.B., Proper, K.I., van der Beek, A.J. 2017. Shift workers have similar leisure-time physical activity levels as day workers but are more sedentary at work. Scand. J. Work Environ. Health. 43(2), 127-135. Epub 2016/12/doi: 10.5271/sjweh.3614. PubMed PMID: 27973676.

Loef, B., Hulsegge, G., Wendel-Vos, G.C., Verschuren, W.M., Vermeulen, R.C., Bakker, M. F., et al. 2017. Non-occupational physical activity levels of shift workers compared with non-shift workers. Occup. Environ. Med. 74(5), 328-335. Epub 2016/11/23. doi: 10.1136/oemed-2016-103878. PubMed PMID: 27872151; PubMed Central PMCID: PMCPMC5520260.

Vandelanotte, C., Short, C., Rockloff, M., Di Millia, L., Ronan, K., Happell, B., et al. 2015. How do different occupational factors influence total, occupational, and leisure-time physical activity? J. Phys. Act Health 12(2), 200-207. Epub 2014/02/11. doi: 10.1123/jpah.2013-0098. PubMed PMID: 24508923.

Sylvia, L.G., Bernstein, E.E., Hubbard, J.L., Keating, L., Anderson, E.J. 2014. Practical guide to measuring physical activity. J. Acad. Nutr. Diet. 114(2), 199-208. Epub 2013/12/03. doi: 10.1016/j.jand.2013.09.018. PubMed PMID: 24290836; PubMed Central PMCID: PMCPMC3915355.

Welk, G.J., Schaben, J.A., Morrow Jr., J.R., 2004. Reliability of accelerometry-based activity monitors: a generalizability study. Med. Sci. Sports Exerc. 36 (9), 1637–1645. Epub 2004/09/09 PubMed PMID: 15354049.

Loef, B., van der Beek, A.J., Holtermann, A., Hulsegge, G., van Baarle, D., Proper. K.I. 2018. Objectively measured physical activity of hospital shift workers. Scand. J. Work Environ. Health 44(3), 265-273. Epub 2018/01/23. doi: 10.5271/sjweh.3709. PubMed PMID: 29355291.

Ma, C.C., Burchfiel, C.M., Fekedulegn, D., Andrew, M.E., Charles, L.E., Gu, J.K., et al. 2011. Association of shift work with physical activity among police officers: the Buffalo cardio-metabolic occupational police stress study. J. Occup. Environ. Med. 53(9), 1030-1036. Epub 2011/08/26. doi: 10.1097/JOM.0b013e31822589f9. PubMed PMID: 21866054.

Loprinzi, P.D. 2015. The effects of shift work on free-living physical activity and sedentary behavior. Prev Med. 76, 43-47. Epub 2015/04/22. doi: 10.1016/j.ypmed.2015.03.025. PubMed PMID: 25895842.

Kolbe-Alexander, T.L., Gomersall, S., Clark, B., Torquati, L., Pavey, T., Brown, W.J. 2019. A hard day's night: time use in shift workers. BMC Public Health 19(Suppl 2), 452. Epub 2019/06/05. doi: 10.1186/s12889-019-6766-5. PubMed PMID: 31159755; PubMed Central PMCID: PMCPMC6546613.

Marqueze, E.C., Ulhôa, M.A., Moreno, C.R. 2013. Effects of irregular-shift work and physical activity on cardiovascular risk factors in truck drivers. Rev. Saude Publica. 47(3), 497-505. Epub 2013/12/19. doi: 10.1590/s0034-8910.2013047004510. PubMed PMID: 24346562.

Rydz, E., Hall, A.L., Peters, C.E., 2020. Prevalence and recent trends in exposure to night shiftwork in Canada. Annals Work Exposures Health 64 (3), 270–281.

Atkinson, G., Fullick, S., Grindey, C., Maclaren, D., 2008. Exercise, energy balance and the shift worker. Sports Med. 38 (8), 671–685. https://doi.org/10.2165/00007256-200838080-00005. PubMed PMID: 18620467.

Vincent, G.E., Jay, S.M., Vandelanotte, C., Ferguson, S.A. 2017. Breaking up sitting with light-intensity physical activity: implications for shift-workers. Int. J. Environ. Res. Public Health 14(10). Epub 2017/10/17. doi: 10.3390/ijerph14101233. PubMed PMID: 29035315; PubMed Central PMCID: PMCPMC5664734.

Ekelund, U., Tarp, J., Steene-Johannessen, J., Hansen, B.H., Jefferis, B., Fagerland, M.W., et al. 2019. Dose-response associations between accelerometry measured physical activity and sedentary time and all cause mortality: systematic review and harmonised meta-analysis. BMJ 366, l4570. Epub 2019/08/23. doi: 10.1136/bmj.l4570. PubMed PMID: 31434697; PubMed Central PMCID: PMCPMC6699591 and declare: no support from any organisation for the submitted work; no financial relationships with any organisations that might have an interest in the submitted work in the previous three years; no other relationships or activities that could appear to have influenced the submitted work.

Tremblay, M.S., Aubert, S., Barnes, J.D., Saunders, T.J., Carson, V., Latimer-Cheung, A. E., et al. 2017. Sedentary behavior research network (SBRN) - terminology consensus project process and outcome. Int. J. Behav. Nutr. Phys. Act 14(1), 75. Epub 2017/06/11. doi: 10.1186/s12966-017-0525-8. PubMed PMID: 28599680; PubMed Central PMCID: PMCPMC5466781.
Bull, F.C., Al-Ansari, S.S., Biddle, S., Borodulin, K., Buman, M.P., Cardon, G., et al. 2020. World Health Organization 2020 guidelines on physical activity and sedentary behaviour. Br. J. Sports Med. 54(24), 1451-1462. Epub 2020/11/27. doi: 10.1136/bjsports-2020-102955. PubMed PMID: 33239350; PubMed Central PMCID: PMCPMC7719906.
Chappel, S.E., Verswijveren, S.J.J.M., Aisbett, B., Considine, J., Ridgers, N.D., 2017. Nurses' occupational physical activity levels: a systematic review. Int. J. Nurs. Stud. 73, 52–62. https://doi.org/10.1016/j.ijnurstu.2017.05.006.
Flahr, H., Brown, W.J., Kolbe-Alexander, T.L. 2018. A systematic review of physical activity-based interventions in shift workers. Prev. Med. Rep. 10, 323-331. Epub 2018/06/06. doi: 10.1016/j.pmedr.2018.04.004. PubMed PMID: 29868387; PubMed Central PMCID: PMCPMC5984233.
Lassen, A.D., Fagt, S., Lennernäs, M., Nyberg, M., Haapalar, I., Thorsen, A.V. et al. 2018. The impact of worksite interventions promoting healthier food and/or physical activity habits among employees working 'around the clock' hours: a systematic review. Food Nutr. Res. 62. Epub 2018/08/08. doi: 10.29219/fnr.v62.1115. PubMed PMID: 30083088; PubMed Central PMCID: PMCPMC6073101.
Charrois, T.L. 2015. Systematic reviews: what do you need to know to get started? Can. J. Hosp. Pharm. 68(2), 144-148. Epub 2015/05/13. doi: 10.4212/cjhp.v68i2.1440. PubMed PMID: 25964686; PubMed Central PMCID: PMCPMC4414076.
Cumpston, M.S., McKenzie, J.E., Thomas, J., Brennan, S.E. 2020. Current practice in systematic reviews including the 'PICO for each synthesis' and methods other than meta-analysis: protocol for a cross-sectional study. F1000Research. 9.
Costa, G., Folkard, S. 2010. Shift work and extended hours of work. 1233-1245.
von Elm, E., Altman, D.G., Egger, M., Pocock, S.J., Gøtzsche, P.C., Vandenbroucke, J.P. 2008. The Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) statement: guidelines for reporting observational studies. J. Clin. Epidemiol. 61(4), 344-349. Epub 2008/03/04. doi: 10.1016/j.jclinepi.2007.11.008. PubMed PMID: 18313558.
Gilson, N.D., Hall, C., Holtermann, A., van der Beek, A.J., Huysmans, M.A., Mathiassen, S.E., et al. 2019. Sedentary and physical activity behavior in "blue-collar" workers: a systematic review of accelerometer studies. J. Phys. Act Health 16(11), 1060-1069. Epub 2019/08/31. doi: 10.1123/jpah.2018-0607. PubMed PMID: 31469366.
Vandenbroucke, J.P., Von Elm, E., Altman, D.G., Gøtzsche, P.C., Mulrow, C.D., Pocock, S. J., et al., 2007. Strengthening the reporting of observational studies in epidemiology (STROBE): explanation and elaboration. PLoS Med. 4 (10), e297.
Torres-Castro, R., Vasconcello-Castillo, L., Acosta-Dighero, R., Sepúlveda-Cáceres, N., Barros-Poblete, M., Puppo, H., et al. 2021. Physical activity in children and adolescents with chronic respiratory diseases: a systematic review and meta-analysis. J. Phys. Act Health 18(2), 219-229. Epub 2021/01/14. doi: 10.1123/jpah.2020-06PubMed PMID: 33440346.
Higgins, J.P., Thompson, S.G., Deeks, J.J., Altman, D.G. 2003. Measuring inconsistency in meta-analyses. BMJ 327(7414), 557-560. Epub 2003/09/06. doi: 10.1136/bmj.327.7414.557. PubMed PMID: 12958120; PubMed Central PMCID: PMCPMC192859.
Haidich, A.-B., 2010. Meta-analysis in medical research. Hippokratia. 14 (Suppl 1), 29.
Alves, M.S., Andrade, R.Z., Silva, G.C., Mota, M.C., Resende, S.G., Teixeira, K.R., et al., 2017. Social jetlag among night workers is negatively associated with the frequency of moderate or vigorous physical activity and with energy expenditure related to physical activity. J. Biol. Rhythms 32 (1), 83–93.
da Silva Garcez, A., Canuto, R., Vieira Paniz, V.M., Anselmo Olinto, B., Macagnan, J., Liane Henn, R., et al. 2015. Association between work shift and the practice of physical activity among workers of a poultry processing plant in Southern Brazil. Nutr. Hosp. 31(5), 2174-2181. Epub 2015/05/02. doi: 10.3305/nh.2015.31.5.8628. PubMed PMID: 25929390.
Panczyk, M., Woynarowska-Sołdan, M., Żmuda-Trzebiatowska, H., Gotlib, J., 2018. Health-enhancing behaviours of nurses in Poland and their association with shift work and age. Collegian 25 (3), 255–261.
Park, H., Suh, B. 2020. Association between sleep quality and physical activity according to gender and shift work. J. Sleep Res. 29(6), e12924. Epub 2019/11/30. doi: 10.1111/jsr.12924. PubMed PMID: 31782219.
Nam, S., Lee, S.-J., 2016. Occupational factors associated with obesity and leisure-time physical activity among nurses: a cross sectional study. Int. J. Nurs. Stud. 57, 60–69.
Sugiura, T., Dohi, Y., Takagi, Y., Yoshikane, N., Ito, M., Suzuki, K., et al., 2020. Impacts of lifestyle behavior and shift work on visceral fat accumulation and the presence of atherosclerosis in middle-aged male workers. Hypertension Res. 43 (3), 235–245.
Hulsegge, G., Proper, K.I., Loef, B., Paagman, H., Anema, J.R., van Mechelen, W., 2021. The mediating role of lifestyle in the relationship between shift work, obesity and diabetes. Int. Arch. Occup. Environ. Health 1–9.
Neil-Sztramko, S.E., Gotay, C.C., Demers, P.A., Campbell, K.L., 2016. Physical activity, physical fitness, and body composition of Canadian shift workers: data from the Canadian Health Measures Survey Cycles 1 and 2. J. Occup. Environ. Med. 58 (1), 94–100.
Loef, B., van der Beek, A.J., Hulsegge, G., van Baarle, D., Proper, K.I., 2020. The mediating role of sleep, physical activity, and diet in the association between shift work and respiratory infections. Scand. J. Work Environ. Health 46 (5), 516.
Peplonska, B., Bukowska, A., Sobala, W. 2014. Rotating night shift work and physical activity of nurses and midwives in the cross-sectional study in Łódź, Poland. Chronobiol. Int. 31(10), 1152-1159. Epub 2014/09/13. doi: 10.3109/07420528.2014.957296. PubMed PMID: 25216072.
Vlahoyiannis, A., Karali, E., Giannaki, C.D., Karioti, A., Pappas, A., Lavdas, E., et al., 2021. The vicious circle between physical, psychological, and physiological characteristics of shift work in nurses: a multidimensional approach. Sleep Breath. https://doi.org/10.1007/s11325-021-02381-5. PubMed PMID: 33864583. Epub 2021/04/18.
Tada, Y., Kawano, Y., Maeda, I., Yoshizaki, T., Sunami, A., Yokoyama, Y., et al. 2014. Association of body mass index with lifestyle and rotating shift work in Japanese female nurses. Obesity (Silver Spring). 22(12), 2489-2493. Epub 2014/09/25. doi: 10.1002/oby.20908. PubMed PMID: 25251576.
Clark, B.K., Kolbe-Alexander, T.L., Duncan, M.J., Brown, W., 2017. Sitting time, physical activity and sleep by work type and pattern—The Australian Longitudinal Study on Women's Health. Int. J. Environ. Res. Public Health 14 (3), 290.
van de Langenberg, D., Vlaanderen, J.J., Dollé, M.E., Rookus, M.A., van Kerkhof, L.W., Vermeulen, R.C., 2019. Diet, physical activity, and daylight exposure patterns in night-shift workers and day workers. Ann. Work Exposures Health 63 (1), 9–21.
Lauren, S., Chen, Y., Friel, C., Chang, B.P., Shechter, A., 2020. Free-living sleep, food intake, and physical activity in night and morning shift workers. J. Am. College Nutr. 39 (5), 450–456.
Vandelanotte, C., Duncan, M.J., Short, C., Rockloff, M., Ronan, K., Happell, B., et al., 2013. Associations between occupational indicators and total, work-based and leisure-time sitting: a cross-sectional study. BMC Public Health 13 (1), 1–8.
Guthold, R., Stevens, G.A., Riley, L.M., Bull, F.C., 2018. Worldwide trends in insufficient physical activity from 2001 to 2016: a pooled analysis of 358 population-based surveys with 1· 9 million participants. Lancet Global Health 6 (10), e1077–e1086.
Zafiropoulos, B., Alison, J.A., Heard, R., 2019. Physical activity levels of allied health professionals working in a large Australian metropolitan health district - an observational study. J. Multidiscip. Healthc. 12, 51–62. https://doi.org/10.2147/JMDH.S189513. PubMed PMID: 30655673.
Cillekens, B., Lang, M., van Mechelen, W., Verhagen, E., Huysmans, M.A., Holtermann, A., et al. 2020. How does occupational physical activity influence health? An umbrella review of 23 health outcomes across 158 observational studies. Br. J. Sports Med. 54(24), 1474-1481. Epub 2020/11/27. doi: 10.1136/bjsports-2020-102587. PubMed PMID: 33239353.
Gupta, N., Dencker-Larsen, S., Lund Rasmussen, C., McGregor, D., Rasmussen, C.D.N., Thorsen, S.V., et al., 2020. The physical activity paradox revisited: a prospective study on compositional accelerometer data and long-term sickness absence. Int. J. Behav. Nutr. Phys. Activity 17 (1), 93. https://doi.org/10.1186/s12966-020-00988-7.
Dalene, K.E., Tarp, J., Selmer, R.M., Ariansen, I.K.H., Nystad, W., Coenen, P., et al. Occupational physical activity and longevity in working men and women in Norway: a prospective cohort study. The Lancet Public Health. doi: 10.1016/S2468-2667(21)00032-3.
Barone Gibbs, B., Kline, C.E., 2018. When does sedentary behavior become sleep? A proposed framework for classifying activity during sleep-wake transitions. Int. J. Behav. Nutr. Phys. Activity 15 (1), 81. https://doi.org/10.1186/s12966-018-0712-2.
Smith, L., McCourt, O., Sawyer, A., Ucci, M., Marmot, A., Wardle, J., et al. 2016. A review of occupational physical activity and sedentary behaviour correlates. Occup. Med. (Lond). 66(3), 185-192. Epub 2016/03/27. doi: 10.1093/occmed/kqv164. PubMed PMID: 27016747.
Dempsey, P.C., Biddle, S.J.H., Buman, M.P., Chastin, S., Ekelund, U., Friedenreich, C.M., et al. 2020. New global guidelines on sedentary behaviour and health for adults: broadening the behavioural targets. Int. J. Behav. Nutr. Phys. Act 17(1), 151. Epub 2020/11/27. doi: 10.1186/s12966-020-01044-0. PubMed PMID: 33239026; PubMed Central PMCID: PMCPMC7691115.
Waters, T.R., Dick. R.B. 2015. Evidence of health risks associated with prolonged standing at work and intervention effectiveness. Rehabilitation nursing: the official journal of the Association of Rehabilitation Nurses. 40(3), 148-165. Epub 2014/07/07. doi: 10.1002/rnj.166. PubMed PMID: 25041875.
Haslam, C., Kazi, A., Duncan, M., Clemes, S., Twumasi, R., 2019. Walking Works Wonders: a tailored workplace intervention evaluated over 24 months. Ergonomics 62 (1), 31–41. https://doi.org/10.1080/00140139.2018.1489982.
Messenger J. Working time and the future of work. ILO future of work research paper series. 2018.
Rajaratnam, S.M.W., Arendt, J., 2001. Health in a 24-h society. Lancet 358 (9286), 999–1005. https://doi.org/10.1016/S0140-6736(01)06108-6.

3.3 Implications and contribution to the advancement of the research area

The main findings of the systematic review and meta-analysis revealed that, the prevalence of workers meeting physical activity guidelines did not differ between shift and non-shift workers. The other finding is that there were no differences on time spent physical activity between shift workers and non-shift workers. Approximately, 40% of shift and non-shift workers met the physical activity guidelines. The results of the meta-analysis showed that shift workers tended to spend less time in sedentary behaviour than non-shift workers. Fewer studies investigated sedentary behaviour; thus more studies are needed to fully understand sedentary behaviour in shift workers.

A large number of studies included used self-report measures, which presented recall and social desirability biases. Measurement tools that can assess domains and determinants while providing feasible, affordable, and practical measures of physical activity and sedentary behaviour are necessary. EMA offers an alternative tool to overcome the retrospective biases of other self-report measures. In addition, it allows for use of newer mobile technologies. While EMA may seem like an important tool to assess behaviours in shift workers, wearable devices like smartwatches are ambitious and have become popular to monitor and promote healthy behaviours (Greiwe & Nyenhuis, 2020; Gualtieri et al., 2016; Wen et al., 2017). Wearable devices provide a convenient, cost-efficient, and innovative tool to improve overall well-being in the workplace, encouraging employees to plan and participate in physical activity (Yen, 2021).

The meta-analysis provided an overview of overall physical activity and sedentary behaviour in shift workers; however a few gaps were identified in the literature. For example, studies included mainly used workers from health care industries. It may be essential to investigate and include other industries like mining for future intervention studies. Moreover, it is important to report and harmonise data by work industries by investigating other shift work industries. In addition, reporting the behaviours by domains is important to understand the determinants of the behaviours in shift workers. To fully understand the movement behaviours future studies may report all domains. Especially that there is evidence that occupational physical activity may not be beneficial for health (Holtermann et al, 2020). Recently, a scoping review summarised longitudinal studies on sleep, physical activity, and nutritional intake in shift workers and showed that some shift workers are physically inactive (Crowther et al., 2022).

CHAPTER 4: PAPER 2-FEASIBILITY OF ECOLOGICAL MOMENTARY ASSESSMENT IN MEASURING PHYSICAL ACTIVITY AND SEDENTARY BEHAVIOUR IN SHIFT AND NON-SHIFT WORKERS

4.1 Introduction

Most of the studies included in the systematic review in chapter 3 used traditional self-report measurement tools (Monnaatsie et al., 2021). There were fewer studies that used devices such as Actigraph (Loef et al, 2018), pedometers (Kwiecień-Jaguś et al., 2019) and activPAL (Chappel et al., 2020) to assess physical activity and sedentary behaviour in shift workers. While devices provide less biases than traditional self-report measures, they are unable to provide the contexts of behaviours (Prince et al., 2019).

Work tasks and factors are hypothesised to influence behaviours in shift workers (Kolbe-Alexander et al., 2019). Understanding the work factors of physical activity and sedentary behaviour in shift workers are particularly important. For example, the workplace environment and work tasks are some of the important determinants to provide the context of behaviour during the development of interventions (Watanabe et al., 2018). If measurement tools provide information on the context of behaviours, health promotion programs could be effective (Uijtdewilligen et al., 2011). Therefore, measurement tools that present less recall bias and more contexts of behaviours are necessary (Mead & Irish, 2022).

Examining the intra-individual variability in movement-related behaviours can provide important insights into shift workers behaviours and health promotion efforts may be improved (Perski et al., 2022). Therefore, the next study (Study 2, Chapter 4) aimed to assess the feasibility of EMA using a mobile application. EMA provides an alternative measure to assess physical activity and sedentary behaviour in shift workers.

4.2 Study 2: Monnaatsie, M., Biddle, S. J. H., Kolbe-Alexander T. Feasibility of ecological momentary assessment in measuring physical activity and sedentary behaviour in shift and non-shift workers. Submitted to *Measurement in Physical Education and Exercise Science* (Q2 Journal, Impact factor: 2.1). Revisions done.

Abstract

Ecological momentary assessment (EMA) evaluates physical activity and sedentary behaviour in real-time and could be adapted to shift work schedules. This study compared the feasibility of EMA to measure physical activity and sedentary behaviour in workers. Shift (n=69) and non-shift (n=51) workers were enrolled. Participants downloaded the EMA app and answered 5 EMA surveys per day, for 7-10 days. The shift workers were sub-divided into 2 groups: Shift workers in group 1 received prompts tailored according to their work schedules (SW-T); shift workers group 2 (SW-S) and non-shift workers (NSW-S) received prompts at standardised times. Feasibility outcomes included overall EMA compliance and factors influencing responses. Participants responded to 64% of EMA prompts, with no differences between groups. EMA prompt responses differed by the timing of prompts (p=0.02), work versus non-workdays (p=0.36) and shift schedule (p=0.02). On average, each participant received 37 prompts per day, of which 24 were answered. Compliance was reduced after the fourth prompt of the day in all participants. SW-T and SW-S

were more likely to answer prompts during non-workdays, while NSW-S answered more prompts during workdays. SW-T answered fewer prompts while working night than day and evening shifts, whereas SW-S prompts answered fewer prompts on their evening shifts. Mobile EMA is feasible to quantify physical activity and sedentary behaviour in shift workers. Tailoring prompts according to shift work schedules influenced the EMA responses. Future EMA research should consider sending four prompts per day to increase EMA completion rates.

Introduction

Physical inactivity is one of the leading modifiable risk factors for cardiovascular disease and all-cause mortality (Lavie et al., 2019) and has a strong association with poor mental health. Globally, 27.5% of the adult population do not meet the physical activity guidelines when activity is self-reported (Guthold et al., 2018). High levels of sedentary time (inactive sitting) has also been associated with all-cause mortality, cardiovascular diseases, cancer mortality and type 2 diabetes (Patterson et al., 2018; Zhao et al., 2020). A recent study shows that adults spend approximately 8.2 hours a day sedentary (Dempsey et al., 2020).

In the shift working population, physical activity and sedentary behaviour may be influenced by shift patterns and schedules (Kolbe-Alexander et al., 2019). Shift work can include work in the early morning, at night, in the late afternoon/evening, or rotating shifts (Cheng & Drake, 2019). Strong evidence shows that working shifts is associated with increased risk of chronic diseases like cardiovascular diseases, breast cancer and diabetes (Torquati et al., 2018; Wu et al., 2022). Further, mental health outcomes, weight gain, sleep disorders and metabolic syndrome are higher in shift workers than in day workers (Lee et al., 2017; Sooriyaarachchi et al., 2022). Because of adverse health outcomes of shift work, there is a need to understand and evaluate the physical activity and sedentary behaviour patterns of shift workers (Crowther et al., 2022). Advancing the field of physical activity and sedentary behaviour in shift workers requires measurement tools that are practical and feasible (Loef et al., 2018; Stevens et al., 2020).

Physical activity and sedentary behaviours in shift workers have been assessed with surveys such as the International Physical Activity Questionnaire (IPAQ), (Vlahoyiannis et al., 2022) IPAQ-short form, (Park & Suh, 2020) questions from the Behavioral Risk Factor Surveillance System (BRFSS), (Chin et al., 2016) or devices including ActiGraph, activPAL and Actical accelerometers, (Loef et al., 2018; Neil-Sztramko et al., 2016) and pedometers. (Kwiecień-Jaguś et al., 2019) Evaluating physical activity and sedentary behaviour with traditional self-report measures are feasible and can be cheaper to implement within population surveillance (Colley et al., 2018). Another advantage is that they can be used in large population studies and place a low burden on participants and researchers (Cleland et al., 2018). For example, in a recent study of 7607 workers, IPAQ-SF was used to compare shift and non-shift workers' physical activity and sleep behaviours (Fenwick et al., 2022). However, self-report measures are often subject to bias and can lead to difficulties in recalling physical activity and sedentary behaviours by participants (von Haaren-Mack et al., 2020).

Device-based measurement tools such as accelerometers allow movement to be continuously and more precisely monitored (Tarp et al., 2020). Devices are feasible and acceptable to researchers in terms of time taken to download data (O'Neill et al., 2017). They record raw accelerations and establish algorithms to produce acceleration or activity counts over specific periods or epochs (Bammann et al., 2021). The activity counts are used to classify the intensity of physical activity (light, moderate, vigorous). Devices have several advantages over self-report methods (Migueles et al., 2017). However, they do not provide information on the environmental context or domains of activity (Mielke et al., 2022). The environmental context, including occupational indicators and work schedules are important to understand shift workers' physical activity and sedentary behaviour (Vandelanotte et al., 2013).

EMA techniques may be useful to overcome methodological limitations associated with self-report and devise-based measures (Knell et al., 2017). EMA assess behaviours based on repeated measures that take place in real-world settings, over time, and across contexts (type and location) (Dunton et al., 2012; Maher et al., 2018). Real-time collection of behaviours minimizes errors caused by recalling what happened in the previous day, week or month (Marszalek et al., 2014). When comparing EMA with other self-report measures (e.g., BRFSS and IPAQ) against accelerometry versus EMA with accelerometry, EMA presented significant agreement and accuracy than self-report measures (Knell et al., 2017). Thus, EMA could be effective for awake and timing challenges when assessing behaviours in shift workers because of its ability to be adapted to in-moment events. Additionally, physical activity and sedentary behaviour are influenced by several factors including individual's social, physical and environment (Stokols, 1996). To understand these behaviours, it is crucial to collect information about context of the behaviour. For example, information about shift schedules, and behaviours during work and non-workdays can be influenced by shift work. EMA is well suited to examine changes in movement behaviours and the factors that influence them as they occur in everyday life (Engelen et al., 2016).

Technological advances allow the use of smartphones to facilitate prompt setting and timestamping responses that are now commonly used in EMA studies (Müller et al., 2018). Smartphone EMA studies involve sending repeated brief surveys assessing current behaviour, as well as contextual information such as location and type of activity (de Vries et al., 2021). An increasing number of studies are exploring the feasibility of EMA with smartphone applications to measure physical activity and sedentary behaviour in adults and older adults, (Dunton et al., 2012; Maher et al., 2018) and in college students. (Bruening et al., 2016) Compliance rates range between 58%-92% for adults (Engelen et al., 2016; Maher et al., 2018), suggesting that EMA is a feasible assessment tool.

Previous research suggests that EMA is feasible in Fly-In-Fly-Out (FIFO) shift workers (Rebar et al., 2018). However, this research did not include information about shift types (day, evening, or night) thus not fully capitalizing on the potential of EMA to be adjusted according to various schedules. Additional studies with non-shift work populations showed that EMA was feasible in assessing health behaviours (Engelen et al., 2016; Weatherson et al., 2019). For instance, 45 adults were recruited for a workplace sit-to-stand desk intervention to assess the feasibility of EMA. Participants received five surveys each day for five workdays via smartphone application and the response rate was 81.4% of EMA prompts (Weatherson et al., 2019). These studies did not tailor EMA surveys according to work schedules. Shift work schedules are variable, even in the same industries and similar workplaces, making EMA a potentially suitable tool for assessing the behaviours during fluctuating rosters.

Consequently, little is known about the use of EMA adapted to work schedules to evaluate physical activity and sedentary behaviour patterns in the shift work population. The aim of this study, therefore, was to evaluate the feasibility of EMA to assess physical activity and sedentary behaviour in shift and non-shift workers. The main objective was to compare EMA survey completion rates shift and non-shift workers**.**

Methods

Participants and procedure

This is a longitudinal EMA design with multiple assessments (Burke et al., 2017), comparing the feasibility of an EMA application for shift workers and non-shift workers. Full time workers were recruited via word of mouth, flyers, and social media. After receiving an information sheet, participants were invited to an in-person visit with the researcher. During the visit participants (1) signed the consent form, (2) completed the questionnaires about their demographic characteristics and health risk appraisal, (3) had anthropometric measures taken and, (4) downloaded the EMA app. Participants completed 7-10 days of EMA data collection. The number of days was dependent on participant individual shift schedules to collect EMA data during all work schedules and non-workdays. Non-shift workers participated in the study for 7 consecutive days including five workdays and 2 non-workdays. This research study was approved by the University of Southern Queensland’s Human Research Ethics Committee.

Measures

Ecological momentary assessment

The *SEMA³* app link (Koval et al., 2019) was sent via email for participants to download onto their mobile phones. The researcher showed participants how to set up and use the app. Upon receiving the EMA prompt on their phones, participants were instructed to stop their current activity, provided it was safe to do so, and complete a 1-minute survey. EMA surveys were sent via the app five times per day. The survey expired after 30 minutes of no response. Shift workers (n=51) SW-T were sent tailored prompts, and a sub-group of shift SW-S (n=18), and non-shift workers NSW-S (n=51) received the standardised prompts. The tailored prompts were set according to shift schedule and were different for each participant, while standardized prompts were sent at the same time of day during work and non-workdays. The tailored prompt times were based on anticipated shift schedules and wake-sleep pattern of the shift workers and adjusted when they reported any change of shift schedule. This avoided shift workers receiving prompts while they were sleeping. The standardized EMA surveys were sent between 10:00 AM and 10:00 PM daily. Each EMA survey consisted of five questions and took less than a minute to complete. Table 4.1 summarises the EMA survey prompting schedule

Table 4.1. EMA prompting patterns and schedule

Group name	Work type	Study period (days)	EMA prompts	Number and timing of prompts per day
SW-T	Shift work	7-10	Tailored	5 at times based on work hours
SW-S	Shift work	7-10	Standardized	5 between 10 a.m. and 10 p.m.
NSW-S	Non-shift work	7	Standardized	5 between 10 a.m. and 10 p.m.

Legend. SW-T: shift workers who received tailored EMA prompts, SW-S: shift workers who received standardized EMA prompts, NSW-S: non-shift workers who received standardized EMA prompts

The EMA app

The *SEMA*[3] app was available in both iPhone and android operating systems (Figure 4.1). The activity, duration, location, detailed physical activity type (if they chose the physical activity option) and sitting were assessed. The survey began with: *"what were you doing in the few minutes before receiving this message?"* Response options included, *"watching television, using mobile phone/computer, eating/drinking, exercise or physical activity, work duties, socializing, driving/travelling, and household/garden chores, caring for children and other."* If the participant selected *"watching television or using mobile phone/computer, work duties, socializing, caring for children"*, the next question was a follow-up and asked about sitting. If exercise or physical activity was reported, a follow-up question asked about specific type of exercise or physical activity. If *"other"* was selected, the participants were asked to provide more detailed information on the *"other"* activity. For each activity reported, participants were asked to report time spent (in minutes) on the activity and their location. Survey responses were downloaded from the SEMA website in CSV format and converted to excel files. Figure 4.1 presents an example of the screen shots from the EMA items. The EMA questions and the number of prompts were adapted from previous EMA studies assessing physical activity and sedentary behaviour (Dunton et al., 2012; Maher et al., 2018).

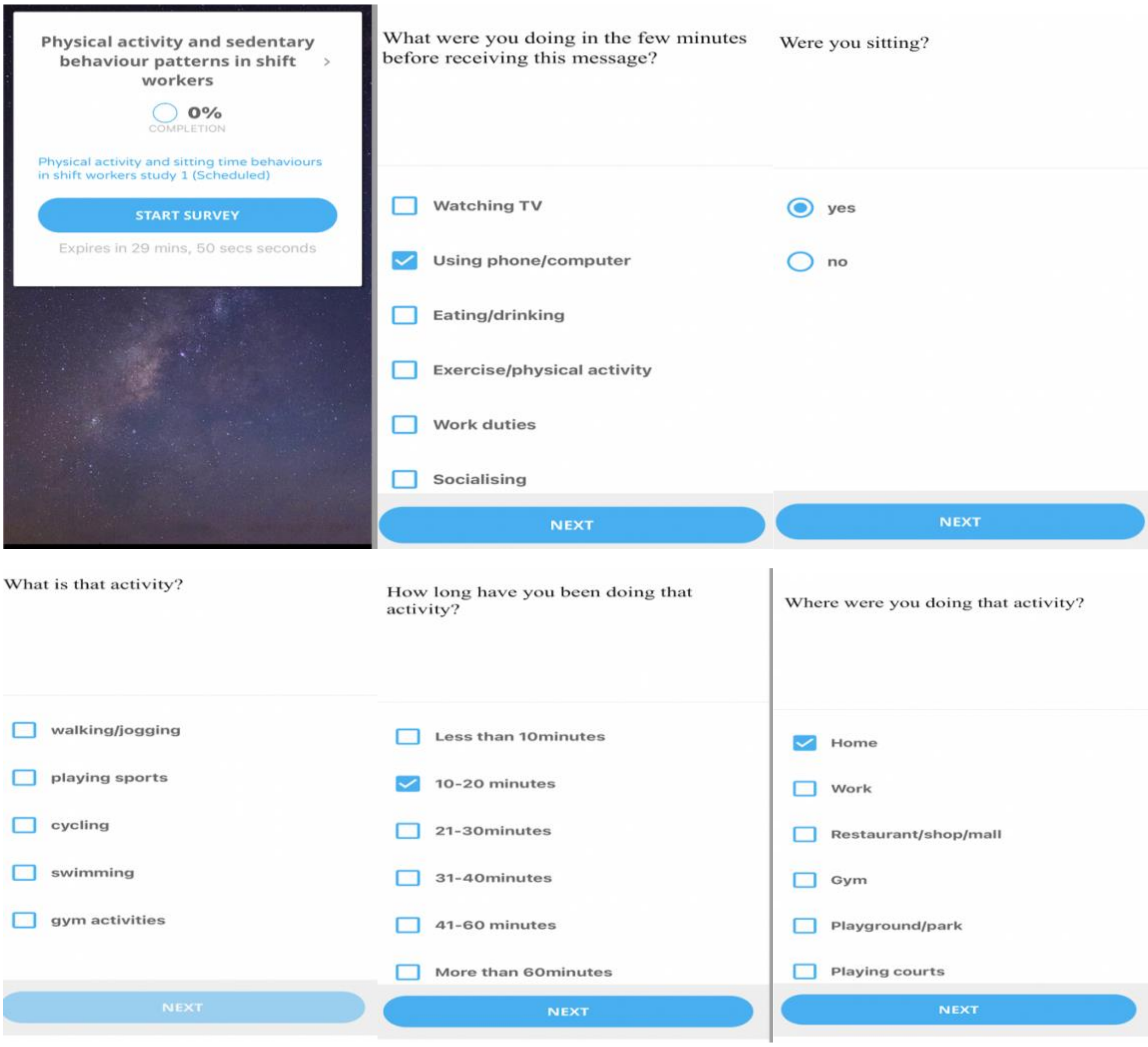


Figure 4.1 SEMA app screenshots from the researcher phone. The images show how the EMA questions appeared on the mobile phone.

EMA feasibility

Our primary outcome was feasibility of the EMA application survey, measured by enrolment rate, retention rate, engagement and adherence, and EMA compliance. Markers of feasibility were reported for all participants and the three groups (SW-T, SW-S and NSW-S).

Enrolment and retention

Enrolment rate represented the percentage of invitees who enrolled in the study, whereas the retention rate represented participants who completed 7-10 days of prompts.

EMA compliance

The percentage of EMA surveys completed out of the sent ones were reported as the overall compliance rate. The unanswered EMA prompts that were delivered to participants' phones were categorised as missed prompts. The time taken to answer each prompt was recorded.

EMA adherence

The adherence to the EMA survey was measured by the number of EMA responses for the 7-10 days and per day and by work factors including work versus non-workdays and shift schedules.

Predictors of EMA compliance

To determine the influence of answering EMA prompts, participant's demographic characteristics were used.

Prevalence of EMA reported physical activity and sedentary behaviour

EMA-reported physical activity was measured by asking participants to report by choosing among other options of EMA survey current activities when they were engaged in any physical activity. Sedentary behaviour was assessed by participants reporting that they were sitting or not with their current activity. To summarize, the EMA-reported physical activity and sedentary behaviour percentages were calculated.

Health risk appraisal questionnaire

Participants' age (years), gender (male, female or prefer not to say), marital status, and shift schedules were reported. The health risk appraisal section asked participants to report their perceived health status by choosing the options 'poor', 'average', 'good' or 'excellent'. Participants also reported how their work schedule impacted their activities, including leisure time and domestic activities. The questionnaire was adapted from a previous shift work study (Kolbe-Alexander et al., 2019).

Anthropometry

Waist circumference measurements (to the nearest 0.5 cm) were taken by placing a tape measure midpoint between the lower border of the rib cage and the iliac crest. (Ross et al., 2020) Participants' height was measured to the nearest 0.1 cm using a stadiometer (Seca) Weight was measured to the nearest 0.1 kg using a digital scale (Seca 803). Body mass index (BMI) was calculated as weight/height squared (m^2).

Statistical analysis

The demographic characteristics and feasibility markers were summarised as means and standard deviation for continuous variables, and frequencies and percentages for categorical variables. To test for normality, we used histograms and Shapiro-Wilk tests. We performed a Kruskal-Wallis test to examine the differences in the demographic characteristics of participants in the three work groups (SW-T, SW-S and NSW-S) and EMA compliance between groups. Pearson correlation coefficients were calculated to test associations between age, sex, and BMI with EMA compliance rate. The association between EMA prompt responses and workdays and shift schedules were examined using multinominal logistic regression analyses. The alpha level was set to 0.05, for all analyses and all statistics were conducted in SPSS version 27.

Results

Participant characteristics

The non-shift workers were significantly older than both the shift work groups (Table 4.2). Body Mass Index was similar for the groups with an average of 27.9 kg/m^2, placing participants in the overweight category.

Most participants were female (70%), and the majority of non-shift workers were married or living with a partner. Most of the shift workers were nurses and paramedics (66%). The remaining shift workers include security guards, drivers and manufacturing workers. The non-shift workers were office workers.

Table 4.2. Participant characteristics for each of the three groups

Demographic characteristic	Total (*n*=120)	SW-T (*n* = 51)	SW-S (*n* = 18)	NSW-S (*n* = 51)	P-value
Age (years) mean ± SD	36.0 ± 10.6	31.6± 8.5	30.0± 8.4	42.1 ± 11.3	0.02
BMI (kg/m^2) mean ± SD	27.9 ±5.7	27.0 ± 4.6	27.7 (5.1)	29.0 ± 6.9	0.90
Gender n (%)					0.71
Male	50.0 (41.7)	24.0 (47.0)	8.0 (44.4)	18.0 (35.3)	
Female	70.0 (58.3)	27.0 (52.9)	10.0 (55.6)	33.0 (64.7)	
Marital status n (%)					0.057
Living with partner	69.0 (59.5)	25.0 (49.0)	9.0 (50.0)	34.0 (66.6)	
Not living with partner	47.0 (40.5)	26.0 (50.9)	9.0 (50.0)	17.0 (33.3)	
Work type n (%)					
Health care	45.0 (37.5)	33.0 (64.7)	12.0 (66.7)	-	
Other	29.0 (24.2)	18.0 (35.3)	6.0 (33.3)	5.0 (9.8)	
Office workers	46.0 (38.3)	-	-	46.0 (90.2)	

Legend: SW-T: shift workers who received tailored EMA prompts, SW-S: shift workers who received standardized EMA prompts, NSW-S: non-shift workers who received standardized EMA prompts, BMI: Body Mass Index. Health care workers include nurses and paramedics, other represented other various industries including security, drivers, and manufacturing. Living with partner include married and not married but living with partner, Not living with partner include participants who reported that they were single, separated/divorced and widowed. Statistically significant difference ($p<0.05$) between SW-T, SW-S and NSW-S using Kruskal Wallis test.

EMA feasibility

Data availability and enrolment

Figure 4.2 is an overview of the participants at each stage of the study. Workers *(n=164)* were invited to participate in the study, with 128 accepting and enrolling (78%). The reasons for declining participation included being unwilling to travel to the university campuses for the in-person visit, or not responding to invitation emails. All the 128 workers who were enrolled completed the study, thus retention was 100%. However, eight participants did not receive EMA surveys due to unknown technical problems. Thus, 120 participants who completed the study were included for final analyses, including 51 shift workers (SW-T) who received EMA tailored prompts, 18 shift workers (SW-S) who received standardized prompts, and 51 non-shift workers (NSW-S) who also received standardized prompts.

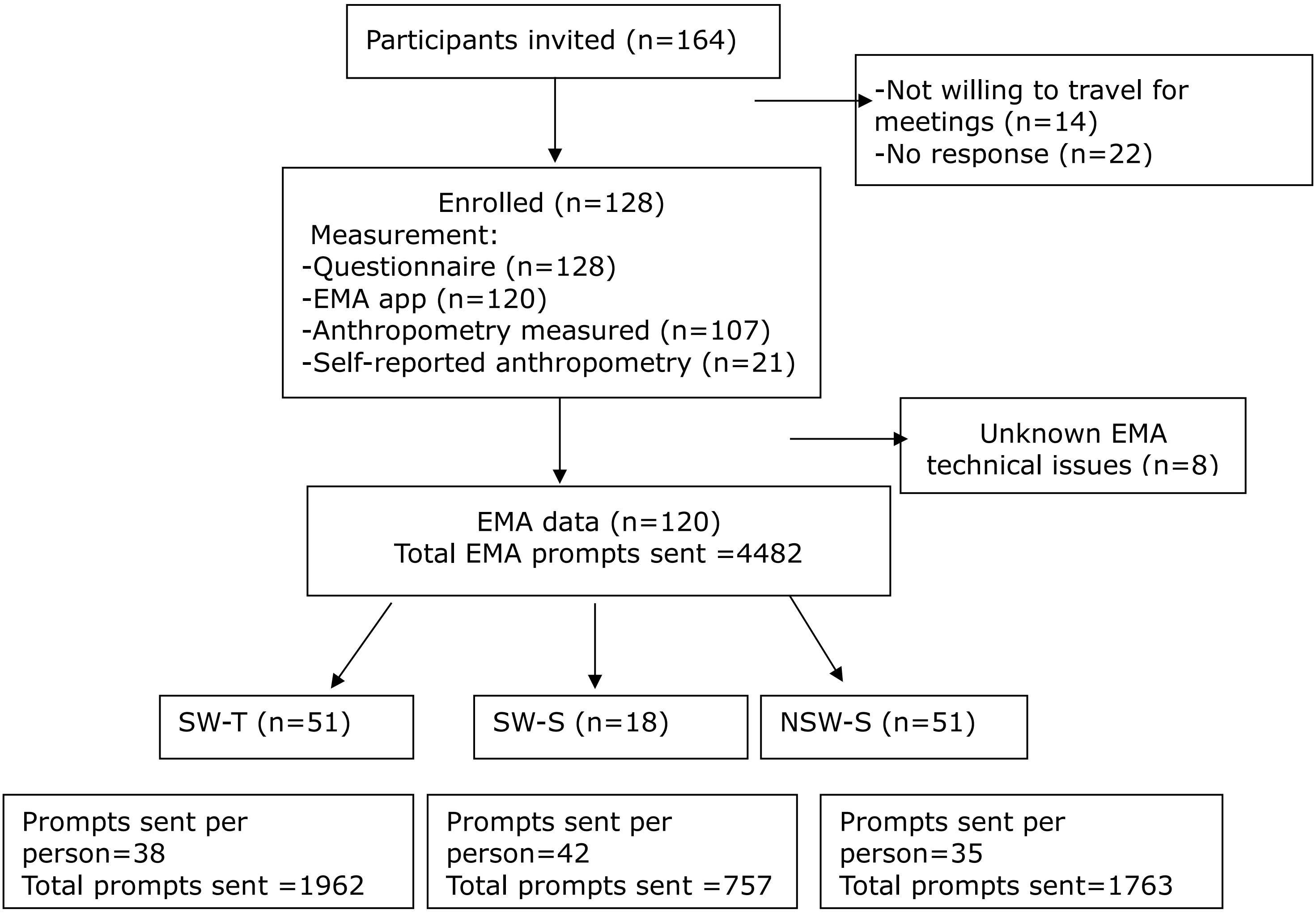


Figure 4.2 Participation at each stage of the study

Legend. HRA: Health risk appraisal, Participants invited represents the number of participants sent emails, EMA prompts sent– the number of EMA surveys successfully sent to mobile phone. EMA prompts per person are number of EMA Surveys sent to each participant. SW-T: shift workers with tailored EMA prompts, SW-S: shift workers who received standardized prompts, NSW-S: non-shift workers with standardised prompts.

EMA prompts compliance

The various measures of EMA compliance are shown in Table 4.3. A total of 4482 EMA prompts were sent to all participants, 2951 EMA prompts were started, and 2900 (64%) completed. On average, each participant received 37 prompts during the study period, of which 24 were answered. SW-S missed more prompts (39%) than SW-T (36%) and NSW-S (32%). Each survey took an average of 24 seconds to complete, and it was similar across the three groups (p=0.26). The prevalence of overall completed prompt and missed prompts were similar for the 3 groups (SW-T, SW-S and NSW-S).

Table 4.3. Summary of EMA overall compliance

EMA	Total (*n*=120)			SW-T (*n* = 51)			SW-S (*n=18)*			NSW-S (*n* = 51)			*P-value*
	Mean	SD	%	Mean	SD	%	Mean	SD	%	Mean	SD	%	
Completed prompts	23.9	8.7	64.0	24.2	8.7	64.0	24.7	12.9	57.0	23.4	6.9	68.0	0.90
Missed prompts	13.1	8.6	36.0	13.8	9.5	36.0	16.7	9.3	39.0	11.1	6.9	32.0	0.05
Response time (min)	0.40	0.25		0.41	0.33		0.45	0.31		0.34	0.10		0.26

Legend. Abbreviations n: total number, SD: standard deviation, min: minutes taken to respond to each survey. SW-T: shift workers with tailored EMA prompts, SW-S: shift workers who received standardized prompts, NSW-S: non-shift workers with standardised prompts. Differences with Kruskal Wallis test between the groups are statistically significant ($p<0.05$).

EMA adherence

Figure 3 shows the completed prompts according to the timing of daily prompts (first to fifth prompt). The most frequently answered was the first prompt of the day (24%), and the fifth was the least answered (14%) in all participants. The post-hoc results show the difference in prompt responses was between fourth ($p=0.04$) and fifth ($p=0.012$) and between SW-T and SW-S ($p=0.008$) and SW-T and NSW-S ($p=0.02$). The mean number of days of EMA completed surveys was 4.4 days (SD 2.3) out of a possible 7 days in non-shift workers, and 5.3 days (SD 4.5) out of a possible 10 days in shift workers. Prompts responses did not differ by days.

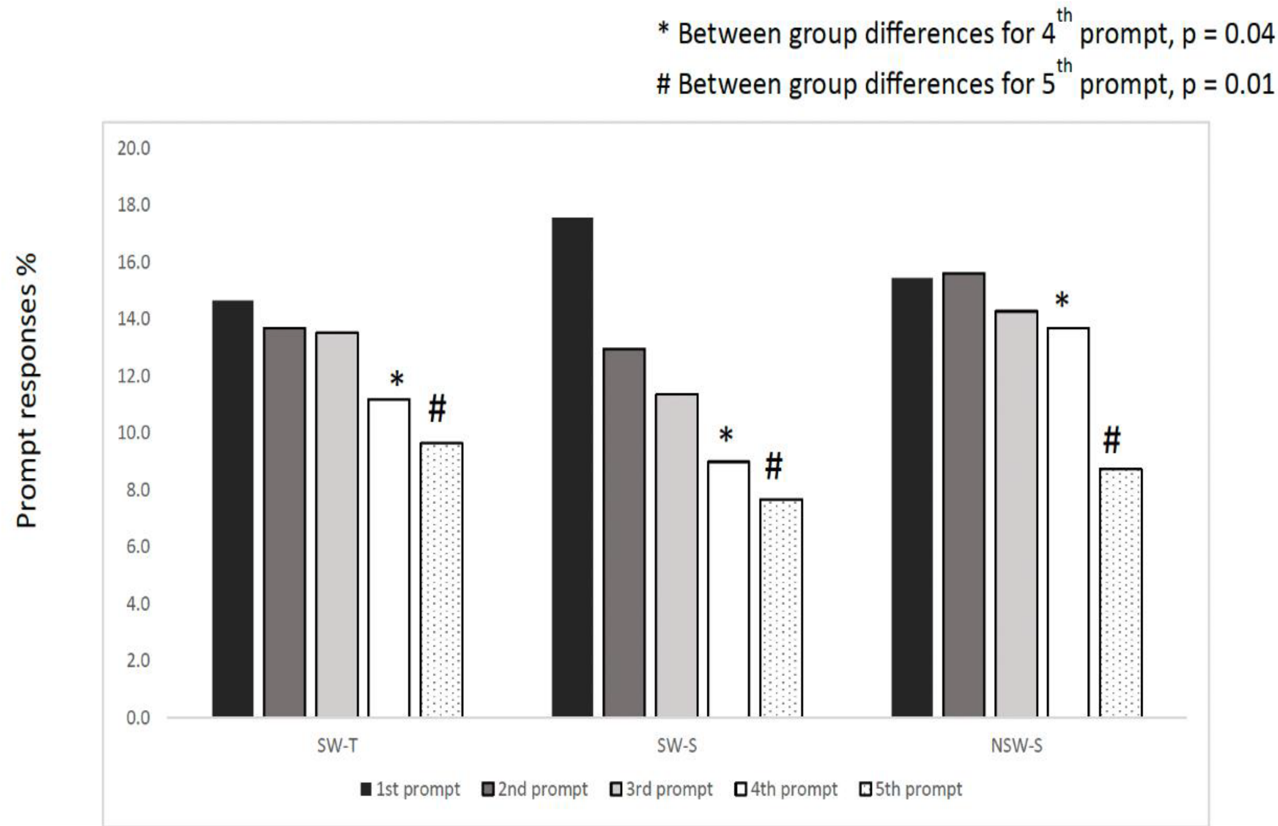


Figure 3. Response to the five EMA prompts between groups
SW-T: shift workers with tailored EMA prompts, SW-S: shift workers who received standardized prompts, NSW-S: non-shift workers with standardised prompts. Differences with Kruskal Wallis test between the groups are statistically significant (p<0.05)

EMA engagement

For comparison of the five EMA prompt responses, participants across all three groups were more likely to answer the second and fourth prompts than the first but not the third and fifth prompts of the day. When compared to the reference group (NSW-S) the EMA tailored prompts group (SW-T) were also less likely to answer the second and fourth prompts than the first prompt but the not 3rd and 5th. The SW-S were less likely to answer all the four prompts than the first prompt of the day (Table 4.4).

Table 4.4. Multinominal regressions predicting the likelihood of answering the first EMA prompt

Prompts	SW-T OR (95% CI)	SW-S OR (95% CI)
Second	0.94 (0.74, 1.20)	0.71* (0.53, 0.94)
Third	1.02 (0.81, 1.30)	0.72* (0.53, 0.96)
Fourth	0.87 (0.68, 1.12)	0.57* (0.42, 0.79)
Fifth	1.17 (0.89, 1.53)	0.82, (0.59, 1.51)

Legend. SW-T: shift workers with tailored EMA prompts, SW-S: shift workers who received standardized prompts. OR=odds ratio, CI: Confidence interval
Note: OR ratio of the likelihood of answering the 2^{nd}-5^{th} prompts than the 1^{st} as the reference category. Non-shift workers as the comparison group to SW-T and SW-S. *$p<0.05$

EMA responses on work versus non-workdays and shift schedules

The missed prompts were used as the reference outcome variable when assessing prompt responses by work and non-workday variables. SW-T answered more prompts during non-workdays than at work. When we compared the shift schedules, SW-T were more likely to answer all the prompts during the day shift and evening shifts, than night. SW-S were more likely to answer the first four prompts during non-workdays than workdays. Additionally, SW-S answered more prompts during day and night shifts than evening shift. In contrast the non-shift work group participants were likely to answer all the five prompts during weekdays than weekends (Table 4.5).

Table 4.5. Prompt responses by work, nonwork days and shift schedules

	SW-T OR (95% CI)			SW-S OR (95% CI)			NSW-S OR (95% CI)
	Non-workday	Dayshift	Nightshift	Non-workday	Dayshift	Nightshift	Workday (weekday)
1st	1.54* (1.01, 2.33)	1.36 (0.86, 2.17)	1.47 (0.88, 2.49)	1.18 (0.54, 2.57)	1.28 (0.54, 3.04)	1.44 (0.61, 3.38)	1.29 (0.94, 1.75)
2nd	2.09* (1.35, 3.26)	1.33 (0.82, 2.14)	1.46 (0.85, 2.92)	1.96 (0.72, 5.34)	1.87 (0.63, 5.58)	2.25 (0.76, 6.64)	1.30 (0.96, 1.78)
3rd	1.98* (1.28, 3.07)	1.21 (0.76, 1.92)	0.86 (0.48, 1.52)	2.56 (0.74, 8.84)	3.26 (0.89, 11.9)	3.26 (0.89, 12.0)	1.42* (1.03, 1.96)
4th	2.23* (1.38, 3.59)	1.83* (1.09, 3.06)	0.86 (0.44, 1.71)	2.02 (0.58, 7.03)	2.20 (0.58, 8.39)	2.40 (0.64, 9.02)	1.39* (1.00, 1.93)
5th	2.33* (1.41, 3.83)	1.67 (0.95, 2.91)	0.90 (0.44, 1.86)	0.88 (0.31, 2.50)	1.02 (0.32, 3.28)	1.56 (0.52, 4.73)	1.64*(1.10, 2.47)

Legend. SW-T: shift workers with tailored EMA prompts, SW-S: shift workers who received standardized prompts, NSW-S: non-shift workers with standardised prompts, OR=odds ratio, CI: Confidence interval.
Note: OR to predict the likelihood of answering prompt 1-5 than missing it as the reference category. For SW-T and SW-S prompt responses during workdays and evening shifts were used as comparison groups, while weekend was used for NSW-S.
*$p<0.05$

EMA compliance and demographics predictors

EMA compliance was unrelated to age (*r*=-0.03; *P*=0.47), gender (*r*=0.08; *P*=0.47), BMI (*r*=0.03; *P*=0.38), and marital status (*r*=0.03; *P*=0.49).

Prevalence of EMA reported physical activity and sedentary behaviour

Engaging in physical activity was reported in 3.7% prompts. Time spent watching television was reported in 8% prompts and using phone or computer in 10% of the prompts. EMA reported sitting and physical activity differed between SW-T (p=0.02) and NSW-S (p=0.00). Non-shift workers reported more time spent sitting and physically active than shift workers. EMA reported sitting and physical activity were similar in the two EMA shift work groups (p>0.05). Supplementary table B.1. presents other EMA-reported activities.

Discussion

Mobile technology is now widely available, and researchers can include electronically delivered EMA surveys to quantify physical activity and sedentary behaviour. Shift work results in irregular work patterns and schedules and using traditional self-report recall measures and devices may be insufficient to cater for irregular work patterns. Therefore, the aim of this study was to determine the feasibility of EMA to quantify physical activity and sedentary behaviour in shift workers. We adapted the EMA prompts to a group of shift workers' work schedules and sent standardized EMA prompts to another group of shift workers and non-shift workers to assess physical activity and sedentary behaviour.

The overall EMA compliance in our study was 64%. This is comparable to other studies involving non-shift workers. Office workers in a 5-day study with four EMA surveys per day completed 58% prompts (Engelen et al., 2016), whereas unversity workers who received five surveys in five working days had a compliance rate of 80% (Weatherson et al., 2019). Although we sent the same number of prompts per day as Weatherson et al., the overall compliance rate was higher than our study. Our EMA survey expired after 30 minutes when unanswered, whereas they sent three reminders before the survey expired. Thus, the higher compliance rate in their study might have been influenced by sending reminders to participants every 10 minutes until the survey expired. It was shown that sending frequent reminders to participants before the survey expires can increase overall compliance (Elavsky et al., 2021).

Results from the present study showed no differences in overall compliance by the EMA prompt groups. Tailoring prompts may have been equally effective in aligning the timing between the tailored EMA prompts for shift workers and standardized prompts for non-shift workers. Additionally, we sent a group of shift workers standardized prompts, resulting in more missed prompts when compared to shift workers with tailored prompts. The missed standardized prompt confirms our initial hypothesis that tailoring EMA prompts to shift schedules are more feasible than standardized prompts. Previous studies also recommended that EMA prompting be tailored to individual participants' schedules to increase compliance (Dunton et al., 2012; Maher et al., 2021). Therefore, the method supports estimating physical activity and sedentary behaviour with various predictors of behaviours, such as work, non-work, and shift schedules with EMA. The use of tailoring prompts can inform future health promotion programs using mobile apps on when to deliver prompts to improve behaviours based on the days and times of the day when they answered more prompts.

Our study compliance rate may have also been affected by a lack of incentives. For example, office workers with the higher compliance rate received $20 (Weatherson et al., 2019). In comparison, office workers who did not receive incentives had a lower completion rate (Engelen et al., 2016). Evidence from a meta-analysis with 477 articles on designs and compliance to ecological momentary assessment showed that giving participants incentives is associated with higher compliance rates compared with no incentives (Wrzus & Neubauer, 2022).

Our study findings also suggest that EMA surveys present low burden to participants. Workers in our study spent less than a minute (0.4 minutes) on average answering each EMA survey. By comparison, office workers in Engelen et al. study also took less than one minute to complete each prompt (Engelen et al., 2016). Similarly, the retention rate was higher in our study, showing that EMA reporting was not overly burdensome. Only a few participants (n=8) were removed due to lack of EMA data.

Our results showed that the first prompt of the day had the highest response rate for shift and non-shift workers. The response rate was reduced after the fourth prompt in all the groups. This might be attributable to the time of the day when EMA prompts were sent. The last prompt of the day for those who received standardised prompts was sent at 10 p.m. Therefore, participants may have been sleeping or not close to their mobile phones. The lower response rate for the SW-T could be related to occupational tasks that did not allow for responses. This is likely to be the case for most of our participants who were nurses and paramedics and might have been attending to a patient when the prompt was received. Whereas non-shift workers, who were mainly office workers, may have more access to their phones at work.

Another advantage of EMA is its ability to capture correlates and time varying factors that influence physical and sedentary behaviours (Dunton, 2017). Our findings showed that prompt response rates did not differ according to demographic factors, including age, body mass index, and gender. Shift workers in our study were younger than non-shift workers.

One would expect that the age differences between shift workers and non-shift workers to influence the prompt compliance because it has been shown that younger participants tend to have lower responses to EMA. Rintala et al. concluded that compliance rates are often reduced in younger population due to their busy daily routine or less interest (Rintala et al., 2019). However, this was not the case in our study as age did not influence compliance rate and this is consistent with the results of Weatherson et al. (Weatherson et al., 2019).

Collectively, these findings show that mobile EMA is feasible in assessing workers' physical activity and sedentary behaviour. This study provides insight into the tailoring of EMA surveys to accommodate shift workers’ work schedules. Therefore, the same tailoring of personalised content to promote healthy behaviours at the right time in the right context can be used in intervention studies for shift workers.

Strengths

Participants provided extensive longitudinal data for 7-10 days about activities during work and non-workdays. Participants in our study received a total of 4482 prompts throughout the study, many data points per person. In addition, the EMA protocol allowed for evaluation of within-individual variation of work, non-work and shift schedule patterns. These interactions are difficult to obtain when using traditional self-report measures. This study used shift and non-shift work populations, therefore expanding the evidence of use of EMA in both working groups.

Limitations

The SEMA[3] application used in this study was still in the development research stage, thus, we were not able to find out why some prompts were not delivered to participants. Further we did not assess participants' mood or stressful events and experiences with ~~using~~ the SEMA application. The overall compliance rates could be related to the prompts occurring at inopportune times. Further, given that the sample included workers in Australia and did not cover all shift work industries, the results cannot be generalised to other countries and all shift workers. It has been reported that mobile EMA may not be appropriate for all industries, however, it was not a validation study and no tailoring by work schedule took place (Rebar et al., 2018). EMA with mobile phones has been used in a study involving mining shift workers (Rebar et al., 2018).

Conclusion

EMA could be considered as an alternative tool to quantify physical activity and sedentary behaviour. The EMA completion rate was acceptable and differed by work and non-work schedules. Shift workers were more likely to answer prompts during non-workdays, while non-shift workers were likely to answer prompts during workdays. Future EMA studies with shift workers should consider tailoring and sending only four prompts per day as compliance reduced with the fifth prompt. The results of our study support tailoring EMA surveys according to the work and non-workdays. This study adds new knowledge about the feasibility of ecological momentary assessment in shift workers.

4.3 Implications and contribution to the advancement of the research area

Investigating the feasibility of EMA in shift workers provided some insights about the possibility of using EMA with a mobile application adapted for variability of shift work schedules. For example, we adapted the EMA prompts according to work schedules for shift workers. While the aim was to investigate the feasibility, the ability of EMA to assess behaviours in real time can provide information on work factors and context of behaviours with lower recall bias. As such, study 2a adds to available studies on the feasibility of mobile EMA application use in assessing physical activity and sedentary behaviour. EMA can be used to examine the activity, to help better understand the context of behaviours and contributing work factors in shift workers.

In addition, investigating the feasibility, there is need to determine if EMA is valid in assessing shift workers' physical activity and sedentary behaviour. Testing validity of EMA will establish if EMA is a reliable measure of physical activity and sedentary behaviour in shift workers (Bannigan & Watson, 2009).

REFERENCES

Bammann, K., Thomson, N. K., Albrecht, B. M., Buchan, D. S., & Easton, C. (2021). Generation and validation of ActiGraph GT3X+ accelerometer cut-points for assessing physical activity intensity in older adults. The OUTDOOR ACTIVE validation study. *PloS One*, *16*(6), e0252615. https://doi.org/10.1371/journal.pone.0252615

Bannigan, K., & Watson, R. (2009). Reliability and validity in a nutshell. *Journal of clinical nursing*, *18*(23), 3237–3243. https://doi.org/10.1111/j.1365-2702.2009.02939.x

Bruening, M., van Woerden, I., Todd, M., Brennhofer, S., Laska, M. N., & Dunton, G. (2016). A Mobile Ecological Momentary Assessment Tool (devilSPARC) for Nutrition and Physical Activity Behaviors in College Students: A Validation Study. *Journal of Medical Internet Research*, *18*(7), e209. https://doi.org/10.2196/jmir.5969

Chappel, S. E., Aisbett, B., Considine, J., & Ridgers, N. D. (2021). Bidirectional associations between emergency nurses' occupational and leisure physical activity: An observational study. *Journal of Sports Sciences*, *39*(6), 705-713. https://doi.org/10.1080/02640414.2020.1841921

Cheng, P., & Drake, C. (2019). Shift Work Disorder. *Neurologic Clinics*, *37*(3), 563–577. https://doi.org/10.1016/j.ncl.2019.03.003

Chin, D. L., Nam, S., & Lee, S. J. (2016). Occupational factors associated with obesity and leisure-time physical activity among nurses: A cross sectional study. *International Journal of Nursing Studies*, *57*, 60–69. https://doi.org/10.1016/j.ijnurstu.2016.01.009

Cleland, C., Ferguson, S., Ellis, G., & Hunter, R. F. (2018). Validity of the International Physical Activity Questionnaire (IPAQ) for assessing moderate-to-vigorous physical activity and sedentary behaviour of older adults in the United Kingdom. *BMC Medical Research Methodology*, *18*(1), 176. https://doi.org/10.1186/s12874-018-0642-3

Colley, R. C., Butler, G., Garriguet, D., Prince, S. A., & Roberts, K. C. (2018). Comparison of self-reported and accelerometer-measured physical activity in Canadian adults. *Health Reports*, *29*(12), 3–15.

Crowther, M. E., Ferguson, S. A., & Reynolds, A. C. (2022). Longitudinal studies of sleep, physical activity and nutritional intake in shift workers: A scoping review. *Sleep Medicine Reviews*, *63*, 101612. https://doi.org/10.1016/j.smrv.2022.101612

de Vries, L. P., Baselmans, B. M. L., & Bartels, M. (2021). Smartphone-based ecological momentary assessment of well-being: a systematic review and recommendations for future studies. *Journal of Happiness Studies*, *22*(5), 2361–2408. https://doi.org/10.1007/s10902-020-00324-7

Dempsey, P. C., Biddle, S. J. H., Buman, M. P., Chastin, S., Ekelund, U., Friedenreich, C. M., Katzmarzyk, P. T., Leitzmann, M. F., Stamatakis, E., van der Ploeg, H. P., Willumsen, J., & Bull, F. (2020). New global guidelines on sedentary behaviour and health for adults: broadening the behavioural targets. *The international Journal of Behavioral Nutrition and Physical Activity*, *17*(1), 151. https://doi.org/10.1186/s12966-020-01044-0

Dunton G. F. (2017). Ecological momentary assessment in physical activity research. *Exercise and Sport Sciences Reviews*, *45*(1), 48–54. https://doi.org/10.1249/JES.0000000000000092

Dunton, G. F., Liao, Y., Kawabata, K., & Intille, S. (2012). Momentary assessment of adults' physical activity and sedentary behavior: feasibility and validity. *Frontiers in Psychology*, *3*, 260. https://doi.org/10.3389/fpsyg.2012.00260

Elavsky, S., Klocek, A., Knapova, L., Smahelova, M., Smahel, D., Cimler, R., & Kuhnova, J. (2021). Feasibility of real-time behavior monitoring via mobile technology in czech adults aged 50 years and above: 12-week study with ecological momentary assessment. *JMIR Aging*, *4*(4), e15220. https://doi.org/10.2196/15220

Engelen, L., Chau, J. Y., Burks-Young, S., & Bauman, A. (2016). Application of ecological momentary assessment in workplace health evaluation. *Health Promotion Journal of Australia*, *27*(3), 259–263. https://doi.org/10.1071/HE16043

Fenwick, M. J., Oftedal, S., Kolbe-Alexander, T. L., & Duncan, M. J. (2022). Comparison of adult shift and non-shift workers’ physical activity and sleep behaviours: cross-sectional analysis from the

Household Income and Labour Dynamics of Australia (HILDA) cohort. *Journal of Public Health*, 1-9. https://doi.org/10.1007/s10389-022-01738-8

Guthold, R., Stevens, G. A., Riley, L. M., & Bull, F. C. (2018). Worldwide trends in insufficient physical activity from 2001 to 2016: a pooled analysis of 358 population-based surveys with 1·9 million participants. *The Lancet. Global health*, *6*(10), e1077–e1086. https://doi.org/10.1016/S2214-109X(18)30357-7

Holtermann, A., Coenen, P., Krause, N. (2020). The Paradoxical Health effects of occupational versus leisure-time physical activity. In: Theorell, T. (eds) Handbook of socioeconomic determinants of occupational health. *Handbook Series in Occupational Health Sciences.* Springer, Cham. https://doi.org/10.1007/978-3-030-31438-5_6

Knell, G., Gabriel, K. P., Businelle, M. S., Shuval, K., Wetter, D. W., & Kendzor, D. E. (2017). Ecological Momentary Assessment of physical activity: validation study. *Journal of Medical Internet Research*, *19*(7), e253. https://doi.org/10.2196/jmir.7602

Kolbe-Alexander, T. L., Gomersall, S., Clark, B., Torquati, L., Pavey, T., & Brown, W. J. (2019). A hard day's night: time use in shift workers. *BMC Public Health*, *19*(Suppl 2), 452. https://doi.org/10.1186/s12889-019-6766-5

Koval, P., Hilton, J., Koval P, Hinton J, Dozo N, Gleeson J, Alvarez M, Harrison A, Vu D, Susanto R, Jayaputera G, Sinnott R.

(2019). Smartphone ecological momentary assessment, Version 3. *Computer software. Retrieved from http://www sema3 com.*

Kwiecień-Jaguś, K., Mędrzycka-Dąbrowska, W., Czyż-Szypenbeil, K., Lewandowska, K., & Ozga, D. (2019). The use of a pedometer to measure the physical activity during 12-hour shift of ICU and nurse anaesthetists in Poland. *Intensive & Critical Care Nursing*, *55*, 102750. https://doi.org/10.1016/j.iccn.2019.07.009

Lavie, C. J., Ozemek, C., Carbone, S., Katzmarzyk, P. T., & Blair, S. N. (2019). Sedentary Behavior, Exercise, and Cardiovascular Health. *Circulation Research*, *124*(5), 799–815. https://doi.org/10.1161/CIRCRESAHA.118.312669

Lee, A., Myung, S. K., Cho, J. J., Jung, Y. J., Yoon, J. L., & Kim, M. Y. (2017). Night shift work and risk of depression: meta-analysis of observational studies. *Journal of Korean Medical Science*, *32*(7), 1091–1096. https://doi.org/10.3346/jkms.2017.32.7.1091

Loef, B., van der Beek, A. J., Holtermann, A., Hulsegge, G., van Baarle, D., & Proper, K. I. (2018). Objectively measured physical activity of hospital shift workers. *Scandinavian Journal of Work, Environment & Health*, *44*(3), 265–273. https://doi.org/10.5271/sjweh.3709

Maher, J. P., Rebar, A. L., & Dunton, G. F. (2018). Ecological Momentary Assessment Is a Feasible and Valid Methodological Tool to Measure Older Adults' Physical Activity and Sedentary Behavior. *Frontiers in Psychology*, *9*, 1485. https://doi.org/10.3389/fpsyg.2018.01485

Maher, J. P., Sappenfield, K., Scheer, H., Zecca, C., Hevel, D. J., & Kennedy-Malone, L. (2021). Feasibility and validity of assessing low-income, African American older adults’ physical activity and sedentary behavior through ecological momentary assessment. *Journal for the Measurement of Physical Behaviour*, *4*(4), 343-352.

Marszalek, J., Morgulec-Adamowicz, N., Rutkowska, I., & Kosmol, A. (2014). Using ecological momentary assessment to evaluate current physical activity. *BioMed Research International*, *2014*, 915172. https://doi.org/10.1155/2014/915172

Mead, M. P., & Irish, L. A. (2022). The theory of planned behaviour and sleep opportunity: An ecological momentary assessment. *Journal of Sleep Research*, *31*(1), e13420. https://doi.org/10.1111/jsr.13420

Mielke, G. I., Burton, N. W., & Brown, W. J. (2022). Accelerometer-measured physical activity in mid-age Australian adults. *BMC Public Health*, *22*(1), 1952. https://doi.org/10.1186/s12889-022-14333-z

Migueles, J. H., Cadenas-Sanchez, C., Ekelund, U., Delisle Nyström, C., Mora-Gonzalez, J., Löf, M., Labayen, I., Ruiz, J. R., & Ortega, F. B. (2017). Accelerometer Data Collection and Processing Criteria to Assess Physical Activity and Other Outcomes: A Systematic Review and Practical Considerations. *Sports Medicine (Auckland, N.Z.)*, *47*(9), 1821–1845. https://doi.org/10.1007/s40279-017-0716-0

Monnaatsie, M., Biddle, S. J. H., Khan, S., & Kolbe-Alexander, T. (2021). Physical activity and sedentary behaviour in shift and non-shift workers: A systematic review and meta-analysis. *Preventive Medicine Reports, 24*, 101597. https://doi.org/10.1016/j.pmedr.2021.101597

Müller, A. M., Maher, C. A., Vandelanotte, C., Hingle, M., Middelweerd, A., Lopez, M. L., DeSmet, A., Short, C. E., Nathan, N., Hutchesson, M. J., Poppe, L., Woods, C. B., Williams, S. L., & Wark, P. A. (2018). Physical activity, sedentary behavior, and diet-related ehealth and mhealth research: bibliometric analysis. *Journal of Medical Internet Research*, *20*(4), e122. https://doi.org/10.2196/jmir.8954

Neil-Sztramko, S. E., Gotay, C. C., Demers, P. A., & Campbell, K. L. (2016). Physical Activity, Physical Fitness, and Body Composition of Canadian Shift Workers: Data From the Canadian Health Measures Survey Cycles 1 and 2. *Journal of Occupational and Environmental Medicine*, *58*(1), 94–100. https://doi.org/10.1097/JOM.0000000000000574

O'Neill, B., McDonough, S. M., Wilson, J. J., Bradbury, I., Hayes, K., Kirk, A., Kent, L., Cosgrove, D., Bradley, J. M., & Tully, M. A. (2017). Comparing accelerometer, pedometer and a questionnaire for measuring physical activity in bronchiectasis: a validity and feasibility study?. *Respiratory Research*, *18*(1), 16. https://doi.org/10.1186/s12931-016-0497-2

Park, H., & Suh, B. (2020). Association between sleep quality and physical activity according to gender and shift work. *Journal of Sleep Research*, *29*(6), e12924. https://doi.org/10.1111/jsr.12924

Patterson, R., McNamara, E., Tainio, M., de Sá, T. H., Smith, A. D., Sharp, S. J., Edwards, P., Woodcock, J., Brage, S., & Wijndaele, K. (2018). Sedentary behaviour and risk of all-cause, cardiovascular and cancer mortality, and incident type 2 diabetes: a systematic review and dose response meta-analysis. *European Journal of Epidemiology*, *33*(9), 811–829. https://doi.org/10.1007/s10654-018-0380-1

Rebar, A. L., Alfrey, K. L., Gardner, B., & Vandelanotte, C. (2018). Health behaviours of Australian fly-in, fly-out workers and partners during on-shift and off-shift days: an ecological momentary assessment study. *BMJ Open*, *8*(12), e023631. https://doi.org/10.1136/bmjopen-2018-023631

Rintala, A., Wampers, M., Myin-Germeys, I., & Viechtbauer, W. (2019). Response compliance and predictors thereof in studies using the experience sampling method. *Psychological Assessment*, *31*(2), 226–235. https://doi.org/10.1037/pas0000662

Ross, R., Neeland, I. J., Yamashita, S., Shai, I., Seidell, J., Magni, P., Santos, R. D., Arsenault, B., Cuevas, A., Hu, F. B., Griffin, B. A., Zambon, A., Barter, P., Fruchart, J. C., Eckel, R. H., Matsuzawa, Y., & Després, J. P. (2020). Waist circumference as a vital sign in clinical practice: a consensus statement from the IAS and ICCR working group on visceral obesity. *Nature Reviews Endocrinology, 16*(3), 177–189. https://doi.org/10.1038/s41574-019-0310-7

Sooriyaarachchi, P., Jayawardena, R., Pavey, T., & King, N. A. (2022). Shift work and the risk for metabolic syndrome among healthcare workers: A systematic review and meta-analysis. *Obesity Reviews, 23*(10), e13489. https://doi.org/10.1111/obr.13489

Stevens, M. L., Crowley, P., Rasmussen, C. L., Hallman, D. M., Mortensen, O. S., Nygård, C. H., & Holtermann, A. (2020). Accelerometer-Measured Physical Activity at Work and Need for Recovery: A Compositional Analysis of Cross-sectional Data. *Annals of Work Exposures and Health*, *64*(2), 138–151. https://doi.org/10.1093/annweh/wxz095

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

Vandelanotte, C., Duncan, M. J., Short, C., Rockloff, M., Ronan, K., Happell, B., & Di Milia, L. (2013). Associations between occupational indicators and total, work-based and leisure-time sitting: a cross-sectional study. *BMC Public Health*, *13*, 1110. https://doi.org/10.1186/1471-2458-13-1110

Vlahoyiannis, A., Karali, E., Giannaki, C. D., Karioti, A., Pappas, A., Lavdas, E., Karatzaferi, C., & Sakkas, G. K. (2022). The vicious circle between physical, psychological, and physiological characteristics of shift work in nurses: a multidimensional approach. *Sleep & Breathing, 26*(1), 149–156. https://doi.org/10.1007/s11325-021-02381-5

von Haaren-Mack, B., Bussmann, J. B., & Ebner-Priemer, U. W. (2020). Physical activity monitoring. *The Wiley encyclopedia of health psychology*, 447-457. https://doi.org/10.1002/9781119057840.ch95

Weatherson, K., Yun, L., Wunderlich, K., Puterman, E., & Faulkner, G. (2019). Application of an ecological momentary assessment protocol in a workplace intervention: assessing compliance, criterion validity, and reactivity. *Journal of Physical Activity & Health*, *16*(11), 985–992. https://doi.org/10.1123/jpah.2019-0152.

Wrzus, C., & Neubauer, A. B. (2022). Ecological momentary assessment: a meta-analysis on designs, samples, and compliance across research fields. *Assessment*, *30*(3), 825–846. https://doi.org/10.1177/10731911211067538

Zhao, R., Bu, W., Chen, Y., & Chen, X. (2020). The Dose-Response Associations of Sedentary Time with Chronic Diseases and the Risk for All-Cause Mortality Affected by Different Health Status: A Systematic Review and Meta-Analysis. *The Journal of Nutrition, Health & aging*, *24*(1), 63–70. https://doi.org/10.1007/s12603-019-1298-3

CHAPTER 5: PAPER 3-ECOLOGICAL MOMENTARY ASSESSMENT OF PHYSICAL ACTIVITY AND SEDENTARY BEHAVIOUR IN SHIFT WORKERS AND NON-SHIFT WORKERS: VALIDATION STUDY

5.1 Introduction

EMA has potential to expand our understanding of contextual and work factors. EMA provides intensive, real-world data collection enable researchers to collect large amounts of information in people's behaviours in their natural environments (Smyth & Heron, 2014). EMA has been validated previously in adults, children, office workers, and older adults (Dunton, 2012, Maher 2018, Knell et al., 2017). However, there is no or little evidence on the validity of EMA in assessing physical activity and sedentary behaviour in shift and non-shift workers. Shift work presents unique problems to those who do it, because of atypical work schedules and work at night. Thus, if EMA is found to be valid, it provides the opportunity to be used for health promotion studies that will improve workers' wellbeing. Therefore, we tested criterion validity against Actigraph devices. Assessing physical activity and sedentary behaviour is based on the presumption that it is valid and practical.

5.2 Study 3: Monnaatsie, M., Mielke, I. G., Biddle, S. J. H., Kolbe-Alexander T. L. Ecological Momentary Assessment of physical activity and sedentary behaviour in shift workers and non-shift workers: Validation Study. Revisions submitted to *Journal of Sports Sciences* (Q2 Journal, Impact factor: 3.943).

Abstract

This study examined the criterion validity of ecological momentary assessment (EMA)-reported physical activity and sedentary time compared with accelerometry in shift workers and non-shift workers. Australian workers (n=102) received prompts through a mobile EMA app and wore the Actigraph accelerometer on the right hip for 7-10 days. Five EMA prompts per day were sent to participants' mobile phones assessing physical activity and sedentary time, location, and time spent on the activity. EMA prompts sent to shift workers (SW-T) were tailored according to their work schedule, while prompts to non-shift workers (NSW-S) were sent at standardised times. Criterion validity was assessed by determining the association of EMA reported activities obtained with the EMA app and the Actigraph accelerometer activity counts and number of steps. Participants were 36 ±11 years and 58% were female. On occasions where participants reported physical activity, the acceleration counts and steps were significantly higher (β=1184 CPM, CI 95%: 1034, 1334) and (β=20.9 steps, CI 95%: 18.2, 23.6) respectively, than each of the other ten EMA activities. Acceleration counts and steps were lower when sitting was reported than when no sitting was reported with EMA survey. The association between EMA reported activities and accelerometer data were similar between SW-T and NSW-S. Our study showed that EMA-reported physical activity and sedentary time was significantly associated with accelerometer-derived data and should be considered as the alternative to use than traditional self-report measures for the shift work population.

Keywords: accelerometer, ecological momentary assessment (EMA), physical activity, sedentary behaviour, shift work

Introduction

Shift work involves any work done outside 9am to 5pm during weekdays (Costa, 2003). Several systematic reviews indicate that shift work is related to increased risk of metabolic syndrome (Sooriyaarachchi et al., 2022), cardiovascular diseases, (Torquati et al., 2018) cancers, (Wei et al., 2022) type 2 diabetes (Ismail et al., 2021) and other adverse health outcomes (Su et al., 2021). Lifestyle behaviours are considered in part, to be related to the increased risk of diseases and adverse health outcomes in shift workers (Nea et al., 2015).

Evidence on the impact of shift work on lifestyle behaviours including physical activity and sedentary behaviour present mixed results. When compared to non-shift workers, studies have reported negative (Mansouri et al., 2022), positive (Peplonska et al., 2014) and no influence (Hulsegge et al., 2017; Lauren et al., 2020) on the level of physical activity. Similarly, some studies show that sedentary behaviour did not differ between shift and non-shift workers, (Alves et al., 2017) while others reported its less in shift workers than non-shift workers (Loef et al., 2018; Loprinzi, 2015), and more in shift workers in some studies (Mansouri et al., 2022). Measurement tools used to assess physical activity and sedentary time may contribute to these equivocal results (Loef et al., 2018).

Monitoring of physical activity and sedentary behaviour by self-report measures remains a practical method for research studies especially national surveillance systems (Prince et al., 2020). However, retrospective self-report measures present recall and social desirability biases (Althubaiti, 2016; Cleland et al., 2018). Accelerometers are designed to record acceleration and posture and provide a good estimate of duration, intensity, and steps, however, they also have limitations (Skender et al., 2016). A key challenge remains regarding contexts of behaviour and incomplete data limits (Pulsford et al., 2023). Recently, more studies are using real-time reporting of behaviours often done with the use of smartphones or a web-based application commonly known as EMA (Knell et al., 2017).

In comparison to traditional self-report measures (e.g., survey recall), EMA eliminates recall bias and provides more contexts of movement behaviours that cannot be captured by devices (Knell et al., 2017). Recently, EMA methods employed smartphone applications to signal people to complete surveys to self-report their daily activities (Burke & Naylor, 2022). Smartphone EMA surveys provide the flexibility in designing data collection and can be customised to individual participants (de Vries et al., 2021). Additionally, using smartphones in EMA studies provides an opportunity to match timestamped EMA data with device-based measures of physical activity and sedentary behaviour (Kracht et al., 2021). Previous research has demonstrated that EMA is a valid tool for monitoring physical activity and sedentary behaviour among adult office workers, (Weatherson et al., 2019) and young adults (Pannicke et al., 2020).

Despite the practical advantages of using EMA, it has not been validated for estimating physical activity and sedentary behaviour in the shift work population. Additionally, while EMA has been used and validated in adults, no studies have been found comparing physical activity and sedentary behaviour in shift and non-shift workers. Measurement tools that consider non-standard work patterns of shift workers are required to inform the impact of different types of work schedules on their physical activity and sedentary behaviours. Therefore, the primary aim of this study was to determine the validity of mobile EMA to physical activity and sedentary behaviour. Secondarily, we compared the validity of EMA between shift and non-shift workers.

Methods

Study design

This is EMA longitudinal design of full-time workers living in and around Brisbane, Australia assessing EMA multiple times. Participants were recruited through word of mouth, flyers, and social media posts. Most of the shift workers were employed in health care (88%) comprising mainly paramedics and nurses doing rotating shifts, while most non-shift workers were office workers. Emails that included the information sheet were sent inviting participants. Once participants agreed to join the study, they were invited to meet with the researcher at the university. This study was approved by the University of Southern Queensland human research ethics committee.

Data collection

The participants signed the consent form and were sent the link to download the EMA app and given instructions on how to use the EMA app and filled the questionnaire. During the first meeting, participants' height and weight were also measured. The ActiGraph accelerometer and instructions on how to wear the device were then given. Shift workers were enrolled in the study for 7-10 days to ensure data collected included their full shift rotation incorporated day, afternoon, evening, and night shifts, as well as non-workdays. The non-shift workers participated for 7 days, allowing for measurement of activity during week and weekend days (Warren et al., 2010). A second meeting with participants was arranged to collect the accelerometers to download data.

Measures

Questionnaire

Demographic information including age, gender, and marital status was obtained with a questionnaire. Marital status was coded as living with partner (married or living together) or not living with partner (single, widowed, separated or divorced). Shift work status was assessed by asking participants to indicate their work shifts.

Anthropometric measures

Participants' body weight was measured using a Seca digital scale and height with a Seca 213 portable stadiometer (Seca GmbH & Co. Germany) (WHO, 1995). Height and weight were used to calculate Body Mass Index (BMI) using the standard formula, combining weight and height (meters^2). Waist circumference (to the nearest 0.5 cm) was measured by placing the measuring tape at the level of the last rib (Ross et al., 2020).

Ecological momentary assessment

The *SEMA* [3] app (Koval et al., 2019) available for iOS and Android devices delivered EMA prompts five times a day, at 3-hour intervals. The study period for shift workers was 7-10 days and 7 days non-shift workers, inclusive of work and non-workdays. Each participant received approximately 35-38 prompts depending on their individual length of study. Upon receiving the EMA prompt, participants completed the short survey on their phones for 1-2 min which disappeared after 30 minutes if unanswered.

The first question asked participants to report their current activity by choosing from 11 options provided; *"watching television, using mobile phone/computer, eating/drinking, exercise or physical activity, work duties, socializing, driving/travelling, sleeping and household/garden chores, caring for children and other."* When they chose the exercise or physical activity option the survey further requested them to report the type of physical activity. If participant's response option of the current activity included any activity that can be done sitting like using mobile/computer, caring for children, socializing or other, they were then asked to report if they were sitting or not. The survey also included questions about the location and time spent to do the activity. Survey responses were downloaded from the SEMA website in CSV files. The EMA prompting scheduled differed between the shift workers and non-shift workers, and were delivered as follows:

1. SW-T group (n=51): The prompts were set according to each participant's work and awake patterns every 3 hours, five times a day
2. NSW-S (n=51): The prompts were sent to participants between 10 am and 10pm every 3 hours, five times a day.

Device-based measure of physical activity and sedentary behaviour

Actigraph GT3X-BT (Actigraph Corp Pensacola, FL) devices were used to measure physical activity and sedentary time. Participants were requested to wear the accelerometer on the right hip attached with an adjustable belt for a consecutive 7-10 days during waking hours (Morris et al., 2018). The Actigraph accelerometer recorded data at 30 Hz and data were downloaded in 1-minute epochs (John & Freedson, 2012). The accelerometer vector magnitude (counts per minute) and steps per minute recorded in the 15 minutes before receiving the EMA prompts were time stamped with the corresponding EMA data. EMA responses were excluded from if the accelerometer activity values were zero (Maher et al., 2021).

Statistical analysis

Descriptive statistics with mean and standard deviations for continuous variables and frequencies and percentages for categorical variables were reported. Actigraph data were then time matched with corresponding EMA data. Box plots were constructed to show the variability and correspondence of EMA reported activities with the matching accelerometer data. To determine the difference between the groups, Kruskal-Wallis test was used for the accelerometer and EMA data. We used linear regression analyses to determine association of EMA reported physical activity and sedentary time. The dummy coded EMA reported activities (ten-level categorical variable) and sitting (yes/no) were used as the independent variables, and concurrent counts and steps per minute (measured by Actigraph) as the dependent variables. For the model testing differences in EMA reported activities, contrasts were examined between the sleeping as the lowest intensity activity with the other EMA-reported activities (mobile/computer, watching TV, work duties, caring for children, socialising, chores, physical activity, others, eating/drinking and travelling and drinking). We regressed EMA reported siting versus no sitting with accelerometer derived data. Analyses were performed using IBM SPSS Statistics version 27.0.

Results

Participant characteristics

Most participants were female (58%), living with partner (60%) and overweight (27.9 kg/m^2±5.7). The average age of participants was 36 years (± 10.6). There were no demographic differences between shift and non-shift workers. Most of the shift workers employed in health care (88%) comprising of mainly paramedics and nurses doing rotating shifts while most of non-shift workers were office workers.

Accelerometer-based summaries

The average wear time was 6 days (± 1.7) in all workers and similar in shift and non-shift workers. Light-intensity physical activity was different ($p=0.04$), whereas time spent in sedentary behaviour and moderate-to-vigorous intensity physical activity was similar in shift and non-shift workers (Supplementary Table C.1.).

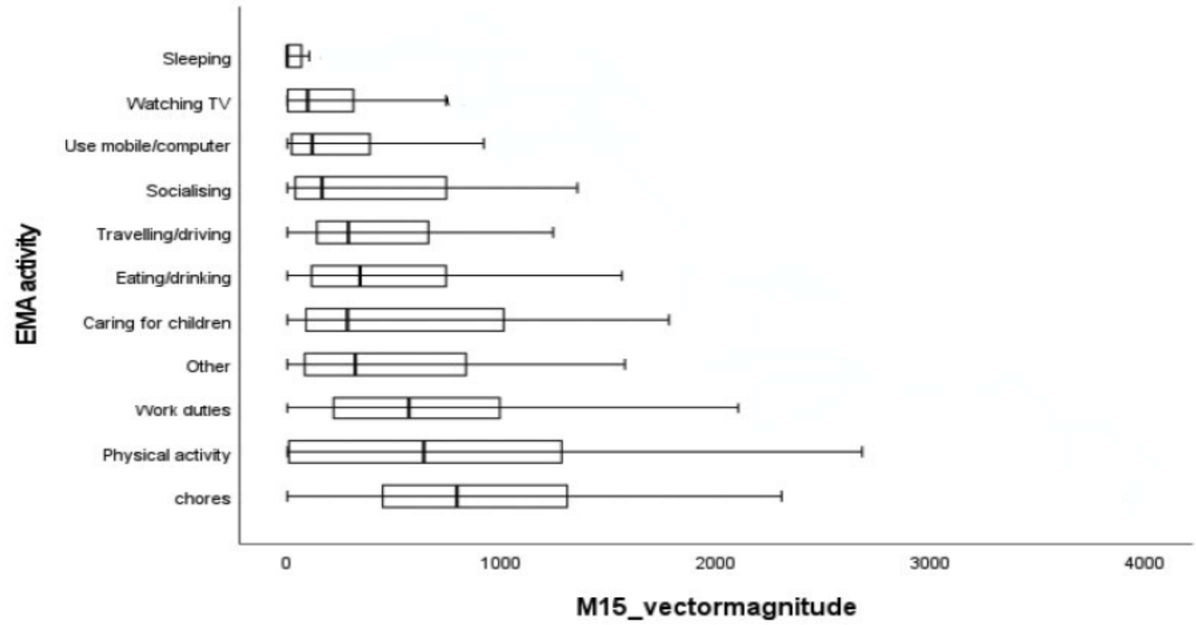
Validity of EMA

Out of the 2917 completed EMA prompts, 2318 EMA prompts were time matched with accelerometer data. As shown in Figure 5.1 and 5.2, accelerometer activity counts and steps were highest in the two groups when physical activity was reported in the EMA app. In addition, the ActiGraph activity counts were lower when sitting was reported. The median acceleration activity counts for EMA-reported physical activity in the SW-T group and NSW-S were 636 (25^{th}-75^{th}: 80-1279) and 1004

(25th-75th: 447-2365) respectively. The steps were also higher in EMA reported physical activity than all other activities in the two groups with the median of 9.4 (25th-75th: 0.0-19.6) in SW-T and 16.3 (25th-75th: 4.1-25.1) in NSW-S.

EMA reported sleep and using mobile/computer shows the least activity counts in both the groups (see Figure 5.1 and 5.2). Another activity that showed low acceleration counts than other EMA reported activities was watching television. The median acceleration counts and steps were lowest when participants reported that they were sitting (Figure 5.3 and 5.4). In the SW-T, the median acceleration counts were 202 (25th-75th: 10.8-480) and 97 (25th-75th: 6.4-357) in the NSW-S group when sitting was reported. Similarly, the steps were lower with EMA reported sitting than not sitting.

a) SW-T



b) NSW-S

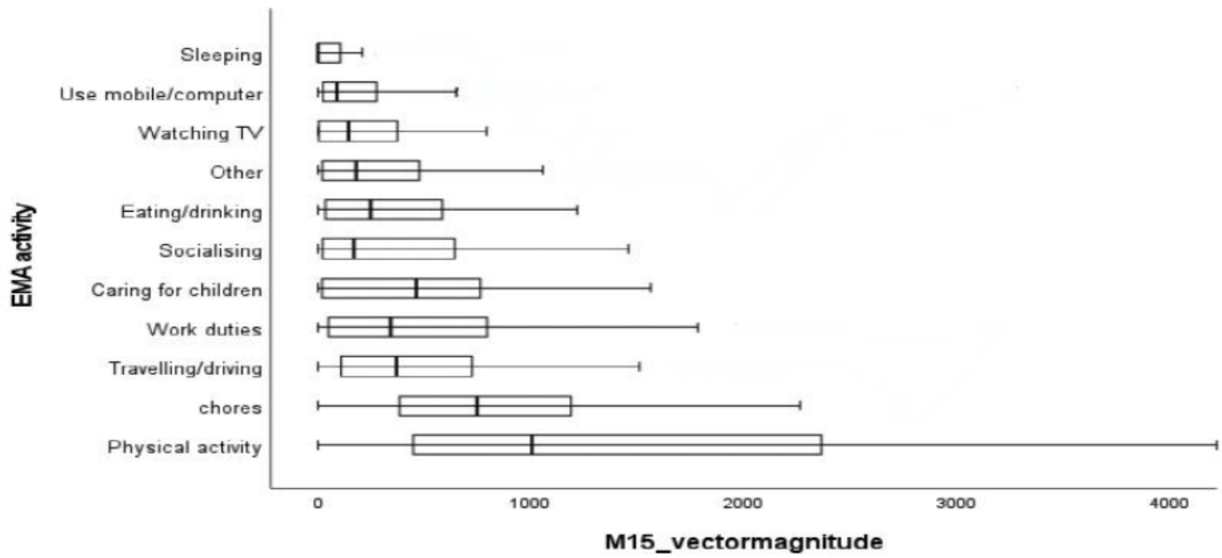


Figure 5.1 Actigraph derived vector magnitude (acceleration counts per minute) with matching EMA reported activities.

Note: SW-T; shift workers with tailored prompts, NSW-S; normal day workers who received standardized prompts M15_vector magnitude; activity counts recorded 15 minutes before EMA prompt

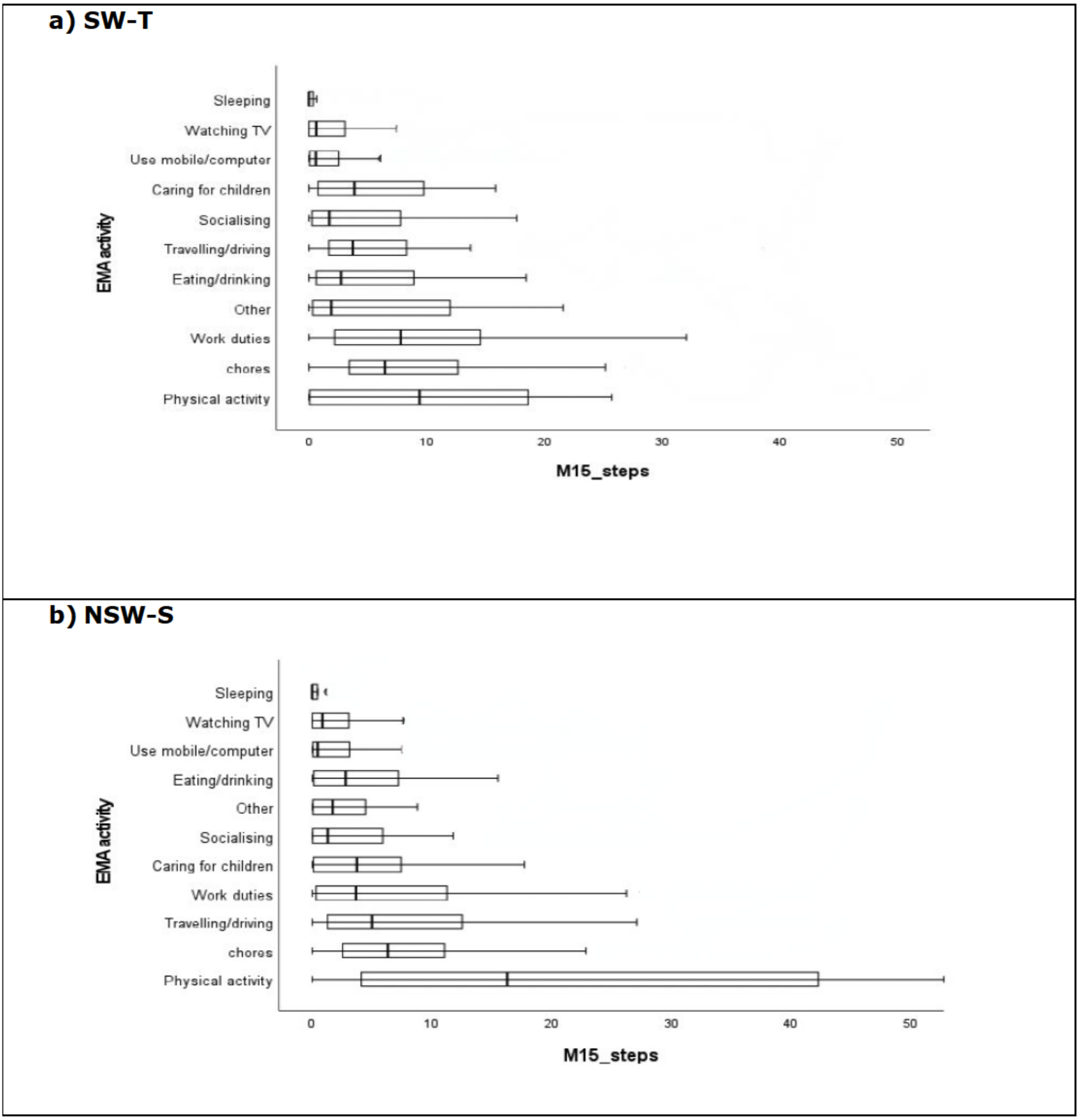
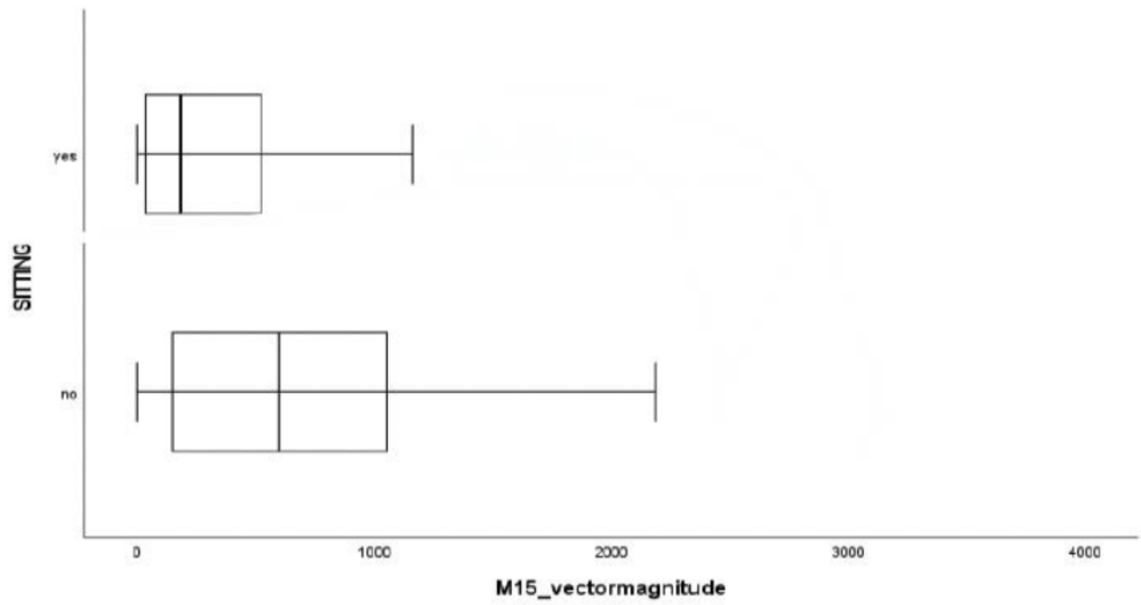


Figure 5.2 Actigraph derived steps with matching EMA reported activities.

Note: SW-T; shift workers with tailored prompts, NSW-S; normal day workers who received standardized prompts M15_steps; steps recorded 15 minutes before EMA prompt

a) SW-T



b) NSW-S

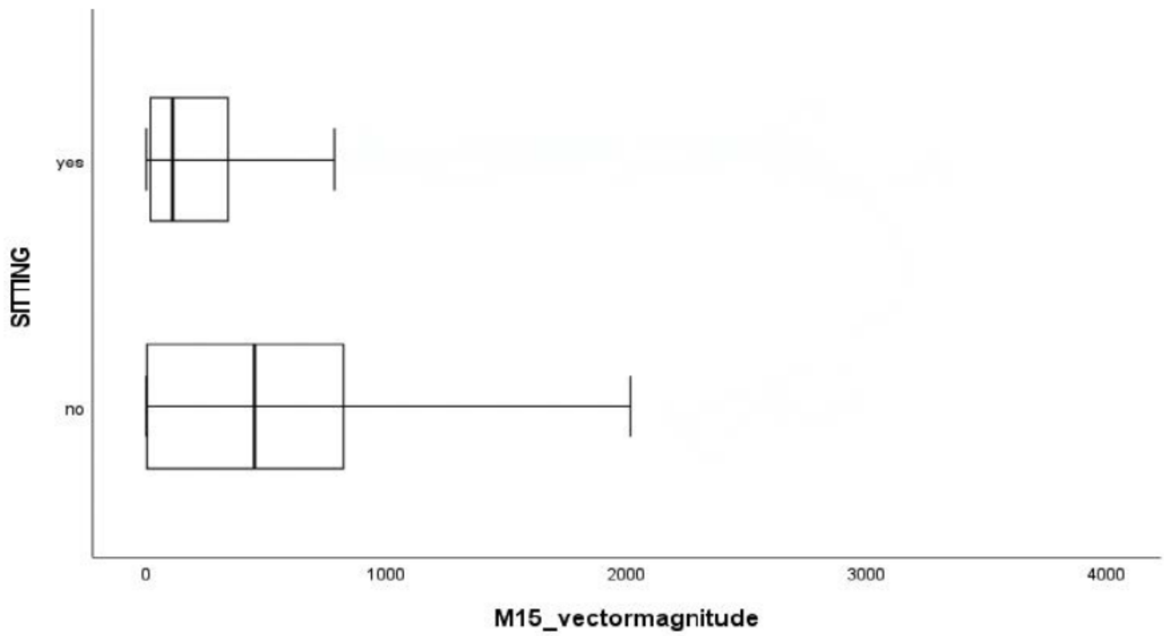


Figure 5.3 Actigraph derived vector magnitude (acceleration counts per minute) with matching EMA sitting.

Note: SW-T; shift workers with tailored prompts, NSW-S; normal day workers who received standardized prompts M15_vector magnitude; activity counts recorded 15

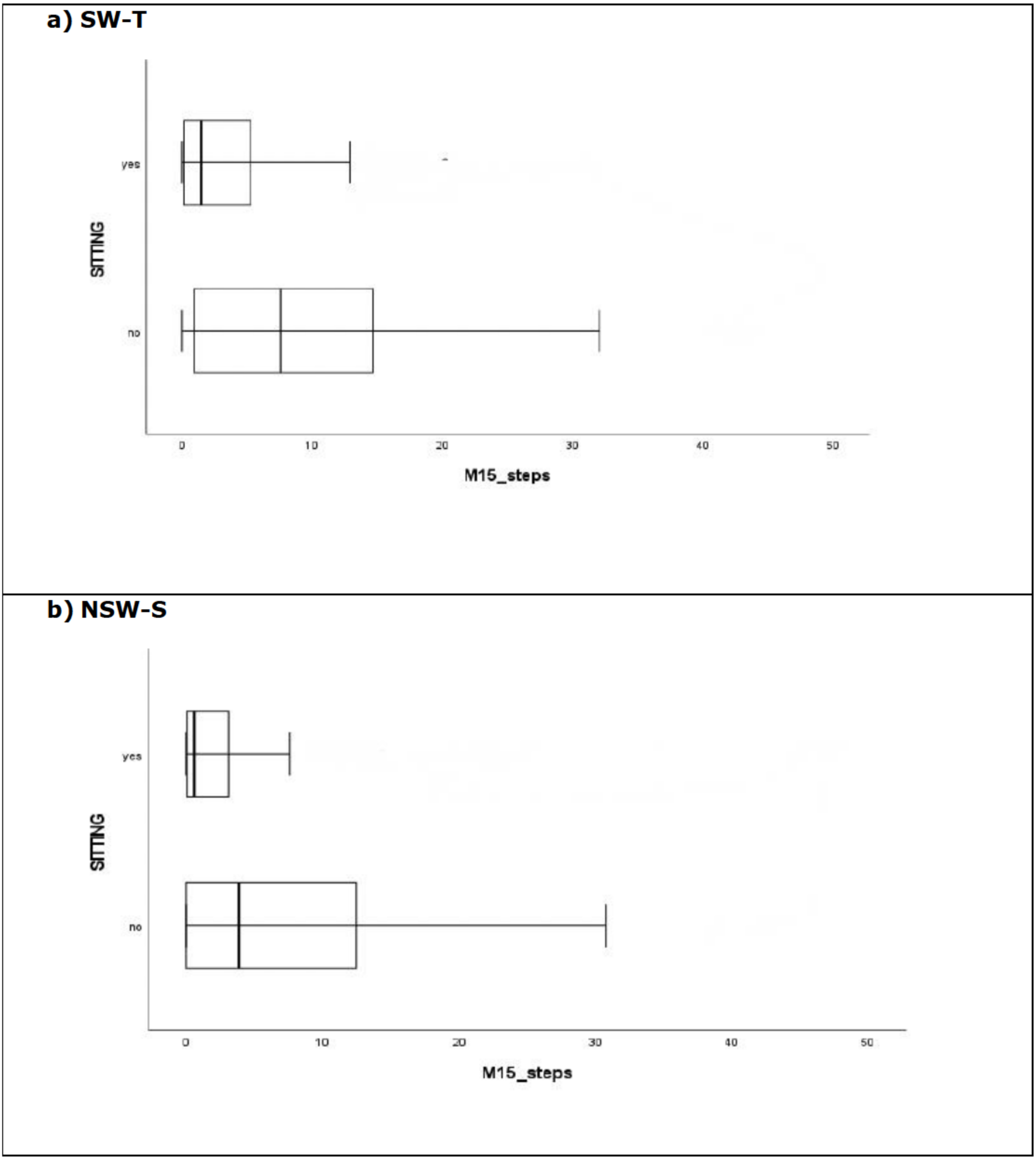


Figure 5.4 Actigraph derived steps with matching EMA reported sitting.

Note: SW-T; shift workers with tailored prompts, NSW-S; normal day workers who received standardized prompts M15_steps; steps recorded 15 minutes before EMA prompt

The Actigraph derived acceleration counts differed between all the EMA reported activities and the reference activity (sleep) except for watching TV and using mobile/computer with the shift work (SW-T) and non-shift workers (NSW-S). On occasions where participants reported physical activity, the corresponding acceleration was highest in NSW-S (*B*=1405 CPM, 95%: 1179.7, 1630.5) and (*B*=775.7 CPM, 95%: 546.7, 1004.6) in SW-T (Table 5.1).

Comparisons of the corresponding Actigraph derived steps with EMA reported activities and EMA reported sleep (reference activity) showed significant differences with the eight EMA reported activities (socialising, eating/drinking, travelling, other, caring for children, work duties, chores, and physical activity) with both the SW-T group and NSW-S.

The steps were significantly higher than sleep with EMA reported physical activity, chores work duties and travelling/driving in the NSW-S, and with seven EMA reported activities including physical activity in the SW-T (Table 5.1). Accelerometer derived accelerations and steps were significantly higher when participants reported no sitting with EMA than sitting (Table 5.1). There were no differences in association between EMA acceleration counts and steps between the SW-T and NSW-S (Supplementary table C.2).

Table 5.1. Description of acceleration activity counts (CPM) and steps in the 15 minutes before prompts corresponding with EMA reported activities according to all workers and groups

	Activity counts (CPM)						Steps					
EMA reported activity	All workers (n=102)		SW-T (n=51)		NSW-S (n=51)		All workers (n=102)		SW-T (n=51)		NSW-S (n=51)	
	Mean difference	95% CI	Mean difference	95% CI	Mean difference	95% CI	Mean difference	95% CI	Mean difference	95% CI	Mean difference	95% CI
Sleeping	93.9	ref	85.6	ref	ref	ref	ref	ref	0.6	ref	ref	ref
Phone/computer	130.5	6.2, 254.8	126.4	-48.7, 301.5	144.3	-56.6, 345.2	1.8	-0.4, 4.1	1.4	-1.7, 4.5	1.6	-2.0, 5.2
Watching TV	136.0	7.7, 264.4	172	-4.7, 349.1	110.7	-82.1, 303.5	1.4	-0.9, 3.8	2.3	-0.8, 5.5	1.7	-1.8, 5.2
Socializing	313.7*	159.6, 467.8	284.9*	72.9, 496.8	289.5*	57.7, 521.3	4.9	2.1, 7.7	4.4	-0.7, 9.4	4.4	-0.7, 9.6
Eating/drinking	332.1*	196.4, 467.8	396.4*	212.7, 580.0	278.9*	68.0, 489.7	4.3*	1.9, 6.8	5.2*	1.4, 8.9	4.3	0.05, 8.4
Travelling	361.7*	219.3, 504.1	300.1*	108.9, 491.4	415.0*	188.1, 641.9	6.3*	3.7, 8.9	5.3*	2.1, 8.6	3.7	-0.2, 7.5
Others	370.8*	222.1, 519.6	442.9*	249.2, 636.7	247.4*	1.7, 493	5.6*	2.9, 8.3	6.9*	3.5, 10.4	3.9	-0.5, 8.4
Caring for children	395.8*	197.9, 593.7	428.9*	143.9, 713.9	360.9*	76.5, 646.3	4.4*	0.9, 8.0	5.2*	1.8, 8.6	7.0*	2.9, 11.1
Work duties	513.9*	394.2, 633.7	582.5*	424.1, 740.8	398.7*	205.8, 591.5	7.8*	5.7, 10.0	8.9*	6.1, 11.7	6.1*	2.6, 9.6
Chores	775.9*	637.9, 913.8	823.9*	629, 1018.4	712.0*	501.8, 922.2	8.2*	5.7, 10.7	9.7*	6.3, 13.2	7.1*	3.3, 10.9
Physical activity	1184.4*	1034.7, 1334	775.7*	546.7, 1004.6	1405.1*	1179.7, 1630.5	20.9*	18.2, 23.6	12.7*	8.6, 16.8	25.8*	21.7, 29.9
Sitting	-353.9	ref	-332.9	ref	-303.7	ref	-5.7	ref	-5.5	ref	-5.0	ref
No Sitting	650.6*	579.2, 722.0	658.5*	578.6, 738.5	563.3*	418, 707	9.3*	8.8, 10.5	9.3*	7.9,10.7	8.6*	5.9, 11.2

Legend. SW-T; shift workers with tailored prompts, NSW-S; normal day workers who received standardized prompts, CPM; count per minute. 95% CI: Confidence Interval. *Note.* (Reference=EMA reported sleep and sitting) *p<0.05

Discussion

The study aimed to evaluate mobile EMA application for assessing physical activity and sedentary time in shift and non-shift workers. The main finding of our study was that EMA reported physical activity and sitting were strongly associated with accelerometer-derived data, thus supporting criterion validity. Compared to other EMA reported activities, high acceleration counts, and steps were higher with EMA reported physical activity. Similarly, acceleration counts and steps were lower when participants reported that they were sitting. There were differences in the association of EMA and Actigraph device data between shift and non-shift workers. Other important findings were that EMA reported chores also corresponded with more acceleration counts and steps, while sleep, watching television, and using a mobile phone or computer corresponded with the lowest steps and acceleration counts.

Collectively, these findings indicate that participants accurately reported their current activity on EMA surveys. Similar to previous EMA studies investigating the validity of EMA against Actigraph assessing physical activity and sedentary time was sufficiently associated with accelerometer data (Maher et al., 2018; Maher et al., 2021; Ponnada et al., 2021). However, Ponnada and colleagues used a smartwatch to send 72 prompts each day for a week (Ponnada et al., 2021). Like our study, five prompts per day were sent to participants (Weatherson et al., 2019). Whereas other studies used six prompts per day for 10 days (Maher et al., 2018) and eight prompts in a 4-day EMA protocol (Dunton et al., 2012). While all these studies showed good validity, the EMA protocols differed. Therefore, it is important to standardize EMA reporting in future studies for comparability and measurement in EMA studies.

Similar to our study, the Actigraph accelerometer was used for device based physical activity (Bruening et al., 2016). Actigraph accelerometer is one of the most commonly used activity monitors that assessed physical activity and sedentary time across various populations (Degroote et al., 2018; Ngueleu et al., 2022). The Actigraph accelerometer has been found to be valid (Chomistek et al., 2017; Kelly et al., 2013), and shows a strong association with EMA reported physical and sedentary behaviours, therefore, EMA could be used as a cheaper alternative to accelerometry. In a study where accelerometer estimates of physical activity and sedentary behaviour were compared with other self-report measures (IPAQ and BRFSS), the EMA measure showed stronger correlations and agreement to accelerometer estimates than IPAQ and BRFSS (Knell et al., 2017).

Concerning sitting, our study findings are consistent with the findings of previous studies where participants accurately reported sitting behaviours (Dunton et al., 2011; Romanzini et al., 2019). In an EMA study of office workers aged 40 years, activPAL accelerometer-derived data was shown to have good agreement with EMA reported sedentary time (Weatherson et al., 2019). Despite using a different criterion instrument (activPAL) for measuring sedentary behaviour, like our study, Weatherson and colleagues had accelerometer data time stamped in the 15 minutes before the EMA prompt. Thus, both studies showed that EMA is valid in assessing sedentary time. However, the activPAL has better agreement compared to direct observation for sedentary behaviour (Koster et al., 2016). Therefore, our results for the validity of EMA in assessing sedentary behaviour should be interpreted with caution.

In our study, we did not distinguish EMA physical activity by levels of intensity. In a study where physical activity intensity was reported, EMA survey did not correspond to the intensity of physical activity in college students (Bruening et al., 2016). Brueining and colleagues concluded that social desirability and/or perception biases may be at play with these results, but other factors like participant’s fitness level could affect perception of intensity levels (Bruening et al., 2016). Like the results of the previous EMA study, our results from ActiGraph data showed that shift workers spent more time in light physical activity than non-shift workers, but no differences were recorded in MVPA (Loef et al., 2018; Prince et al., 2019). Future EMA studies for workers should consider including EMA reported physical activity intensity of participants to specify if workers are sufficiently active.

Previous evidence suggests that EMA is a helpful tool to adapt to shift worker's schedules (de Vries et al., 2021). Our results suggest that there were no differences in EMA validity between shift and non-shift workers. Thus, showing that tailoring EMA did not influence the validity. However, the agreement with the criterion, Actigraph was strong. The similarity may emerge because both shift and non-shift workers may have accurately reported their activities on the EMA survey, thus EMA-reported activities sufficiently associated with device data in the two groups. The use of a mobile app allowed for ease of testing the feasibility and the results showed that compliance can be improved, especially if prompts are reduced to only four per day and providing reminders when prompts are unanswered.

In contrast to our study, EMA tailored to meal timing increased the correspondence of EMA and device measure for energy and nutrient measures (Martin et al., 2012). However, we did not find any other study to compare the findings with our study as most EMA studies assessing physical activity and sedentary behaviours in workers did not adapt EMA to work schedules. For example, in a study using EMA in a workplace intervention, the EMA surveys were sent across the five working days and not on weekend days (Weatherson et al., 2019).

While it was not the focus of this study, the EMA survey was able to report additional activities, including socialising, taking care of children, and travelling. Therefore, showing the ability of EMA surveys to monitor types of activities that are important to elucidate the health risks associated with various activities on work and non-workdays. This study provides evidence supporting EMA as a valid measure of physical activity and sedentary behaviour in shift workers, therefore could be used in workplace health promotion interventions.

Strengths

Our study provided intensive longitudinal datasets near or in real-time, minimizing retrospective bias. After time-matching accelerometer and EMA data substantial data points were available. Most previous studies evaluating the validity of EMA did not tailor EMA prompts to individual participants work schedules as was done in our study. In our study we adapted the timing of EMA surveys in accordance to shift workers work and shift patterns. Thus, allowing for flexibility and highly adaptable measurements using EMA in the shift work population was sufficient.

Limitations

One of the limitations of this study was that we matched accelerometer data with EMA before a prompt, thus we could not determine if responding to EMA disrupts activities. Determining the use of

EMA to influence activities could be used for intervention studies in order nudge or change movement related behaviours. Additionally, the EMA survey prompts set from 10 a.m. to 10 p.m. could have resulted missing physical activity and sedentary behaviour early morning and late night in non-shift work and shift workers who received standardized prompts.

Conclusion

The aim of the study was to assess validity of EMA for assessing physical activity and sedentary behaviour in workers. The findings of this study showed that EMA-reported physical activity and sedentary behaviour was accurately associated with accelerometer-derived data in shift and non-shift workers. Using mobile EMA opens opportunities for reaching a large number of participants at a relatively low cost. The findings of the study showed that an EMA tailoring approach was possible and can be integrated into intervention studies to provide tailored feedback and support in real-time and in a real-world setting.

5.3 Implications and contribution to the advancement of the research area

EMA provides a valid and cheaper alternative measure of physical activity and sedentary compared to other wearable devices and can be used in both surveillance and health promotion studies to provide real-time support. Physical activity and sedentary behaviour assessed with EMA in worker’s naturalistic settings and in real time could be useful to evaluate work related determinants. Consequently, EMA may be used investigate psychological drivers and work factors associations with lifestyle behaviours, which in turn can better inform public health and policymakers on strategies to promote physical activity and reduce sedentary behaviours (Markus Reichert et al., 2020). For example if we need to understand why a person engages in physical activity at a certain time of the day or in a certain context a promising approach will be use of EMA (Reichert et al., 2020).

The findings from study 2a and 2b highlight the feasibility and validity of EMA using mobile phones, therefore presenting a possible intervention tool to be considered in health promotion for shift workers. Moreover, identifying the barriers and facilitators for improving physical activity will help to lay the groundwork in understanding work factors and participants' experiences about health promotion to shift workers in a mining company.

REFERENCES

Alves, M. S., Andrade, R. Z., Silva, G. C., Mota, M. C., Resende, S. G., Teixeira, K. R., Gonçalves, B. F., & Crispim, C. A. (2017). Social Jetlag Among Night Workers is Negatively Associated with the Frequency of Moderate or Vigorous Physical Activity and with Energy Expenditure Related to Physical Activity. *Journal of Biological Rhythms*, *32*(1), 83–93. https://doi.org/10.1177/0748730416682110

Bruening, M., van Woerden, I., Todd, M., Brennhofer, S., Laska, M. N., & Dunton, G. (2016). A mobile ecological momentary assessment tool (devilsparc) for nutrition and physical activity behaviors in college students: a validation study. *Journal of Medical Internet Research*, *18*(7), e209. https://doi.org/10.2196/jmir.5969

Burke, L., & Naylor, G. (2022). Smartphone app-based noncontact ecological momentary assessment with experienced and naïve older participants: feasibility study. *JMIR Formative Research*, *6*(3), e27677. https://doi.org/10.2196/27677

Chomistek, A. K., Yuan, C., Matthews, C. E., Troiano, R. P., Bowles, H. R., Rood, J., Barnett, J. B., Willett, W. C., Rimm, E. B., & Bassett, D. R., Jr (2017). Physical activity assessment with the ActiGraph GT3X and Doubly Labeled Water. *Medicine and Science in Sports and Exercise*, *49*(9), 1935–1944. https://doi.org/10.1249/MSS.0000000000001299

Costa G. (2003). Shift work and occupational medicine: an overview. *Occupational Medicine, 53*(2), 83–88. https://doi.org/10.1093/occmed/kqg045

de Vries, L. P., Baselmans, B. M. L., & Bartels, M. (2021). Smartphone-based ecological momentary assessment of well-being: a systematic review and recommendations for future studies. *Journal of Happiness Studies*, *22*(5), 2361–2408. https://doi.org/10.1007/s10902-020-00324-7

Degroote, L., De Bourdeaudhuij, I., Verloigne, M., Poppe, L., & Crombez, G. (2018). The accuracy of smart devices for measuring physical activity in daily life: validation study. *JMIR mHealth and uHealth*, *6*(12), e10972. https://doi.org/10.2196/10972

Degroote, L., DeSmet, A., De Bourdeaudhuij, I., Van Dyck, D., & Crombez, G. (2020). Content validity and methodological considerations in ecological momentary assessment studies on physical activity and sedentary behaviour: a systematic review. *The International Journal of Behavioral Nutrition and Physical activity*, *17*(1), 35. https://doi.org/10.1186/s12966-020-00932-9

Dunton, G. F., Liao, Y., Intille, S. S., Spruijt-Metz, D., & Pentz, M. (2011). Investigating children's physical activity and sedentary behavior using ecological momentary assessment with mobile phones. *Obesity, 19*(6), 1205–1212. https://doi.org/10.1038/oby.2010.302

Dunton, G. F., Liao, Y., Kawabata, K., & Intille, S. (2012). Momentary assessment of adults' physical activity and sedentary behavior: feasibility and validity. *Frontiers in psychology*, *3*, 260. https://doi.org/10.3389/fpsyg.2012.00260

Freedson, P. S., Melanson, E., & Sirard, J. (1998). Calibration of the Computer Science and Applications, Inc. accelerometer. *Medicine and Science in Sports and Exercise*, *30*(5), 777–781. https://doi.org/10.1097/00005768-199805000-00021

Hulsegge, G., Gupta, N., Holtermann, A., Jørgensen, M. B., Proper, K. I., & van der Beek, A. J. (2017). Shift workers have similar leisure-time physical activity levels as day workers but are more sedentary at work. *Scandinavian Journal of Work, Environment & Health*, *43*(2), 127–135. https://doi.org/10.5271/sjweh.3614

Ismail, L., Materwala, H., & Al Kaabi, J. (2021). Association of risk factors with type 2 diabetes: A systematic review. *Computational and Structural Biotechnology Journal*, *19*, 1759–1785. https://doi.org/10.1016/j.csbj.2021.03.003

John, D., & Freedson, P. (2012). ActiGraph and Actical physical activity monitors: a peek under the hood. *Medicine and Science in Sports and Exercise*, *44*(1 Suppl 1), S86–S89. https://doi.org/10.1249/MSS.0b013e3182399f5e

Kelly, L. A., McMillan, D. G., Anderson, A., Fippinger, M., Fillerup, G., & Rider, J. (2013). Validity of actigraphs uniaxial and triaxial accelerometers for assessment of physical activity in adults in laboratory conditions. *BMC Medical Physics*, *13*(1), 5. https://doi.org/10.1186/1756-6649-13-5

Knell, G., Gabriel, K. P., Businelle, M. S., Shuval, K., Wetter, D. W., & Kendzor, D. E. (2017). Ecological Momentary Assessment of Physical Activity: Validation Study. *Journal of Medical Internet Research*, *19*(7), e253. https://doi.org/10.2196/jmir.7602

Koster, A., Shiroma, E. J., Caserotti, P., Matthews, C. E., Chen, K. Y., Glynn, N. W., & Harris, T. B. (2016). Comparison of sedentary estimates between activPAL and hip- and wrist-worn ActiGraph. *Medicine and Science in Sports and Exercise*, *48*(8), 1514–1522. https://doi.org/10.1249/MSS.0000000000000924

Koval, P., Hilton, J., Koval P, Hinton J, Dozo N, Gleeson J, Alvarez M, Harrison A, Vu D, Susanto R, Jayaputera G, Sinnott R. (2019). Smartphone ecological momentary assessment, Version 3. *Computer software. Retrieved from http://www sema3 com.*

Lauren, S., Chen, Y., Friel, C., Chang, B. P., & Shechter, A. (2020). Free-living sleep, food intake, and physical activity in night and morning shift workers. *Journal of the American College of Nutrition*, *39*(5), 450–456. https://doi.org/10.1080/07315724.2019.1691954

Loef, B., van der Beek, A. J., Holtermann, A., Hulsegge, G., van Baarle, D., & Proper, K. I. (2018). Objectively measured physical activity of hospital shift workers. *Scandinavian Journal of Work, Environment & Health*, *44*(3), 265–273. https://doi.org/10.5271/sjweh.3709

Loprinzi P. D. (2015). The effects of shift work on free-living physical activity and sedentary behavior. *Preventive Medicine*, *76*, 43–47. https://doi.org/10.1016/j.ypmed.2015.03.025

Maher, J. P., Rebar, A. L., & Dunton, G. F. (2018). Ecological Momentary Assessment Is a Feasible and Valid Methodological Tool to Measure Older Adults' Physical Activity and Sedentary Behavior. *Frontiers in Psychology*, *9*, 1485. https://doi.org/10.3389/fpsyg.2018.01485

Maher, J. P., Sappenfield, K., Scheer, H., Zecca, C., Hevel, D. J., & Kennedy-Malone, L. (2021). Feasibility and validity of assessing low-income, African American older adults' physical activity and sedentary behavior through ecological momentary assessment. *Journal for the Measurement of Physical Behaviour*, *4*(4), 343-352. https://doi.org/10.1123/jmpb.2021-0024

Mansouri, T., Hostler, D., Temple, J. L., & Clemency, B. M. (2022). Eating and physical activity patterns in day and night shift ems clinicians. *Prehospital Emergency Care*, *26*(5), 700–707. https://doi.org/10.1080/10903127.2021.1996662

Martin, C. K., Correa, J. B., Han, H., Allen, H. R., Rood, J. C., Champagne, C. M., Gunturk, B. K., & Bray, G. A. (2012). Validity of the Remote Food Photography Method (RFPM) for estimating energy and nutrient intake in near real-time. *Obesity*, *20*(4), 891–899. https://doi.org/10.1038/oby.2011.344

Morris, A., Lopez, R., Stevenback, E., & Ingram, K. H. (2018). Validity of adhesive worn Actigraph GT3X+ accelerrometer: 292 Board# 133 May 30 9: 30 AM-11: 00 AM. *Medicine & Science in Sports & Exercise*, *50*(5S), 58.

Nea, F. M., Kearney, J., Livingstone, M. B., Pourshahidi, L. K., & Corish, C. A. (2015). Dietary and lifestyle habits and the associated health risks in shift workers. *Nutrition Research Reviews*, *28*(2), 143–166. https://doi.org/10.1017/S095442241500013X

Ngueleu, A. M., Barthod, C., Best, K. L., Routhier, F., Otis, M., & Batcho, C. S. (2022). Criterion validity of ActiGraph monitoring devices for step counting and distance measurement in adults and older adults: a systematic review. *Journal of Neuroengineering and Rehabilitation*, *19*(1), 112. https://doi.org/10.1186/s12984-022-01085-5

Pannicke, B., Reichenberger, J., Schultchen, D., Pollatos, O., & Blechert, J. (2020). Affect improvements and measurement concordance between a subjective and an accelerometric estimate of physical activity. *European Journal of Health Psychology, 27*(2). https://doi.org/10.1027/2512-8442/a000050

Peplonska, B., Bukowska, A., & Sobala, W. (2014). Rotating night shift work and physical activity of nurses and midwives in the cross-sectional study in Łódź, Poland. *Chronobiology International*, *31*(10), 1152–1159. https://doi.org/10.3109/07420528.2014.957296

Ponnada, A., Thapa-Chhetry, B., Manjourides, J., & Intille, S. (2021). Measuring criterion validity of microinteraction ecological momentary assessment (micro-ema): exploratory pilot study with physical activity measurement. *JMIR mHealth and uHealth*, *9*(3), e23391. https://doi.org/10.2196/23391

Reichert, M., Giurgiu, M., Koch, E., Wieland, L. M., Lautenbach, S., Neubauer, A. B., von Haaren-Mack, B., Schilling, R., Timm, I., Notthoff, N., Marzi, I., Hill, H., Brüβler, S., Eckert, T., Fiedler, J., Burchartz, A., Anedda, B., Wunsch, K., Gerber, M., Jekauc, D., … Liao, Y. (2020). Ambulatory assessment for physical activity research: state of the science, best practices and future directions. *Psychology of Sport and Exercise*, *50*, 101742. https://doi.org/10.1016/j.psychsport.2020.101742

Romanzini, C. L. P., Romanzini, M., Barbosa, C. C. L., Batista, M. B., Shigaki, G. B., & Ronque, E. R. V. (2019). Characterization and Agreement Between Application of Mobile Ecological Momentary Assessment (mEMA) and Accelerometry in the Identification of Prevalence of Sedentary Behavior (SB) in Young Adults. *Frontiers in Psychology*, *10*, 720. https://doi.org/10.3389/fpsyg.2019.00720

Ross, R., Neeland, I. J., Yamashita, S., Shai, I., Seidell, J., Magni, P., Santos, R. D., Arsenault, B., Cuevas, A., Hu, F. B., Griffin, B. A., Zambon, A., Barter, P., Fruchart, J. C., Eckel, R. H., Matsuzawa, Y., & Després, J. P. (2020). Waist circumference as a vital sign in clinical practice: a Consensus Statement from the IAS and ICCR

Working Group on Visceral Obesity. *Nature reviews Endocrinology*, *16*(3), 177–189. https://doi.org/10.1038/s41574-019-0310-7

Smyth, J. M., & Heron, K. E. (2014). Ecological momentary assessment (EMA) in family research. *Emerging methods in family research*, 145-161. doi: 10.1007/978-3-319-01562-0_9

Sooriyaarachchi, P., Jayawardena, R., Pavey, T., & King, N. A. (2022). Shift work and the risk for metabolic syndrome among healthcare workers: A systematic review and meta-analysis. *Obesity Reviews*, *23*(10), e13489. https://doi.org/10.1111/obr.13489

Su, F., Huang, D., Wang, H., & Yang, Z. (2021). Associations of shift work and night work with risk of all-cause, cardiovascular and cancer mortality: a meta-analysis of cohort studies. *Sleep Medicine*, *86*, 90–98. https://doi.org/10.1016/j.sleep.2021.08.017

Torquati, L., Mielke, G. I., Brown, W. J., & Kolbe-Alexander, T. (2018). Shift work and the risk of cardiovascular disease. A systematic review and meta-analysis including dose-response relationship. *Scandinavian Journal of Work, Environment & Health*, *44*(3), 229–238. https://doi.org/10.5271/sjweh.3700

Warren, J. M., Ekelund, U., Besson, H., Mezzani, A., Geladas, N., Vanhees, L., & Experts Panel (2010). Assessment of physical activity - a review of methodologies with reference to epidemiological research: a report of the exercise physiology section of the European Association of Cardiovascular Prevention and Rehabilitation. *European Journal of Cardiovascular Prevention and Rehabilitation*, *17*(2), 127–139. https://doi.org/10.1097/HJR.0b013e32832ed875

Weatherson, K., Yun, L., Wunderlich, K., Puterman, E., & Faulkner, G. (2019). Application of an ecological momentary assessment protocol in a workplace intervention: assessing compliance, criterion validity, and reactivity. *Journal of Physical Activity & Health*, *16*(11), 985–992. https://doi.org/10.1123/jpah.2019-0152

Wei, F., Chen, W., & Lin, X. (2022). Night-shift work, breast cancer incidence, and all-cause mortality: an updated meta-analysis of prospective cohort studies. *Sleep & Breathing, 26*(4), 1509–1526. https://doi.org/10.1007/s11325-021-02523-9

WHO, World Health Organisation. (1995). Physical status: The use of and interpretation of anthropometry, *World Health Organization technical report series*, *854*, 1–452. Retrieved from https://pubmed.ncbi.nlm.nih.gov/8594834

CHAPTER 6: PAPER 5 - EFFICACY OF A TEXT MESSAGING INTERVENTION TO IMPROVE PHYSICAL ACTIVITY IN MINING SHIFT WORKERS: PILOT STUDY

6.1 Introduction

The results of study one (chapter 3) highlighted the need for physical activity interventions, as only 41% of shift workers were sufficiently active (Monnaatsie et al., 2021). Mobile health (mHealth) provides diverse methods and approaches for workplace health promotion. Findings from our EMA studies showed that EMA is feasible and valid measure of physical activity and sedentary behaviours in workers. These findings reinforced the idea of using EMA in the intervention study, as a reliable and practical self-reporting measure.

This chapter reports the efficacy of an intervention designed to increase physical activity in a 24-day period during workdays and non-workdays in shift workers at a mining company. The results of the study will provide preliminary evidence on a physical activity intervention and the role of the intervention in improving shift workers health and wellbeing. In addition, there is little exploration of appropriate interventions to improve workers' wellbeing, especially in Sub-Saharan Africa (Ledikwe et al., 2019). However, the increase of NCDs in Botswana, as in many LMICs, has been attributed to the changing lifestyles and urbanisation (Keetile et al., 2020). Given that the NCDs are now common in Botswana, it is important to develop and plan health promotion programs, especially in the workplace as most working adults spend more than half of their time in this context (Mulchandani et al., 2019).

6.2 Paper 5: **Monnaatsie, M.,** Biddle, S. J. H., Kolbe-Alexander, T. L. Efficacy of a text messaging intervention to improve physical activity in shift workers: pilot study. ***To be submitted*** to Journal of Physical Activity and Health, Q2; Journal Impact Factor 3.0.

Abstract

Previous research has shown that workplace health promotion programs (WHPPs) can increase employees' habitual physical activity levels. We investigated the efficacy of a text messaging workplace health promotion program to increase physical activity for shift workers. Shift workers at a mining company (n=51) recruited from three departments were allocated to intervention and comparison groups. All participants completed GPAQ, PSQI, and WHO-5 questionnaires and wore the activPAL device for 11-14 days during the first and second shift cycles (24 days each). Intervention participants received feedback on their physical activity, had an action planning session, and received text messages and EMA prompts to encourage PA. The comparison group received generic information on the benefits of healthy behaviours. After completing the program, the intervention and comparison group participants received mi fitness band as an incentive. The primary outcome was the time spent walking with a cadence ≥100 steps/min (equivalent to MVPA). Average MVPA increased in the intervention group on all days and non-workdays. We found no significant changes in the overall number of steps, standing, sitting, and lying time or quality of life and sleep in both groups. Since there were no improvements in physical activity during some workdays, it may be necessary to consider collaborating with workers to discover work-related factors when designing physical activity interventions in the workplace.

Keywords: shift work, physical activity, EMA, text-messaging, Workplace health promotion program, intervention

Introduction

Shift work researchers need to cater for all the shift schedules and patterns as they can impact lifestyle behaviours differently. For example, in a study involving night and non-night work patterns, participants were less physically active during the night-shift session than the non-night-shift session because of limited leisure activities (van de Langenberg et al., 2019).

In addition to considering work schedules and factors, there is support for the use of theories and implementing behaviour change techniques in promoting physical activity behaviour (McDermott et al., 2016). We used the COM-B framework which encompasses the components of capability (C), opportunity (O), and motivation (M) to guide text messaging development that, in turn, influences behaviour (B). The COM-B framework lies in the centre of the Behaviour Change Wheel (BCW) and has been used in intervention studies to guide and create a change in behaviour (Munir et al., 2018). The COM-B model can be used on creation of text messages to motivate change in behaviour.

Mobile phones offer new approaches for measuring and promoting walking and health behaviours (Sullivan & Lachman, 2017; Zhao et al., 2016). Using brief text messages delivered through personal smartphones were effective for improving health outcomes (Burns et al., 2020). Mobile phones can also allow for self-reporting of behaviour in real time, often referred to as EMA. Using EMA in interventions showed that improving health behaviours including physical activity (Cruciani et al., 2017), sedentary behaviour (Müller et al., 2017), diet and sleep is possible (Pulantara et al., 2018). With the use of mobile phones, the ability to adapt the intervention to work schedules is also possible (Nahum-Shani et al., 2018; Neil-Sztramko et al., 2017). In the study by Van Drongelen et al. (2014) in which a control group received general information regarding fatigue and health behaviours, tailoring information to work schedules was suggested.

Health promotion programs targeting physical activity often have limited shift work representation (Flahr et al., 2018; Lassen et al., 2018). Because of the increasing prevalence of shift work worldwide, WHPPs for shift workers are needed. While there has been significant efforts in promoting health and physical activity for shift workers, interventions are rarely investigated in different shift schedules. For example, in a 20-week intervention, healthcare workers who were engaged in shift work, appeared to be more responsive to interventions than non-shift workers (Cheng et al.,2022). They concluded that shift workers should be a priority group for workplace health promotion with work status and schedules considered (Cheng et al., 2022). The results of a systematic review and meta-analysis of non-pharmacological interventions to improve chronic diseases in shift workers reported that all the studies included were conducted within healthcare populations (Crowther et al., 2021). Therefore, the need to consider shift workers from other occupations, to identify specific worker populations respond to interventions. In addition, there is little exploration on appropriate interventions to improve workers' wellbeing especially in Sub-Saharan Africa (Keetile et al., 2020). Investigating the efficacy of physical activity interventions with respect to shift schedules, is therefore essential for shift workers in low-and-middle income countries and other industries other than healthcare.

The aim of this study was to investigate the efficacy of a text messaging health promotion program to improve physical activity in shift workers in a mining company. We hypothesised that moderate to vigorous intensity physical activity steps (using step cadence of more than 100 steps/min as a proxy measure) would increase for those in the intervention group, while there would be no changes in the comparison group. We also hypothesised that the total number of steps would be increased. Moreover, the intervention should reduce sitting time, and improve sleep and quality of life.

Methods

Participants and Recruitment

Shift workers who met the following inclusion criteria were invited to participate; at least 18 years old, working as a full-time shift worker, able to communicate in English, owning a smartphone and willing to download the EMA application, and no history medical diagnosis that might pose health risk due to increased physical activity. A total of 51 shift workers employed at a mining company in Botswana were recruited via email invitations, presentations at staff meetings, posters at the workplace and snowball sampling

Shift workers in the mine hospital, mine processing, and mine pit departments doing similar shift rotation schedules were invited to participate. The shift cycle comprised of three schedules, 6 days each of a morning, afternoon and night (in that order) with two non-workdays between each pattern, resulting in a 24-day shift cycle (Figure 6.1).

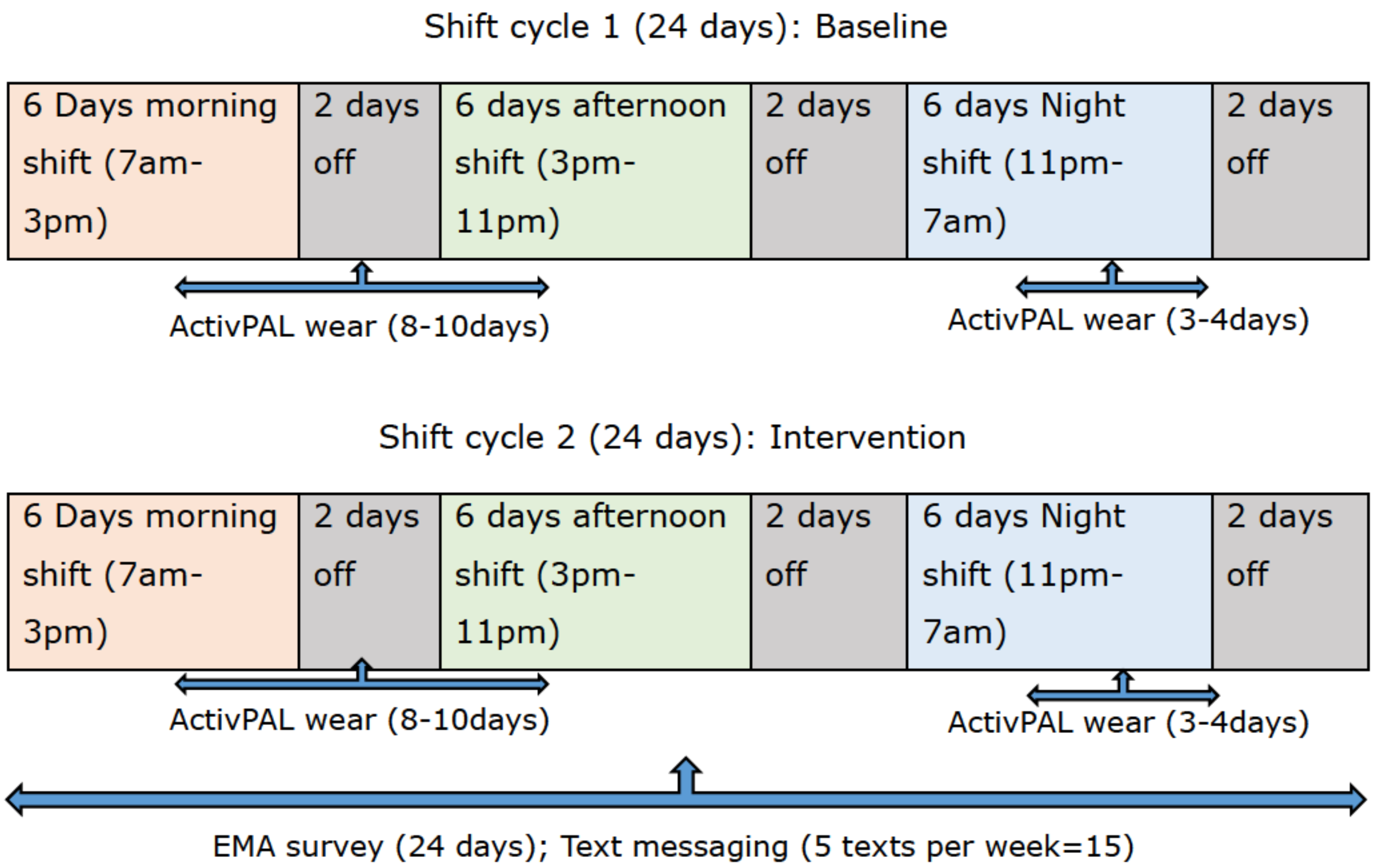


Figure 6.1 Shift schedules at the mining company

Measures

Primary outcome

Device-measured physical activity

ActivPAL4 devices (PAL Technologies Ltd., Glasgow, UK) were used to assess movement-related behaviours. Participants were asked to wear the activPAL on the front thigh, one third between hip and knee (Kozey-Keadle et al., 2011). The activPAL uses accelerometer-derived information about thigh position to estimate time spent in the different body postures of lying, sitting, or standing (Edwardson et al., 2017). The primary outcome measure was moderate-to-vigorous physical activity (MVPA) steps, equivalent of to a walking cadence of ≥ 100 steps/min (Tudor-Locke & Rowe, 2012). Other variables from the activPAL were number of steps/days, mean sedentary time, standing and lying time. Valid wear time was defined by a minimum of 10 hours per day (King et al., 2011). For each variable, daily averages were calculated across all valid days, as well as for the three shift schedules (morning, afternoon, and night) and non-workdays.

Self-reported physical activity

The Global Physical Activity Questionnaire (GPAQ) was used to measure physical activity at baseline (Bull et al., 2009). The GPAQ consists of 16 questions designed to estimate an individual's level of physical activity in 3 domains (work, transport, and leisure time) and time spent in sedentary behaviour (Bull et al., 2009). While the GPAQ was initially developed as a surveillance tool, to be used for evaluation both at local and international level, its use in behaviour interventions is gaining popularity (Cleland et al., 2014). The GPAQ evaluated time in MVPA at baseline.

Sleep quality

Pittsburgh Sleep Quality Index (PSQI) assessed sleep at baseline and post-intervention. The PSQI measures sleep quality during the previous month quality index consists of 19 items and seven components (subjective sleep quality, sleep latency, sleep duration, habitual sleep efficiency, sleep disturbances, use of sleeping medication, and daytime dysfunction with scores ranging from zero to 21 (Buysse et al., 1989). The overall score of sleep quality score ranges from 0 to 21, a score >5 is indicative of poor sleep (Moghaddam et al., 2012).

Mental health and quality of life

The World Health Organisation's well-being index (WHO-5) scale (Topp et al., 2015) assessed quality of life and psychological well-being. The WHO-5 consists of five positively worded items reflecting present mental well-being within the previous two weeks. The items rated on a 6-point Likert scale, ranged from 0 'at no time" to 5 "all the time (e.g., "Over the last two weeks I have felt cheerful and in good spirits") (Krieger et al., 2014). Scores were from all the components were summated, with a raw score ranging from 0 to 25. A score of 0 represents the worst possible well-being, while a score of 25 represents the best possible well-being (Volinn, 2007).

EMA survey

EMA survey prompted participants to report physical activity, location and total time spent in physical activity during the intervention (Burke et al., 2017). The EMA survey began with: "*Did you do any physical activity for at least 10 min at least one time today? Response options will include "yes", "no" and "do not know/prefer not to answer".* If the participant indicated that they have done some physical activity, the next question was: *How long did it last?* Response options included *"10–20 min", "20–30 min", "30–40 min", "40–50 min", "More than 60 min" and "Do not know/Prefer not to answer".* The EMA compliance rate and the association of EMA reporting and physical activity changes were reported. EMA was used to report physical activity during the intervention. The EMA survey prompts were delivered once per day for the 24 days. The timing of the EMA prompts for the days on which text messages were delivered, was set as one hour after the text message was sent. The EMA survey expired after an hour of non-response.

Intervention group

One-on-one meeting

The intervention was conducted during the second 24-day shift cycle. Participants in the intervention group took in part in a one-on-one meeting with the researcher. The 5A's action planning framework was followed during the meeting. For action planning during the meeting, we used the 5As (Ask, Assess, Advise, Assist, and Arrange) to guide discussion. Participants received feedback, and guidance to set goals and identify possible barriers to engaging in physical activity (Carroll, Antognoli & Flocke, 2011). At the end of the meeting, the times to send text messages and EMA prompts were agreed upon by the researcher and individual participants. Following action planning, participants were sent a link to download the EMA application.

Text messages

Each participant received five text messages per week (one per day) during the second shift cycle of 24 days for 15 days only (see Figure 1). The COM-B components of capability and opportunity were used to develop text messages to motivate improvement in physical activity (Michie et al., 2011). For example, a text message targeted at increasing psychological capability would be: “Why not aim for a morning walk before your afternoon shift? A 30-minute walk is about 3500 steps!” An example of social opportunity message was: “Today is a great day for a jog! Have you tried suggesting an afternoon jog/run to a friend or family member?”

Incentive

At the end of the program participants received the Mi fitness band (Xiaomi band 5) (Concheiro-Moscoso et al., 2021) as an incentive. The Mi fitness band measures number of steps and biomedical parameters including heart rate and sleep. It uses age, height, weight, and gender in the native Mi Fit application to calculate the activity (Concheiro-Moscoso et al., 2021). The fitness band was given to participants to monitor and improve physical activity beyond the intervention study.

Comparison group

Following the baseline measures, participants in the comparison group received generic advice on the guidelines and benefits of physical activity. They did not receive any text messages or EMA prompts. The comparison group participants also received the Mi fitness band at the end of the program.

Study procedure

The study procedure is described in detail elsewhere in the thesis chapter 7 (Monnaatsie et al., 2023). Workers were allocated (1:1) to the intervention and comparison groups stratified by department and the current shift schedule. In order to avoid contamination, workers who started the program with similar shift schedules and in the same department were allocated to the same group (Robinson et al., 2020).

Measures were taken at baseline during the first cycle and at follow-up (second shift cycle). The activPAL accelerometer was worn for 11-14 days during the first cycle, and 11-14 days in last shift cycle in the same pattern; three to four days of activPAL wear from the three shift schedules and two non-workdays. Online questionnaires, including the demographic questions, Global Physical Activity Questionnaire (GPAQ), Pittsburgh Sleep Quality Index (PSQI) and World Health Organisation’s well-being index (WHO-5) scale were also completed at baseline and follow-up.

Figure 6.2 shows an overview of study enrolment and participation in the intervention and comparison groups. Of the 71 workers interested in participating, 60 were eligible and completed baseline measures. The remaining individuals were excluded if they did not complete the baseline measurements or changed to traditional day time shifts. Of the 60 workers enrolled, 9 did not complete follow up measures resulting in 51 workers (see Figure 6.2)

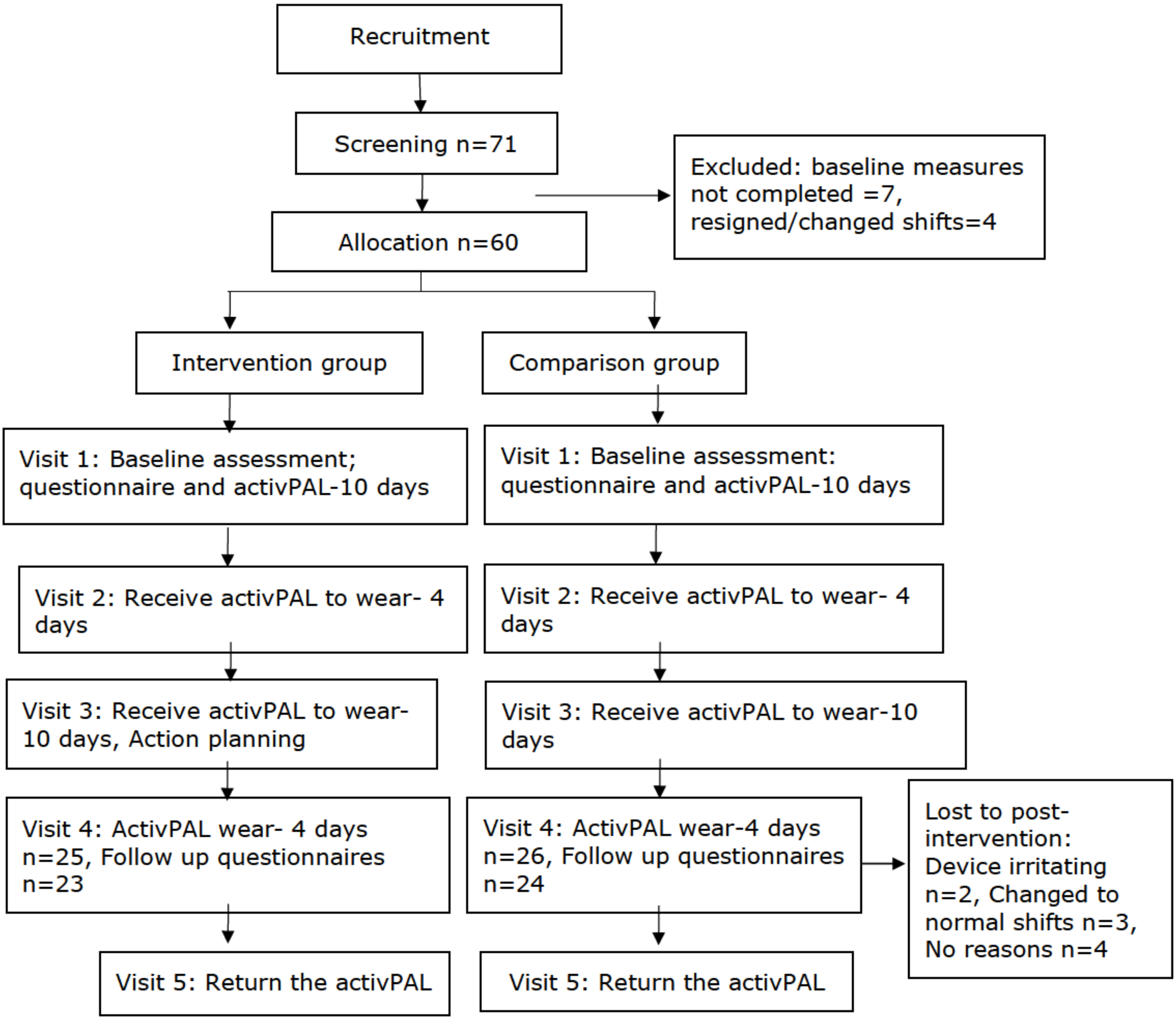


Figure 6.2 Flow chart of study participation with baseline and post-intervention measures

Ethical Considerations

The study was approved by the Ethics Committee of University of Southern Queensland (H22REA021). All participants provided written informed consent before data collection.

Data analysis

Demographic and baseline characteristics with continuous variables are expressed as means (±SD), median (25^{th}, 75^{th} percentiles), and categorical variables as proportions (%). We used paired t-test for normal distributed data and Wilcoxon-Mann-Whitney test for non-normal data to determine differences between baseline and follow up (Duan et al., 2020). Repeated measures Analysis of Variance (ANOVA) (Group X Time) were performed for the primary and secondary outcomes. Covariates were age, gender, and the work department. Spearman correlations was used to test association between EMA response rate and the primary outcome (De Winter et al., 2016). All outcome measures were reported by all the shift schedules and non-workdays (Moyer et al., 2022). Statistical analysis was performed using IBM Statistical Package for Social Sciences (SPSS), version 27. The alpha level indicating statistical significance was accepted at $p < 0.05$.

The sample size required for analysis based on increasing the number of steps by 1200 per day given 80% power significance level of 0.05, effect size (Cohen's *f*) of 0.50 was 27 per group (intervention and control) (Martin et al., 2015; Lee et al., 2019). Therefore, our projected sample size was 70 participants (35 per group), allowing for a drop-out rate of up to 20% based on previous studies (Aittasalo et al., 2012; Mathew et al., 2019).

Results

Participant Characteristics

Table 6.1 presents demographic characteristics of the workers at the mining company. Participants from three departments with a larger proportion as the mine hospital shift workers (n=24) and a smaller proportion form the mine pit (n=11) were targeted. The mean age of participants included in the data analysis (n=51) was 39 years (SD= 5.4), and mean Body Mass Index was 26.2 kg/m^2 (SD=5.8). There were no differences in demographic characteristics between the two groups. The average time spent in MVPA was 10 min/per day, and it did not differ between the intervention and comparison groups. At baseline workers accumulated an average of 9173 (95% CI 7871, 10501) steps, only 1311 (95% CI 894, 1817) MVPA steps and 455 (95% CI 414, 495) minutes was spent sitting.

Table 6.1. Baseline characteristics of participants in the intervention and comparison group

Characteristics	Total (n=51)	Intervention group (n=25)	Comparison group (n=26)	P-value
Work department (n, %)				0.10
Hospital mine	24.0 (47.0)	14.0 (58.0)	10.0 (41.7)	
Mine Processing	16.0 (31.4)	7.0 (43.8)	9.0 (56.3)	
Mine Pit	11.0 (21.6)	5.0 (45.5)	6.0 (54.5)	
Age years (mean, SD)	39.3 (5.4)	39.1 (5.8)	39.4 (5.2)	0.89
BMI kg/m^2 (mean, SD)	26.2 (5.8)	26.0 (7.2)	26.4 (4.2)	0.42
Gender (n, %)				0.39
Male	27.0 (53.0)	12.0 (44)	15.0 (55.5)	
Female	24.0 (47.0)	13.0 (54.2)	11.0 (45.8)	
Marital status (n, %)				0.06
Living with partner	20.0 (41.0)	12.0 (27.1)	8.0 (17.0)	
Health status (n, %)				0.07
Poor	15.0 (30.6)	10.0 (20.8)	5.0 (10.4)	
average	20.0 (40.8)	10.0 (20.8)	10.0 (20.8)	
excellent	2.0 (4.1)	0.0 (0)	2.0 (4.2)	
Overall Time in MVPA (n, %)	18.0 (16)	16.0 (19)	14.0 (17)	0.77

Legend: SD: Standard Deviation, BMI: Body Mass Index computed from weight and height, MVPA: Moderate-to-Vigorous Intensity Physical Activity. Differences between the groups test with independent-test, significance $p<0.05$.
Note: Living with partner included both participants married and not married living with partners

Effects on MVPA

The results of changes in MVPA are presented in Table 6.2. and Figure 6.3. MVPA was significantly increased in the intervention group with about 15 minutes, whereas there was only a minute increase of MVPA in the comparison group. This was group by time and time by group effect. The increase in MVPA was significant on the total days. However, the improvement was mainly from non-workdays.

There were no significant changes in MVPA on night, and afternoon. However, MVPA morning shift tended to towards significance increase in MVPA at a time level (p=0.05).

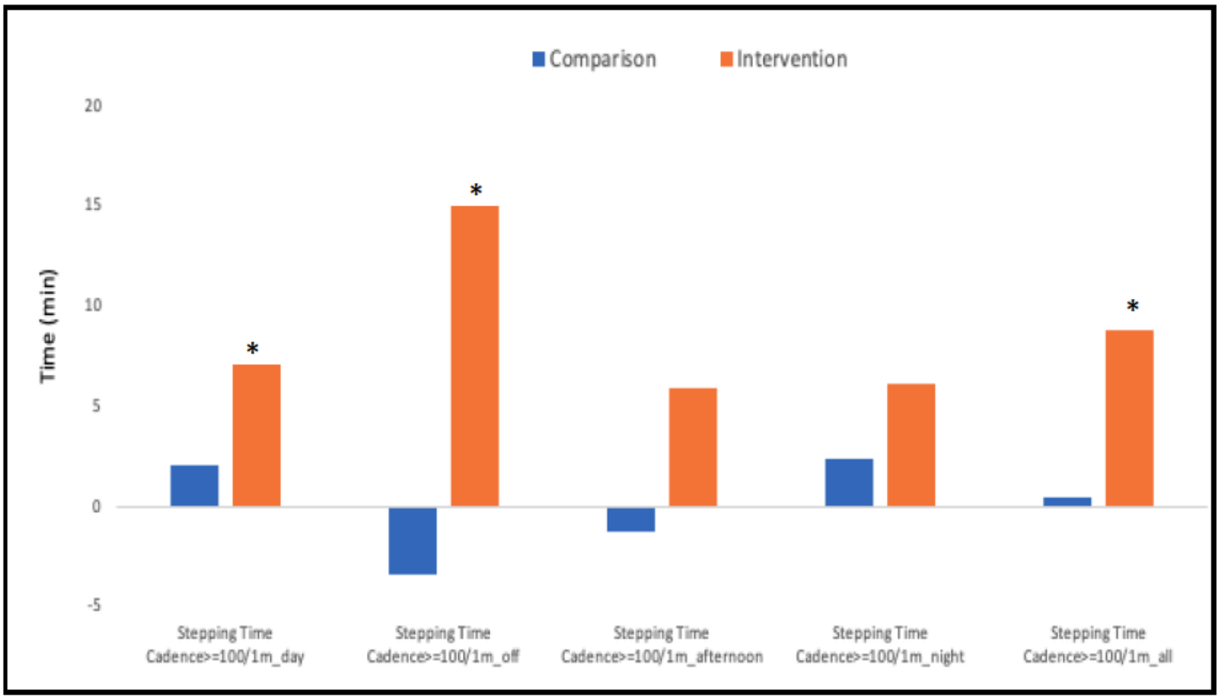


Figure 6.3 Device-based changes in MVPA

*Legend: *p<0.05 significant.*

Effects on steps

MVPA steps were increased significantly on all days, morning and day shift and non-workdays in the intervention group. During day shift the MVPA was increased significantly by time effect (figure 6.4). The MVPA steps were slightly increased in the comparison group on day, night shifts and all days.

There were no significant increases in total steps per day for both groups (p=0.91, 0.42). However, the total number of steps were increased on non-workdays, night and all days in the intervention group and during day and afternoon in the comparison group. These were all not significant.

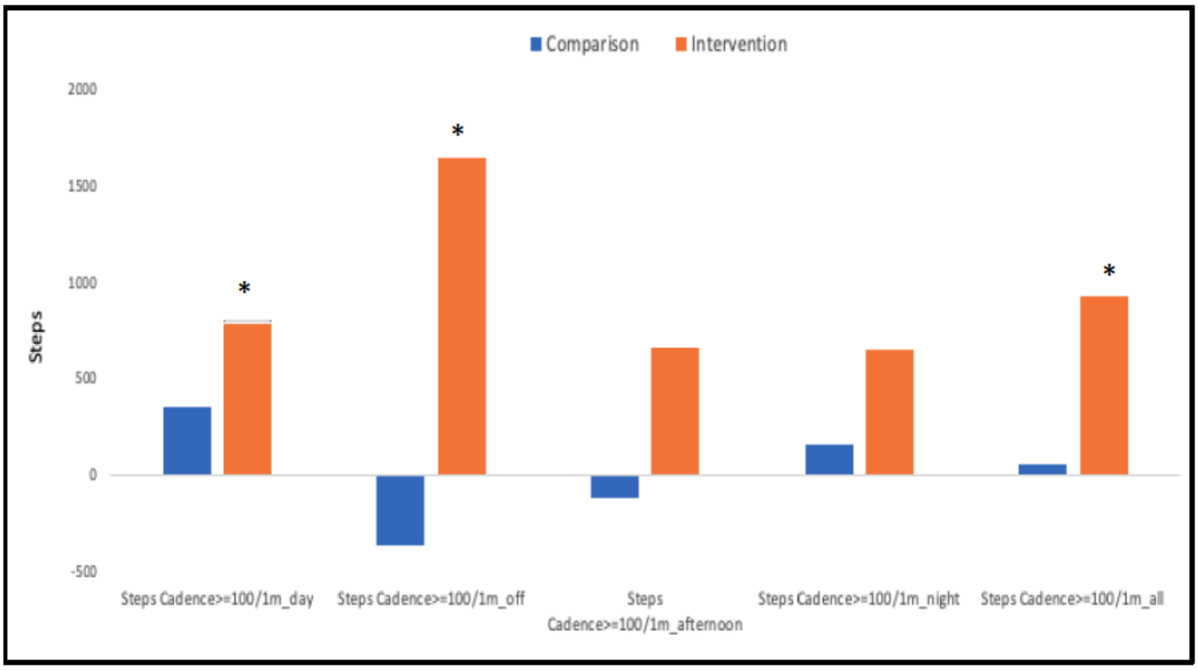


Figure 6.4 Device-based changes in MVPA steps

*Legend: *p<0.05 significant.*

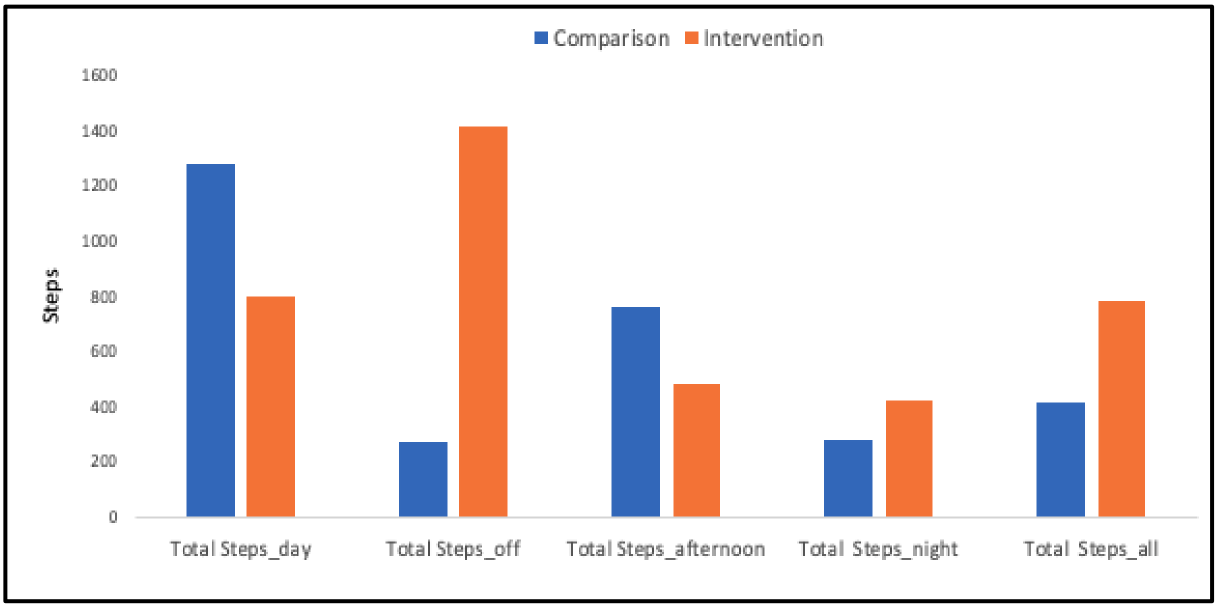


Figure 6.5 Device-based changes in total steps

Effects on the minutes of sitting

The mean differences of sitting time among the intervention and comparison groups are presented in Table 6.3. There were no significant differences in the sitting, but there were some reductions observed in sitting time in intervention group on day, afternoon, afternoon shifts non-workdays and all days, but not during night shift. Similarly, sitting time was slightly reduced in the comparison group on day, afternoon shifts, and on non-workdays (Figure 6.6).

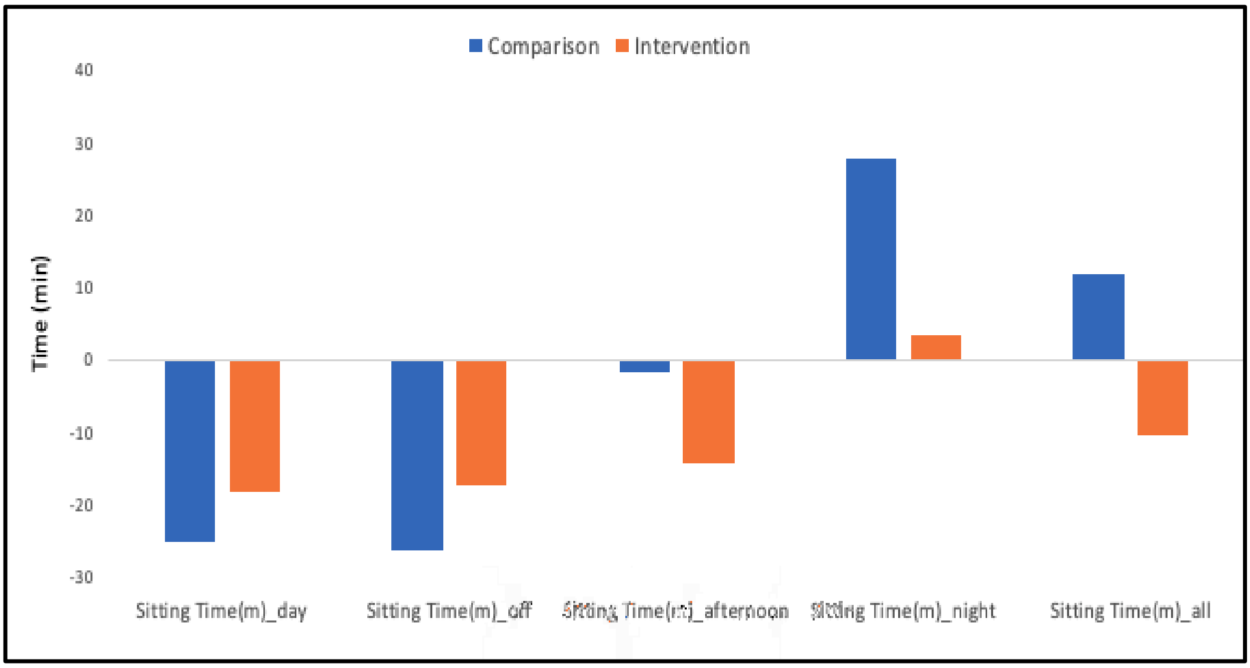


Figure 6.6 Device-based changes on sitting time

Effect on standing and lying down

No significant differences were observed in standing and lying time in the intervention group, compared to the comparison both within and between the groups.

Ecological Momentary Assessment

On average, participants responded to 59% of the EMA prompts. The EMA response rate was highest in day 2 (87%) of the 24-day intervention period. However, the EMA responses did not differ by days. Moreover, the EMA compliance rate was unrelated to the change in MVPA (r=-0.17; p=0.46).

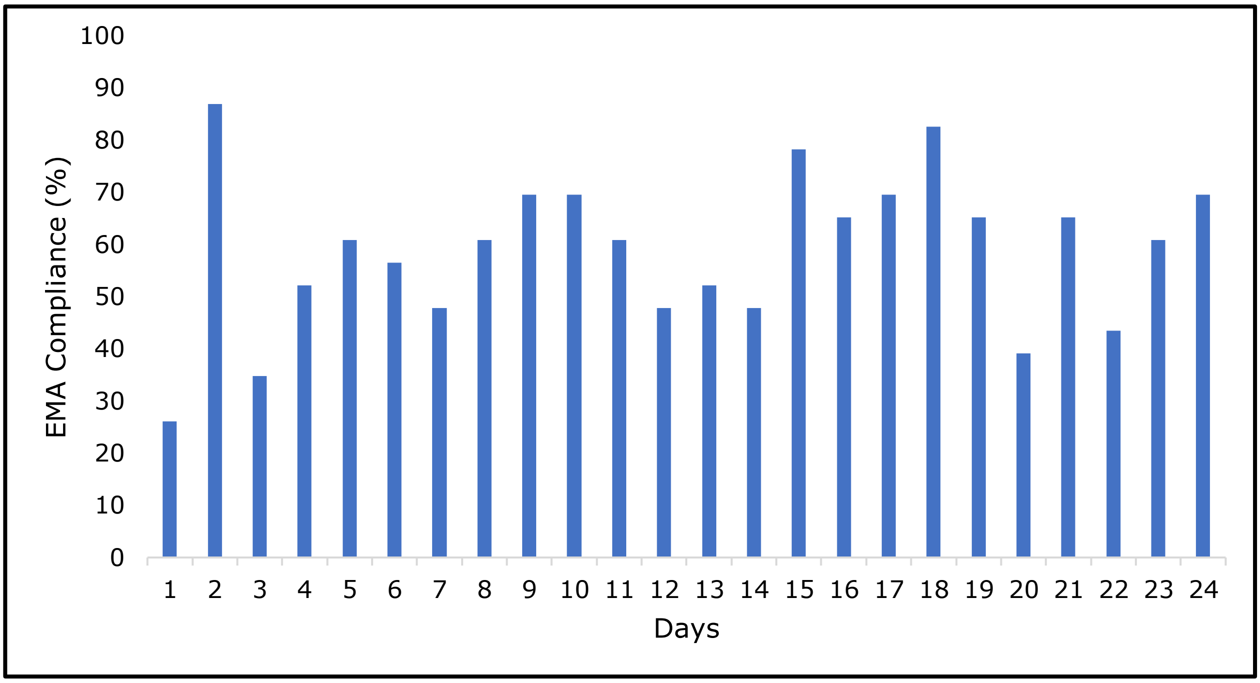


Figure 6.7 EMA compliance rate during the intervention period

Effects on total sleep quality and quality of life

Participants' quality of life and sleep quality are compared both within and between groups in Table 6.4. No significant changes were observed in overall quality of life and sleep quality within and between both the intervention and comparison groups.

Table 6.2. Device-based measures of total mean physical activity (minutes and steps) for the intervention and comparison group from baseline to follow-up

	Intervention group		Comparison group			P-value	
	Baseline (n=25) M (95% CI)	Post-intervention (n=24) M (95% CI)	Baseline (n=26) M (95% CI)	Post-intervention (n=21) M (95% CI)	Mean dif (95% CI)	Time	Time* Group
All days							
Time≥100steps/min	12 (8, 16)	21 (15, 27)	11 (7, 17)	12 (5, 19)	5 (1, 8)	0.00*	0.01*
Steps≥100steps/cadence	1361 (872, 1851)	2289 (1600,2977)	1260 (736, 1783)	1311 (574, 2047)	489 (148, 830)	0.00*	0.01*
Total steps	9273 (7973,10572)	10059 (8828,11290)	9072 (7683,10461)	9351 (8035, 10667)	532 (-89,1154)	0.91	0.42
Morning shift							
Time in ≥100steps/min	16 (10, 22)	24 (15, 32)	15 (9, 21)	18 (8, 26)	5 (-0.05, 10)	*0.05*	0.34
Steps≥100steps/cadence	1760 (1102, 2418)	2563 (1606, 3520)	1600 (856, 2263)	1974 (951, 2998)	609 (46, 1171)	0.04*	0.49
Total steps	10441 (8961, 11922)	11240 (9258, 12814)	10230 (8646, 11812)	10940 (9258,12622)	754 (-138, 1648)	0.09	0.92
Afternoon shift							
Time in ≥100steps/min	15 (9, 21)	20 (14, 27)	14 (7, 20)	12 (4, 18)	2 (-3, 6)	0.40	0.07
Steps≥100steps/cadence	1604 (962, 2246)	2266 (1522, 3010)	1520 (734, 2107)	1301 (405, 1996)	220 (-272, 713)	0.37	0.78
Total steps	9365 (7614, 11116)	9937 (8473, 11848)	9911 (8273, 11548)	9986 (8433, 11539)	553 (-513, 1620)	0.30	0.90
Night shift							
Time≥100steps/min	13 (8,18)	18 (12, 25)	11 (5, 16)	15 (7, 22)	5 (0.5, 9)	*0.05*	0.66
Steps≥100steps/cadence	1127 (610, 1645)	1782 (1028, 2537)	1069 (419, 1623)	1164 (359, 1971)	424 (-21, 870)	0.06	0.60
Total steps	8771 (7144, 10399)	9194 (7767, 10622)	8415 (6672, 10152)	8592 (7066, 101118)	301 (-843, 1446)	0.30	0.83
Non-workdays							
Time in ≥100steps/min	8 (3, 13)	23 (13, 33)	12 (7, 17)	11 (1, 20)	6 (-0.7, 13)	0.07	0.01*
Steps≥100steps/cadence	879 (347, 1411)	2521 (1454, 3588)	1330 (768, 1906)	1024 (-116, 2165)	664 (-60, 1390)	0.07	0.00*
Total steps	9273 (7973, 10572)	10059 (8828, 11290)	9073 (7683, 10461)	9351 (8035, 10668)	532 (-88, 1154)	0.09	0.41

Legend: All measures are calculates using general linear models adjusted for age, gender, and work departments with *$p<0.05$ significant. M: mean, M dif: Mean difference, 95% CI: Confidence Intervals

Table 6.3. Device-based measures of total mean time spent standing, sitting, lying (minutes) for the intervention and comparison group from baseline to follow-up

	Intervention group		Comparison group			P-value	
	Baseline (n=25) M (95% CI)	Post-intervention (n=24) M (95% CI)	Baseline (n=26) M (95% CI)	Post-intervention (n=21) M (95% CI)	M dif (95% CI)	Time	Time*Group
All days- Time (min)							
Standing	264 (235, 293)	262 (232, 297)	286 (255, 316)	275 (240, 310)	-5 (-14, 24)	0.60	0.58
Sitting	453 (413, 492)	442 (403,481)	458 (415, 500)	477 (435, 519)	5 (-20, 29)	0.72	0.24
Lying	430 (398, 463)	441 (412, 469)	406 (371, 441)	393 (363, 423)	-1 (-26, 24)	0.92	0.33
Morning shift-Time (min)							
Standing	310 (272, 349)	304 (266, 343)	299 (263, 335)	293 (257, 328)	-6 (-34,22)	0.68	0.99
Sitting	131 (114, 149)	139 (121, 156)	130 (111, 148)	137 (119, 156)	-11 (-49, 27)	0.57	0.70
Lying	442 (404, 480)	440 (398, 481)	467 (427, 508)	452 (407, 496)	-9 (-43, 24)	0.59	0.70
Afternoon shift-Time (min)							
Standing	254 (220, 288)	264 (228, 301)	278 (242, 314)	295 (257, 334)	13 (-11, 38)	0.28	0.80
Sitting	454 (401, 507)	440 (386, 493)	450 (393, 507)	425 (368, 482)	-19 (-53, 14)	0.25	0.76
Lying	485 (446, 524)	458 (425, 491)	508 (466, 549)	506 (471, 542)	-14 (-46, 18)	0.38	0.42
Night shift-Time (min)							
Standing							
Sitting	253 (215, 292)	250 (214, 286)	278 (236, 319)	255 (217, 293)	-13 (-43, 18)	0.39	0.52
Lying	453 (410, 495)	457 (417, 496)	458 (413, 503)	501 (459, 543)	23 (-13, 60)	0.21	0.29
	307 (260, 354)	335 (286, 385)	279 (229, 329)	267 (214, 320)	8 (-36, 52)	0.71	0.37
Non-workdays							
Standing	249 (211, 286)	251 (207, 294)	247 (207, 287)	280 (233, 327)	18 (-18, 54)	0.33	0.37
Sitting	429 (382, 477)	412 (361, 463)	479 (428, 530)	443 (389, 498)	-27(-67, 14)	0.19	0.64
Lying	526 (467, 586)	551 (458, 585)	521 (458, 585)	524 (464, 586)	14 (-36, 64)	0.58	0.66

Legend: All measures are calculated using general linear models adjusted for age, gender, and work departments with *$p<0.05$ significant. M: mean, M dif: Mean difference, 95% CI: Confidence Intervals

Table 6.4. Mean changes in quality of life (WHO-5) and sleep (PQSI) for the intervention and comparison group from baseline to follow-up

	Intervention group		Comparison group		P-value	
	Baseline (n=25) M (95% CI)	Post-intervention (n=24) M (95% CI)	Baseline (n=26) M (95% CI)	Post-intervention (n=21) M (95% CI)	Time	Time*Group
Sleep quality PQSI total score (0-21)	9.1 (7.9,10.4)	9.3 (81, 10.6)	8.8 (7.4,10.1)	9.0 (7.6,10.3)	0.64	0.96
Quality of life WHO-5 score (0-25)	14.4 (12.8, 16.0)	14.3 (12.6, 15.9)	15.6 (13.9, 17.3)	14.6 (12.8, 16.3)	0.06	0.13

Legend: All measures are calculated using general linear models adjusted for age, gender, and work departments with *$p<0.05$ significant. M: mean, M dif: Mean difference, 95% CI: Confidence Intervals

Discussion

This study aimed to test the efficacy of a text-messaging workplace health promotion program targeting physical activity in shift workers. The MVPA steps (cadence ≥100 steps/min) were increased in all workdays combined, morning/day shift and nonwork days for the intervention group. However, MVPA steps remained unchanged during other shift schedules (afternoon and night). The other findings include no changes in total number of steps, sitting, and standing in both intervention and comparison group.

Our study showed that a text-messaging intervention during one shift cycle resulted significant increases in time spent in MVPA mainly during non-workdays. The findings are consistent with the results of studies showing changes in physical activity during non-workdays in shift working drivers (Clemes et al., 2022; Yeongmi Ha et al., 2022; Rapisarda et al., 2021; Viester et al., 2018). We observed some increase in the number steps with moderate-to-vigorous intensity during the day/morning shift, but there were no changes in time spent in MVPA during morning, afternoon, and night shifts. The morning or day shift started at 7 am and ended at 3 pm. As such, more daytime remaining for engaging in physical activity after work. These findings are important given that shift work has been predicted to reduce opportunities for physical activities (Atkinson et al., 2008).

Moreover, the action planning time was used to identify the times that workers indicated that there might find time to be active. For example, for afternoon and night shifts text messages were sent before work. However, while not shown in our study it might be the desire to do physical activity might be higher in the evening than in the morning or before work. In a recent study involving US population, using EMA to assess motivations for physical activity showed the least excitement to engage in physical activity in the morning (Crosley-Lyons et al., 2023). Therefore, physical activity intervention programs performed during work hours maybe beneficial when planned in the afternoon or evening.

Our findings showed that participants accumulated high levels of steps during baseline. Continuous and long periods of stepping with no rest at work may result in fatigue thus less improvement in physical activity during workdays (Oakman et al., 2019). In our process evaluation results (chapter 7), work related fatigue was reported as one of the barriers to improve physical activity (Monnaatsie et al., 2023). Like the results of a study investigating lifestyle behaviours and workplace health across a range of shift workers (Nea et al., 2017). Participants reported that factors like insufficient breaks and high workload resulting in fatigue influenced unhealthy behaviours (Nea et al., 2017).

The mining industry present unique occupational factors associated with long work hours. In a study of 204 employees from the dairy industry, a four-month resistance exercise program improved musculoskeletal symptoms and fatigue (Santos et al., 2020). Perhaps a resistance training physical activity intervention aimed at workers who experience work-related fatigue may benefit more from physical activity. The effectiveness of resistance exercise programs for fatigue has been shown (Santos et al., 2020). In addition, implementing work breaks to reduce fatigue may result in improvement in engaging in physical activity programs in shift workers.

Most participants in our study were nurses, followed by diamond-processing mine workers. The occupational tasks of these workers required long periods of standing and walking (Bezzina et al., 2021). This was shown in our device data showing significant steps and standing hours spent at work. The recent physical activity guidelines encourage adults to increase physical activity all domains (Bull et al., 2020), however, disputed evidence on the benefits of occupational physical in improving health and wellbeing, known as 'physical activity paradox', is increasing. Epidemiological data shows that high occupational physical activity is associated with increased risk for diseases and adverse health effects (Holtermann et al., 2018; Quinn et al., 2021). Thus, while high total steps were recorded in shift workers in our study, the moderate-intensity were lower. Proving that the shift workers did not meet physical activity guidelines at baseline. In the study by Chastin et al., the dose-response associations between time spent in physical activity and all-cause mortality was strongest for MVPA (Chastin et al., 2021). Thus MVPA, is associated with great health benefits, than light physical activity (Powell et al., 2018). Therefore, shift workers may benefit from improving MVPA, as more health benefits and lower mortality risks are gained.

In our study, we saw the benefits of assessing behaviours in changing schedule of shift-workers, showing more significant changes during non-workdays. The comparison of physical activity changes by shift schedules provided a deeper understanding of occupational physical activity across all shift schedules and non-workdays. Thus, it is important to assess physical activity during work and non-workdays and in the shift working population by different shift patterns. These findings are important given that shift work has been predicted to reduce opportunities for physical activities. As such, for shift workers in a mining set up with three shift types (morning/day, evening, and night), intervention to increase physical activity may be beneficial planned during non-workdays and after morning shifts.

The time spent sitting, standing, and sleeping did not change in both the intervention and comparison groups. Participants received feedback on their time spent sitting, standing and sleep. A possible reason that these measures showed no change could be due to including only physical activity motivation in the text messages. There is growing evidence that shows that physical activity, sleep, and sedentary behaviour are interrelated over the course of 24 hours (Clarke & Janssen, 2021). A multicomponent intervention targeting improving all the behaviours together may be useful to improve overall physical and mental health for shift workers.

No changes in self-reported outcomes of sleep, mental health, and quality of life. Similar to our study, no significant differences were found in self-reported health markers of US workers in multiple worksites enrolled in a workplace wellness program (Song & Baicker, 2021). In the present study, the intervention group participated in an action planning and self-monitoring using a mobile app. Using EMA app for self-reporting did not influence physical activity in our study. Our results suggest that using text messaging with EMA may have increased participant burden. Significant improvements in the behavioural and health outcomes were shown by Schoeppe et al. when self-monitoring and performance feedback in the application design were included (Schoeppe et al., 2016).

One of the strengths our study is use of mobile technology, which is increasingly becoming accessible to many individuals. Mobile phones allow for real time support and feedback to users (Schoeppe et al., 2016). However, we did not find any evidence related to using both EMA and text-messaging in the intervention together. However, evidence suggests that EMA is beneficial for real-time support to improve healthy behaviour and can be adapted to shift schedules. Future studies should consider using EMA as a nudging tool (Dao et al., 2021).

Our analytical sample was below the number we pre-set to achieve change in MVPA; however, it was only short by five participants after dropouts. It would be beneficial to conduct the study with more participants, however, the results are encouraging as there were some improvements even with a smaller sample size. The other limitation is that we used activPAL to assess physical activity instead of Actigraph device. The activPAL has high reliability and validity for sedentary behaviour estimates rather than physical activity (Kim & Kang, 2019; Koster et al., 2016). It can classify behaviour into time spent sitting/lying, standing, and walking (Chastin et al., 2018). However, because it can detect the cadence of walking, we used it to assess MVPA steps. The intervention resulted in a few changes even with only 24 days. Intervention studies targeting physical activity for mining shift workers should consider more than one shift cycle for more benefits.

Conclusions

The workplace health promotion was effective in improving physical activity during the morning shift and non-workdays. Shift work health promotion studies should consider including physical activity programs during non-workdays due to more time available on non-workdays and less fatigue. We found no improvements in other health behaviours. The program offers potential to be adapted to improve physical activity in shift workers in a mining company. Further research should continue to investigate innovative interventions targeting healthy behaviours in shift workers to improve their physical and mental health. Shift workers in a mining company may benefit from health promotion programs during day/morning shifts and on non-workdays.

CHAPTER 7: THE FEASIBILITY OF A TEXT-MESSAGING INTERVENTION PROMOTING PHYSICAL ACTIVITY IN SHIFT WORKERS: A PROCESS EVALUATION

7.1 Introduction

The ubiquity of mobile phones offers a convenient and relatively inexpensive way to access adults (Willoughby & Brickman, 2021). Text-messaging interventions have been used in several intervention studies such improving physical activity (Foccardi et al., 2021) and reduction in sedentary behaviour (Castro et al., 2021). Similarly, EMA have emerged as a popular methodology in the physical activity research that uses mobile technology. There is growing evidence to support the potential of ecological momentary intervention (EMI) approaches. EMA facilitates tailoring (i.e., personalizing) support to participants' needs in real time in health promotion programs, especially shift workers with atypical work schedules. The RE-AIM framework provided a guide to assess the study process.

In order to help understand whether a workplace health promotion program was implemented as planned, process evaluations are necessary. This is important specifically to understanding the intervention process and implementation to provide the context to the research findings for translation into real world. Using a mixed methods approach and RE-AIM framework, this chapter highlights the process evaluation of a text-messaging health promotion intervention for mining shift workers during a 24-day shift cycle. However, the efficacy of the intervention is the focus of Chapter 6 and thus not included in this chapter.

7.2 Paper 4: Monnaatsie, M., Biddle, S. J. H., Kolbe-Alexander T. (2023) The feasibility of a text-messaging intervention promoting physical activity in shift workers: a process evaluation. *International Journal of Environmental Research and Public Health*, 20(4), 3260. doi.org/10.3390/ijerph20043260

International Journal of *Environmental Research and Public Health*

MDPI

Article

The Feasibility of a Text-Messaging Intervention Promoting Physical Activity in Shift Workers: A Process Evaluation

Malebogo Monnaatsie [1,2,3,*], Stuart J. H. Biddle [3,4] and Tracy Kolbe-Alexander [1,3,5]

1 School of Health and Medical Sciences and Centre for Health Research, University of Southern Queensland, Ipswich, QLD 4305, Australia
2 Department of Sport Science, Faculty of Education, University of Botswana, Gaborone 0022, Botswana
3 Centre for Health Research, Physically Active Lifestyles, University of Southern Queensland, Springfield, QLD 4300, Australia
4 Faculty of Sport & Health Sciences, University of Jyväskylä, 40014 Jyväskylä, Finland
5 Research Centre for Health through Physical Activity, Lifestyle and Sport (HPALS), Division of Physiological Sciences, Department of Human Biology, Faculty of Health Sciences, University of Cape Town, Cape Town 7700, South Africa
* Correspondence: malebogo.monnaatsie@usq.edu.au

Abstract: Workplace health promotion programs (WHPPs) can improve shift workers' physical activity. The purpose of this paper is to present the process evaluation of a text messaging health promotion intervention for mining shift workers during a 24-day shift cycle. Data collected from intervention participants with a logbook (n = 25) throughout the intervention, exit interviews (n = 7) and online surveys (n = 17) examined the WHPP using the RE-AIM (Reach, Efficacy, Adoption, Implementation and Maintenance) framework. The program reached 66% of workers across three departments, with 15% of participants dropping out. The program showed the potential to be adopted if the recruitment strategies are improved to reach more employees, especially when involving work managers for recruitment. A few changes were made to the program, and participant adherence was high. Facilitators to adopt and implement the health promotion program included the use of text messaging to improve physical activity, feedback on behaviour, and providing incentives. Work-related fatigue was reported as a barrier to implementing the program. Participants reported that they would recommend the program to other workers and use the Mi fitness band to continue monitoring and improving their health behaviour. This study showed that shift workers were optimistic about health promotion. Allowing for long-term evaluation and involving the company management to determine scale-up should be considered for future programs.

Keywords: workplace health promotion; physical activity; process evaluation; RE-AIM; shift work

Citation: Monnaatsie, M.; Biddle, S.J.H.; Kolbe-Alexander, T. The Feasibility of a Text-Messaging Intervention Promoting Physical Activity in Shift Workers: A Process Evaluation. *Int. J. Environ. Res. Public Health* **2023**, *20*, 3260. https://doi.org/10.3390/ijerph20043260

Academic Editor: Paul B. Tchounwou

Received: 13 January 2023
Revised: 9 February 2023
Accepted: 10 February 2023
Published: 13 February 2023

1. Introduction

Shift work is defined as any work schedule outside the normal work hours of 7 am and 6 pm and is often characterized by fixed or rotating shifts, night work, and early morning or late evening work [1,2]. Industries such as healthcare, manufacturing, and mining depend on 24 h service to meet economic and health care demands. Approximately one-fifth of the global workforce undertakes shift work [3].

When compared to employees who work traditional daytime hours, shift workers are at an increased risk for metabolic syndrome, cardiovascular diseases, cancers, overweight and obesity, type 2 diabetes, and mental health issues [4–6]. Insufficient physical activity is one of the leading risk factors for non-communicable diseases [7–9]. Shift workers may benefit from physical activity health promotion programs due to the health benefits associated with meeting the physical activity guidelines of 150–300 min of moderate intensity physical activity per week [10]. Despite these benefits, only 41% of shift workers meet physical activity guidelines [11].

The workplace provides an ideal environment for health promotion programs to improve physical activity in employees [12]. Research on workplace health promotion programs (WHPP's) shows that they may be effective in increasing physical activity and quality of life [13]. A stretching exercise program decreased neck and shoulder pain and quality of life in office workers [14]. Several systematic reviews have demonstrated the efficacy of workplace health promotion interventions at increasing physical activity [12,13,15–17]; however, they mainly involved normal daytime workers.

The workplace is complex, with multiple factors and determinants that influence physical activity [18,19]. For shift workers, lack of time and work-related fatigue may explain workers' low levels of physical activity [20]. According to a study conducted in shift working South African doctors, more steps were reported when working longer shifts, thus resulting in more physical activity at work [21]. The factors influencing the implementation and effectiveness of health promotion programs in both shift and regular day workers need to be understood to improve workers' health. Considering specific work tasks and ergonomics when planning health promotion programs may be useful. For example, a specific strength training program for welders resulted in improvement in working tasks and reduced the subjective determination of exhaustion [22].

Whereas there are still mixed results from studies on the effectiveness of WHPPs to increase physical activity, most were conducted in high-income countries. For the shift work population, it is recommended that studies be expanded to include workers on a variety of different schedules, with modifications to the strategies used to meet individual needs [23].

The reporting of effectiveness outcomes is essential in intervention studies; however, process evaluations are also necessary to determine whether workplace programs were implemented as planned [24]. There are few process evaluations that have been reported in the literature on WHPPs targeting shift workers [25–27]. Process evaluation provides context to the research findings and identifies barriers and enablers for translation into real world settings [28]. The RE-AIM framework provides a structure for the assessment of interventions and includes five dimensions: reach, efficacy, adoption, implementation, and maintenance, and has been applied in multiple interventions including those targeting physical activity [29,30]. Through the RE-AIM components, interventions can be assessed at both individual and organizational levels [31]. *Reach* is the total number of participants available to take part in the program along with the assessment of the representativeness of participants. *Efficacy* refers to the impact of the program on key outcomes including both the positive and negative consequences. *Adoption* is the number and representativeness of participants who adopt the program and barriers to adoption. *Implementation* is the extent to which the intervention was delivered as planned and refers to the fidelity and adaptations of an intervention. *Maintenance* can be considered as the degree to which the intervention has been adopted beyond the end of the study period or the potential to be adopted by participants or within the structure of the workplace [30,32].

Therefore, the aim of this study was to conduct a process evaluation, using the RE-AIM framework, of a workplace health promotion intervention that aimed to increase physical activity in shift workers.

2. Materials and Methods

2.1. Study Design

A mixed methods study design was used to evaluate a workplace health promotion program that aimed to increase physical activity in shift workers who worked a 24-day shift cycle. The RE-AIM framework guided both the qualitative and quantitative methods to evaluate the health promotion program (Table 1).

Table 1. Process evaluation measures and data sources using the RE-AIM framework.

Dimension	Indicator	Data Source
Reach	Participation rate	Researcher logbook
	Dropout rate	Recorded number of enrolled and completed assessment workers
	Individual reasons for non-participation	Researcher logbook and online questionnaires and interviews
	Barriers and facilitators for participation	Online questionnaires and interviews
Adoption	Representativeness of work departments and drop-out	Researcher logbook
	Factors that affect individual participation and engagement with intervention components	Online questionnaires and interviews
	Method used to target various departments	Researcher logbook
Implementation	Barriers and facilitators of intervention process	Online questionnaires and interviews
	Expectations of intervention components	Researcher logbook and online questionnaires
Maintenance	Individual reporting on the continuation of intervention beyond the intervention period	Online questionnaires and interviews
	Barriers to maintaining the program	Online questionnaires and interviews

2.2. Recruitment and Participants

An overview of recruitment and the study design is presented in Figure 1. Eligible participants were sent an information sheet via email and were invited to attend the first meeting at their workplace. The inclusion criteria were: being a full-time shift worker at the chosen mining company, having a previous diagnosis whereby physical activity might pose an adverse risk to health, own a smartphone and be willing to download the mobile application, and being able to communicate in English. The workplace had the shift employees working six days in each period (morning, evening and night) followed by two non-workdays resulting in a 24-day shift cycle. Therefore, the program was conducted in two shift cycles of 24 days each. The researcher obtained department information and shift schedules from participants prior to allocation to the intervention or control group. Allocation to the intervention and control groups allowed participants who started the program with similar shift schedules and in the same department to be allocated to one group to avoid contamination [33]. Ethical approval was obtained from the University of Southern Queensland.

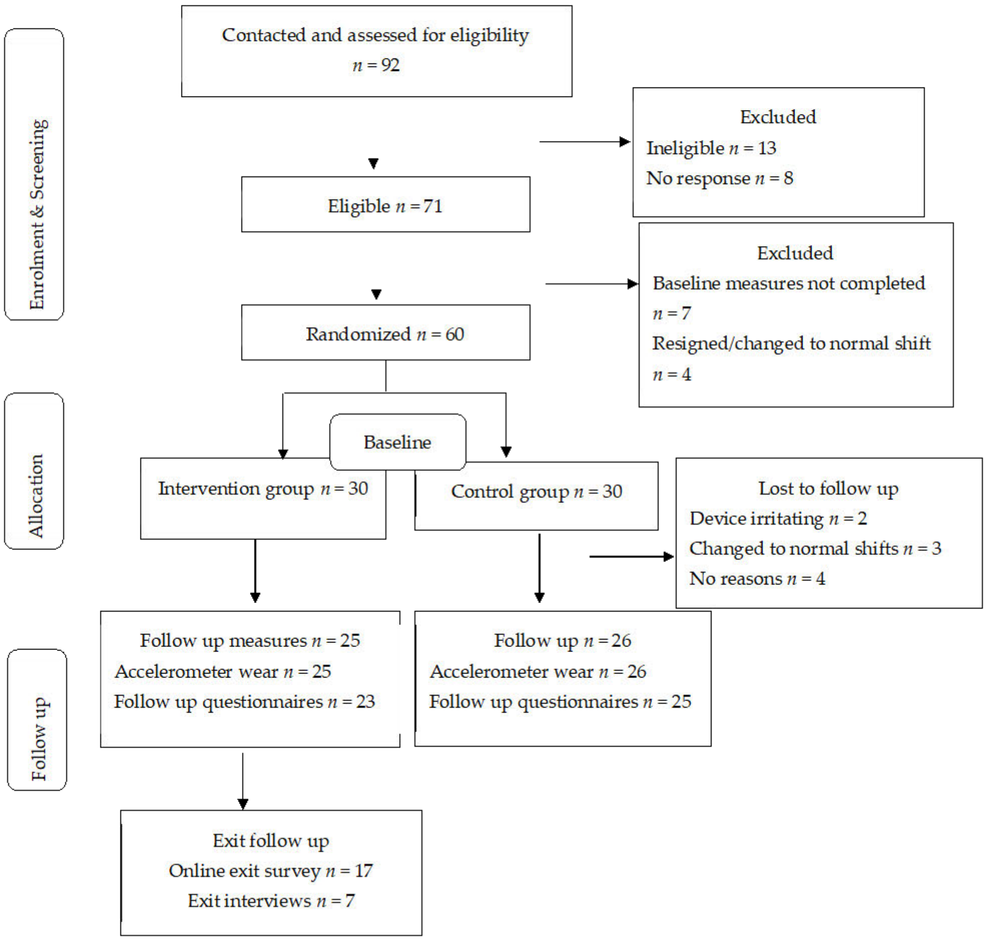


Figure 1. Flow chart of participants.

2.3. Intervention

The physical activity intervention was designed to increase daily moderate-to-vigorous physical activity (MVPA), defined as a walking cadence of ≥ 100 steps/ min for ≥ 1 min during a 24-day shift cycle. Baseline measures included an online questionnaire and wearing the activPAL accelerometer device (see Section 2.5) during the first 14 days of the first shift cycle to cover four days in each shift and two non-workdays in the first 24-day shift cycle. During the last five days of the first shift cycle, participants were invited to a one-on-one meeting at their workplace. After completing follow-up measures, participants received the *Mi* fitness band (Xiaomi Mi band 5) as an incentive to monitor and improve their lifestyle behaviors after the program had ended. The Mi fitness band 5 is a wristband that measures several health parameters including heart rate, steps, stress level and sleep. The band can be connected to the companion, Mi Fit application on a smartphone via Bluetooth [34].

2.3.1. Action Planning

During the one-on-one meeting, feedback on physical activity and other outcomes recorded by the activPAL were provided (time spent sitting, standing, and stepping). To guide change in physical activity action planning and specific goal setting, the researcher discussed strategies to improve habitual levels of physical activity following the 5As approach (assess, advise, agree, assist, and arrange) [35]. Implementing the behaviour change techniques, including feedback on physical activity, action planning and specific goal setting, is important, as each offers motivation to change behaviours [36]. The discussions also identified possible barriers to change in physical activity behaviour. Each action planning session was planned for 30–45 min at the workers' workplace at a time convenient for them.

2.3.2. Text Messages

Participants received individually tailored text messages five days per week designed to increase motivation to undertake physical activity. A total of 15 text messages were sent per person and delivered according to the participant's shift schedule (day, afternoon, or night). The text messages were designed to fit into the COM-B components of capability, opportunity, and motivation to engage in the physical activity [37], and were based on baseline measures and discussions that came from the action planning. For example, a text message targeted to improve the intention to engage in moderate-intensity physical activity was: 'A 30-min brisk walk can help increase your moderate physical activity'. An example of social opportunity to increase the behaviour was: 'Today is a great day to get some physical activity before your afternoon shift. Want to suggest a jog this morning to a family member?'. Participants were requested to not respond to text messages, but to use them as motivation to increase their physical activity.

2.3.3. Ecological Momentary Assessment Survey

Participants received an email link to download the mobile application onto their phones to use it for self-reporting their physical activity. The EMA survey took less than 1 min to complete and was sent daily for the 24-days of the intervention period during the second shift cycle. The survey began with: 'Did you do any physical activity for 10 min at least one time today?', and the response options were 'yes', 'no' and 'do not know'. The subsequent questions required participants to report the physical activity type, location and time spent on the activity. On the days when participants received text messages, EMA surveys were sent 1 h after the text messages to report if they engaged in any physical activity. EMA assessed the participant's daily current physical activity [38].

2.4. Control Group

The control group wore the activPAL at baseline and follow up for 14 days in the first cycle and second cycle. Generic information related to the benefits of physical activity was provided to the control group participants. They did not participate in the action-planning session and did not receive text messages and EMA prompts, and thus were not offered the program (comparison group). After completing follow-up measures, the control group participants also received the *Mi* fitness band.

2.5. Data Collection

2.5.1. Questionnaires

Participants reported their age, sex, smoking status, marital status, weight and height, and the impact of shift work on leisure time activities on a questionnaire used in a previous shift work study [39]. The Global Physical Activity Questionnaire (GPAQ) [40] was adapted to measure physical activity at baseline.

2.5.2. Device-Based Accelerometer Measures

The activPAL (PAL Technologies Ltd., Glasgow, UK) accelerometer was used to assess physical activity. This is a small device worn on the thigh that uses static and dynamic acceleration information to distinguish body posture as sitting/lying, standing and stepping, and stepping cadence [39]. Outcome measures included time spent in a walking cadence of 100 steps/min depicting moderate-to-vigorous physical activity, total minutes of sitting time, lying down, standing, and stepping. A minimum of 5 days of activPAL use for a week, including at least one weekend day, provides a reliable estimate of the assessment outcomes [34].

2.5.3. Researcher Logbook

Process evaluation data in line with the RE-AIM framework were collected during the intervention allowing evaluation throughout the study period. An online exit survey and semi-structured interviews were administered at the end of the program. Participants' enrolment rates and attendance at all meetings were recorded in a spreadsheet, together with action planning sessions attended, dropouts and the reasons for dropping out (an example is attached as Supplementary File S1). Notes were used to record device wear and non-wear times. To record and report on the 5As during action planning, a printed document with all the sections was used for each participant.

2.5.4. Online Exit Questionnaire

At the end of the program, participants in the intervention group were invited to take part in one-on-one interviews and complete an online exit survey for intervention process evaluation. An online exit survey and semi-structured interviews were administered at the end of the program.

Participants in the intervention group were invited to complete the online exit questionnaire link via email invitation after completing the intervention [41]. Examples of questions included, "Did the program meet your expectations?" with options for answers being 'yes', 'uncertain', or 'no'. If they answered 'no', they were further asked to report the barriers experienced.

Participants (n = 17, 68%) also answered questions about the perceived impact of the intervention on their habitual levels of physical activity. The last component of the questionnaire included open-ended questions whereby participants could report on barriers and facilitators that were not addressed in the previous questions (Supplementary File S2).

2.5.5. Interviews

Intervention participants were invited via email to participate in interviews at the end of the intervention. A semi-structured interview guide using the RE-AIM framework explored each participant's perception of the intervention (Supplementary File S3). Seven interviews were conducted with participants from the intervention group representing all the departments in the mining company. All interviews were conducted online by the first author using Microsoft Teams and lasted between 20 to 30 min. Permission to record was sought from participants before the interview.

2.6. Data Analyses

2.6.1. Sample Size

A power analysis was performed based on similar studies; 27 participants per group were sufficient to have 80% power to detect a difference in time spent walking at a difference of 30 min per day or 1200 steps/day (as measured by activPAL) [42,43].

2.6.2. Quantitative Data

The data from the online exit questionnaire were downloaded and summarised in an Excel table. Descriptive statistics, including frequencies, means and standard deviations, were calculated for the demographic characteristics and overall summaries of the questionnaire components. In order to ascertain differences in demographic characteristics at baseline between the intervention and control groups, we used independent t-tests [44].

Statistical significance was defined as $p < 0.05$ and all analyses were conducted using SPSS version 27.

2.6.3. Qualitative Data Analysis

The interview transcripts were uploaded to NVivo 12 [45]. Audio recordings of the interviews were transcribed, and a summary of each interview was sent to the participant so they could review the content. A deductive coding based on the RE-AIM framework (reach, adoption, implementation, and maintenance), was used to group themes and sub-themes [46].

3. Results

The characteristics of the intervention and control groups are presented in Table 2. Employees who took part in the text messaging intervention to improve physical activity were aged (39.3; SD ± 5.5) years, predominantly (53%) male and overweight with an average BMI of (26.4; SD ± 5.8) kg/m^2. There were no significant differences in demographic characteristics between the intervention and control group participants. Most reported their health status as average. At baseline, 56% of participants reported that they are motivated to participate in leisure time physical activity. Seventeen participants (68%) completed the exit online questionnaire after completing the intervention and seven semi-structured interviews were performed (28% of the intervention participants). The findings were reported according to the RE-AIM framework elements of reach, adoption, implementation, and maintenance.

Table 2. Baseline characteristics of participants in the intervention and control groups [mean, *n* (%)].

Characteristics	Total (*n* = 51)	Intervention Group (*n* = 25)	Control Group (*n* = 26)	*p*-Value
Age years (mean, SD)	39.3 (5.4)	39.1 (5.8)	39.4 (5.2)	0.89
BMI kg/m^2 (mean, SD)	26.2 (5.8)	26.0 (7.2)	26.4 (4.2)	0.42
Gender (*n*, %)				0.39
Male	27.0 (53.0)	12.0 (44)	15.0 (55.5)	
Female	24.0 (47.0)	13.0 (54.2)	11.0 (45.8)	
Marital status (*n*, %)				0.06
Living with partner	20.0 (41.0)	12.0 (27.1)	8 (17.0)	
Health status (*n*, %)				0.07
Poor	15.0 (30.6)	10 (20.8)	5 (10.4)	
Average	20.0 (40.8)	10 (20.8)	10 (20.8)	
Excellent	2.0 (4.1)	0 (0)	2 (4.2)	
Number of participants reporting LTPA (*n*, %)	30.0 (56)	16.0 (29)	14.0 (27)	0.77

Legend: SD: Standard Deviation, BMI: Body Mass Index computed from weight and height, LTPA: Leisure Time Physical Activity. Differences between the groups were determined via an independent *t*-test with significance $p < 0.05$. Note: Living with a partner included both participants married and those not married living with partners.

3.1. Process Outcome Results

3.1.1. Reach

A variety of recruitment strategies were used to reach the mining employees. We sent emails, distributed flyers to shift workers in the workplace, posted the advertisement with a brief explanation about the study on workplace boards, presented during workers' meetings and received referrals from other enrolled participants. An overview of participants reached, assessed for eligibility and enrolled is presented in Figure 1.

We contacted 92 employees involved in shift work from all departments in the mining company, including the hospital, and the processing and mining pit departments. Ninety-two employees were screened and assessed for eligibility, and 71 provided consent (77%). Reasons for non-consent include no response ($n = 8$) and not eligible ($n = 13$). Sixty participants (84%) completed baseline measures and were allocated to intervention and control groups equally. Of the 60, 51 completed the follow-up measures (85%), and changing shifts resulted in four participants dropping out. All three mine departments were represented (Table 3). A total of 17 out of 25 participants from the intervention group completed the exit survey (68%), and seven took part in the semi-structured interviews (28%) (Figure 1). The other participants did not respond to calls, text messages or WhatsApp messages.

Table 3. Employees reached at the company.

Department	Total Number of Employees Who Signed Up for the Intervention	Total Dropout Rate
Hospital mine	30	6
Mining processing	18	2
Mining pit	12	1

Some facilitators and barriers with regard to reaching the workers in the company were identified. The common theme that facilitated reaching more employees was the information provided during recruitment about the incentive at the end of the program, hence the theme was 'incentives motivated'. The theme 'no work management involvement' highlighted the participant's perception about recruitment strategies used without the manager as a barrier for recruiting more participants. Other reasons reported by participants during interviews were prior knowledge about the health benefits of physical activity.

3.1.2. Adoption

All participants in the intervention group completed the baseline measures including the activPAL measures and online questionnaires. The action planning meetings were conducted at the employees' workplaces. Participants who missed the first action planning session were sent reminders via email and text message until all of the sessions were completed by all of the participants.

The themes relating to adoption were developed from analysing the exit questionnaires and semi-structured interviews. Participants that did not complete the follow up measures reported changed shifts and skin irritations from activPAL wear as reasons for not completing the program. Some participants reported their dislike with the activPAL accelerometer during the interviews even though they completed the measures. The number of the accelerometer wear days emerged as a possible barrier to adopting the intervention because of skin irritations reported, thus the theme "ActivPAL wear skin irritations". Participants perceived the information about physical activity through the action planning session facilitated adoption of the program according to the exit survey responses. The theme "Awareness of the benefits of physical activity" emerged as a facilitator for intervention adoption. The themes, along with the participants' quotes, are presented in Table 4. A small number of participants reported that the new information gained from the researcher feedback, particularly about sitting and the benefits of reducing sitting time, was well-received. One of the male employees reported that they are now aware of the health effects of prolonged standing and sitting and that they will now change.

Ten out of 17 participants rated the action planning session as 'excellent'. Nine participants also rated the text messages as 'excellent' as their reasons for adopting the program, and eight rated the EMA app and perceived benefits of the program as 'excellent'. The summary of exit questionnaires revealed positive responses to intervention components enhancing the adoption of the program (Figure 2).

Table 4. Themes related to indicators of reach, adoption, implementation and maintenance.

RE-AIM Components	Theme	Facilitator /Barrier	Quotes
Reach	Incentive promised	Facilitator	Female hospital nurse: "*Well, I saw one on the colleagues wearing the fitness band, honestly, I got excited and felt you know, I really need to get this myself. Remember I even approached you and asked you to give me one before I can even join program*".
	Aware of the benefits	Facilitator	Male pit mine worker: "*Once I heard the program was about wellness, I joined because I am some who likes being active. But I haven't exerciced since COVID. I thought this is the chance to improve my physical activity*".
	No work management involvement	Barrier	Male mine processing worker: "*I think because you are a researcher from outside. People in the mine are usually keen if the employer was more involved. Maybe in future the mine management should be involved so more people will participate than just you alone*".
	ActivPAL wear skin irritations	Barrier	Female hospital nurse: "*I wish there could be something else to use than the stickers because some skin are very sensitive causing some irritation*".
Implementation	Text messages useful	Facilitator	Male mine pit worker: "*The text messages were helpful. They were a reminder especially on a lazy day and I receive a text. Then I will get up and something. They assisted me to be active*".
	Program beneficial	Facilitator	Male hospital nurse: "*This program is very reliable to shift workers because they can do their physical activity in a planned manner and time*".
	Work factors	Barrier	Female hospital nurse: "*I wanted to do more, but because of work, I get home really tired*".
Maintenance	Continuation in use of information from program	Facilitator	Male mine processing worker: "*The program has helped with the monitoring, so it motivated me to be active. These days I hardly skip gym. Had a slow week last week, but back to gym this week*".
	Continuation use of the *Mi* fitness band	Facilitator	Male mine pit worker: "*I set myself a standard that it should be 10,000 steps a day so if I haven't done those 10,000 steps so I stand up and start doing some exercises. Even if it's not walking now. I have a machine step that I use*".
	Recommendation to use the program for the company	Facilitator	Female hospital nurse: "*It was a very beneficial program for me personally and for the company. I have been regularly engaging in physical activity ever since participating in the study. I also hope the results will reach relevant authorities*".

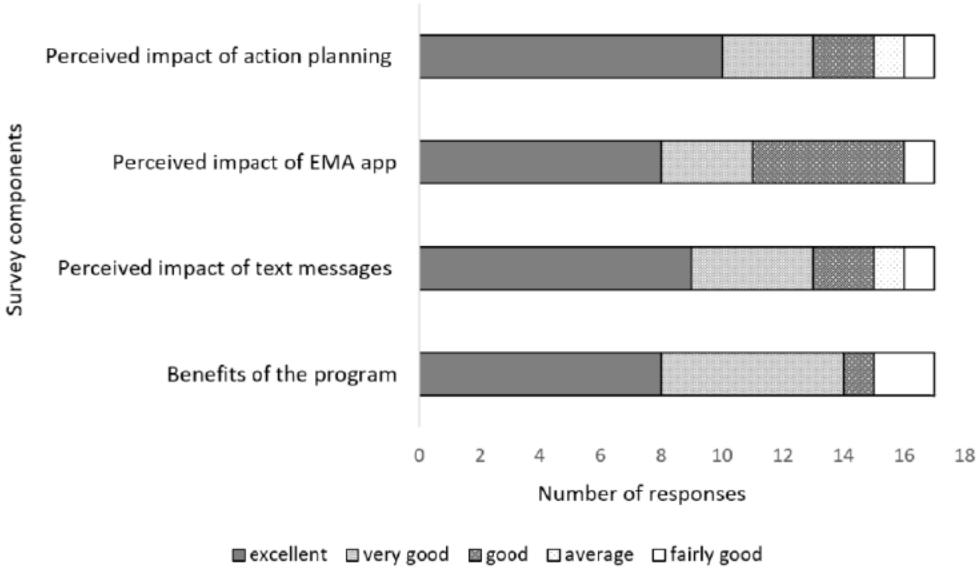


Figure 2. Summary of exit survey questions on adoption of intervention components. **Perceived impact of action planning**: participants reporting how they rate action planning, **Perceived impact of EMA app**: participants reporting their rating for the EMA app, **Perceived impact of text messages:** participants reporting their rating for the text messages, **Benefits of the program**: participants reporting their rating for the health promotion program.

3.1.3. Implementation

Action planning sessions took 30 min on average per person. Each session involved giving participants feedback on their physical activity data downloaded from the activPAL. The feedback was then followed by the use of the 5As to facilitate the discussion about changing physical activity, assisting with goal setting, and assessing readiness for change. The discussions were recorded on a sheet of paper, and then participants were informed about the follow-up measures at the end of the intervention.

The activPAL accelerometer device wear days ranged from 10–14 days. However, data downloaded showed that three devices did not record data due to device malfunction. All three participants agreed to repeat the measurements with a different device.

The EMA application link was sent to participants via email to be downloaded at the end of the action planning session. Participants (n = 20) successfully downloaded the app during the meeting. Five participants who could not download the EMA app due to internet connection difficulties were instructed to download it later once they had a good internet connection. Out of the five, two reported that they were not receiving EMA surveys after downloading the app. They were invited to attend another meeting at their workplace to set up the app with the help of the researcher. However, the EMA surveys were still not received due to unknown reasons, resulting in 23 participants receiving the EMA surveys as planned. Participants were sent one EMA survey per day for 24 days during the intervention. Participants responded to 59% of the EMA surveys. The timing of the EMA surveys and text messages were agreed upon, and a pre-determined time was set during action planning. On average, each participant received 15 text messages. All of the text messages were sent as planned, and 10% of the text messages were responded to.

Themes and participants' quotes relating to intervention implementation are presented in Table 4 and illustrate the facilitators and barriers identified from the exit questionnaires and interviews conducted. Participants' perceived work-related factors was one of the main barriers to implementing the program. Work-related fatigue was associated with lack of increasing physical activity during workdays, as participants reported that they were too tired to engage in any physical activity after work. Similarly, some participants reported that working night shifts had a negative impact on their sleep patterns. One the other hand, the text messages forming part of the intervention were well-received, and motivated participants to increase their physical activity. Moreover, the *Mi* fitness band was desired by most participants.

The exit surveys revealed that the intervention met expectations of 16 of 17 participants. Only three reported that they experienced some barriers during the program (Figure 3). However, only one participant indicated on the survey that their change of shifts was a barrier for the implementing of the program.

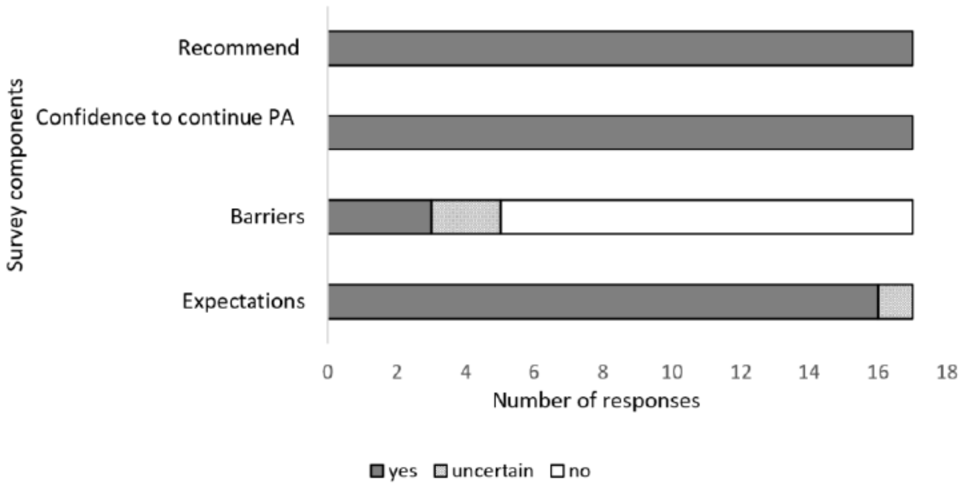


Figure 3. Summary of exit questionnaires on implementation and maintenance of the program. **Recommend**: number of participants reporting that they would recommend the program to other shift workers, **Confidence to continue PA**: number of participants who reported that they will continue to be physically active, **Barriers:** participants reporting that they encountered barriers to taking part in the program, **Expectations**: participants reporting whether their expectations about the program were met.

3.1.4. Maintenance

Long-term outcomes were not assessed in this study, with the exit survey and interviews focused on perceptions of the future use of the intervention components. The majority of participants had shown appreciation for the usefulness of the health promotion program. The theme "Continuation use of information from program" emerged to indicate that participants may continue to sustain their change in physical activity. To sustain and monitor healthy behaviour beyond the intervention, *Mi* fitness bands were given as incentives. The majority of participants had shown appreciation of the fitness band and reported that they were using it. The interviews also revealed that participants found the program to be useful and that they would recommend it to other shift workers in the future. Table 4 presents themes and quotes from interviews related to the maintenance of the program.

All participants (100%) reported that they would recommend the program to other shift workers in their workplace and that they intended to continue engaging in physical activities (Figure 3).

4. Discussion

The main aim of this study was to conduct a process evaluation of a text messaging intervention to increase physical activity in shift workers based at a mining company. The RE-AIM framework was adopted. Our study findings showed that the program was largely implemented as intended, resulting in good uptake and adherence by employees.

4.1. Reach

Overall, results indicate that the program reached 66% of shift workers in the company. The proportion of participants signing up for our study was higher than other workplace health promotion programs, with the reach ranging from 23% to 59% [32,47,48]. The proportion of workers enrolled in our study suggested that the strategy of using several recruitment strategies was successful. In a workplace intervention designed to reduce sitting, participants were approached mainly via email, resulting in a 59% participation rate [48] across four companies, with the higher participation in smaller companies [48]. This was supported by the results on recruitment rates in workplace physical activity interventions, showing higher recruitment rates in smaller companies [49].

However, the analysis from interviews showed that the recruitment in our study may have been higher if the program recruitment was driven by the organisation. Barriers reported by participants in the study suggest that not involving company managers may have decreased participation in the program. Furthermore, participants showed the need for clarity regarding whether the researcher has workplace permission and if the program was communicated with the management. Evidence shows that organisational management support during the recruitment for workplace health promotion programs result in enhanced participation [49]. In a study with low recruitment rates, participants reported that the program had not been effectively communicated by the management teams [32]. To improve future study participation rates, it may be important to prioritise management involvement to encourage workers to participate in health promotion programs.

4.2. Adoption

There were high ratings for the intervention components, with most participants reporting the benefit in using these components. The text messages were regarded as useful for improving physical activity. This finding was corroborated by previous studies that indicated that text messaging was feasible and had promising effects on physical activity [50–52]. Similar to our study, truck drivers participating in an intervention that also included text messages reported that the messages were appropriate and informative [25]. Although Guest and colleagues used Social Cognitive Theory for behaviour change [53], they recommended that the COM-B model would be the best fit to change behaviours for the health intervention for truckers [25]. In our study, text messages were developed using the COM-B model, with capability, opportunity and motivation components [37] playing an important role in the adoption of our physical activity health promotion program. Therefore, interventions should consider including text messages guided by the COM-B in health promotion programs to improve physical activity in shift workers. Furthermore, the use of evidence- and theory-based frameworks to develop the intervention and conduct the process evaluation resulted in the program being desired by workers in the mine more than the previous workplace interventions. Participants reported that the previous workplace wellness programs focused mainly on weight loss with no feedback on physical activity behaviour or much information on physical activity guidelines. The text messaging intervention has the potential to increase physical activity, thus reducing the disease burden in shift workers.

In addition to text messages, action planning appeared to be important for successful adoption and implementation. The majority of participants attended the action planning session, and those who missed it responded after receiving the reminders. Our study was robust in explaining the benefits of physical activity for shift workers' health and well-being. Our study findings showed that action planning was important in facilitating program adoption, similar to other health promotion programs [54]. The action planning used with other behaviour change techniques has been shown to elicit motivation in participants and to result in increased physical activity [36]. Similar to our study, using multi-approaches rather than unidimensional ones for office workers resulted in improved posture [55]. Even though shift workers in our study seemed to appreciate the information and understand the benefit of changing their physical activity, work factors, including fatigue, may prevent them from being active. With workplaces involving shift work, it will be important to include physical activity during work times. Furthermore, the action planning session might have overcome other potential barriers to adopt the intervention.

4.3. Implementation

The intervention was fully delivered, in the correct order, and within the shift cycle (24 days) as planned, and no adverse events were reported. There were some minor changes in the number of activPAL wear days due to skin irritation complaints. However, this was expected due to the length of the shifts and was reported on the information sheets. Previous studies have also reported skin irritation with activPAL wear [56,57]. Therefore, we accepted 11 days of activPAL wear in place of the initial proposed 16 days of four days per shift. Three days in each work shift and two non-workdays were captured with the 11 days of activPAL wear. However, participants who were willing to wear the device for the 14–16 days were still allowed to. This is supported by a previous study that used a continuous five days of activPAL wear, including the weekend. This was seen as acceptable [58], since all shift schedules and two workdays were included.

Our finding concerning the low EMA response rate is comparable to an EMA study in another low-and-middle income country [59]. We set the EMA prompts according to the pre-agreed time from the action planning session. However, some participants later reported a change of shifts, suggesting that unexpected shift changes might have affected EMA response rates. Previous studies have shown that EMA surveys with a smartwatch can have a significantly higher response rate than those using a smartphone application [60]. The use of smartwatches or fitness bands would have been a better choice to self-report physical activity, especially for the mine workers who are not allowed to carry their phones during work hours. However, smartphones were chosen for the current study due to their being more practical and cost-effective than smartwatches.

However, there were some challenges reported during the program. A few participants reported that the questionnaires were too long and only completed them after several reminders. Long questionnaires, especially at follow up, seem to present a concern for the workers. Thus, shorter surveys with the use of mobile EMA with more ecological validity could be useful to measure healthy behaviours for baseline and follow-up measures. Walthouwer et al. also reported decreased uptake because participants reported that it took too long to complete the questionnaires [61].

4.4. Maintenance

Participants were optimistic and reported that they would recommend the health promotion program to other shift workers. Whilst enthusiasm and feedback were positive about continuing with the program, maintenance at the organisational level was not assessed. Therefore, interventions need to evaluate the company setting, especially targeting management to influence intervention uptake and continuity in the workplace [48]. The *Mi* fitness band received as an incentive was useful beyond the period of the intervention. Therefore, giving fitness bands as an incentive rather than money may increase changes in physical activity behaviour.

The results of our study suggest that the text-messaging health promotion program was well received by shift workers. These findings are encouraging, as adapting the intervention to participants' shift cycles might increase uptake and encourage them to increase and maintain habitual levels of physical activity. In addition, it was encouraging to know that the program was well-received by participants, and that they were all willing to promote it to their colleagues. The text messages in particular encouraged participants to increase their physical activity. Furthermore, workers emphasized the *Mi* fitness band as being a strong motivator for taking part in the program and continued to use it after the program. Workers expressed that they desired the physical activity program, however there is a need to address some work factors including fatigue and more involvement from company management. Our findings therefore suggest that future interventions among shift workers should incorporate action planning based on the shift worker's schedule, include text messages, and include the use of physical activity monitors/wearables, such as the Mi fitness wristband. Future research should explore the effectiveness of the intervention over more than 1 shift cycle and the optimal frequency and content of the text messages. For workplaces with fatigue-related issues, frequent breaks should be emphasized in future studies to reduce fatigue in order to promote physical activity during workdays.

5. Strengths and Limitations

The process evaluation combined quantitative and qualitative components, and therefore provided a strong insight into participants' perceptions of the health promotion program and also lessons for future research involving shift workers. Furthermore, the intervention development was guided by the behaviour change wheel COM-B components and was evaluated using the RE-AIM framework. However, some limitations should be noted. This study involved one diamond mining company in Botswana. The mining company chosen represents a dominant private employer in Botswana and has similar operations in other towns. The results may not be generalizable to other mines, industries, and countries. Similarly, the workplace in the mining town in the south of Botswana may differ from other mining towns within the same company. Furthermore, we may not have identified all the barriers and potential enablers for increasing physical activity and promoting healthy behaviours. The number of workers recruited did not match our sample size calculation; however, this was a pilot study, and thus 25 individuals per group would be acceptable [62].

6. Conclusions

This study showed that a text messaging health promotion program to improve physical activity is feasible for mining shift workers. The health promotion program was well-received, but recruitment strategies involving work management should be considered to increase uptake. Our findings showed that the program has the potential to change physical activity and increase awareness of the benefits of physical activity for the shift work population. Providing feedback on physical activity and giving the fitness band as an incentive were successful approaches that are viable for future workplace health promotions for shift workers. However, understanding the long-term impact of the intervention is needed, including how continued participation by employees and companies may impact the intervention. This evaluation provides insights for researchers and practitioners planning and implementing health promotion programs in a mining workplace targeting the shift working population.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/ijerph20043260/s1, File S1: Participant enrolment; File S2: Exit online survey; File S3: Interview guide.

Author Contributions: Conceptualization, M.M., S.J.H.B. and T.K.-A.; Methodology, M.M., S.J.H.B. and T.K.-A.; Investigation, M.M.; Writing—original draft, M.M., S.J.H.B. and T.K.-A.; Writing—review & editing, S.J.H.B. and T.K.-A.; Supervision, S.J.H.B. and T.K.-A.; Project administration, M.M. All authors have read and agreed to the published version of the manuscript.

Funding: This work is part of the lead author's PhD research project supported primarily by the University of Botswana staff scholarship and University of Southern Queensland.

Institutional Review Board Statement: This study was conducted in accordance with the protocols and procedures outlined in the proposal as approved by University of Southern Queensland's Human Research Ethics Committee (USQ HREC) (No: H22REA021) on 08/04/2022.

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Acknowledgments: We thank participants who took part in our study and the company that the study was conducted at. We would also like to thank the researchers from the University of Melbourne, Australian Catholic University and Orygen—The National Centre of Excellence in Youth Mental Health researchers who developed the Smartphone Ecological Momentary Assessment (SEMA3) application that was used for this study.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Min, A.; Hong, H.C.; Kim, Y.M. Work schedule characteristics and occupational fatigue/recovery among rotating-shift nurses: A cross-sectional study. *J. Nurs. Manag.* **2022**, *30*, 463–472. [CrossRef] [PubMed]
2. Costa, G. Introduction to Problems of Shift Work. In *Social and Family Issues in Shift Work and Non Standard Working Hours*; Iskra-Golec, I., Barnes-Farrell, J., Bohle, P., Eds.; Springer: Cham, Switzerland, 2016; pp. 19–35.
3. Williams, C.C.; Schneider, F. *Measuring the Global Shadow Economy: The Prevalence of Informal Work and Labour*; Edward Elgar Publishing: Cheltenham, UK, 2016.
4. Brown, J.P.; Martin, D.; Nagaria, Z.; Verceles, A.C.; Jobe, S.L.; Wickwire, E.M. Mental Health Consequences of Shift Work: An Updated Review. *Curr. Psychiatry Rep.* **2020**, *22*, 7. [CrossRef] [PubMed]
5. Sooriyaarachchi, P.; Jayawardena, R.; Pavey, T.; King, N.A. Shift work and the risk for metabolic syndrome among healthcare workers: A systematic review and meta-analysis. *Obes. Rev.* **2022**, *23*, e13489. [CrossRef]
6. Su, F.; Huang, D.; Wang, H.; Yang, Z. Associations of shift work and night work with risk of all-cause, cardiovascular and cancer mortality: A meta-analysis of cohort studies. *Sleep Med.* **2021**, *86*, 90–98. [CrossRef] [PubMed]
7. Kassa, M.; Grace, J. The global burden and perspectives on non-communicable diseases (NCDs) and the prevention, data availability and systems approach of NCDs in low-resource countries. In *Public Health in Developing Countries-Challenges and Opportunities*; IntechOpen: London, UK, 2019.
8. Saqib, Z.A.; Dai, J.; Menhas, R.; Mahmood, S.; Karim, M.; Sang, X.; Weng, Y. Physical Activity is a Medicine for Non-Communicable Diseases: A Survey Study Regarding the Perception of Physical Activity Impact on Health Wellbeing. *Risk Manag. Healthc. Policy* **2020**, *13*, 2949–2962. [CrossRef] [PubMed]
9. Guthold, R.; Stevens, G.A.; Riley, L.M.; Bull, F.C. Worldwide trends in insufficient physical activity from 2001 to 2016: A pooled analysis of 358 population-based surveys with 1·9 million participants. *Lancet Glob. Health* **2018**, *6*, e1077–e1086. [CrossRef]
10. Bull, F.C.; Al-Ansari, S.S.; Biddle, S.; Borodulin, K.; Buman, M.P.; Cardon, G.; Carty, C.; Chaput, J.P.; Chastin, S.; Chou, R.; et al. World Health Organization 2020 guidelines on physical activity and sedentary behaviour. *Br. J. Sports Med.* **2020**, *54*, 1451–1462. [CrossRef]
11. Monnaatsie, M.; Biddle, S.J.; Khan, S.; Kolbe-Alexander, T. Physical activity and sedentary behaviour in shift and non-shift workers: A systematic review and meta-analysis. *Prev. Med. Rep.* **2021**, *24*, 101597. [CrossRef]
12. Ramezani, M.; Tayefi, B.; Zandian, E.; SoleimanvandiAzar, N.; Khalili, N.; Hoveidamanesh, S.; Massahikhaleghi, P.; Rampisheh, Z. Workplace interventions for increasing physical activity in employees: A systematic review. *J. Occup. Health* **2022**, *64*, e12358. [CrossRef]
13. Malik, S.H.; Blake, H.; Suggs, L.S. A systematic review of workplace health promotion interventions for increasing physical activity. *Br. J. Health Psychol.* **2014**, *19*, 149–180. [CrossRef]
14. Tunwattanapong, P.; Kongkasuwan, R.; Kuptniratsaikul, V. The effectiveness of a neck and shoulder stretching exercise program among office workers with neck pain: A randomized controlled trial. *Clin. Rehabil.* **2016**, *30*, 64–72. [CrossRef] [PubMed]
15. Freak-Poli, R.; Cumpston, M.; Albarqouni, L.; Clemes, S.A.; Peeters, A. Workplace pedometer interventions for increasing physical activity. *Cochrane Database Syst. Rev.* **2020**, *7*, Cd009209. [CrossRef] [PubMed]
16. Gutermuth, L.K.; Hager, E.R.; Pollack Porter, K. Using the CDC's Worksite Health ScoreCard as a Framework to Examine Worksite Health Promotion and Physical Activity. *Prev. Chronic Dis.* **2018**, *15*, E84. [CrossRef] [PubMed]
17. To, Q.G.; Chen, T.T.; Magnussen, C.G.; To, K.G. Workplace physical activity interventions: A systematic review. *Am. J. Health Promot.* **2013**, *27*, e113–e123. [CrossRef] [PubMed]
18. Kaveh, M.H.; Layeghiasl, M.; Nazari, M.; Ghahremani, L.; Karimi, M. What Are the Determinants of a Workplace Health Promotion? Application of a Social Marketing Model in Identifying Determinants of Physical Activity in the Workplace (a Qualitative Study). *Front. Public Health* **2020**, *8*, 614631. [CrossRef]
19. Jain, R.; Verma, V.; Rana, K.B.; Meena, M.L. Effect of physical activity intervention on the musculoskeletal health of university student computer users during homestay. *Int. J. Occup. Saf. Ergon.* **2023**, *29*, 25–30. [CrossRef]

20. Kelly, C.; Nea, F.M.; Pourshahidi, L.K.; Kearney, J.M.; O'Brien, V.; Livingstone, M.B.E.; Corish, C.A. Adherence to dietary and physical activity guidelines among shift workers: Associations with individual and work-related factors. *BMJ Nutr. Prev. Health* **2020**, *3*, 229–238. [CrossRef]
21. Beringer, C.; Wells, M.; Goldstein, L. Let's get physical: A prospective pedometer study of doctors working in a South African emergency department. *SAMJ S. Afr. Med. J.* **2020**, *110*, 1124–1127. [CrossRef]
22. Krüger, K.; Petermann, C.; Pilat, C.; Schubert, E.; Pons-Kühnemann, J.; Mooren, F.C. Preventive strength training improves working ergonomics during welding. *Int. J. Occup. Saf. Ergon.* **2015**, *21*, 150–157. [CrossRef]
23. Neil-Sztramko, S.E.; Gotay, C.C.; Sabiston, C.M.; Demers, P.A.; Campbell, K.C. Feasibility of a telephone and web-based physical activity intervention for women shift workers. *Transl. Behav. Med.* **2017**, *7*, 268–276. [CrossRef]
24. Thøgersen-Ntoumani, C.; Quested, E.; Biddle, S.J.H.; Kritz, M.; Olson, J.; Burton, E.; Cerin, E.; Hill, K.D.; McVeigh, J.; Ntoumanis, N. Trial feasibility and process evaluation of a motivationally-embellished group peer led walking intervention in retirement villages using the RE-AIM framework: The residents in action trial (RiAT). *Health Psychol. Behav. Med.* **2019**, *7*, 202–233. [CrossRef]
25. Guest, A.J.; Paine, N.J.; Chen, Y.L.; Chalkley, A.; Munir, F.; Edwardson, C.L.; Gray, L.J.; Johnson, V.; Ruettger, K.; Sayyah, M.; et al. The structured health intervention for truckers (SHIFT) cluster randomised controlled trial: A mixed methods process evaluation. *Int. J. Behav. Nutr. Phys. Act.* **2022**, *19*, 79. [CrossRef] [PubMed]
26. Varela-Mato, V.; Caddick, N.; King, J.A.; Yates, T.; Stensel, D.J.; Nimmo, M.A.; Clemes, S.A. A Structured Health Intervention for Truckers (SHIFT): A Process Evaluation of a Pilot Health Intervention in a Transport Company. *J. Occup. Environ. Med.* **2018**, *60*, 377–385. [CrossRef] [PubMed]
27. Punnett, L.; Nobrega, S.; Zhang, Y.; Rice, S.; Gore, R.; Kurowski, A. Safety and Health through Integrated, Facilitated Teams (SHIFT): Stepped-wedge protocol for prospective, mixed-methods evaluation of the Healthy Workplace Participatory Program. *BMC Public Health* **2020**, *20*, 1463. [CrossRef]
28. Antikainen, I.; Ellis, R. A RE-AIM evaluation of theory-based physical activity interventions. *J. Sport Exerc. Psychol.* **2011**, *33*, 198–214. [CrossRef]
29. Caperchione, C.M.; Duncan, M.; Kolt, G.S.; Vandelanotte, C.; Rosenkranz, R.R.; Maeder, A.; Noakes, M.; Karunanithi, M.; Mummery, W.K. Examining an Australian physical activity and nutrition intervention using RE-AIM. *Health Promot. Int.* **2015**, *31*, 450–458. [CrossRef] [PubMed]
30. Glasgow, R.E.; Harden, S.M.; Gaglio, B.; Rabin, B.; Smith, M.L.; Porter, G.C.; Ory, M.G.; Estabrooks, P.A. RE-AIM planning and evaluation framework: Adapting to new science and practice with a 20-year review. *Front. Public Health* **2019**, *7*, 64. [CrossRef]
31. Kwan, B.M.; McGinnes, H.L.; Ory, M.G.; Estabrooks, P.A.; Waxmonsky, J.A.; Glasgow, R.E. RE-AIM in the Real World: Use of the RE-AIM Framework for Program Planning and Evaluation in Clinical and Community Settings. *Front. Public Health* **2019**, *7*, 345. [CrossRef]
32. Brinkley, A.; McDermott, H.; Munir, F. Team Sport in the Workplace? A RE-AIM Process Evaluation of 'Changing the Game'. *AIMS Public Health* **2017**, *4*, 466–489. [CrossRef]
33. Robinson, K.; Allen, F.; Darby, J.; Fox, C.; Gordon, A.L.; Horne, J.C.; Leighton, P.; Sims, E.; Logan, P.A. Contamination in complex healthcare trials: The falls in care homes (FinCH) study experience. *BMC Med. Res. Methodol.* **2020**, *20*, 46. [CrossRef]
34. Concheiro-Moscoso, P.; Martínez-Martínez, F.J.; Miranda-Duro, M.D.C.; Pousada, T.; Nieto-Riveiro, L.; Groba, B.; Mejuto-Muiño, F.J.; Pereira, J. Study Protocol on the Validation of the Quality of Sleep Data from Xiaomi Domestic Wristbands. *Int. J. Environ. Res. Public Health* **2021**, *18*, 1106. [CrossRef] [PubMed]
35. Glasgow, R.E.; Emont, S.; Miller, D.C. Assessing delivery of the five 'As' for patient-centered counseling. *Health Promot. Int.* **2006**, *21*, 245–255. [CrossRef]
36. Schroé, H.; Van Dyck, D.; De Paepe, A.; Poppe, L.; Loh, W.W.; Verloigne, M.; Loeys, T.; De Bourdeaudhuij, I.; Crombez, G. Which behaviour change techniques are effective to promote physical activity and reduce sedentary behaviour in adults: A factorial randomized trial of an e- and m-health intervention. *Int. J. Behav. Nutr. Phys. Act.* **2020**, *17*, 127. [CrossRef]
37. Michie, S.; Van Stralen, M.M.; West, R. The behaviour change wheel: A new method for characterising and designing behaviour change interventions. *Implement. Sci.* **2011**, *6*, 42. [CrossRef]
38. Burke, L.E.; Shiffman, S.; Music, E.; Styn, M.A.; Kriska, A.; Smailagic, A.; Siewiorek, D.; Ewing, L.J.; Chasens, E.; French, B.; et al. Ecological Momentary Assessment in Behavioral Research: Addressing Technological and Human Participant Challenges. *J. Med. Internet Res.* **2017**, *19*, e77. [CrossRef] [PubMed]
39. Kolbe-Alexander, T.L.; Gomersall, S.; Clark, B.; Torquati, L.; Pavey, T.; Brown, W.J. A hard day's night: Time use in shift workers. *BMC Public Health* **2019**, *19*, 452. [CrossRef] [PubMed]
40. Bull, F.C.; Maslin, T.S.; Armstrong, T. Global physical activity questionnaire (GPAQ): Nine country reliability and validity study. *J. Phys. Act. Health* **2009**, *6*, 790–804. [CrossRef] [PubMed]
41. Forman, J.; Heisler, M.; Damschroder, L.J.; Kaselitz, E.; Kerr, E.A. Development and application of the RE-AIM QuEST mixed methods framework for program evaluation. *Prev. Med. Rep.* **2017**, *6*, 322–328. [CrossRef]
42. Dall, P.M.; Ellis, S.L.H.; Ellis, B.M.; Grant, P.M.; Colyer, A.; Gee, N.R.; Granat, M.H.; Mills, D.S. The influence of dog ownership on objective measures of free-living physical activity and sedentary behaviour in community-dwelling older adults: A longitudinal case-controlled study. *BMC Public Health* **2017**, *17*, 496. [CrossRef]

43. Carr, L.J.; Bartee, R.T.; Dorozynski, C.; Broomfield, J.F.; Smith, M.L.; Smith, D.T. Internet-delivered behavior change program increases physical activity and improves cardiometabolic disease risk factors in sedentary adults: Results of a randomized controlled trial. *Prev. Med.* **2008**, *46*, 431–438. [CrossRef]
44. De Muth, J.E. Overview of biostatistics used in clinical research. *Am. J. Health Syst. Pharm.* **2009**, *66*, 70–81. [CrossRef] [PubMed]
45. Braun, V.; Clarke, V. Using thematic analysis in psychology. *Qual. Res. Psychol.* **2006**, *3*, 77–101. [CrossRef]
46. Ritchie, J.; Lewis, J.; Nicholls, C.M.; Ormston, R. *Qualitative Research Practice: A Guide for Social Science Students and Researchers*; Sage: Thousand Oaks, CA, USA, 2013.
47. Blake, H.; Lai, B.; Coman, E.; Houdmont, J.; Griffiths, A. Move-It: A Cluster-Randomised Digital Worksite Exercise Intervention in China: Outcome and Process Evaluation. *Int. J. Environ. Res. Public Health* **2019**, *16*, 3451. [CrossRef] [PubMed]
48. MacDonald, B.; Gibson, A.M.; Janssen, X.; Hutchinson, J.; Headley, S.; Matthews, T.; Kirk, A. Should We Scale-Up? A Mixed Methods Process Evaluation of an Intervention Targeting Sedentary Office Workers Using the RE-AIM QuEST Framework. *Int. J. Environ. Res. Public Health* **2019**, *17*, 239. [CrossRef] [PubMed]
49. Ryde, G.C.; Gilson, N.D.; Burton, N.W.; Brown, W.J. Recruitment Rates in Workplace Physical Activity Interventions: Characteristics for Success. *Am. J. Health Promot.* **2013**, *27*, e101–e112. [CrossRef] [PubMed]
50. Buchholz, S.W.; Wilbur, J.; Ingram, D.; Fogg, L. Physical activity text messaging interventions in adults: A systematic review. *Worldviews Evid. Based Nurs.* **2013**, *10*, 163–173. [CrossRef]
51. Patterson, K.; Davey, R.; Keegan, R.; Freene, N. Smartphone applications for physical activity and sedentary behaviour change in people with cardiovascular disease: A systematic review and meta-analysis. *PLoS ONE* **2021**, *16*, e0258460. [CrossRef]
52. Rathbone, A.L.; Prescott, J. The Use of Mobile Apps and SMS Messaging as Physical and Mental Health Interventions: Systematic Review. *J. Med. Internet Res.* **2017**, *19*, e295. [CrossRef]
53. Schunk, D.H.; Usher, E.L. Social cognitive theory and motivation. *Oxf. Handb. Hum. Motiv.* **2012**, *2*, 11–26.
54. De Cocker, K.; De Bourdeaudhuij, I.; Cardon, G.; Vandelanotte, C. What are the working mechanisms of a web-based workplace sitting intervention targeting psychosocial factors and action planning? *BMC Public Health* **2017**, *17*, 382. [CrossRef]
55. Sanaeinasab, H.; Saffari, M.; Valipour, F.; Alipour, H.R.; Sepandi, M.; Al Zaben, F.; Koenig, H.G. The effectiveness of a model-based health education intervention to improve ergonomic posture in office computer workers: A randomized controlled trial. *Int. Arch. Occup. Environ. Health* **2018**, *91*, 951–962. [CrossRef] [PubMed]
56. Shi, Y.; Huang, W.Y.; Yu, J.J.; Sheridan, S.; Sit, C.H.-P.; Wong, S.H.-S. Compliance and Practical Utility of Continuous Wearing of activPAL™ in Adolescents. *Pediatr. Exerc. Sci.* **2019**, *31*, 363–369. [CrossRef] [PubMed]
57. Schrack, J.A.; Cooper, R.; Koster, A.; Shiroma, E.J.; Murabito, J.M.; Rejeski, W.J.; Ferrucci, L.; Harris, T.B. Assessing Daily Physical Activity in Older Adults: Unraveling the Complexity of Monitors, Measures, and Methods. *J. Gerontol. Ser. A* **2016**, *71*, 1039–1048. [CrossRef] [PubMed]
58. Aguilar-Farias, N.; Martino-Fuentealba, P.; Salom-Diaz, N.; Brown, W.J. How many days are enough for measuring weekly activity behaviours with the ActivPAL in adults? *J. Sci. Med. Sport* **2019**, *22*, 684–688. [CrossRef]
59. Beres, L.K.; Mbabali, I.; Anok, A.; Katabalwa, C.; Mulamba, J.; Thomas, A.G.; Bugos, E.; Grabowski, M.K.; Nakigozi, G.; Chang, L. Acceptability and feasibility of mobile phone-based ecological momentary assessment and intervention in Uganda: A pilot randomized controlled trial. *PLoS ONE* **2022**, *17*, e0273228. [CrossRef]
60. Ponnada, A.; Thapa-Chhetry, B.; Manjourides, J.; Intille, S. Measuring criterion validity of microinteraction ecological momentary assessment (micro-ema): Exploratory pilot study with physical activity measurement. *JMIR mHealth uHealth* **2021**, *9*, e23391. [CrossRef]
61. Walthouwer, M.J.; Oenema, A.; Lechner, L.; de Vries, H. Comparing a Video and Text Version of a Web-Based Computer-Tailored Intervention for Obesity Prevention: A Randomized Controlled Trial. *J. Med. Internet Res.* **2015**, *17*, e236. [CrossRef]
62. Lewis, M.; Bromley, K.; Sutton, C.J.; McCray, G.; Myers, H.L.; Lancaster, G.A. Determining sample size for progression criteria for pragmatic pilot RCTs: The hypothesis test strikes back! *Pilot Feasibility Stud.* **2021**, *7*, 40. [CrossRef]

7.3 Implications and contribution to the advancement of the research area

This study provide good insights about the experiences of shift workers who took part in the intervention. The use of RE-AIM framework provided a comprehensive guide to identify barriers and facilitators (Glasgow et al., 2019). All the 25 participants in the intervention group were invited for the interviews, however only seven agreed to be interviewed. Future research should aim to recruit more participants, to improve the quality and accuracy of the results.

While EMA compliance rate was relatively low (59%) we learnt important lessons regarding procedures with assessing physical activity, adapting text messages and EMA to different shift schedules. COM-B model and the behaviour change techniques including feedback on behaviour, action planning were desired by participants. The process evaluation and intervention were designed systematically using RE-AIM and COM-B frameworks. This adds to the body of knowledge on intervention that use theories and frameworks in health promotion programs. However, a participatory approach with workers and the employer involved in the planning of the intervention would be beneficial. This study provides support for using tailored text messages for future interventions to influence physical activity in mining shift workers.

However, the use of EMA needs further investigation to use for the intervention as the compliance was low.

The intervention resulted in some changes in physical activity, mainly when working morning/day shifts and non-workdays. Thus, shift workers could benefit from leisure activities that are enjoyable and more beneficial for their well-being than occupational physical activity, which may not be necessarily good for their health. In addition, it is worth investigating the effectiveness of the intervention in improving shift workers’ physical activity.

CHAPTER 8: OVERALL DISCUSSION AND CONCLUSION

8.1. Overview of the chapter

This final chapter provides a summary of findings, overall discussion, implications, recommendations for future research, strengths/limitations, and conclusions. Figure 8.1 presents thesis summary.

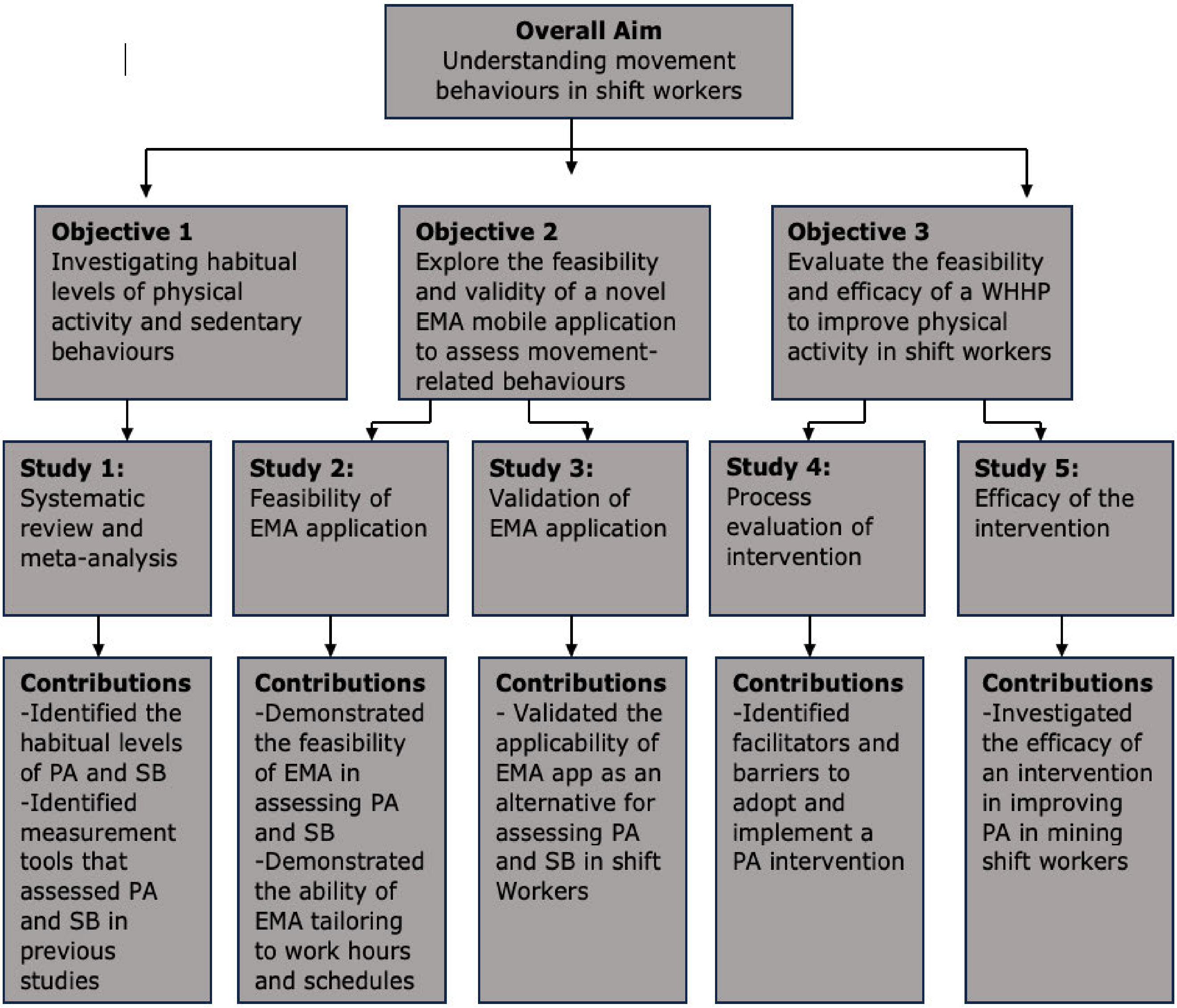


Figure 8.1 Overview of research activities and outcomes

8.2. Summary of Aims and Main Findings

The main aim of the overall PhD was to investigate the habitual levels of physical activity and sedentary behaviour in shift workers. We collated the evidence to determine if shift workers are less active or more sedentary than non-shift workers. In addition, a pilot of a novel mobile EMA application was investigated to assess its feasibility and validity. EMA was also used with the text messages in the health promotion program to improve physical activity in mining shift workers.

The result of our systematic review and meta-analysis showed that habitual levels of physical activity was similar for shift and non-shift workers (Monnaatsie et al., 2021). Since the habitual levels of physical activity are similar for shift and non-shift workers, it can then be suggested that the shift work-related health risks are unlikely to be the result of decreased physical activity and high sedentary behaviour. However, the physical activity was low in both groups, thus both could benefit from taking part in health promotion programs.

Our meta-analysis only included overall physical activity. However, it is important to note that physical activity is a complex behaviour, and multiple domains and factors contribute to daily physical activity levels (Rhodes et al., 2019). Opportunities to be active exist in several domains including at work, household or at school, for travel or during leisure time (Strain et al., 2020). Information on domains is necessary to fully understand the dynamics of physical activity in shift workers especially as evidence shows that different domains may contribute to health in different ways as discussed in chapter 7 (Holtermann et al., 2021). Strong evidence suggests that EMA can provide context-rich data (Engelen et al., 2016; Maher et al., 2018). Thus, could be possible with the use of EMA that was shown to be feasible to use in shift workers in chapter 4.

Our findings also revealed that shift workers spent less time in sedentary behaviour than non-shift workers. The results may be mainly influenced by differences in occupational industries and work tasks. Moreover, most studies included in the analysis used retrospective self-report measures. Because of the challenges of using self-report measures reported in the previous chapters one and two, there was a need to determine the feasibility and validity of EMA to overcome the limitations of other self-report measures. EMA was shown to be feasible and valid, future studies could use it for assessing context of behaviours and tailor interventions that would be beneficial for shift workers' unique work schedules. The intervention improved physical activity during morning and non-workdays and was desired by intervention participants. Based on the process evaluation results, barriers including work-related fatigue and low work management involvement should be addressed to increase the intervention implementation and effectiveness.

Another important finding from the systematic review results was the heterogeneity of methods, shift work definitions, and measures, the latter being mainly self-reported. Self-reporting these behaviours in studies often results in over-reporting actual physical activity and under-reporting sedentary time (Bir & Widmar, 2020; Gardner et al., 2020). The heterogeneity in definition of shift work and shift patterns and schedules is a concern and made comparability of studies difficult. Therefore, there is need to standardise the definitions of shift work and measurement tools. Understanding movement behaviour in shift workers by work industries may contribute to the development of health promotion strategies that are targeted at specific work contexts. Further, greater insights into occupational physical activities would help design effective interventions suitable for work demands and job tasks

Like other studies that used EMA to assess physical activity and sedentary behaviour in workers, EMA was feasible and valid to use in shift and non-shift workers. (Engelen et al., 2016; Weatherson et al., 2019). The use of mobile EMA protocols is promising in contributing to insights on the determinants, domains and the context of physical activity and sedentary behaviours in shift workers (Dunton, 2017). In addition, EMA can be tailored to time prompts to be delivered when participants are bound to be more active to nudge to change behaviour. However, tailoring prompts did not influence the validity of EMA in shift and non-shift workers, but more missed prompts were recorded when a group of shift workers received non-tailored prompts. EMA methods may be used in combinations with device-based measures to provide robust data on movement behaviours.

EMA provides longitudinal, real-time physical activity and sedentary behaviour data that allows for reaching a large population affordably (Engelen et al., 2016; Smyth et al., 2017). There is no consensus on the influence of exposure to shift work overtime, and more research is required to differentiate the effect of years of work and intensity of shift schedules on movement behaviours. Therefore, future cohort studies can start with use of EMA to yield intensive longitudinal data. Perhaps longitudinal studies will provide more information about lifestyle behaviour development with shift working experience.

Our results also showed that shift workers engaged in less sedentary behaviour than non-shift workers (Monnaatsie et al., 2021) (chapter 3). This was supported by the findings of the EMA validity study (chapter 5). While the focus of the study (chapter 5) was not to assess sedentary behaviour, the Actigraph data showed that shift workers spent more time sedentary. A call centre worker or driver is likely to spend more time in sitting positions, whereas a production or hospital worker may mainly adopt a standing posture to carry out tasks at work (Smith et al., 2016). However, fewer studies investigating sedentary behaviours were included in the meta-analysis. Apart from the paucity of data on levels of sedentary behaviour in shift workers, half of the studies included in our review were from health care industries, mainly nurses Therefore, differing industries and domains needs to be investigated and reported in future studies. For intervention to be effective, they need to be suited for workers health concerns, thus more beneficial for their physical and mental health. Owing to differing work tasks, reporting sedentary time by work industries and domain is also necessary. Like physical activity, environmental and occupational factors influence both total and occupational sitting (Vandelanotte et al., 2013). However, because of the paucity of research on workplace health promotion in Botswana mining companies, our study results have limited comparative data.

The health promotion program resulted in changes in MVPA mainly during non-workdays and morning/day shift as shown in chapter 6. In addition, the intervention did not improve shift workers' quality of life and sleep. Conducting needs assessment before the intervention could have helped inform identifying possible barriers and an intervention that is likely to have positive impacts on health (Skivington et al., 2021). Involvement of workers to co-develop the intervention, therefore, is important. However, we could not co-develop the intervention because of the PhD time constraints. Participants in the intervention group, (chapter 7) reported positive experiences with using both EMA and text messages, however EMA reporting did not influence physical activity changes as discussed in chapter 6.

No improvement in physical activity during some shift schedules led us to conclude that it is possible that job constraints, fatigue and limited time during workdays affected changes in physical activity. A structured health intervention for truckers in the UK also resulted in less changes in physical activity during workdays compared to non-workdays (Clemes et al., 2022). As discussed in Chapter 7, work-related fatigue was reported as a barrier for changing physical activity (Monnaatsie et al., 2023). Intervention strategies should therefore consider implementing changes in the workplace to improve job constraints. For example, it may be beneficial to provide frequent breaks for shift workers with high occupational physical activity.

Workplace initiatives to increase physical activity may be particularly important among individuals employed in predominantly sedentary jobs like drivers, as well low physically demanding occupations (Varela-Mato et al., 2017). Health care and manual workers may benefit from interventions that targets recovery than just increasing physical activity (Brown, 2020). Because of the demanding work tasks and lots of time spent walking in the mining company, workers could also benefit from interventions that involves ~~s~~ workplace tasks as suggested by the Goldilocks Work Paradigm (Holtermann et al., 2021). Epidemiological data shows that high occupational physical activity is associated with increased risk for diseases and adverse health effects, while leisure time activities are beneficial for health (Holtermann et al., 2018; Quinn et al., 2021). Thus our intervention may result in improved wellbeing in mining shift workers if conducted for a longer period.

The intervention did not improve time spent in standing and sitting and increasing time spent lying down. A possible explanation for lack of improvements in the healthy behaviours maybe the use of a wearable device which provides a more rigorous measure of physical activity/movement instead of self-report measures. While we also applied the COM-B model to inform the development of text messages in our intervention, the feedback on other behaviours were not framed according to the model (Michie et al., 2014). It is also important to note that the intervention was implemented in one shift cycle of 24 days. The duration of the intervention also needs to be longer to establish effects on sleep and quality of life (Vanderlinden et al., 2022).

While several previous studies have shown that physical activity can improve sleep quality (Wang & Boros, 2021; Yang et al., 2012), mental health and quality of life (Gothe et al., 2020). Our findings and results of previous studies revealed that, the physical activity intervention did not influence sleep quality or quality of life (Vanderlinden et al., 2022). The quantitative and qualitative methods contributed to our understanding of the process of the text messaging physical activity intervention. The results of the process evaluation showed that emphasis should be placed on action planning, providing feedback on behaviour, and providing incentives as they were desired by participants (Chapter 7) (Monnaatsie et al., 2023). For example, the Mi fitness tracker could be provided to monitor and promote continued engagement in physical activity. The results of the process evaluation revealed that the health promotion program has the potential to be adopted if barriers identified including fatigue and low management involvement are overcome.

8.3. Implications and Recommendations for Future Research

Our meta-analysis revealed information about the overall physical activity and sedentary behaviours. However, most of the studies have assessed these behaviours with self-report surveys. Thus, use of EMA with devices to assess all behaviours in all domains repeatedly, may provide a richer context understanding of the healthy behaviours in shift workers. Workers' behaviours reported by different occupations with domains and the context of the behaviour is necessary for future research. This will allow for planning and developing interventions for the different work occupations, thus beneficial for workers' wellbeing.

Future studies in a mining workplace should consider including assessments of physical activity and regular physical tests for shift workers to provide real-time support. This could be easily done with mobile EMA in real-time and their workplaces. The text message effects varied between weekdays and weekends, supporting the view that future studies should assess work schedule as a potential moderator for improving physical activity in shift workers (NeCamp et al., 2020). For the mining shift workers, health promotion program that follow the 'Goldilocks Principle' as discussed in the previous chapters may be useful to design health promoting activities.

8.4. Strengths and limitations

This thesis used both quantitative and qualitative methods, and both self-report and device-based measures. The empirical studies used shift workers from high-income (Australia) and middle-income (Botswana) countries, thus contributing to research in both types of countries. Secondly, the systematic review and EMA feasibility studies included shift and non-shift work populations, thus providing comprehensive, rich methods and data to understand the dynamics of shift work and physical behaviours. Another strength is the use and incorporation of the COM-B model and RE-AIM framework to provide guidance for the intervention implementation and evaluation. The use of mobile technology in Studies 2 and 3 provides novelty in EMA use in shift workers and contributes to the growing area of mHealth technologies.

Limitations of this thesis include the homogeneity of the population used in Studies 2 and 3. Therefore the results cannot be generalised to other countries and all shift workers. More studies in different industries catering for work tasks and schedules are essential. The SEMA[3] application used in this study was still in the development research stage, thus we were not able to find out why some prompts were not delivered to participants. While EMA could provide context of behaviour and domain specific activities, we did not take advantage of analysing the contexts of the behaviours because of time and thesis restrictions. In addition, we used different devices for the validity/feasibility studies and intervention study, therefore, limiting comparability of the studies. The intervention study had a smaller sample size than the pre-calculated powered sample size with 24-day intervention period. However, as discussed in the previous chapter only a few participants dropped out.

More studies are needed to explore the efficacy of the intervention in a randomised controlled trial with larger sample size and longer duration. A sample that is larger will be a better representative of the population and will hence provide more accurate results (Andrade, 2020). Another limitation is that we did not involve employees and management for needs assessment, therefore a wider participatory approach could have provided a more detailed picture of the workplace health promotion that is beneficial for workers. However, workers were involved in determining time that they were likely to be active and the time to send text-messages and EMA prompts predetermined with the researcher.

8.5. Conclusions

Based on the findings of this thesis, it can be concluded that shift workers are not less active or more sedentary than normal day workers. The majority of shift workers included in the meta-analysis do not meet physical activity guidelines. In addition, extensive epidemiological evidence from the reviewed literature proved that improving shift workers' healthy behaviours should be a public health priority to improve their mental and physical health. The health promotion program in our study was only during one shift circle of 24 days, however the results are promising since the MVPA steps were improved during morning and non-workdays. Similarly, based on our intervention study, shift workers may benefit from improving their physical activity especially during non-workdays. More innovative and tailored health promotion programs are essential to target improving physical activity during afternoon and night shifts. Because of the differing work duties and tasks, interventions that cater for different job tasks, patterns of work and individuals could be beneficial and mobile EMA tailoring would be useful. While EMA is valid and feasible to assess movement-related behaviours in shift workers. More research is needed to expand on the use of EMA to provide information on the context of behaviour and how shift schedules affect the healthy behaviours of shift workers. More evidence is needed about physical activity and sedentary behaviour domains in the shift working population.

REFERENCES

Abu Farha, R., & Alefishat, E. (2018). Shift Work and the Risk of Cardiovascular Diseases and Metabolic Syndrome Among Jordanian Employees. *Oman Medical Journal*, *33*(3), 235-242. https://doi.org/10.5001/omj.2018.43

Ahmad, M., Md. Din, N. S. B., Tharumalay, R. D., Che Din, N., Ibrahim, N., Amit, N., Farah, N. M., Osman, R. A., Abdul Hamid, M. F., Ibrahim, I. A., Jamsari, E. A., Palil, M. R., & Ahmad, S. a. (2020). The effects of circadian rhythm disruption on mental health and physiological responses among shift workers and general population. *International Journal of Environmental Research and Public Health*, *17*(19), 7156. https://www.mdpi.com/1660-4601/17/19/7156

Aittasalo, M., Rinne, M., Pasanen, M., Kukkonen-Harjula, K., & Vasankari, T. (2012). Promoting walking among office employees - evaluation of a randomized controlled intervention with pedometers and e-mail messages. *BMC Public Health*, *12*, 403-403. https://doi.org/10.1186/1471-2458-12-403

Åkerstedt, T. (1990). Psychological and psychophysiological effects of shift work. *Scandinavian Journal of Work, Environment & Health*(1), 67-73. https://doi.org/10.5271/sjweh.1819

Alves, M. S., Andrade, R. Z., Silva, G. C., Mota, M. C., Resende, S. G., Teixeira, K. R., Gonçalves, B. F., & Crispim, C. A. (2017). Social jetlag among night workers is negatively associated with the frequency of moderate or vigorous physical activity and with energy expenditure related to physical activity. *Journal of Biological Rhythms*, *32*(1), 83-93. https://doi.org/10.1177/0748730416682110

Andrade C. (2020). Sample Size and its Importance in Research. *Indian Journal of Psychological Medicine*, *42*(1), 102–103. https://doi.org/10.4103/IJPSYM.IJPSYM_504_19

Anothaisintawee, T., Reutrakul, S., Van Cauter, E., & Thakkinstian, A. (2016). Sleep disturbances compared to traditional risk factors for diabetes development: Systematic review and meta-analysis. *Sleep Medicine Reviews*, *30*, 11-24. https://doi.org/https://doi.org/10.1016/j.smrv.2015.10.002

Arlinghaus, A., Bohle, P., Iskra-Golec, I., Jansen, N., Jay, S., & Rotenberg, L. (2019). Working Time Society consensus statements: evidence-based effects of shift work and non-standard working hours on workers, family and community. *Industrial Health*, *57*(2), 184-200. https://doi.org/10.2486/indhealth.SW-4

Astiz, M., Heyde, I., & Oster, H. (2019). Mechanisms of communication in the mammalian circadian timing system. *International Journal of Molecular Sciences, 20*(2). https://doi.org/10.3390/ijms20020343

Atkinson, G., Fullick, S., Grindey, C., & Maclaren, D. (2008). Exercise, energy balance and the shift worker. *Sports Medicine, 38*(8), 671-685. https://doi.org/10.2165/00007256-200838080-00005

Australian Bureau of Statistics A (2019) Characteristics of Employment, Australia, August 2019. Characteristics of Employment, vol 6333.0, 2019 edn, Canberra

Ball, J., Maben, J. E., Murrells, T. J., Day, T. L., & Griffiths, P. (2015). 12-hour shifts: prevalence, views and impact.

Bammann, K., Thomson, N., Albrecht, B., Buchan, D., & Easton, C. (2021). Generation and validation of ActiGraph GT3X+ accelerometer cut-points for assessing physical activity intensity in older adults. The OUTDOOR ACTIVE validation study. *PLoS One*, *16*, e0252615. https://doi.org/10.1371/journal.pone.0252615

Barger, L. K., Sullivan, J. P., Lockley, S. W., & Czeisler, C. A. (2021). Exposure to short wavelength-enriched white light and exercise improves alertness and performance in operational nasa flight controllers working overnight shifts. *Journal of Occupational and Environmental Medicine*, *63*(2), 111-118. https://doi.org/10.1097/jom.0000000000002054

Behrens, T., Rabstein, S., Wichert, K., Erbel, R., Eisele, L., Arendt, M., Dragano, N., Brüning, T., & Jöckel, K. H. (2017). Shift work and the incidence of prostate cancer: a 10-year follow-up of a German population-based cohort study. *Scandinavian Journal of Work,* *Environment & Health*, *43*(6), 560-568. https://doi.org/10.5271/sjweh.3666

Bezzina, A., Austin, E. K., Watson, T., Ashton, L., & James, C. L. (2021). Health and wellness in the Australian coal mining industry: A cross sectional analysis of baseline findings from the RESHAPE workplace wellness program. *PLoS One*, *16*(6), e0252802.

Biddle, S. J. H., O'Connell, S. E., Davies, M. J., Dunstan, D., Edwardson, C. L., Esliger, D. W., Gray, L. J., Yates, T., & Munir, F. (2020). Reducing sitting at work: process evaluation of the SMArT Work (Stand More At Work) intervention. *Trials*, *21*(1), 403-403. https://doi.org/10.1186/s13063-020-04300-7

Bir, C., & Widmar, N. O. (2020). Consistently biased: documented consistency in self-reported holiday healthfulness behaviors and associated social desirability bias. *Humanities and Social Sciences Communications*, *7*(1), 1-11.

Boini, S., Bourgkard, E., Ferrières, J., & Esquirol, Y. (2022). What do we know about the effect of night-shift work on cardiovascular risk factors? An umbrella review. *Frontiers in Public Health*, *10*, 1034195. https://doi.org/10.3389/fpubh.2022.1034195

Boivin, D. B., & Boudreau, P. (2014). Impacts of shift work on sleep and circadian rhythms. *Pathologie-Biologie*, *62*(5), 292-301. https://doi.org/10.1016/j.patbio.2014.08.001

Boivin, D. B., Boudreau, P., & Kosmadopoulos, A. (2022). Disturbance of the circadian system in shift work and its health impact. *Journal of*

Biological Rhythms, *37*(1), 3-28. https://doi.org/10.1177/07487304211064218

Bonham, M. P., Bonnell, E. K., & Huggins, C. E. (2016). Energy intake of shift workers compared to fixed day workers: a systematic review and meta-analysis. *Chronobiology International*, *33*(8), 1086-1100. https://doi.org/10.1080/07420528.2016.1192188

Bort-Roig, J., Chirveches-Pérez, E., Giné-Garriga, M., Navarro-Blasco, L., Bausà-Peris, R., Iturrioz-Rosell, P., González-Suárez, A. M., Martínez-Lemos, I., Puigoriol-Juvanteny, E., Dowd, K., & Puig-Ribera, A. (2020). An mHealth workplace-based "sit less, move more" program: impact on employees' sedentary and physical activity patterns at work and away from work. *International Journal of Environmental Research and Public Health*, *17*(23). https://doi.org/10.3390/ijerph17238844

Brauner, C., Wöhrmann, A. M., Frank, K., & Michel, A. (2019). Health and work-life balance across types of work schedules: A latent class analysis. *Applied Ergonomics*, *81*, 102906. https://doi.org/https://doi.org/10.1016/j.apergo.2019.102906

Brogan, E., Rossiter, C., Fethney, J., Duffield, C., & Denney-Wilson, E. (2022). Start healthy and stay healthy: a workplace health promotion intervention for new graduate nurses: a mixed-methods study. *Journal of Advanced Nursing*, *78*(2), 541-556.

Broussard, J. L., & Van Cauter, E. (2016). Disturbances of sleep and circadian rhythms: novel risk factors for obesity. *Current Opinion in*

Endocrinology & Diabetes and Obesity, *23*(5), 353-359. https://doi.org/10.1097/med.0000000000000276

Brown W. J. (2020). Is remarriage of public health and occupational health advice on physical activity really necessary?. *British Journal of Sports Medicine*, *54*(23), 1379–1380. https://doi.org/10.1136/bjsports-2020-102507

Brown, B. W. J., Crowther, M. E., Appleton, S. L., Melaku, Y. A., Adams, R. J., & Reynolds, A. C. (2022). Shift work disorder and the prevalence of help seeking behaviors for sleep concerns in Australia: A descriptive study. *Chronobiology International*, *39*(5), 714-724. https://doi.org/10.1080/07420528.2022.2032125

Brown, W. J., Bauman, A. E., Bull, F., & Burton, N. W. (2013). Development of Evidence-based Physical Activity Recommendations for Adults (18-64 years). Report prepared for the Australian Government Department of Health, August 2012.

Brown, J. P., Martin, D., Nagaria, Z., Verceles, A. C., Jobe, S. L., & Wickwire, E. M. (2020). Mental health consequences of shift work: an updated review. *Current Psychiatry Reports*, *22*(2), 7. https://doi.org/10.1007/s11920-020-1131-z

Brown, W. J. (2020). Is remarriage of public health and occupational health advice on physical activity really necessary? *British Journal of Sports Medicine*, *54*(23), 1379–1380. https://doi.org/10.1136/bjsports-2020-102507

Bruening, van Woerden, I., Todd, M., Brennhofer, S., Laska, M. N., & Dunton, G. (2016). A mobile ecological momentary assessment tool (devilSPARC) for nutrition and physical activity behaviors in college students: a validation study. *Journal of Medical Internet Research*, *18*(7), e209. https://doi.org/10.2196/jmir.5969

Brunet, J., Black, M., Tulloch, H. E., Pipe, A. L., Reid, R. D., & Reed, J. L. (2021). Work-related factors predict changes in physical activity among nurses participating in a web-based worksite intervention: A randomized controlled trial. *BMC Nursing Journal*, *20*, 1-13.

Buchvold, H. V., Pallesen, S., Waage, S., Moen, B. E., & Bjorvatn, B. (2019). Shift work and lifestyle factors: a 6-year follow-up study among nurses. *Frontiers in Public Health*, *7*, 281.

Buckingham, S. A., Williams, A. J., Morrissey, K., Price, L., & Harrison, J. (2019). Mobile health interventions to promote physical activity and reduce sedentary behaviour in the workplace: A systematic review. *Digital Health*, *5*, https://doi.org/10.1177/2055207619839883

Bull, F. C., Al-Ansari, S. S., Biddle, S., Borodulin, K., Buman, M. P., Cardon, G., Carty, C., Chaput, J. P., Chastin, S., Chou, R., Dempsey, P. C., DiPietro, L., Ekelund, U., Firth, J., Friedenreich, C. M., Garcia, L., Gichu, M., Jago, R., Katzmarzyk, P. T., . . . Willumsen, J. F. (2020). World Health Organization 2020 guidelines on physical activity and sedentary behaviour. *British Journal of*

Sports Medicine, *54*(24), 1451-1462. https://doi.org/10.1136/bjsports-2020-102955

Bull, F. C., Maslin, T. S., & Armstrong, T. (2009). Global physical activity questionnaire (GPAQ): nine country reliability and validity study. *Journal of Physical Activity and Health*, *6*(6), 790-804. https://doi.org/10.1123/jpah.6.6.790

Burke, L. E., Shiffman, S., Music, E., Styn, M. A., Kriska, A., Smailagic, A., Siewiorek, D., Ewing, L. J., Chasens, E., French, B., Mancino, J., Mendez, D., Strollo, P., & Rathbun, S. L. (2017). Ecological momentary assessment in behavioral research: addressing technological and human participant challenges. *Journal of Medical Internet Research*, *19*(3), e77-e77. https://doi.org/10.2196/jmir.7138

Burke, L., & Naylor, G. (2022). Smartphone app-based noncontact ecological momentary assessment with experienced and naïve older participants: feasibility study. *JMIR Formative Research*, *6*(3), e27677-e27677. https://doi.org/10.2196/27677

Burns, K., Nicholas, R., Beatson, A., Chamorro-Koc, M., Blackler, A., & Gottlieb, U. (2020). Identifying mobile health engagement stages: interviews and observations for developing brief message content. *Journal of Medical Internet Research*, *22*(9), e15307. https://doi.org/10.2196/15307

Buysse, D. J., Reynolds, C. F., 3rd, Monk, T. H., Berman, S. R., & Kupfer, D. J. (1989). The Pittsburgh Sleep Quality Index: a new instrument for psychiatric practice and research. *Psychiatry Research*, *28*(2), 193-213. https://doi.org/10.1016/0165-1781(89)90047-4

Casjens, S., Brenscheidt, F., Tisch, A., Beermann, B., Brüning, T., Behrens, T., & Rabstein, S. (2022). Social jetlag and sleep debts are altered in different rosters of night shift work. *Plos One*, *17*(1), e0262049. https://doi.org/10.1371/journal.pone.0262049

Caspersen, C. J., Powell, K. E., & Christenson, G. M. (1985). Physical activity, exercise, and physical fitness: definitions and distinctions for health-related research. *Public Health Reports*, *100*(2), 1

Castro, O., Vergeer, I., Bennie, J., & Biddle, S. J. H. (2021). Feasibility of reducing and breaking up university students' sedentary behaviour: pilot trial and process evaluation. *Frontiers in Psychology,12*, 661994. https://doi.org/10.3389/fpsyg.2021.661994

Chastin, S. F. M., McGregor, D. E., Biddle, S. J. H., Cardon, G., Chaput, J. P., Dall, P. M., Dempsey, P. C., DiPietro, L., Ekelund, U., Katzmarzyk, P. T., Leitzmann, M., Stamatakis, E., & Van der Ploeg, H. P. (2021). Striking the right balance: evidence to inform combined physical activity and sedentary behavior recommendations. *Journal of Physical Activity and Health*, *18*(6), 631-637. https://doi.org/10.1123/jpah.2020-0635

Chellappa, S. L., Vujovic, N., Williams, J. S., & Scheer, F. A. J. L. (2019). Impact of circadian disruption on cardiovascular function and disease. *Trends in Endocrinology & Metabolism*, *30*(10), 767-779. https://doi.org/https://doi.org/10.1016/j.tem.2019.07.008

Chen, H. T. (2014). *Practical program evaluation: Theory-driven evaluation and the integrated evaluation perspective*. Sage Publications

Cheng, P., & Drake, C. (2019). Shift work disorder. *Neurologic Clinics*, *37*(3), 563-577. https://doi.org/10.1016/j.ncl.2019.03.003

Cheng, W.-J., Härmä, M., Ropponen, A., Karhula, K., Koskinen, A., & Oksanen, T. (2020). Shift work and physical inactivity: findings from the Finnish Public Sector Study with objective working hour data. *Scandinavian Journal of Work, Environment & Health*, 293-301. https://doi.org/10.5271/sjweh.3868

Chiang, S. L., Chiang, L. C., Tzeng, W. C., Lee, M. S., Fang, C. C., Lin, C. H., & Lin, C. H. (2022). Impact of rotating shifts on lifestyle patterns and perceived stress among nurses: a cross-sectional study. *International Journal of Environmental Research and Public Health, 19*(9), 5235. https://doi.org/10.3390/ijerph19095235

Chin, D. L., Nam, S., & Lee, S. J. (2016). Occupational factors associated with obesity and leisure-time physical activity among nurses: A cross sectional study. *International Journal of Nursing Studies 57,* 60–69. https://doi.org/10.1016/j.ijnurstu.2016.01.009

Cho, S. S., Lee, D. W., & Kang, M. Y. (2020). The Association between Shift Work and Health-Related Productivity Loss due to Either Sickness Absence or Reduced Performance at Work: A Cross-Sectional Study of Korea. *International Journal of Environmental*

Research and Public Health, 17(22), 8493.
https://doi.org/10.3390/ijerph17228493

Chomistek, A. K., Yuan, C., Matthews, C. E., Troiano, R. P., Bowles, H. R., Rood, J., Barnett, J. B., Willett, W. C., Rimm, E. B., & Bassett Jr, D. R. (2017). Physical activity assessment with the ActiGraph GT3X and doubly labeled water. *Medicine and Science in Sports and Exercise*, *49*(9), 1935.

Chu, A. H., Ng, S. H., Tan, C. S., Win, A., Koh, D., & Müller-Riemenschneider, F. (2016). A systematic review and meta-analysis of workplace intervention strategies to reduce sedentary time in white-collar workers. *Obesity Reviews*, *17*(5), 467-481. https://doi.org/10.1111/obr.12388

Cillekens, B., Huysmans, M. A., Holtermann, A., van Mechelen, W., Straker, L., Krause, N., van der Beek, A. J., & Coenen, P. (2022). Physical activity at work may not be health enhancing. A systematic review with meta-analysis on the association between occupational physical activity and cardiovascular disease mortality covering 23 studies with 655 892 participants. *Scandinavian Journal of Work, Environment & Health*, *48*(2), 86-98. https://doi.org/10.5271/sjweh.3993

Clark, B. K., Brakenridge, C. L., & Healy, G. N. (2022). The Importance of Research on Occupational Sedentary Behaviour and Activity Right Now. *International Journal of Environmental Research and Public Health*, *19*(23). https://doi.org/10.3390/ijerph192315816

Clark, B. K., Kolbe-Alexander, T. L., Duncan, M. J., & Brown, W. (2017). Sitting Time, Physical Activity and Sleep by Work Type and Pattern-The Australian Longitudinal Study on Women's Health. *International Journal of Environmental Research and Public Health*, *14*(3). https://doi.org/10.3390/ijerph14030290

Clarke, A. E., & Janssen, I. (2021). A compositional analysis of time spent in sleep, sedentary behaviour and physical activity with all-cause mortality risk. *International Journal of Behavioral Nutrition and Physical Activity*, *18*(1), 25. https://doi.org/10.1186/s12966-021-01092-0

Cleland, C., Ferguson, S., Ellis, G., & Hunter, R. F. (2018). Validity of the International Physical Activity Questionnaire (IPAQ) for assessing moderate-to-vigorous physical activity and sedentary behaviour of older adults in the United Kingdom. *BMC Medical Research Methodology*, *18*(1), 1-12.

Clemes, S. A., Varela-Mato, V., Bodicoat, D. H., Brookes, C. L., Chen, Y. L., Edwardson, C. L., . . . King, J. A. (2022). The effectiveness of the Structured Health Intervention For Truckers (SHIFT): a cluster randomised controlled trial (RCT). *BMC Medicine, 20*(1), 195. doi:10.1186/s12916-022-02372-7

Coenen, P., Huysmans, M. A., Holtermann, A., Krause, N., van Mechelen, W., Straker, L. M., & van der Beek, A. J. (2018). Do highly physically active workers die early? A systematic review with meta-analysis of data from 193 696 participants. *British Journal of Sports*

Medicine, *52*(20), 1320. https://doi.org/10.1136/bjsports-2017-098540

Coenen, P., Huysmans, M. A., Holtermann, A., Krause, N., van Mechelen, W., Straker, L. M., & van der Beek, A. J. (2020). Towards a better understanding of the 'physical activity paradox': the need for a research agenda. *British Journal of Sports Medicine*, *54*(17), 1055–1057. https://doi.org/10.1136/bjsports-2019-101343

Colley, R. C., Butler, G., Garriguet, D., Prince, S. A., & Roberts, K. C. (2018). Comparison of self-reported and accelerometer-measured physical activity in Canadian adults. *Health Reports*, *29*(12), 3-1

Concheiro-Moscoso, P., Martínez-Martínez, F. J., Miranda-Duro, M. d. C., Pousada, T., Nieto-Riveiro, L., Groba, B., Mejuto-Muiño, F. J., & Pereira, J. (2021). Study protocol on the validation of the quality of sleep data from Xiaomi domestic wristbands. *International Journal of Environmental Research and Public Health*, *18*(3), 1106.

Cordina-Duverger, E., Menegaux, F., Popa, A., Rabstein, S., Harth, V., Pesch, B., Brüning, T., Fritschi, L., Glass, D. C., Heyworth, J. S., Erren, T. C., Castaño-Vinyals, G., Papantoniou, K., Espinosa, A., Kogevinas, M., Grundy, A., Spinelli, J. J., Aronson, K. J., & Guénel, P. (2018). Night shift work and breast cancer: a pooled analysis of population-based case-control studies with complete work history. *European Journal of Epidemiology*, *33*(4), 369-379. https://doi.org/10.1007/s10654-018-0368-x

Costa, G. (2003). Shift work and occupational medicine: an overview. *Occupational Medicine*, *53*(2), 83-88. https://doi.org/10.1093/occmed/kqg045

Costa, G., Sartori, S., & Åkerstedt, T. (2006). Influence of flexibility and variability of working hours on health and well-being. *Chronobiology International*, *23*(6), 1125-1137.

Courtney, J. A., Francis, A. J., & Paxton, S. J. (2010). Caring for the carers: Fatigue, sleep, and mental health in Australian paramedic shiftworkers. *The Australasian Journal of Organisational Psychology*, *3*, 32-41.

Craig, P., Dieppe, P., Macintyre, S., Michie, S., Nazareth, I., & Petticrew, M. (2008). Developing and evaluating complex interventions: the new Medical Research Council guidance. *BMJ Open*, *337*, a1655. https://doi.org/10.1136/bmj.a1655

Croker, H., Russell, S. J., Gireesh, A., Bonham, A., Hawkes, C., Bedford, H., Michie, S., & Viner, R. M. (2020). Obesity prevention in the early years: A mapping study of national policies in England from a behavioural science perspective. *PLoS One*, *15*(9), e0239402-e0239402. https://doi.org/10.1371/journal.pone.0239402

Croot, L., O'Cathain, A., Sworn, K., Yardley, L., Turner, K., Duncan, E., & Hoddinott, P. (2019). Developing interventions to improve health: a systematic mapping review of international practice between 2015 and 2016. *Pilot Feasibility Study*, *5*, 127. https://doi.org/10.1186/s40814-019-0512-8

Crowley, P., Ikeda, E., Islam, S. M. S., Kildedal, R., Jacobsen, S. S., Larsen, J. R., Johansson, P. J., Hettiarachchi, P., Aadahl, M., & Mork, P. J. (2022). The Surveillance of Physical Activity, Sedentary Behavior, and Sleep: Protocol for the Development and Feasibility Evaluation of a Novel Measurement System. *JMIR research protocols*, *11*(6), e35697.

Crowther, M. E., Ferguson, S. A., Vincent, G. E., & Reynolds, A. C. (2021). Non-pharmacological interventions to improve chronic disease risk factors and sleep in shift workers: a systematic review and meta-analysis. *Clocks & sleep*, *3*(1), 132–178. https://doi.org/10.3390/clockssleep3010009

Crowther, M. E., Ferguson, S. A., & Reynolds, A. C. (2022). Longitudinal studies of sleep, physical activity and nutritional intake in shift workers: A scoping review. *Sleep Medicine Reviews*, *63*, 101612. https://doi.org/10.1016/j.smrv.2022.101612

Cruciani, F., Nugent, C., Cleland, I., & McCullagh, P. (2017). Rich context information for just-in-time adaptive intervention promoting physical activity. *Annu Int Conf IEEE Eng Med Biol Soc*, *2017*, 849-852. https://doi.org/10.1109/embc.2017.8036957

Cusatis, R., & Garbarski, D. (2019). Different domains of physical activity: The role of leisure, housework/care work, and paid work in socioeconomic differences in reported physical activity. *SSM - Population Health*, *7*, 100387. https://doi.org/https://doi.org/10.1016/j.ssmph.2019.100387

Dao, K. P., De Cocker, K., Tong, H. L., Kocaballi, A. B., Chow, C., & Laranjo, L. (2021). Smartphone-Delivered Ecological Momentary Interventions Based on Ecological Momentary Assessments to Promote Health Behaviors: Systematic Review and Adapted Checklist for Reporting Ecological Momentary Assessment and Intervention Studies. *JMIR Mhealth Uhealth*, *9*(11), e22890. https://doi.org/10.2196/22890

Davis, R., Campbell, R., Hildon, Z., Hobbs, L., & Michie, S. (2015). Theories of behaviour and behaviour change across the social and behavioural sciences: a scoping review. *Health Psychology Review*, *9*(3), 323-344. https://doi.org/10.1080/17437199.2014.941722

de Vries, L. P., Baselmans, B. M. L., & Bartels, M. (2021). Smartphone-Based Ecological Momentary Assessment of Well-Being: A Systematic Review and Recommendations for Future Studies. *Journal of Happiness Studies*, *22*(5), 2361-2408. https://doi.org/10.1007/s10902-020-00324-7

De Winter, J. C., Gosling, S. D., & Potter, J. (2016). Comparing the Pearson and Spearman correlation coefficients across distributions and sample sizes: A tutorial using simulations and empirical data. *Psychological methods*, *21*(3), 273.

Degroote, L., De Bourdeaudhuij, I., Verloigne, M., Poppe, L., & Crombez, G. (2018). The Accuracy of Smart Devices for Measuring Physical Activity in Daily Life: Validation Study. *JMIR Mhealth Uhealth*, *6*(12), e10972. https://doi.org/10.2196/10972

Degroote, L., DeSmet, A., De Bourdeaudhuij, I., Van Dyck, D., & Crombez, G. (2020). Content validity and methodological considerations in ecological momentary assessment studies on physical activity and sedentary behaviour: a systematic review. *International Journal of Behavioral Nutrition and Physical Activity*, *17*(1), 35. https://doi.org/10.1186/s12966-020-00932-9

Demou, E., MacLean, A., Cheripelli, L. J., Hunt, K., & Gray, C. M. (2018). Group-based healthy lifestyle workplace interventions for shift workers: a systematic review. *Scandinavian Journal of Work, Environment & Health*, *44*(6), 568-584. https://doi.org/10.5271/sjweh.3763

Dempsey, P. C., Biddle, S. J., Buman, M. P., Chastin, S., Ekelund, U., Friedenreich, C. M., Katzmarzyk, P. T., Leitzmann, M. F., Stamatakis, E., & van der Ploeg, H. P. (2020). New global guidelines on sedentary behaviour and health for adults: broadening the behavioural targets. *International Journal of Behavioral Nutrition and Physical Activity*, *17*(1), 1-12.

Dong, C., Zeng, H., Yang, B., Zhang, Y., & Li, Z. (2022). The association between long-term night shift work and metabolic syndrome: a cross-sectional study of male railway workers in southwest China. *BMC Cardiovascular Disorders*, *22*(1), 263. https://doi.org/10.1186/s12872-022-02705-7

Donnelly, E. A., Bradford, P., Davis, M., Hedges, C., Socha, D., & Morassutti, P. (2019). Fatigue and safety in paramedicine. *Canadian Journal of Emergency Medicine*, *21*(6), 762-765.

Duan, J., Levine, M., Luo, J., & Qu, Y. (2020). Estimation of group means in generalized linear mixed models. *Pharmaceutical Statistics*, *19*(5), 646-661. https://doi.org/10.1002/pst.2022

Dun, A., Zhao, X., Jin, X., Wei, T., Gao, X., Wang, Y., & Hou, H. (2020). Association between night-shift work and cancer risk: updated systematic review and meta-analysis. *Frontiers in Oncology*, *10*, 1006.

Duncan, M., Vandelanotte, C., Kolt, G. S., Rosenkranz, R. R., Caperchione, C. M., George, E. S., Ding, H., Hooker, C., Karunanithi, M., Maeder, A. J., Noakes, M., Tague, R., Taylor, P., Viljoen, P., & Mummery, W. K. (2014). Effectiveness of a web- and mobile phone-based intervention to promote physical activity and healthy eating in middle-aged males: randomized controlled trial of the ManUp study. *Journal of Medical Internet Research*, *16*(6), e136. https://doi.org/10.2196/jmir.3107

Dunstan, D. W., Dogra, S., Carter, S. E., & Owen, N. (2021). Sit less and move more for cardiovascular health: emerging insights and opportunities. *Nature Reviews Cardiology*, *18*(9), 637-648. https://doi.org/10.1038/s41569-021-00547-y

Dunton, G. F. (2017). Ecological Momentary Assessment in Physical Activity Research. *Exercise and Sport Sciences Reviews, 45*(1), 48-54. doi:10.1249/jes.0000000000000092

Dunton, G. F., Liao, Y., Kawabata, K., & Intille, S. (2012). Momentary assessment of adults' physical activity and sedentary behavior: feasibility and validity. *Frontiers in Psychology*, *3*, 260. https://doi.org/10.3389/fpsyg.2012.00260

Dunton, Liao, Intille, Spruijt-Metz, & Pentz. (2011). Investigating children's physical activity and sedentary behavior using ecological momentary assessment with mobile phones. *Obesity*, *19*(6), 1205-1212. https://doi.org/10.1038/oby.2010.3

Edwardson, C. L., Winkler, E. A. H., Bodicoat, D. H., Yates, T., Davies, M. J., Dunstan, D. W., & Healy, G. N. (2017). Considerations when using the activPAL monitor in field-based research with adult populations. *Journal of Sport and Health Science*, *6*(2), 162-178. https://doi.org/10.1016/j.jshs.2016.02.002

Ekelund, Tarp, J., Steene-Johannessen, J., Hansen, B. H., Jefferis, B., Fagerland, M. W., Whincup, P., Diaz, K. M., Hooker, S. P., Chernofsky, A., Larson, M. G., Spartano, N., Vasan, R. S., Dohrn, I.-M., Hagströmer, M., Edwardson, C., Yates, T., Shiroma, E., Anderssen, S. A., & Lee, I.-M. (2019). Dose-response associations between accelerometry measured physical activity and sedentary time and all cause mortality: systematic review and harmonised meta-analysis. *BMJ*, *366*, l4570. https://doi.org/10.1136/bmj.l4570

Ekelund, U., Steene-Johannessen, J., Brown, W. J., Fagerland, M. W., Owen, N., Powell, K. E., Bauman, A., & Lee, I. M. (2016). Does physical activity attenuate, or even eliminate, the detrimental association of sitting time with mortality? A harmonised meta-analysis of data from more than 1 million men and women. *Lancet*, *388*(10051), 1302-1310. https://doi.org/10.1016/s0140-6736(16)30370-1

Elavsky, S., Klocek, A., Knapova, L., Smahelova, M., Smahel, D., Cimler, R., & Kuhnova, J. (2021). Feasibility of real-time behavior monitoring via mobile technology in Czech adults aged 50 years and above: 12-week study with ecological momentary assessment. *JMIR Aging*, *4*(4), e15220. https://doi.org/10.2196/15220

Engelen, L., Chau, J. Y., Burks-Young, S., & Bauman, A. (2016). Application of ecological momentary assessment in workplace health evaluation. *Health Promotion Journal of Australia, 27*(3), 259-263. doi:10.1071/he16043

Erren, T. C., Morfeld, P., Groß, J. V., Wild, U., & Lewis, P. (2019). IARC 2019: “Night shift work” is probably carcinogenic: What about disturbed chronobiology in all walks of life? *Journal of Occupational Medicine and Toxicology*, *14*(1), 29. https://doi.org/10.1186/s12995-019-0249-6

Esquirol, Y., Bongard, V., Mabile, L., Jonnier, B., Soulat, J. M., & Perret, B. (2009). Shift work and metabolic syndrome: respective impacts of job strain, physical activity, and dietary rhythms. *Chronobiology*

International, 26(3), 544-559. https://doi.org/10.1080/07420520902821176

European Foundation for the Improvement of Living and Working Conditions. (2019). *Working conditions in a global perspective*. Publications Office of the European Union.

Farrahi Moghaddam, J., Nakhaee, N., Sheibani, V., Garrusi, B., & Amirkafi, A. (2012). Reliability and validity of the persian version of the Pittsburgh Sleep Quality Index (PSQI-P). *Sleep and Breathing*, *16*(1), 79-82. https://doi.org/10.1007/s11325-010-0478-5

Fenwick, M. J., Oftedal, S., Kolbe-Alexander, T. L., & Duncan, M. J. (2022). Comparison of adult shift and non-shift workers' physical activity and sleep behaviours: cross-sectional analysis from the Household Income and Labour Dynamics of Australia (HILDA) cohort. *Journal of Public Health*. https://doi.org/10.1007/s10389-022-01738-8

Figueiro, M. G. (2017). Disruption of Circadian Rhythms by Light During Day and Night. *Current Sleep Medicine Reports*, *3*(2), 76-84. https://doi.org/10.1007/s40675-017-0069-0

Flahr, H., Brown, W. J., & Kolbe-Alexander, T. L. (2018). A systematic review of physical activity-based interventions in shift workers. *Preventive Medicine Reports*, *10*, 323-331.

Fletcher, A., Jamal, F., Moore, G., Evans, R. E., Murphy, S., & Bonell, C. (2016). Realist complex intervention science: Applying realist principles across all phases of the Medical Research Council framework for developing and evaluating complex interventions. *Evaluation*, *22*(3), 286–303. https://doi.org/10.1177/1356389016652743

Fournier, d'Arripe-Longueville, F., & Radel, R. (2017). Testing the effect of text messaging cues to promote physical activity habits: a worksite-based exploratory intervention. *Scandivanian Journal of Medicine & Science in Sports*, *27*(10), 1157-1165. https://doi.org/10.1111/sms.127

Gabriel, B. M., & Zierath, J. R. (2019). Circadian rhythms and exercise—re-setting the clock in metabolic disease. *Nature Reviews Endocrinology*, *15*(4), 197-206.

Gan, Y., Yang, C., Tong, X., Sun, H., Cong, Y., Yin, X., Li, L., Cao, S., Dong, X., Gong, Y., Shi, O., Deng, J., Bi, H., & Lu, Z. (2015). Shift work and diabetes mellitus: a meta-analysis of observational studies. *Occupational and Environmental Medicine*, *72*(1), 72. https://doi.org/10.1136/oemed-2014-102150

Gao, Y., Gan, T., Jiang, L., Yu, L., Tang, D., Wang, Y., Li, X., & Ding, G. (2020). Association between shift work and risk of type 2 diabetes mellitus: a systematic review and dose-response meta-analysis of observational studies. *Chronobiology International*, *37*(1), 29-46. https://doi.org/10.1080/07420528.2019.1683570

Gardner, B., Louca, I., Mourouzis, D., Calabrese, A., Fida, A., & Smith, L. (2020). How do people interpret and respond to self-report sitting time questionnaires? A think-aloud study. *Psychology of Sport and*

Exercise, *50*, 101718. https://doi.org/10.1080/17437199.2015.1082146

Gardner, B., Smith, L., Lorencatto, F., Hamer, M., & Biddle, S. J. (2016). How to reduce sitting time? A review of behaviour change strategies used in sedentary behaviour reduction interventions among adults. *Health Psychology Review*, *10*(1), 89-112. https://doi.org/10.1080/17437199.2015.1082146

Garland, A., Weinfurt, K., & Sugarman, J. (2021). Incentives and payments in pragmatic clinical trials: Scientific, ethical, and policy considerations. *Clinical Trials, 18*(6), 699–705. https://doi.org/10.1177/17407745211048178

Genin, P., Beaujouan, J., Thivel, D., & Duclos, M. (2019). Is workplace an appropriate setting for the promotion of physical activity? A new framework for worksite interventions among employees. *Work*, *62*(3), 421-426. https://doi.org/10.3233/wor-192873

Gilson, Hall, C., Holtermann, A., van der Beek, A. J., Huysmans, M. A., Mathiassen, S. E., & Straker, L. (2019). Sedentary and physical activity behavior in “blue-collar” workers: a systematic review of accelerometer studies. *Journal of Physical Activity and Health*, *16*(11), 1060-1069.

Gilson, Pavey, T. G., Vandelanotte, C., Duncan, M. J., Gomersall, S. R., Trost, S. G., & Brown, W. J. (2016). Chronic disease risks and use of a smartphone application during a physical activity and dietary intervention in Australian truck drivers. *Public Health*, *40*(1), 91-93. https://doi.org/10.1111/1753-6405.12501

Glasgow, R. E., Harden, S. M., Gaglio, B., Rabin, B., Smith, M. L., Porter, G. C., Ory, M. G., & Estabrooks, P. A. (2019). RE-AIM Planning and Evaluation Framework: Adapting to New Science and Practice With a 20-Year Review. *Frontiers in Public Health*, *7*. https://doi.org/10.3389/fpubh.2019.00064

González, Fuentes, J., & Márquez, J. L. (2017). Physical Inactivity, Sedentary Behavior and Chronic Diseases. *Korean Journal of Family Medicine*, *38*(3), 111-115. https://doi.org/10.4082/kjfm.2017.38.3.111

Gothe, N. P., Ehlers, D. K., Salerno, E. A., Fanning, J., Kramer, A. F., & McAuley, E. (2020). Physical activity, sleep and quality of life in older adults: influence of physical, mental and social well-being. *Behavioral Sleep Medicine*, *18*(6), 797-808. https://doi.org/10.1080/15402002.2019.1690493

Gualtieri, L., Rosenbluth, S., & Phillips, J. (2016). Can a free wearable activity tracker change behavior? the impact of trackers on adults in a physician-led wellness group. *JMIR Research Protocols*, *5*(4), e237. https://doi.org/10.2196/resprot.6534

Greiwe, J., & Nyenhuis, S. M. (2020). Wearable technology and how this can be implemented into clinical practice. *Current Allergy and Asthma Reports*, *20*(8), 36. https://doi.org/10.1007/s11882-020-00927-3

Guest, A. J., Paine, N. J., Chen, Y. L., Chalkley, A., Munir, F., Edwardson, C. L., Gray, L. J., Johnson, V., Ruettger, K., Sayyah, M., Sherry, A., Troughton, J., Varela-Mato, V., Yates, T., King, J., & Clemes, S. A. (2022). The structured health intervention for truckers (SHIFT) cluster randomised controlled trial: a mixed methods process evaluation. *International Journal of Behavioral Nutrition and Physical Activity*, *19*(1), 79. https://doi.org/10.1186/s12966-022-01316-x

Guest, A. J., Chen, Y. L., Pearson, N., King, J. A., Paine, N. J., & Clemes, S. A. (2020). Cardiometabolic risk factors and mental health status among truck drivers: a systematic review. *BMJ Open*, *10*(10), e038993. https://doi.org/10.1136/bmjopen-2020-038993

Gupta, C. C., Coates, A. M., Dorrian, J., & Banks, S. (2019). The factors influencing the eating behaviour of shiftworkers: what, when, where and why. *Industrial Health*, *57*(4), 419-453. https://doi.org/10.2486/indhealth.2018-0147

Gusmão, W. D. P., Pureza, I. R. O. M., & Moreno, C. R. C. (2022). Shift Work and Early Arterial Stiffness: A Systematic Review. *International Journal of Environmental Research and Public Health*, *19*(21), 14569. https://www.mdpi.com/1660-4601/19/21/14569

Guthold, Stevens, Riley, & Bull. (2018). Worldwide trends in insufficient physical activity from 2001 to 2016: a pooled analysis of 358 population-based surveys with 1·9 million participants. *The lancet* *global health*, *6*(10), e1077-e1086. https://doi.org/https://doi.org/10.1016/S2214-109X(18)30357-

Ha, Y., Lee, S. H., Lee, D. H., Kang, Y. H., Choi, W., & An, J. (2022). Effectiveness of a mobile wellness program for nurses with rotating shifts during COVID-19 Pandemic: a pilot cluster-randomized trial. *International Journal of Environmental Research and Public Health*, *19*(2). https://doi.org/10.3390/ijerph19021014

Hemmer, A., Mareschal, J., Dibner, C., Pralong, J. A., Dorribo, V., Perrig, S., Genton, L., Pichard, C., & Collet, T. H. (2021). The effects of shift work on cardio-metabolic diseases and eating patterns. *Nutrients*, *13*(11). https://doi.org/10.3390/nu13114178

Holmes, L., LaHurd, A., Wasson, E., McClarin, L., & Dabney, K. (2016). Racial and Ethnic heterogeneity in the association between total cholesterol and pediatric obesity. *International Journal of Environmental Research and Public Health*, *13*(1), 19. https://www.mdpi.com/1660-4601/13/1/19

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

Holtermann, A., Coenen, P., Krause, N. (2020). The paradoxical health effects of occupational versus leisure-time physical activity. In: Theorell, T. (eds) Handbook of Socioeconomic Determinants of Occupational Health. *Handbook Series in Occupational Health*

Sciences. Springer, Cham. https://doi.org/10.1007/978-3-030-31438-5_6

Holtermann, A., Schnohr, P., Nordestgaard, B. G., & Marott, J. L. (2021). The physical activity paradox in cardiovascular disease and all-cause mortality: the contemporary Copenhagen General Population Study with 104 046 adults. *European Heart Journal, 42*(15), 1499-1511. doi:10.1093/eurheartj/ehab087

Hulsegge, G., Proper, K. I., Loef, B., Paagman, H., Anema, J. R., & van Mechelen, W. (2021). The mediating role of lifestyle in the relationship between shift work, obesity and diabetes. *International Archives of Occupational and Environmental Health*, *94*(6), 1287–1295. https://doi.org/10.1007/s00420-021-01662-6

Hulsegge, Gupta, N., Holtermann, A., Jørgensen, M. B., Proper, K. I., & van der Beek, A. J. (2017). Shift workers have similar leisure-time physical activity levels as day workers but are more sedentary at work. *Scandinavian Journal of Work, Environment & Health*(2), 127-135. https://doi.org/10.5271/sjweh.3614

IARC. (2010). Definition and Occurrence of Exposure. In *Painting, Firefighting, and Shiftwork*. International Agency for Research on Cancer.

International Labour Organization. (1990). Night Work Convention. C171, Geneva, ILO. Retrieved from

Ismail, L., Materwala, H., & Al Kaabi, J. (2021). Association of risk factors with type 2 diabetes: A systematic review. *Computational and*

Structural Biotechnology Journal, *19*, 1759-1785. https://doi.org/https://doi.org/10.1016/j.csbj.2021.03.003

James, S. M., Honn, K. A., Gaddameedhi, S., & Van Dongen, H. P. (2017). Shift work: disrupted circadian rhythms and sleep—implications for health and well-being. *Current Sleep Medicine Reports*, *3*, 104-112.

Johansson, J. F., Lam, N., Ozer, S., Hall, J., Morton, S., English, C., Fitzsimons, C. F., Lawton, R., Forster, A., & Clarke, D. (2022). Systematic review of process evaluations of interventions in trials investigating sedentary behaviour in adults. *BMJ Open*, *12*(1), e053945. https://doi.org/10.1136/bmjopen-2021-053945

John, D., & Freedson, P. (2012). ActiGraph and Actical physical activity monitors: a peek under the hood. *Medicine and Science in Sports and Exercise*, *44*(1 Suppl 1), S86.

Kastelic, K., & Šarabon, N. (2019). Comparison of Self-Reported Sedentary Time on Weekdays with an Objective Measure (activPAL). *Measurement in Physical Education and Exercise Science*, *23*(3), 227-236. https://doi.org/10.1080/1091367X.2019.1603153

Keadle, S. K., Conroy, D. E., Buman, M. P., Dunstan, D. W., & Matthews, C. E. (2017). Targeting reductions in sitting time to increase physical activity and improve health. *Medicine and Science in sports and Exercise*, *49*(8), 1572–1582. https://doi.org/10.1249/MSS.0000000000001257

Kecklund, G., & Axelsson, J. (2016). Health consequences of shift work and insufficient sleep. *BMJ*, *355*, i5210. https://doi.org/10.1136/bmj.i5210

Keetile, M., Navaneetham, K., & Letamo, G. (2020). Prevalence and correlates of multimorbidity among adults in Botswana: A cross-sectional study. *PloS One*, *15*(9), e0239334. https://doi.org/10.1371/journal.pone.0239334

Kelly, C., Nea, F. M., Pourshahidi, L. K., Kearney, J. M., Brien, V., Livingstone, M. B. E., & Corish, C. A. (2020). Adherence to dietary and physical activity guidelines among shift workers: associations with individual and work-related factors. *BMJ Nutrition, Prevention & Health*, bmjnph-2020-000091. https://doi.org/10.1136/bmjnph-2020-000091

Kelly, L. A., McMillan, D. G. E., Anderson, A., Fippinger, M., Fillerup, G., & Rider, J. (2013). Validity of actigraphs uniaxial and triaxial accelerometers for assessment of physical activity in adults in laboratory conditions. *BMC Medical Physics*, *13*(1), 5. https://doi.org/10.1186/1756-6649-13-5

Kervezee, L., Kosmadopoulos, A., & Boivin, D. B. (2020). Metabolic and cardiovascular consequences of shift work: The role of circadian disruption and sleep disturbances. *European Journal of Neuroscience*, *51*(1), 396-412. https://doi.org/https://doi.org/10.1111/ejn.14216

Khan, W. A. A., Conduit, R., Kennedy, G. A., & Jackson, M. L. (2020). The relationship between shift-work, sleep, and mental health among paramedics in Australia. *Sleep Health*, *6*(3), 330-337. https://doi.org/10.1016/j.sleh.2019.12.002

Khosravipour, M., Khanlari, P., Khazaie, S., Khosravipour, H., & Khazaie, H. (2021). A systematic review and meta-analysis of the association between shift work and metabolic syndrome: The roles of sleep, gender, and type of shift work. *Sleep Medicine Reviews*, *57*, 101427. https://doi.org/https://doi.org/10.1016/j.smrv.2021.101427

King, W. C., Li, J., Leishear, K., Mitchell, J. E., & Belle, S. H. (2011). Determining activity monitor wear time: an influential decision rule. *Journal of Physical Activity and Health*, *8*(4), 566-580. https://doi.org/10.1123/jpah.8.4.566

KivimÄki, M., Kuisma, P., Virtanen, M., & Elovainio, M. (2001). Does shift work lead to poorer health habits? A comparison between women who had always done shift work with those who had never done shift work. *Work & Stress*, *15*(1), 3-13.

Knell, G., Gabriel, K. P., Businelle, M. S., Shuval, K., Wetter, D. W., & Kendzor, D. E. (2017). Ecological momentary assessment of physical activity: validation study. *Journal of Medical Internet Research*, *19*(7), e253. https://doi.org/10.2196/jmir.7602

Knutsson, A. (1989). Shift Work and Coronary Heart Disease. *Scandinavian Journal of Social Medicine. Supplementum*, *44*, 1-36. http://www.jstor.org/stable/45199759

Knutsson, A. (2003). Health disorders of shift workers. *Occupational Medicine, 53*, 103-108. https://doi.org/10.1093/occmed/kqg048

Koitsiwe, K., & Adachi, T. (2017). Linkages between mining and non-mining sectors in Botswana. *Mineral Economics*, *30*, 95-105.

Kolbe-Alexander, T. L., Gomersall, S., Clark, B., Torquati, L., Pavey, T., & Brown, W. J. (2019). A hard day's night: time use in shift workers. *BMC Public Health*, *19*(Suppl 2), 452. https://doi.org/10.1186/s12889-019-6766-5

Kolstad, H. A. (2008). Nightshift work and risk of breast cancer and other cancers—a critical review of the epidemiologic evidence. *Scandinavian Journal of Work, Environment & Health*, 5-22.

Koster, A., Shiroma, E. J., Caserotti, P., Matthews, C. E., Chen, K. Y., Glynn, N. W., & Harris, T. B. (2016). Comparison of Sedentary Estimates between activPAL and Hip- and Wrist-Worn ActiGraph. *Med and Science in Sports and Exercise*, *48*(8), 1514-1522. https://doi.org/10.1249/mss.0000000000000924

Koval, P., Hinton, J., Dozo, N., Gleeson, J., Alvarez, M., Harrison, A., Vu, D., Susanto, R., Jayaputera, G., & Sinnott, R. (2019). SEMA3: Smartphone Ecological Momentary Assessment, Version 3. *Computer software. Retrieved from http://www. sema3. com*.

Kozey-Keadle, S., Libertine, A., Lyden, K., Staudenmayer, J., & Freedson, P. S. (2011). Validation of wearable monitors for assessing sedentary behavior. *Medicine and Science in Sports and Exercise*, *43*(8), 1561-1567. https://doi.org/10.1249/MSS.0b013e31820ce174

Kracht, Beyl, R. A., Maher, J. P., Katzmarzyk, P. T., & Staiano, A. E. (2021). Adolescents' sedentary time, affect, and contextual factors: An ecological momentary assessment study. *International Journal of Behavioral Nutrition and Physical Activity*, *18*(1), 53. https://doi.org/10.1186/s12966-021-01121-y.

Krieger, T., Zimmermann, J., Huffziger, S., Ubl, B., Diener, C., Kuehner, C., & Holtforth, M. G. (2014). Measuring depression with a well-being index: further evidence for the validity of the WHO Well-Being Index (WHO-5) as a measure of the severity of depression. *Journal of Affective Disorders*, *156*, 240-244.

Kwan, B. M., McGinnes, H. L., Ory, M. G., Estabrooks, P. A., Waxmonsky, J. A., & Glasgow, R. E. (2019). RE-AIM in the real world: use of the re-aim framework for program planning and evaluation in clinical and community settings. *Frontiers in Public Health*, *7*. https://doi.org/10.3389/fpubh.2019.00345

Kwiecień-Jaguś, K., Mędrzycka-Dąbrowska, W., Czyż-Szypenbeil, K., Lewandowska, K., & Ozga, D. (2019). The use of a pedometer to measure the physical activity during 12-hour shift of ICU and nurse anaesthetists in Poland. *Intensive & Critical Care Nursing*, *55*, 102750. https://doi.org/10.1016/j.iccn.2019.07.009

Lassen, A. D., Fagt, S., Lennernäs, M., Nyberg, M., Haapalar, I., Thorsen, A. V., Møbjerg, A. C. M., & Beck, A. M. (2018). The impact of worksite interventions promoting healthier food and/or physical activity habits among employees working 'around the clock' hours: a systematic review. *Food & Nutrition Research*, *62*, 10.29219/fnr.v29262.21115. https://doi.org/10.29219/fnr.v62.1115

Lauren, S., Chen, Y., Friel, C., Chang, B. P., & Shechter, A. (2020). Free-living sleep, food intake, and physical activity in night and morning shift workers. *Journal of American College of Nutrition*, *39*(5), 450-456. https://doi.org/10.1080/07315724.2019.1691954

Lavie, C. J., Ozemek, C., Carbone, S., Katzmarzyk, P. T., & Blair, S. N. (2019). Sedentary behavior, exercise, and cardiovascular health. *Circulation Research*, *124*(5), 799-815. https://doi.org/10.1161/CIRCRESAHA.118.312669

Ledikwe, J. H., Kleinman, N. J., Mpho, M., Mothibedi, H., Mawandia, S., Semo, B. W., & O'Malley, G. (2018). Associations between healthcare worker participation in workplace wellness activities and job satisfaction, occupational stress and burnout: a cross-sectional study in Botswana. *BMJ Open*, *8*(3), e018492. https://doi.org/10.1136/bmjopen-2017-018492

Lee, A., Myung, S.-K., Cho, J. J., Jung, Y.-J., Yoon, J. L., & Kim, M. Y. (2017). Night shift work and risk of depression: meta-analysis of observational studies. *Journal of Korean Medical Science*, *32*(7), 1091-1096. https://doi.org/10.3346/jkms.2017.32.7.1091

Lee, S.-H., Ha, Y., Jung, M., Yang, S., & Kang, W.-S. (2019). The effects of a mobile wellness intervention with Fitbit use and goal setting for workers. *Telemedicine and e-Health*, *25*(11), 1115-1122. https://doi.org/10.1089/tmj.2018.0185

Leroith, D. (2012). Pathophysiology of the metabolic syndrome: implications for the cardiometabolic risks associated with type 2 diabetes. *The American Journal of the Medical Sciences*, *343*(1) 13-16. https://doi.org/https://doi.org/10.1097/MAJ.0b013e31823ea214

Li, W., Chen, Z., Ruan, W., Yi, G., Wang, D., & Lu, Z. (2019). A meta-analysis of cohort studies including dose-response relationship between shift work and the risk of diabetes mellitus. *European Journal of Epidemiology*, *34*(11), 1013-1024. https://doi.org/10.1007/s10654-019-00561-y

Lieberman, H. R., Agarwal, S., Caldwell, J. A., & Fulgoni, V. L., III. (2019). Demographics, sleep, and daily patterns of caffeine intake of shift workers in a nationally representative sample of the US adult population. *Sleep*, *43*(3). https://doi.org/10.1093/sleep/zsz240

Liu, Q., Shi, J., Duan, P., Liu, B., Li, T., Wang, C., Li, H., Yang, T., Gan, Y., Wang, X., Cao, S., & Lu, Z. (2018). Is shift work associated with a higher risk of overweight or obesity? A systematic review of observational studies with meta-analysis. *International Journal of Epidemiology*, *47*(6), 1956-1971. https://doi.org/10.1093/ije/dyy079

Loef, Baarle, D. V., van der Beek, A. J., Beekhof, P. K., van Kerkhof, L. W., & Proper, K. I. (2019). The association between exposure to different aspects of shift work and metabolic risk factors in health care workers, and the role of chronotype. *Plos One*, *14*(2), e0211557. https://doi.org/10.1371/journal.pone.0211557

Loef, Hulsegge, G., Wendel-Vos, G. C., Verschuren, W. M., Vermeulen, R. C., Bakker, M. F., van der Beek, A. J., & Proper, K. I. (2017). Non-occupational physical activity levels of shift workers compared with non-shift workers. *Occupational and Environmental Medicine*, *74*(5), 328-335. https://doi.org/10.1136/oemed-2016-103878

Loef, van der Beek, A. J., Holtermann, A., Hulsegge, G., van Baarle, D., & Proper, K. I. (2018). Objectively measured physical activity of hospital shift workers. *Scandinavian Journal of Work, Environment & Health*, *44*(3), 265-273. https://doi.org/10.5271/sjweh.3709

Loprinzi, P. D. (2015). The effects of shift work on free-living physical activity and sedentary behavior. *Preventive Medicine*, *76*, 43-47. https://doi.org/https://doi.org/10.1016/j.ypmed.2015.03.025

Lowe, H., Haddock, G., Mulligan, L. D., Gregg, L., Fuzellier-Hart, A., Carter, L. A., & Kyle, S. D. (2019). Does exercise improve sleep for adults with insomnia? A systematic review with quality appraisal. *Clinical Psychology Review, 68*, 1-12. doi:10.1016/j.cpr.2018.11.002

Lynch, B. M., Nguyen, N. H., Moore, M. M., Reeves, M. M., Rosenberg, D. E., Boyle, T., Vallance, J. K., Milton, S., Friedenreich, C. M., & English, D. R. (2019). A randomized controlled trial of a wearable technology-based intervention for increasing moderate to vigorous physical activity and reducing sedentary behavior in breast cancer survivors: The ACTIVATE Trial. *Cancer*, *125*(16), 2846–2855. https://doi.org/10.1002/cncr.32143

Ma, J. K., Chan, A., Sandhu, A., & Li, L. C. (2020). Wearable physical activity measurement devices used in arthritis. *Arthritis Care & Research*, *72* (10), 703–716. https://doi.org/10.1002/acr.24262

Maher, J. P., Rebar, A. L., & Dunton, G. F. (2018). Ecological momentary assessment is a feasible and valid methodological tool to measure older adults' physical activity and sedentary behavior. *Frontiers in Psychology, 9*, 1485. doi:10.3389/fpsyg.2018.01485

Maher, J. P., Sappenfield, K., Scheer, H., Zecca, C., Hevel, D. J., & Kennedy-Malone, L. (2021). Feasibility and validity of assessing low-income, African American older adults’ physical activity and sedentary behavior through ecological momentary assessment.

Journal for the Measurement of Physical Behaviour, *4*(4), 343-35. https://doi.org/10.1123/jmpb.2021-0024

Malete, L., Ricketts, C., Chen, S., & Jackson, J. (2022). Correlates of physical activity among adults in Botswana: sociodemographic factors, health status, and body image. *Journal of Physical Activity & Health*, *19*(9), 599–606. https://doi.org/10.1123/jpah.2022-0243

Mamen, A., Øvstebø, R., Sirnes, P. A., Nielsen, P., & Skogstad, M. (2020). High-intensity training reduces cvd risk factors among rotating shift workers: an eight-week intervention in industry. *International Journal of Environmental Research and Public Health*, *17*(11). https://doi.org/10.3390/ijerph17113943

Marobela, M.N. (2014), "Industrial relations in Botswana – workplace conflict: behind the diamond sparkle", 4(2). https://doi.org/10.1108/EEMCS-2014-5555

Marqueze, E. C., Ulhôa, M. A., & Castro Moreno, C. R. (2014). Leisure-time physical activity does not fully explain the higher body mass index in irregular-shift workers. *International Archives of Occupation, Environment and Health*, *87*(3), 229-239. https://doi.org/10.1007/ ofs00420-013-0850-4

Marszalek, J., Morgulec-Adamowicz, N., Rutkowska, I., & Kosmol, A. (2014). Using ecological momentary assessment to evaluate current physical activity. *Biomedical Research International*, *2014*, 915172. https://doi.org/10.1155/2014/915172

Martin-Gill, C., Barger, L. K., Moore, C. G., Higgins, J. S., Teasley, E. M., Weiss, P. M., Condle, J. P., Flickinger, K. L., Coppler, P. J., & Sequeira, D. J. (2018). Effects of napping during shift work on sleepiness and performance in emergency medical services personnel and similar shift workers: a systematic review and meta-analysis. *Prehospital Emergency Care*, *22*(1), 47-57.

Martin, C. K., Correa, J. B., Han, H., Allen, H. R., Rood, J. C., Champagne, C. M., Gunturk, B. K., & Bray, G. A. (2012). Validity of the Remote Food Photography Method (RFPM) for estimating energy and nutrient intake in near real-time. *Obesity*, *20*(4), 891-899.

Martin, S. S., Feldman, D. I., Blumenthal, R. S., Jones, S. R., Post, W. S., McKibben, R. A., Michos, E. D., Ndumele, C. E., Ratchford, E. V., & Coresh, J. (2015). mActive: a randomized clinical trial of an automated mHealth intervention for physical activity promotion. *Journal of the American Heart Association*, *4*(11), e002239. https://doi.org/10.1007/s00125-019-05059-6

Mason, I. C., Qian, J., Adler, G. K., & Scheer, F. A. J. L. (2020). Impact of circadian disruption on glucose metabolism: implications for type 2 diabetes. *Diabetologia*, *63*(3), 462-472. https://doi.org/10.1007/s00125-019-05059-6

Mathiassen, S. E., Liv, P., & Wahlström, J. (2013). Cost-efficient measurement strategies for posture observations based on video recordings. *Applied Ergonomics*, *44*(4), 609–617. https://doi.org/10.1016/j.apergo.2012.12.003

Mathew, V., Akkilagunta, S., Kumar, D., Lakshminarayanan, S., & Kar, S. S. (2019). Effectiveness of pedometer-based walking program to improve physical activity of workers in a software industry: an experimental study. *International Journal of Preventive Medicine*, *10*, 49-49. https://doi.org/10.4103/ijpvm.IJPVM_378_17

Matsugaki, R., Kuhara, S., Saeki, S., Jiang, Y., Michishita, R., Ohta, M., & Yamato, H. (2017). Effectiveness of workplace exercise supervised by a physical therapist among nurses conducting shift work: a randomized controlled trial. *Journal of Occupational Health*, *59*(4), 327-335.

McDermott, M. S., Oliver, M., Iverson, D., & Sharma, R. (2016). Effective techniques for changing physical activity and healthy eating intentions and behaviour: A systematic review and meta-analysis. *British Journal of Health Psychology*, *21*(4), 827–841. https://doi.org/10.1111/bjhp.12199

Medic, G., Wille, M., & Hemels, M. E. H. (2017). Short- and long-term health consequences of sleep disruption. *Nature and Science of Sleep*, *9*, 151-161. https://doi.org/10.2147/NSS.S134864

Messenger, J. (2018). Working time and the future of work. *ILO future of work research paper series*, *6*(8), 33-37.

Michie, S., Atkins, L., & West, R. (2014). The behaviour change wheel. *A guide to designing interventions. 1st ed. Great Britain: Silverback Publishing*, 1003-1010.

Michie, van Stralen, M. M., & West, R. (2011). The behaviour change wheel: a new method for characterising and designing behaviour change interventions. *Implementation Science*, *6*, 42. https://doi.org/10.1186/1748-5908-6-42

Mielke, G. I., Burton, N. W., & Brown, W. J. (2022). Accelerometer-measured physical activity in mid-age Australian adults. *BMC Public Health*, *22*(1), 1952. https://doi.org/10.1186/s12889-022-14333-z

Migueles, J. H., Cadenas-Sanchez, C., Ekelund, U., Delisle Nyström, C., Mora-Gonzalez, J., Löf, M., Labayen, I., Ruiz, J. R., & Ortega, F. B. (2017). Accelerometer data collection and processing criteria to assess physical activity and other outcomes: a systematic review and practical considerations. *Sports Medicine*, *47*(9), 1821-1845.

Monnaatsie, M., Biddle, S. J. H., Khan, S., & Kolbe-Alexander, T. (2021). Physical activity and sedentary behaviour in shift and non-shift workers: A systematic review and meta-analysis. *Preventive Medicine Reports, 24*, 101597. doi:https://doi.org/10.1016/j.pmedr.2021.101597

Monnaatsie, M., Biddle, S. J. H., & Kolbe-Alexander, T. (2023). The feasibility of a text-messaging intervention promoting physical activity in shift workers: a process evaluation. *International Journal of Environmental Research and Public Health, 20*(4), 3260. https://www.mdpi.com/1660-4601/20/4/3260

Moore, G. F., Evans, R. E., Hawkins, J., Littlecott, H., Melendez-Torres, G. J., Bonell, C., & Murphy, S. (2019). From complex social interventions to interventions in complex social systems: Future directions and unresolved questions for intervention development and evaluation. *Evaluation, 25*(1), 23–45. https://doi.org/10.1177/1356389018803219

Morris, A., Lopez, R., Stevenback, E., & Ingram, K. H. (2018). Validity Of Adhesive Worn Actigraph GT3X+ Accelerrometer: 292 Board# 133 May 30 9: 30 AM-11: 00 AM. *Medicine & Science in Sports & Exercise*, *50*(5S), 58.

Motlhatlhedi, K., Bogatsu, Y., Maotwe, K., & Tsima, B. (2020). Coronavirus disease 2019 in Botswana: Contributions from family physicians. *African Journal of Primary Health Care & Family medicine*, *12*(1), e1–e3. https://doi.org/10.4102/phcfm.v12i1.2497

Moyer, J. C., Heagerty, P. J., & Murray, D. M. (2022). Analysis of multiple-period group randomized trials: random coefficients model or repeated measures ANOVA? *Trials*, *23*(1), 987. https://doi.org/10.1186/s13063-022-06917-2

Müller, A. M., Maher, C. A., Vandelanotte, C., Hingle, M., Middelweerd, A., Lopez, M. L., DeSmet, A., Short, C. E., Nathan, N., Hutchesson, M. J., Poppe, L., Woods, C. B., Williams, S. L., & Wark, P. A. (2018). Physical activity, sedentary behavior, and diet-related eHealth and mhealth research: Bibliometric Analysis. *Journal of medical Internet research*, *20*(4), e122. https://doi.org/10.2196/jmir.8954

Munir, F., Biddle, S. J. H., Davies, M. J., Dunstan, D., Esliger, D., Gray, L. J., Jackson, B. R., O'Connell, S. E., Yates, T., & Edwardson, C. L.

(2018). Stand More AT Work (SMArT Work): using the behaviour change wheel to develop an intervention to reduce sitting time in the workplace. *BMC Public Health*, *18*(1), 319. https://doi.org/10.1186/s12889-018-5187-1

Murray, J. M., Brennan, S. F., French, D. P., Patterson, C. C., Kee, F., & Hunter, R. F. (2017). Effectiveness of physical activity interventions in achieving behaviour change maintenance in young and middle aged adults: A systematic review and meta-analysis. *Social Science & Medicine (1982)*, *192*, 125–133. https://doi.org/10.1016/j.socscimed.2017.09.021

Nahum-Shani, I., Smith, S. N., Spring, B. J., Collins, L. M., Witkiewitz, K., Tewari, A., & Murphy, S. A. (2018). Just-in-Time Adaptive Interventions (JITAIs) in mobile health: key components and design principles for ongoing health behavior support. *Annals of Behavioral Medicine, 52*(6), 446–462. https://doi.org/10.1007/s12160-016-9830-8

Nea, F. M., Kearney, J., Livingstone, M. B., Pourshahidi, L. K., & Corish, C. A. (2015). Dietary and lifestyle habits and the associated health risks in shift workers. *Nutrition Research Reviews*, *28*(2), 143–166. https://doi.org/10.1017/S095442241500013X

Nea, Pourshahidi, L. K., Kearney, J., Livingstone, M. B. E., Bassul, C., & Corish, C. A. (2017). A Qualitative exploration of the shift work experience: the perceived barriers and facilitators to a healthier lifestyle and the role of the workplace environment. *Journal of*

Occupational and Environmental Medicine, *59*(12), 1153-1160. https://doi.org/10.1097/jom.0000000000001126

NeCamp, T., Sen, S., Frank, E., Walton, M. A., Ionides, E. L., Fang, Y., . . . Wu, Z. (2020). Assessing real-time moderation for developing adaptive mobile health interventions for medical interns: micro-randomized trial. *Journal of Medical Internet Research, 22*(3), e15033. doi:10.2196/15033

Neil-Sztramko, S. E., Gotay, C. C., Demers, P. A., & Campbell, K. L. (2016). Physical activity, physical fitness, and body composition of canadian shift workers: data from the Canadian health measures survey cycles 1 and 2. *Journal of Occupational and Environmental Medicine*, *58*(1), 94-100. https://doi.org/10.1097/jom.0000000000000574

Neil-Sztramko, S. E., Gotay, C. C., Sabiston, C. M., Demers, P. A., & Campbell, K. C. (2017). Feasibility of a telephone and web-based physical activity intervention for women shift workers. *Translational Behavioral Medicine*, *7*(2), 268-276. https://doi.org/10.1007/s13142-017-0471-7

Neil-Sztramko, S. E., Pahwa, M., Demers, P. A., & Gotay, C. C. (2014). Health-related interventions among night shift workers: a critical review of the literature. *Scandinavian Journal of Work, Environment & Health,* (6), 543-556. https://doi.org/10.5271/sjweh.3445

Ngueleu, A.-M., Barthod, C., Best, K. L., Routhier, F., Otis, M., & Batcho, C. S. (2022). Criterion validity of ActiGraph monitoring devices for step counting and distance measurement in adults and older adults: a systematic review. *Journal of NeuroEngineering and Rehabilitation*, *19*(1), 112. https://doi.org/10.1186/s12984-022-01085-5

Nigg, C. R., Fuchs, R., Gerber, M., Jekauc, D., Koch, T., Krell-Roesch, J., Lippke, S., Mnich, C., Novak, B., Ju, Q., Sattler, M. C., Schmidt, S. C. E., van Poppel, M., Reimers, A. K., Wagner, P., Woods, C., & Woll, A. (2020). Assessing physical activity through questionnaires – A consensus of best practices and future directions. *Psychology of Sport and Exercise*, *50*, 101715. https://doi.org/https://doi.org/10.1016/j.psychsport.2020.101715

Nyman, T., Rhén, I. M., Johansson, P. J., Eliasson, K., Kjellberg, K., Lindberg, P., Fan, X., & Forsman, M. (2023). Reliability and validity of six selected observational methods for risk assessment of hand intensive and repetitive work. *International Journal of Environmental Research and Public Health*, *20*(8), 5505. https://doi.org/10.3390/ijerph20085505

O'Cathain, A., Croot, L., Duncan, E., Rousseau, N., Sworn, K., Turner, K. M., Yardley, L., & Hoddinott, P. (2019). Guidance on how to develop complex interventions to improve health and healthcare. *British Medical Journal*, *9*(8), e029954. https://doi.org/10.1136/bmjopen-2019-029954

O’Neill, B., McDonough, S. M., Wilson, J. J., Bradbury, I., Hayes, K., Kirk, A., Kent, L., Cosgrove, D., Bradley, J. M., & Tully, M. A. (2017).

Comparing accelerometer, pedometer and a questionnaire for measuring physical activity in bronchiectasis: a validity and feasibility study. *Respiratory Research*, *18*(1), 16. https://doi.org/10.1186/s12931-016-0497-2

Oakman, J., Clays, E., Jørgensen, M. B., & Holtermann, A. (2019). Are occupational physical activities tailored to the age of cleaners and manufacturing workers? *International Archives of Occupational and Environmental Health*, *92*(2), 185-193. https://doi.org/10.1007/s00420-018-1364-x

Oftedal, S., Burrows, T., Fenton, S., Murawski, B., Rayward, A. B., & Duncan, M. J. (2019). Feasibility and Preliminary Efficacy of an m-Health Intervention Targeting Physical Activity, Diet, and Sleep Quality in Shift-Workers. *International Journal of Environmental Research and Public Health*, *16*(20), 3810. https://www.mdpi.com/1660-4601/16/20/3810

Owen, N., Sugiyama, T., Eakin, E. E., Gardiner, P. A., Tremblay, M. S., & Sallis, J. F. (2011). Adults' Sedentary Behavior: Determinants and Interventions. *American Journal of Preventive Medicine*, *41*(2), 189-196. https://doi.org/10.1016/j.amepre.2011.05.013

Pannicke, B., Reichenberger, J., Schultchen, D., Pollatos, O., & Blechert, J. (2020). Affect improvements and measurement concordance between a subjective and an accelerometric estimate of physical activity. *European Journal of Health Psychology*, *27*(2), 66.

Park, H., & Suh, B. (2020). Association between sleep quality and physical activity according to gender and shift work. *Journal of Sleep Research*, *29*(6), e12924.https://doi.org/10.1111/jsr.1292

Patterson, R., McNamara, E., Tainio, M., de Sá, T. H., Smith, A. D., Sharp, S. J., Edwards, P., Woodcock, J., Brage, S., & Wijndaele, K. (2018). Sedentary behaviour and risk of all-cause, cardiovascular and cancer mortality, and incident type 2 diabetes: a systematic review and dose response meta-analysis. *European Journal of Epidemiology*, *33*(9), 811-829. https://doi.org/10.1007/s10654-018-0380-1

Peplonska, B., Bukowska, A., & Sobala, W. (2014). Rotating night shift work and physical activity of nurses and midwives in the cross-sectional study in Ł ódź, Poland. *Chronobiology International*, *31*(10), 1152-1159.https://doi.org/10.3109/07420528.2014.957296

Pepłońska, B., Nowak, P., & Trafalska, E. (2019). The association between night shift work and nutrition patterns among nurses: a literature review. *Medycyna Pracy*, *70*.https://doi.org/10.13075/mp.5893.00816

Physical Activity Guidelines Advisory Committee. (2018). 2018 physical activity guidelines advisory committee scientific report.

Pietroiusti, A., Neri, A., Somma, G., Coppeta, L., Iavicoli, I., Bergamaschi, A., & Magrini, A. (2010). Incidence of metabolic syndrome among night-shift healthcare workers. *Occupational and Environmental Medicine*, *67*(1), 54-57. https://doi.org/10.1136/oem.2009.046797

Ponnada, A., Thapa-Chhetry, B., Manjourides, J., & Intille, S. (2021). Measuring criterion validity of microinteraction ecological momentary assessment (micro-ema): exploratory pilot study with physical activity measurement. *JMIR mHealth and uHealth*, *9*(3), e23391.

Prince, Elliott, C. G., Scott, K., Visintini, S., & Reed, J. L. (2019). Device-measured physical activity, sedentary behaviour and cardiometabolic health and fitness across occupational groups: a systematic review and meta-analysis. *International Journal of Behavioral Nutrition and Physical Activity*, *16*(1), 1-15. https://doi.org/10.1186/s12966-019-0790-9

Prince, Reed, J., McFetridge, C., Tremblay, M., & Reid, R. (2017). Correlates of sedentary behaviour in adults: a systematic review. *Obesity Reviews*, *18*(8), 915-935. https://doi.org/10.1111/obr.12529

Prince, S. A., Blanchard, C. M., Grace, S. L., & Reid, R. D. (2016). Objectively-measured sedentary time and its association with markers of cardiometabolic health and fitness among cardiac rehabilitation graduates. *European Journal of Preventive Cardiology*, *23*(8), 818-825. https://doi.org/10.1177/2047487315617101

Prince, S. A., Rasmussen, C. L., Biswas, A., Holtermann, A., Aulakh, T., Merucci, K., & Coenen, P. (2021). The effect of leisure time physical activity and sedentary behaviour on the health of workers with different occupational physical activity demands: a systematic review. *The International Journal of Behavioral Nutrition and physical activity*, *18*(1), 100. https://doi.org/10.1186/s12966-021-01166-z

Proper, K. I., van de Langenberg, D., Rodenburg, W., Vermeulen, R. C. H., van der Beek, A. J., van Steeg, H., & van Kerkhof, L. W. M. (2016). The Relationship between shift work and metabolic risk factors: a systematic review of longitudinal studies. *American Journal of Preventive Medicine*, *50*(5), e147-e157. https://doi.org/https://doi.org/10.1016/j.amepre.2015.11.013

Pulantara, I. W., Parmanto, B., & Germain, A. (2018). Clinical feasibility of a just-in-time adaptive intervention app (irest) as a behavioral sleep treatment in a military population: feasibility comparative effectiveness study. *Journal of Medical Internet Research*, *20*(12), e10124-e10124. https://doi.org/10.2196/10124

Rapisarda, V., Cannizzaro, E., Barchitta, M., Vitale, E., Cinà, D., Minciullo, F., Matera, S., Bracci, M., Agodi, A., & Ledda, C. (2021). A combined multidisciplinary intervention for health promotion in the workplace: a pilot study. *Journal of Clinical Medicine, 10*(7). https://doi.org/10.3390/jcm10071512

Rebar, A. L., Alfrey, K. L., Gardner, B., & Vandelanotte, C. (2018). Health behaviours of Australian fly-in, fly-out workers and partners during on-shift and off-shift days: an ecological momentary assessment study. *British Medical Journal*, *8*(12), e023631. https://doi.org/10.1136/bmjopen-2018-023631

Reed, J. L., Prince, S. A., Elliott, C. G., Mullen, K.-A., Tulloch, H. E., Hiremath, S., Cotie, L. M., Pipe, A. L., & Reid, R. D. (2017). Impact of workplace physical activity interventions on physical activity and cardiometabolic health among working-age women: a systematic review and meta-analysis. *Circulation, 10*(2), e003516.

Reed, J. L., Prince, S. A., Pipe, A. L., Attallah, S., Adamo, K. B., Tulloch, H. E., Manuel, D., Mullen, K.-A., Fodor, G., & Reid, R. D. (2018). Influence of the workplace on physical activity and cardiometabolic health: Results of the multi-centre cross-sectional Champlain Nurses' study. *International Journal of Nursing Studies*, *81*, 49-60.

Reichert, M., Giurgiu, M., Koch, E. D., Wieland, L. M., Lautenbach, S., Neubauer, A. B., von Haaren-Mack, B., Schilling, R., Timm, I., Notthoff, N., Marzi, I., Hill, H., Brüßler, S., Eckert, T., Fiedler, J., Burchartz, A., Anedda, B., Wunsch, K., Gerber, M., . . . Liao, Y. (2020). Ambulatory assessment for physical activity research: State of the science, best practices and future directions. *Psychology of Sport and Exercise*, *50*, 101742. https://doi.org/https://doi.org/10.1016/j.psychsport.2020.101742

Reynolds, A. C., Paterson, J. L., Ferguson, S. A., Stanley, D., Wright, K. P., & Dawson, D. (2017). The shift work and health research agenda: Considering changes in gut microbiota as a pathway linking shift work, sleep loss and circadian misalignment, and metabolic disease. *Sleep Medicine Reviews*, *34*, 3-9. https://doi.org/10.1016/j.smrv.2016.06.009

Rhodes, R. E., McEwan, D., & Rebar, A. L. (2019). Theories of physical activity behaviour change: A history and synthesis of approaches. *Psychology of Sport and Exercise, 42*, 100-109.

Rintala, A., Wampers, M., Myin-Germeys, I., & Viechtbauer, W. (2019). Response compliance and predictors thereof in studies using the experience sampling method. *Psychological Assessment*, *31*(2), 226–235. https://doi.org/10.1037/pas0000662

Rivera, A. S., Akanbi, M., O'Dwyer, L. C., & McHugh, M. (2020). Shift work and long work hours and their association with chronic health conditions: a systematic review of systematic reviews with meta-analyses. *Plos One*, *15*(4), e0231037.

Robinson, K., Allen, F., Darby, J., Fox, C., Gordon, A. L., Horne, J. C., Leighton, P., Sims, E., & Logan, P. A. (2020). Contamination in complex healthcare trials: the falls in care homes (FinCH) study experience. *BMC Medical Research Methodology*, *20*(1), 46. https://doi.org/10.1186/s12874-020-00925-z

Romanzini, C. L. P., Romanzini, M., Barbosa, C. C. L., Batista, M. B., Shigaki, G. B., & Ronque, E. R. V. (2019). Characterization and agreement between application of Mobile ecological momentary assessment (mEMA) and accelerometry in the identification of prevalence of sedentary behavior (SB) in young adults. *Frontiers in Psychology*, *10*, 720.

Roskoden, F. C., Krüger, J., Vogt, L. J., Gärtner, S., Hannich, H. J., Steveling, A., . . . Aghdassi, A. A. (2017). Physical Activity, Energy Expenditure, Nutritional Habits, Quality of Sleep and Stress Levels in Shift-Working Health Care Personnel. *Plos One, 12*(1), e0169983. doi:10.1371/journal.pone.0169983

Ross, R., Neeland, I. J., Yamashita, S., Shai, I., Seidell, J., Magni, P., Santos, R. D., Arsenault, B., Cuevas, A., Hu, F. B., Griffin, B. A., Zambon, A., Barter, P., Fruchart, J.-C., Eckel, R. H., Matsuzawa, Y., & Després, J.-P. (2020). Waist circumference as a vital sign in clinical practice: a Consensus Statement from the IAS and ICCR Working Group on Visceral Obesity. *Nature Reviews Endocrinology*, *16*(3), 177-189. https://doi.org/10.1038/s41574-019-0310-7

Santos, H. G., Chiavegato, L. D., Valentim, D. P., & Padula, R. S. (2020). Effectiveness of a progressive resistance exercise program for industrial workers during breaks on perceived fatigue control: a cluster randomized controlled trial. *BMC Public Health*, *20*(1), 849. https://doi.org/10.1186/s12889-020-08994-x

Schernhammer, E. S., Laden, F., Speizer, F. E., Willett, W. C., Hunter, D. J., Kawachi, I., Fuchs, C. S., & Colditz, G. A. (2003). Night-shift work and risk of colorectal cancer in the nurses' health study. *Journal of the National Cancer Institute*, *95*(11), 825-828.

Schoeppe, S., Alley, S., Van Lippevelde, W., Bray, N. A., Williams, S. L., Duncan, M. J., & Vandelanotte, C. (2016). Efficacy of interventions that use apps to improve diet, physical activity and sedentary behaviour: a systematic review. *International Journal of Behavioral Nutrition and Physical Activity*, *13*(1), 127. https://doi.org/10.1186/s12966-016-0454-y

Schroé, H., Van Dyck, D., De Paepe, A., Poppe, L., Loh, W. W., Verloigne, M., Loeys, T., De Bourdeaudhuij, I., & Crombez, G. (2020). Which behaviour change techniques are effective to promote physical activity and reduce sedentary behaviour in adults: a factorial randomized trial of an e- and m-health intervention. *International Journal of Behavioral Nutrition and Physical Activity*, *17*(1), 127. https://doi.org/10.1186/s12966-020-01001-x

Short, M. A., Agostini, A., Lushington, K., & Dorrian, J. (2015). A systematic review of the sleep, sleepiness, and performance implications of limited wake shift work schedules. *Scandinavian Journal of Work, Environment & Health*, *41*(5), 425-440. https://doi.org/10.5271/sjweh.3509

Silva, A., Silva, A., Duarte, J., & da Costa, J. T. (2020). Shift-work: a review of the health consequences. *International Journal of Occupational and Environmental Safety*, *4*(2), 48-79.

Skivington, K., Matthews, L., Simpson, S. A., Craig, P., Baird, J., Blazeby, J. M., . . . Moore, L. (2021). A new framework for developing and evaluating complex interventions: update of Medical Research Council guidance. *British Medical Journal, 374*, n2061. doi:10.1136/bmj.n2061

Smith, Danyluk, A. B., Munir, S. S., & Covassin, N. (2022). Shift Work and Obesity Risk—Are There Sex Differences? *Current Diabetes Reports*, *22*(8), 341-352. https://doi.org/10.1007/s11892-022-01474-z

Smith, L., McCourt, O., Sawyer, A., Ucci, M., Marmot, A., Wardle, J., & Fisher, A. (2016). A review of occupational physical activity and sedentary behaviour correlates. *Occupational Medicine, 66*(3), 185-192. doi:10.1093/occmed/kqv164

Smyth, J. M., Juth, V., Ma, J., & Sliwinski, M. (2017). A slice of life: Ecologically valid methods for research on social relationships and health across the life span. *Social and Personality Psychology Compass*, *11*(10), e12356.

Song, Z., & Baicker, K. (2021). Health and economic outcomes up to three years after a workplace wellness program: a randomized controlled trial: study examines the health and economic outcomes of a workplace wellness program. *Health Affairs*, *40*(6), 951-960.

Sooriyaarachchi, P., Jayawardena, R., Pavey, T., & King, N. A. (2022). Shift work and the risk for metabolic syndrome among healthcare workers: A systematic review and meta-analysis. *Obesity Reviews*, *23*(10), e13489. https://doi.org/10.1111/obr.13489

Souza, R. V., Sarmento, R. A., de Almeida, J. C., & Canuto, R. (2019). The effect of shift work on eating habits: a systematic review. *Scandinavian Journal of Work, Environment & Health*, *45*(1), 7–21. https://doi.org/10.5271/sjweh.3759

Speakman, J. R., Yamada, Y., Sagayama, H., Berman, E. S. F., Ainslie, P. N., Andersen, L. F., Anderson, L. J., Arab, L., Baddou, I., Bedu-Addo, K., Blaak, E. E., Blanc, S., Bonomi, A. G., Bouten, C. V. C., Bovet, P., Buchowski, M. S., Butte, N. F., Camps, S. G. J. A., Close, G. L., Cooper, J. A., … IAEA DLW database group (2021). A standard calculation methodology for human doubly labeled water studies. *Cell Reports Medicine*, *2*(2), 100203. https://doi.org/10.1016/j.xcrm.2021.100203

Stamatakis, E., Hamer, M., Tilling, K., & Lawlor, D. A. (2012). Sedentary time in relation to cardio-metabolic risk factors: differential associations for self-report vs accelerometry in working age adults. *International Journal of Epidemiology*, *41*(5), 1328–1337. https://doi.org/10.1093/ije/dys077

Stevens, M. L., Crowley, P., Rasmussen, C. L., Hallman, D. M., Mortensen, O. S., Nygård, C. H., & Holtermann, A. (2020). Accelerometer-measured physical activity at work and need for recovery: a compositional analysis of cross-sectional data. *Annals of*

Work Exposures and Health, *64*(2), 138–151. https://doi.org/10.1093/annweh/wxz095

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

Strain, T., Wijndaele, K., Garcia, L., Cowan, M., Guthold, R., Brage, S., & Bull, F. C. (2020). Levels of domain-specific physical activity at work, in the household, for travel and for leisure among 327 789 adults from 104 countries. *British Journal of Sports Medicine, 54*(24), 1488. doi:10.1136/bjsports-2020-102601

Straker, L., Mathiassen, S. E., & Holtermann, A. (2018). The 'Goldilocks Principle': designing physical activity at work to be 'just right' for promoting health. *British Journal of Sports Medicine*, *52*(13), 818–819. https://doi.org/10.1136/bjsports-2017-097765

Su, F., Huang, D., Wang, H., & Yang, Z. (2021). Associations of shift work and night work with risk of all-cause, cardiovascular and cancer mortality: a meta-analysis of cohort studies. *Sleep Medicine*, *86*, 90-98. https://doi.org/10.1016/j.sleep.2021.08.017

Sullivan, A. N., & Lachman, M. E. (2017). Behavior Change with Fitness Technology in Sedentary Adults: A Review of the Evidence for Increasing Physical Activity. *Frontiers in Public Health*, *4*, 289-289. https://doi.org/10.3389/fpubh.2016.00289

Sun, M., Feng, W., Wang, F., Li, P., Li, Z., Li, M., Tse, G., Vlaanderen, J., Vermeulen, R., & Tse, L. A. (2018). Meta-analysis on shift work and risks of specific obesity types. *Obesity Reviews*, *19*(1), 28-40. https://doi.org/10.1111/obr.12621

Sweeney, E., Cui, Y., Yu, Z. M., Dummer, T. J. B., DeClercq, V., Forbes, C., Grandy, S. A., Keats, M. R., & Adisesh, A. (2021). The association between mental health and shift work: Findings from the Atlantic PATH study. *Preventive Medicine*, *150*, 106697. 106697https://doi.org/10.1016/j.ypmed.2021.106697

Sweeney, Sandler, D. P., Niehoff, N. M., & White, A. J. (2020). Shift work and working at night in relation to breast cancer incidence. *Cancer Epidemiology, Biomarkers & Prevention*, *29*(3), 687-689. https://doi.org/10.1158/1055-9965.Epi-19-1314

Sweet, S. N., Ginis, K. A., Estabrooks, P. A., & Latimer-Cheung, A. E. (2014). Operationalizing the RE-AIM framework to evaluate the impact of multi-sector partnerships. *Implementation Science : IS*, *9*, 74. https://doi.org/10.1186/1748-5908-9-74

Sweileh W. M. (2022). Analysis and mapping of global research publications on shift work (2012-2021). *Journal of Occupational Medicine and Toxicology, 17*(1), 22. https://doi.org/10.1186/s12995-022-00364-0

Sylvia, L. G., Bernstein, E. E., Hubbard, J. L., Keating, L., & Anderson, E. J. (2014). Practical guide to measuring physical activity. *Journal of* *the Academy of Nutrition and Dietetics*, *114*(2), 199–208. https://doi.org/10.1016/j.jand.2013.09.018

Takala, E. P., Pehkonen, I., Forsman, M., Hansson, G. Å., Mathiassen, S. E., Neumann, W. P., Sjøgaard, G., Veiersted, K. B., Westgaard, R. H., & Winkel, J. (2010). Systematic evaluation of observational methods assessing biomechanical exposures at work. *Scandinavian Journal of Work, Environment & Health*, *36*(1), 3–24. https://doi.org/10.5271/sjweh.2876

Tarp, J., Hansen, B. H., Fagerland, M. W., Steene-Johannessen, J., Anderssen, S. A., & Ekelund, U. (2020). Accelerometer-measured physical activity and sedentary time in a cohort of US adults followed for up to 13 years: the influence of removing early follow-up on associations with mortality. *International Journal of Behavioral Nutrition and Physical Activity*, *17*(1), 39. https://doi.org/10.1186/s12966-020-00945-4

Thøgersen-Ntoumani, C., Loughren, E. A., Taylor, I. M., Duda, J. L., & Fox, K. R. (2014). A step in the right direction? Change in mental well-being and self-reported work performance among physically inactive university employees during a walking intervention. *Mental Health and Physical Activity*, *7*(2), 89-94. https://doi.org/https://doi.org/10.1016/j.mhpa.2014.06.004

Thøgersen-Ntoumani, C., Quested, E., Biddle, S. J. H., Kritz, M., Olson, J., Burton, E., Cerin, E., Hill, K. D., McVeigh, J., & Ntoumanis, N. (2019). Trial feasibility and process evaluation of a motivationally-embellished group peer led walking intervention in retirement villages using the RE-AIM framework: the residents in action trial (RiAT). *Health Psychology and Behavioral Medicine*, *7*(1), 202-233. https://doi.org/10.1080/21642850.2019.1629934

Thompson, J. F., Severson, R. L., & Rosecrance, J. C. (2018). Occupational physical activity in brewery and office workers. *Journal of Occupational and Environmental Hygiene*, *15*(9), 686-699. https://doi.org/10.1080/15459624.2018.1492136

Thorp, A. A., Healy, G. N., Winkler, E., Clark, B. K., Gardiner, P. A., Owen, N., & Dunstan, D. W. (2012). Prolonged sedentary time and physical activity in workplace and non-work contexts: a cross-sectional study of office, customer service and call centre employees. *The International Journal of Behavioral Nutrition and Physical Activity*, *9*, 128. https://doi.org/10.1186/1479-5868-9-128

Topp, C. W., Østergaard, S. D., Søndergaard, S., & Bech, P. (2015). The WHO-5 Well-Being Index: A Systematic Review of the Literature. *Psychotherapy and Psychosomatics*, *84*(3), 167-176. https://doi.org/10.1159/000376585

Torquati, L., Mielke, G. I., Brown, W. J., & Kolbe-Alexander, T. (2018). Shift work and the risk of cardiovascular disease. A systematic review and meta-analysis including dose-response relationship. *Scandinavian Journal of Work, Environment & Health*, *44*(3), 229-238. https://doi.org/10.5271/sjweh.3700

Torquati, L., Mielke, G. I., Brown, W. J., Burton, N. W., & Kolbe-Alexander, T. L. (2019). Shift work and poor mental health: a meta-analysis of longitudinal studies. *American Journal of Public Health*, *109*(11), e13-e20. https://doi.org/10.2105/ajph.2019.305278

Tremblay, M. S., Aubert, S., Barnes, J. D., Saunders, T. J., Carson, V., Latimer-Cheung, A. E., Chastin, S. F. M., Altenburg, T. M., Chinapaw, M. J. M., Altenburg, T. M., Aminian, S., Arundell, L., Atkin, A. J., Aubert, S., Barnes, J., Barone Gibbs, B., Bassett-Gunter, R., Belanger, K., Biddle, S., . . . on behalf of, S. T. C. P. P. (2017). Sedentary Behavior Research Network (SBRN) – Terminology Consensus Project process and outcome. *International Journal of Behavioral Nutrition and Physical Activity*, *14*(1), 75. https://doi.org/10.1186/s12966-017-0525-8

Garland, A., Weinfurt, K., & Sugarman, J. (2021). Incentives and payments in pragmatic clinical trials: Scientific, ethical, and policy considerations. *Clinical Trials, 18*(6), 699–705. https://doi.org/10.1177/17407745211048178

van de Langenberg, D., Vlaanderen, J. J., Dollé, M. E. T., Rookus, M. A., van Kerkhof, L. W. M., & Vermeulen, R. C. H. (2019). Diet, Physical Activity, and Daylight Exposure Patterns in Night-Shift Workers and Day Workers. *Annals of Work Exposures and Health*, *63*(1), 9-21. https://doi.org/10.1093/annweh/wxy097

Vandelanotte, Duncan, M. J., Short, C., Rockloff, M., Ronan, K., Happell, B., & Di Milia, L. (2013). Associations between occupational indicators and total, work-based and leisure-time sitting: a cross-sectional study. *BMC Public Health*, *13*(1), 1110. https://doi.org/10.1186/1471-2458-13-1110

Vandelanotte, Short, C. E., Plotnikoff, R. C., Rebar, A., Alley, S., Schoeppe, S., . . . Duncan, M. J. (2021). Are web-based personally tailored physical activity videos more effective than personally tailored text-based interventions? Results from the three-arm randomised controlled TaylorActive trial. *British Journal of Sports Medicine, 55*(6), 336-343. doi:10.1136/bjsports-2020-102521

Vandelanotte, Short, C., Rockloff, M., Di Millia, L., Ronan, K., Happell, B., & Duncan, M. J. (2015). How do different occupational factors influence total, occupational, and leisure-time physical activity? *J The Journal of Physical Activity and Health*, *12*(2), 200-207. https://doi.org/10.1123/jpah.2013-0098

Vanderlinden, J., Boen, F., Puyenbroeck, S. V., & van Uffelen, J. G. Z. (2022). The effects of a real-life lifestyle program on physical activity and objective and subjective sleep in adults aged 55+ years. *BMC Public Health, 22*(1), 353. doi:10.1186/s12889-022-12780-2

Varela-Mato, Caddick, N., King, J. A., Yates, T., Stensel, D. J., Nimmo, M. A., & Clemes, S. A. (2018). A Structured Health Intervention for Truckers (SHIFT): A Process Evaluation of a Pilot Health Intervention in a Transport Company. *Journal of Occupational and*

Environmental Medicine, *60*(4), 377-385. https://doi.org/10.1097/jom.0000000000001258

Varela-Mato, O'Shea, O., King, J. A., Yates, T., Stensel, D. J., Biddle, S. J., Nimmo, M. A., & Clemes, S. A. (2017). Cross-sectional surveillance study to phenotype lorry drivers' sedentary behaviours, physical activity and cardio-metabolic health. *British Medical Journal*, *7*(6), e013162. https://doi.org/10.1136/bmjopen-2016-013162

Varela-Mato, Yates, T., Stensel, D. J., Biddle, S. J. H., & Clemes, S. A. (2016). Time spent sitting during and outside working hours in bus drivers: A pilot study. *Preventive Medicine Reports*, *3*, 36-39. https://doi.org/https://doi.org/10.1016/j.pmedr.2015.11.011

Viester, L., Verhagen, E., Bongers, P. M., & van der Beek, A. J. (2018). Effectiveness of a Worksite Intervention for Male Construction Workers on Dietary and Physical Activity Behaviors, Body Mass Index, and Health Outcomes: Results of a Randomized Controlled Trial. *American Journal of Health Promotion*, *32*(3), 795-805. https://doi.org/10.1177/0890117117694450

Vlahoyiannis, A., Karali, E., Giannaki, C. D., Karioti, A., Pappas, A., Lavdas, E., Karatzaferi, C., & Sakkas, G. K. (2022). The vicious circle between physical, psychological, and physiological characteristics of shift work in nurses: a multidimensional approach. *Sleep Breath*, *26*(1), 149-156. https://doi.org/10.1007/s11325-021-02381-5

Volinn, E. (2007). WHO-five well-being index (WHO-5), 2007.

von Haaren-Mack, B., Bussmann, J. B., & Ebner-Priemer, U. W. (2020). Physical activity monitoring. *The Wiley Encyclopedia of Health Psychology*, 447-457.

Wallner, M., Mayer, H., Adlbrecht, L., Hoffmann, A. L., Fahsold, A., Holle, B., Zeller, A., & Palm, R. (2023). Theory-based evaluation and programme theories in nursing: A discussion on the occasion of the updated Medical Research Council (MRC) Framework. *International Journal of Nursing Studies*, *140*, 104451. https://doi.org/10.1016/j.ijnurstu.2023.104451

Wang, & Boros, S. (2021). The effect of physical activity on sleep quality: a systematic review. *European Journal of Physiotherapy, 23*(1), 11-18.

Wang, Ruan, W., Chen, Z., Peng, Y., & Li, W. (2020). Shift work and risk of cardiovascular disease morbidity and mortality: A dose–response meta-analysis of cohort studies. *European Journal of Preventive Cardiology, 25*(12), 1293-1302. doi:10.1177/2047487318783892

Warren, J. M., Ekelund, U., Besson, H., Mezzani, A., Geladas, N., & Vanhees, L. (2010). Assessment of physical activity - a review of methodologies with reference to epidemiological research: a report of the exercise physiology section of the European Association of Cardiovascular Prevention and Rehabilitation. *Journal of the European Association for Cardiovascular Prevention and*

Rehabilitation, *17*(2), 127-139. https://doi.org/10.1097/HJR.0b013e32832ed875

Watanabe, K., Kawakami, N., Otsuka, Y., & Inoue, S. (2018). Associations among workplace environment, self-regulation, and domain-specific physical activities among white-collar workers: a multilevel longitudinal study. *The International Journal of Behavioral Nutrition and Physical Activity*, *15*(1), 47. https://doi.org/10.1186/s12966-018-0681-5

Weatherson, K., Yun, L., Wunderlich, K., Puterman, E., & Faulkner, G. (2019). Application of an Ecological Momentary Assessment Protocol in a Workplace Intervention: Assessing Compliance, Criterion Validity, and Reactivity. *Journal of Physical Activity and Health, 16*(11), 985-992. doi:10.1123/jpah.2019-0152

Webb, J., Foster, J., & Poulter, E. (2016). Increasing the frequency of physical activity very brief advice for cancer patients. Development of an intervention using the behaviour change wheel. *Public Health*, *133*, 45-56. https://doi.org/https://doi.org/10.1016/j.puhe.2015.12.009

Wegrzyn, L. R., Tamimi, R. M., Rosner, B. A., Brown, S. B., Stevens, R. G., Eliassen, A. H., Laden, F., Willett, W. C., Hankinson, S. E., & Schernhammer, E. S. (2017). Rotating Night-Shift Work and the Risk of Breast Cancer in the Nurses' Health Studies. *American Journal of Epidemiology*, *186*(5), 532-540. https://doi.org/10.1093/aje/kwx140

Wei, F., Chen, W., & Lin, X. (2022). Night-shift work, breast cancer incidence, and all-cause mortality: an updated meta-analysis of prospective cohort studies. *Sleep Breath*, *26*(4), 1509-1526. https://doi.org/10.1007/s11325-021-02523-9

Welch, A., Healy, G., Straker, L., Comans, T., O'Leary, S., Melloh, M., Sjøgaard, G., Pereira, M., Chen, X., & Johnston, V. (2020). Process evaluation of a workplace-based health promotion and exercise cluster-randomised trial to increase productivity and reduce neck pain in office workers: a RE-AIM approach. *BMC Public Health*, *20*(1), 1-15.

Weldegiorgis, F. S., Dietsche, E., & Ahmad, S. (2023). Inter-sectoral economic linkages in the mining industries of Botswana and Tanzania: analysis using partial hypothetical extraction method. *Resources*, *12*(7), 78. https://doi.org/10.3390/resources12070078

Wen, D., Zhang, X., Liu, X., & Lei, J. (2017). Evaluating the consistency of current mainstream wearable devices in health monitoring: a comparison under free-living conditions. *Journal of Medical Internet Research*, *19*(3), e68. https://doi.org/10.2196/jmir.6874

Westerterp, K. R. (2015). Measurement of energy expenditure. Translational Research Methods for Diabetes, Obesity and Cardiometabolic Drug Development: A Focus on Early Phase *Clinical Studies*, 169-187.

WHO, W. H. O. (1995). *Physical status: The use of and interpretation of anthropometry, Report of a WHO Expert Committee*. World Health Organization.

Williams, S. P., Malik, H. T., Nicolay, C. R., Chaturvedi, S., Darzi, A., & Purkayastha, S. (2018). Interventions to improve employee health and well-being within health care organizations: A systematic review. *Journal of Healthcare Risk Management*, *37*(4), 25-51. https://doi.org/10.1002/jhrm.21284

Willmott, T. J., Pang, B., & Rundle-Thiele, S. (2021). Capability, opportunity, and motivation: an across contexts empirical examination of the COM-B model. *BMC Public Health*, *21*(1), 1014. https://doi.org/10.1186/s12889-021-11019-w

Winckers, A. N. E., Mackenbach, J. D., Compernolle, S., Nicolaou, M., van der Ploeg, H. P., De Bourdeaudhuij, I., Brug, J., & Lakerveld, J. (2015). Educational differences in the validity of self-reported physical activity. *BMC Public Health*, *15*(1), 1299. https://doi.org/10.1186/s12889-015-2656-7

World Health Organization. (2012). Global Physical Activity Questionnaire (GPAQ) Analysis Guide. surveillance and population-based prevention. prevention of noncommunicable diseases department. Geneva: World Health Organization. Retrieved from www. who. int/chp/steps.

Wrzus, C., & Neubauer, A. B. (2022). Ecological momentary assessment: a meta-analysis on designs, samples, and compliance across research fields. *Assessment*, 10731911211067538.

Wu, Q. J., Sun, H., Wen, Z. Y., Zhang, M., Wang, H. Y., He, X. H., Jiang, Y. T., & Zhao, Y. H. (2022). Shift work and health outcomes: an umbrella review of systematic reviews and meta-analyses of epidemiological studies. *Journal of Clinical Sleep Medicine*, *18*(2), 653-662. https://doi.org/10.5664/jcsm.9642

Yang, Ho, K.-H., Chen, H.-C., & Chien, M.-Y. (2012). Exercise training improves sleep quality in middle-aged and older adults with sleep problems: a systematic review. *Journal of Physiotherapy, 58*(3), 157-163. doi:https://doi.org/10.1016/S1836-9553(12)70106-6

Yang, L., Luo, Y., He, L., Yin, J., Li, T., Liu, S., Li, D., Cheng, X., & Bai, Y. (2022). Shift Work and the Risk of Cardiometabolic Multimorbidity Among Patients With Hypertension: A Prospective Cohort Study of UK Biobank. *Journal of the American Heart Association*, *11*(17), e025936. https://doi.org/doi:10.1161/JAHA.122.025936

Yang, Maher, J. P., & Conroy, D. E. (2015). Implementation of Behavior Change Techniques in Mobile Applications for Physical Activity. *American Journal of Preventive Medicine*, *48*(4), 452-455. https://doi.org/https://doi.org/10.1016/j.amepre.2014.10.010

Takala, E. P., Pehkonen, I., Forsman, M., Hansson, G. Å., Mathiassen, S. E., Neumann, W. P., Sjøgaard, G., Veiersted, K. B., Westgaard, R. H., & Winkel, J. (2010). Systematic evaluation of observational methods assessing biomechanical exposures at work. *Scandinavian Journal of Work, Environment & Health*, *36*(1), 3–24. https://doi.org/10.5271/sjweh.2876

Zhao, J., Freeman, B., & Li, M. (2016). Can Mobile Phone Apps Influence People's Health Behavior Change? An Evidence Review. *Journal of Medical Internet Research*, *18*(11), e287. https://doi.org/10.2196/jmir.5692

Zhao, R., Bu, W., Chen, Y., & Chen, X. (2020). The dose-response associations of sedentary time with chronic diseases and the risk for all-cause mortality affected by different health status: a systematic review and meta-analysis. *The Journal of Nutrition, Health & Aging*,

APPENDICES

Appendix A

Table A.1 Search strategy

Search terms	Data bases	Limits (English)	Results
(("physical activity" or "sedentary behaviour" or "Sedentary behaviour" or inactivit* or exercise)) AND (("shift work" or "shift worker" or "non-shift worker" or "day worker"))	Scopus	yes	683
(("physical activity" or "sedentary behaviour" or "Sedentary behaviour" or inactivit* or exercise)) AND (("shift work" or "shift worker" or "non-shift worker" or "day worker"))	Ebscot megafile ultimate: CINHAL, E-journals, Academic search ultimate, health source consumer edition, SPORT Discus	Yes	213
("physical activity" OR "sedentary behaviour" OR "Sedentary behaviour" OR inactivity or exercise) AND ("shift work" OR "shift worker" OR "non-shift worker" OR "day work")	Science direct	yes	2045
((physical activity or sedentary behaviour or Sedentary behaviour or inactivit* or exercise)) AND ((shift work or shift worker or non-shift worker or day worker))	Web of Science	yes	840
(("physical activity" or "sedentary behaviour" or "Sedentary behaviour" or inactivit* or exercise)) AND (("shift work" or "shift worker" or "non-shift worker" or "day worker"))	PubMed	yes	74

Table A.2 Characteristics of included studies reporting prevalence of workers who meet physical activity guidelines

Author (Year) country	Research design	Sample characteristic: n; mean age % female	Occupation Shift type	Measurement tool	Outcome measures	Data inputted in the meta-analysis No. of SW and non-SW
Alves et al. (2017) Brazil	Cross-sectional	423; 30.7 years 58% female	Poultry processing early morning, day, night shift	IPAQ	Physically active (≥150 min/wk.)	78 SW; 69 non-SW
Ma (2011) USA	Cross-sectional	350; 41.2 years; 28.6% female	Police; Day, afternoon, midnight shift	PAR questionnaire	Prevalence of workers who do ≥ 150 min/week PA	SW-104; non-SW-126
Marqueze (2013) Brazil	Cross-sectional	57; 39.8 years; 0% female	Truck drivers; Irregular, day shift	IPAQ	≥ 150 min/week PA	SW-8; nonSW-1
Neil-Sztramko (2016) Canada	Cross-sectional	4323; 39.1 years; 46% female	Various industries; Shift and day worker	Questionnaire	≥ 150 min/week PA	SW-72; non-SW-474

Panczyk et al (2018) Poland	Cross-sectional	1017; 43.2 years; 100% female	Nurses & midwives; shift and non-shift	Positive Health Behaviours Scale (PHBS)	≥ 150 min/week PA	SW-372; nonSW-140
Park & Suh (2019) South Korea	Cross-sectional	185958; 39.6 years; 28.4% female	Various industries, day, and shift workers	IPAQ-SF	≥ 600 METs min/week PA	SW-6112; Non-SW-101120
Chin et al (2016) USA	Cross-sectional	393; 48.4 years; 90% female	Nurses Day, non-day	Questionnaire	(≥150 min/week), Regular muscle strengthening physical activity (≥2 days/week)	SW-108; 41-non-SW
Garcez et al. (2015) Brazil	Cross-sectional	1206; 30.5 years; 65% female	Poultry processing Day, night shift	IPAQ	≥ 150 min/week PA	SW-312; non-SW-125
Hulsegge et al (2020) Netherlands	Cross-sectional	7417, 45.8 years; 13% female	Industrial production	Questionnaire	≥ 150 min/week MVPA	SW-1482; non-SW-2716
Hulsegge et al (2021) Netherlands	Cross-sectional	9583; 45.8 years; 12% female	Industrial production	Questionnaire	≥ 150 min/week MVPA	SW-1850; non-SW-3701
Sugiura et al. (2020) Japan	Cross-sectional	10073; 46.6 years; 100% female	Health care support; day and shift workers	Questionnaire	Regular exercise (more than 30 min per day)	SW-2096; Non-SW-4138

Loef et al (2020) Netherlands	Data from prospective cohort study	396; 43.7 years; 86.3% female	Health care workers; shift and non-shift	Actigraph GT3X	Physically active (≥150 min/wk.)	SW-151; non-SW-25
Awosoga et al. (2020) Canada	Cross-sectional	918; 39 years; 91% female	Care givers; day, night, evening and rotating	Questionnaire	Exercise 3 times/week for at least 20 mins	None, data doesn't show meeting PA guidelines 71 SW; 23 non-SW
Buchvold et al. (2019) Norway	Baseline data	1371; 32.6 years; 90% female	Nurses; day, night workers	Questionnaire	>1hr/week	None, assessed PA by >1hr per week; 364 SW; 493 non-SW
Bushnell (2010) USA & Different countries	Baseline data-Longitudinal	266442; 42.6 years 31.3% female	Manufacturing company; Day, rotating, night shifts	Online questionnaire	Lack of exercise	None, reported risk ratios
Chen et al (2020) USA	Cross-sectional	26, 44.2 years; 86% female	Healthcare workers Day, rotating, night shifts	Actiwatch	Motion counts	None, reported counts; SW-270000; non-SW 250000 counts
Farais et al (2020) Chille	Cross-sectional	50; 37.1 years; 94% female	Health care	IPAQ	≥ 150 min/week PA	None, reported zero min of MVPA both SW and NonSW
Kwiecien et (2019) Poland	Cross-sectional	158; 58% female	Nurses; day and night	Pedometer	Number of steps	None, steps reported day-292.3 kcal; night-146.3kcal

Lim et al (2019) South Korea	Cross-sectional	339; 27 years; 99% female	Nurses; rotating shift work	Questionnaire	exercise was recorded as never, rarely, sometimes, regularly, or competitively	None; reported 12 % of shift workers did no regular exercise
Lim (2016) Singapore	Cross-sectional	231; 31.6 years; 100% female	Hospital employees	Questionnaire	exercise was recorded as never, rarely, sometimes, regularly, or competitively	None
Kawada (2008) Japan	Cross-sectional	17, 0% female	Managers in car manufacturing Rotating, evening, morning shift	Actiwatch	Activity counts	None, reported activity counts; SW-164319; non-Sw-146528
Pham & Park (2019) Korea	Cross-sectional	26985; 39.8 years; 50% female	Various industries; day evening and night	Interview guided questionnaire	Yes/no PA	None, PA assessed by yes or no; SW-10386; non-SW-680
Roskoden (2017) Germany	Cross-sectional	44, 36.3 years; 77.3% female	Medical university employees; shift and non-shift	Actigraph	Energy intake kcal	None, reported energy intake

Wakui (2002) Japan	Cross-sectional	9; 48.7 years; 100% female	Care workers; day and night shift	Calorie counter	No. of steps	None, Steps reported; SW-18660 steps; nonSw-10294

Legend: SW-Shift workers, NonSW-non-shift workers, IPAQ-International Physical Activity Questionnaire, PA-Physical activity, MVPA-Moderate-to-Vigorous Physical Activity, min/day-minutes per day.

Table A.3 Characteristics of included studies reporting time spent in physical activity by workers

Author (Year) country	**Research design**	**Sample characteristic: n; mean age % female**	**Occupation Shift group**	**Measurement tool**	**Outcome measures**	**Data inputted in the meta-analysis % of time spent in PA**
Loef et al (2017) Netherlands	Cross-sectional	6512; 47.7 years; 75.4% female	Various industries Shift, non-shift workers	Questionnaire	Moderate PA & Vigorous PA (hours/week)	SW-18%; non-SW-15.4%
Clark et al (2017) Australia	Cross-sectional	7835; 33.7 years; 100% female	Various industries Shift/night and not shift/night	Active Australia Questionnaire	Moderate to Vigorous Physical Activity (h/week)	SW-12.5%; non-SW-11.5%
Loprinzi (2015) USA	Cross-sectional	1536; 39.9 years; 46.1% female	Various industries; daytime and shift	Questionnaire	MVPA, min/day overall 8–10 min bouts	SW-25.8%; non-SW-28.5%
Tada (2014) Japan	Cross-sectional	2758; 42.1 years; 100% female	Nurse Day workers	Questionnaire	Time in PA	SW-25.2%; nonSw-24.7%
Peplonska et al (2014) Poland	Cross-sectional	725; 49.3 years 100% female	Nurses and midwives Rotating night shift, day shifts	IPAQ	(MET hrs/week)	SW-26%; non-SW-20.9%
Vandelanotte (2015) Australia	Cross-sectional	1194; 45.3 years; 53.9% female	Various industries Non-shift, shift worker	IPAQ	Total Physical Activity (min/wk.)	SW-26.8%; nonSW-24.9%
Vlahoylannis et al (2021) Greece	Cross-sectional	40; 42.9 years	Nurses; shift and non-shift workers	IPAQ	IPAQ score	SW-15.5%; non-SW-12.4%

Van de Langenberg (2019) Netherlands	Cross-sectional	69; 47 years; 100% female	Health care workers Day worker, rotating shift worker	Questionnaire Actigraph GT3X	MVPA mean min/day self-reported PA mean min/day	SW-40.1%; nonSw-38.2%
Hulsegge et al (2017) Denmark	Cross-sectional	812; 45 years; 46% female	Various industries Day worker, night, and non-night shift	Actigraph GT3X	Time in MVPA	SW-13.9%; non-SW-15.5%
Lauren et al (2019) USA	Cross-sectional	24; 34.8 years; 100% female	Medical staff	Actigraph wGT3X-BT	Moderate intensity PA, min/d	SW-12.8%; non-SW-14.3%
Loef et al (2018) Netherlands	Baseline data-Cohort study	479; 44.1 years; 87% female	Hospital shift workers Shift, non-shift worker	Actigraph GT3X	Mean and SD time spent in different physical activity types	SW-11.7%; non-SW-12.5%
Neil-Sztramko et al (2016) Canada	Cross-sectional	4323; 39.1 years; 46.7% female	Shift worker, day worker	Actical accelerometer	MVPA min/day	SW-10.1%; non-SW-10.2%
Esquirol et al (2009) France	Cross-sectional	198; 39yrs; 0% female	Chemical plant workers Rotating, regular day Worker	Baecke questionnaire	Index score	None, reported index score; SW-9.1%; nonSW-8.6%
Yu et al. (2020) New Zealand	Cross-sectional	102; 72.5% female	Hospital shift workers; 12hr shifts	Axivity AX3	Time walking	None, Shift workers only; SW-64.3%

Legend: SW-Shift workers, NonSW-non-shift workers, IPAQ-International Physical Activity Questionnaire, PA-Physical activity, MVPA-Moderate-to-Vigorous Physical Activity, min/day-minutes per day, MET hrs/week-metabolic equivalent hours per week

Table A.4 Characteristics of included studies reporting time sedentary by workers

Author (Year) country	**Research design**	**Sample characteristic: n; mean age % female**	**Occupation Shift schedule**	**Measurement tool**	**Outcome measures**	**Data inputted in the meta-analysis % of time spent in SB**
Clark et al (2017) Australia	Cross-sectional	7835; 33.7 years; 100% female	Various industries Shift/night and not shift/night	Active Australia Questionnaire	Sitting Time(h/day)	SW-29.6%; non-SW-34.2%
Hulsegge et al (2017) Denmark	Cross-sectional	812; 45 years; 46% female	Various industries Day worker, night, and non-night shift	Actigraph GT3X	Sedentary behaviour (lying/sitting)	SW-13.9%; non-SW-15.5%
Lauren et al (2019) USA	Cross-sectional	24; 34.8 years; 100% female	Medical staff	Actigraph wGT3X-BT	Sedentary time, min/d	SW-12.8%; non-SW-14.3%
Loef et al (2018) Netherlands	Baseline data- Cohort study	479; 44.1 years; 87% female	Hospital shift workers Shift, non-shift worker	Actigraph GT3X	Mean time in SB	SW-11.7%; non-SW-12.5%
Loprinzi (2015) USA	Cross-sectional	1536; 39.9 years; 46.1% female	Various industries; daytime and shift	Questionnaire	SB, min/day	SW-25.8%; non-SW-28.5%
Neil-Sztramko et al (2016) Canada	Cross-sectional	4323; 39.1 years; 46.7% female	Shift worker, day worker	Actical accelerometer	SB min/day	SW-10.1%; non-SW-10.2%
Vandelanotte et al (2013) Australia	Cross-sectional	1194; 45.3 years; 53.9% female	Various industries; shift and non-shift	Workforce sitting questionnaire	Total sitting time (min/day)	SW-37.1%; non-SW-38%

KivimAki et al (2001) Finland	Cross-sectional	689; 41.6 years; 100% female	Nurses; shift and day workers	Questionnaire	Sedentary lifestyle	None, SB assessed as yes or no fast walk

Legend: SW-Shift workers, NonSW-non-shift workers, SB-sedentary behaviour.

Table A.5 Characteristics of studies with shift workers only

Author (Year) country	Research design	Sample characteristic: n; mean age % female	Occupation Shift schedule	Measurement tool	Outcome measures	Data inputted in the meta-analysis
Abu Hanifah et al. (2020) Malaysia	Cross-sectional	255; 39 years; 100% female	Electronics manufacturing; shift workers only	Questionnaire	Exercise routine (yes/no)	None, SW only
Buchvold et al. (2015) Norway	Cross-sectional	2059; 33.1 years 90.6% female	Nurses Night work	Questionnaire	>1hr/week	none
Hajo et al. (2020) Canada	Cross-sectional	342, 45.8 years 94% female	Nurses; fixed and rotating shifts	Actigraph	(MVPA min/day) SB (min/day)	None; SW-41.5 %;
Reed (2018) Canada	Cross-sectional	410; 42.9 years; 94% female	Nurses; fixed and rotating shifts	IPAQ, Actigraph GT3X	≥ 150 min/week PA	All SW-PA-4.7%; SB-49.5%
Kolbe-Alexander et al (2019) Australia	Cross-sectional	30; 43.7 years; 15% female	Drivers and manufacturing; day and night shifts	MARA; ActivPal	24-h activity recall; time in PA & SB	SW steps & SB
Reed (2018) Canada	Cross-sectional	410; 42.9 years; 94% female	Nurses; fixed and rotating shifts	IPAQ, Actigraph GT3X	≥ 150 min/week PA	All SW-PA-4.7%; SB-49.5%
Chappel et al (2020) Australia	Cross-sectional	62; 33 years; 92% female	Nurses; morning, afternoon, or night	Actigraph, ActivPal	Time spent in MVPA	Reported beta coefficient

Fullick (2009) England	Cross-sectional	95; 37.2 years; 25.3% female	Various industries; shift workers	Questionnaire	Kilojoules	none SW only
Oftedal et al (2019) Australia	Baseline data	40; 35.7 years; 53% female	Did not say occupation; rotating shifts	Active Australia Questionnaire	≥ 150 min/week PA	None, shift work only SW-18
Kelly et al. (2020) Ireland	Cross-sectional	450; 48% female	Various industries; shift workers only	Telephone interview	Physically active (>150/wk.)	None, reported SW only SW-509
Park et al (2020) South Korea	Cross-sectional	5196; 38.1 years; 7.6% female	Firefighters, 3 and 21 circuits shift	Questionnaire	Exercise training ≥ 150 min/week	None, SW only All SW-2324
Theodoro et al (2020) Brazil	Cross-sectional	450; 36 years; 100% female	Manufacturing; hybrid and night shift workers	Questionnaire	PA as yes or no	None, Shift workers only SW-385

Legend: PA (Physical activity), MVPA (moderate-to-vigorous physical activity), SB (Sedentary behaviour) IPAQ (International Physical Activity Questionnaire), SW (shift worker), Non-SW (Non-SW) various industries (different occupation group within the study population)

Table A.6. Quality assessment for all studies

Study	1A. Sample	1B. Sample	2A. Measures	3A. Analyses	3B. Analyses	4A. Variables	4C. Variables	4D. Variables	4E. Variables	5A. Results	Total	%
Abu-Hanifah (2020)	Yes	yes	n/a	n/a	n/a	yes	yes	yes	n/a	yes	6/6	**100**
Alves et al (2017)	Yes	yes	n/a	n/a	n/a	yes	yes	yes	yes	yes	7/7	**100**
Awosoga (2020)	Yes	yes	n/a	n/a	n/a	yes	yes	yes	n/a	no	5/6	**83**
Buchvold et al (2015)	Yes	yes	n/a	n/a	n/a	yes	yes	yes	n/a	yes	6/6	**100**
Buchvold et al (2019)	Yes	yes	n/a	n/a	n/a	yes	yes	yes	n/a	yes	6/6	**100**
Bushnell et al (2010)	Yes	yes	n/a	n/a	n/a	yes	yes	yes	n/a	yes	6/6	**100**
Chappel (2020)	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	10/10	**100**
Chen et al (2020)	Yes	no	yes	yes	yes	yes	no	yes	yes	no	8/10	**80**
Chin et al (2016)	Yes	yes	n/a	n/a	n/a	yes	yes	yes	n/a	yes	6/6	**100**
Clark et al (2017)	Yes	yes	n/a	n/a	n/a	yes	yes	yes	yes	yes	8/8	**100**

Esquirol et al (2009)	Yes	yes	n/a	n/a	n/a	yes	no	yes	n/a	no	4/6	**67**
Fullick et al (2009)	No	yes	n/a	n/a	n/a	yes	no	yes	n/a	no	3/6	**50**
da Silva Garcez et al (2015)	Yes	yes	n/a	n/a	n/a	yes	yes	yes	n/a	yes	6/6	**100**
Hajo et al (2020)	Yes	yes	yes	yes	yes	yes	yes	yes	unclear	yes	9/10	**90**
Hulsegge et al (2017)	Yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	10/ 10	**100**
Hulsegge et al (2020)	Yes	yes	n/a	n/a	n/a	yes	yes	yes	n/a	yes	6/6	**100**
Hulsegge et al (2021)	yes	yes	n/a	n/a	n/a	yes	yes	yes	n/a	yes	6/6	**100**
Kawada et al (2008)	No	no	yes	no	yes	yes	no	yes	unclear	yes	5/10	**50**
KivimAki et al (2001)	Yes	yes	n/a	n/a	n/a	yes	yes	yes	n/a	yes	6/6	**100**
Kelly (2020)	Yes	yes	n/a	n/a	n/a	yes	yes	yes	yes	yes	7/7	**100**
Kolbe-Alexander et al (2019)	Yes	yes	yes	yes	yes	yes	yes	yes	unclear	yes	9/10	**90**

Kwiecuen-Jagus et al (2019)	Yes	yes	yes	no	yes	yes	no	yes	n/a	yes	7/9	**78**
Lauren et al (2019)	Yes	no	yes	yes	yes	yes	yes	yes	Yes	yes	9/10	**90**
Lim et al (2016)	Yes	yes	n/a	n/a	n/a	yes	yes	yes	n/a	no	5/6	**83**
Lim et al (2019)	Yes	yes	n/a	n/a	n/a	no	no	yes	n/a	no	3/6	**50**
Loef et al (2020)	Yes	yes	yes	yes	yes	yes	yes	yes	unclear	yes	9/10	**90**
Loef et al (2017)	Yes	yes	n/a	n/a	n/a	yes	yes	yes	n/a	yes	6/6	**100**
Loef et al (2018)	Yes	yes	yes	yes	yes	yes	yes	yes	Yes	yes	10/10	**100**
Loprinzi (2015)	Yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	10/10	**100**
Ma et al (2011)	Yes	yes	n/a	n/a	n/a	yes	yes	yes	n/a	yes	6/6	**100**
Marqueze et al (2013)	Yes	no	n/a	n/a	n/a	yes	yes	yes	n/a	no	4/6	**67**
Neil-Sztramko et al (2016)	Yes	yes	unclear	yes	yes	yes	yes	yes	yes	yes	9/10	**90**
Oftedal et al (2019)	Yes	yes	n/a	n/a	n/a	no	yes	yes	yes	yes	6/7	**86**
Panczyk et al (2018)	Yes	yes	n/a	n/a	n/a	yes	yes	yes	n/a	yes	6/6	**100**

Park & Suh (2019)	Yes	yes	n/a	n/a	n/a	yes	yes	yes	unclear	yes	6/7	**86**
Park et al (2020)	Yes	yes	n/a	n/a	n/a	yes	no	yes	n/a	no	4/6	**67**
Peplonska et al (2014a)	Yes	yes	n/a	n/a	n/a	yes	yes	yes	n/a	yes	6/6	**100**
Pham & Park (2019)	Yes	yes	n/a	n/a	n/a	yes	yes	yes	n/a	no	5/6	**83**
Reed et al (2018)	Yes	yes	yes	yes	no	yes	yes	yes	yes	yes	9/10	**90**
Roskoden et al (2017)	Yes	yes	no	unclear	yes	yes	no	yes	yes	no	6/10	**60**
Sugiura et al (2020)	No	yes	n/a	n/a	n/a	yes	yes	yes	n/a	no	4/6	**67**
Tada et al (2014)	Yes	yes	n/a	n/a	n/a	yes	yes	yes	n/a	yes	6/6	**100**
Theodoro (2020)	Yes	yes	n/a	n/a	n/a	no	yes	yes	n/a	yes	5/6	**83**
Van de Langenberg et al (2019)	Yes	yes	unclear	unclear	yes	yes	yes	yes	n/a	yes	7/9	**78**
Vandelanotte et al (2013)	Yes	yes	n/a	n/a	n/a	yes	yes	yes	yes	yes	7/7	**100**

Vandelanotte et al (2015)	Yes	yes	n/a	n/a	n/a	yes	yes	yes	n/a	yes	6/6	**100**
Vlahoylannis et al (2021)	yes	no	unclear	unclear	no	yes	yes	yes	n/a	yes	5/9	**56**
Wakui et al (2002)	No	no	n/a	n/a	n/a	yes	yes	yes	yes	yes	5/7	**71**
Yu et al (2020)	Yes	yes	unclear	unclear	no	yes	yes	yes	yes	yes	7/10	**70**
Total score n (%)	**44/49 (90)**	**42/49 (86)**	**11/17 (65)**	**11/17 (65)**	**14/17 (82)**	**46/49 (93)**	**41/49 (84)**	**49/49 (100)**	**16/21 (76)**	**38/49 (77)**		

Legend: Each item to be scored a “yes” (1 point) and “no” or “unclear” (0 point) “n/a” item not applicable/included for the study

Appendix B
Supplementary File B.1.: EMA information sheet

[redacted]

UNIVERSITY OF SOUTHERN QUEENSLAND AUSTRALIA

[redacted]

Project Details

Title of Project:	**The Feasibility of Ecological Momentary Assessment to measure physical activity, sedentary behaviour, and sleep in adults**
Human Research Ethics Approval Number:	H19REA056

Research Team Contact Details

Principal Investigator Details
Dr Tracy Kolbe-Alexander
[redacted]

Co-Investigator Details
Ms Malebogo Monnaatsie
Email:
[redacted]

Co-Investigator
Prof Stuart Biddle
[redacted]

Co-Investigator
Mr Adam Schmidt
[redacted]

Co-Investigator
Ms Amy Williams
Email:
[redacted]

Co-Investigator
Ms Anna Rogers
[redacted]

Thank you for your interest in participating in this research initiative. Please read this form, and feel free to ask any questions before you make your final decision to join the research study and sign the consent form.

Description

This project is being undertaken as part of a PhD Project.

The purpose of this project is to determine the feasibility of an Ecological momentary assessment (EMA) to measure sleep, physical activity and sitting behaviours. EMA means that we are asking people to provide us with information at various times during the day, with regards to their current activity. The EMA we will be using is called SEMA[3], which we will ask you to download onto your phone (at no cost).

In addition, we would like to measure morning and eveningness (chronotype) and sleep quality and determine a relationship exists between these measures and self-reported health status.

The research team requests your assistance because some traditional instruments that are being used to measure physical activity, sitting time and sleep do not always provide accurate results. They also don't take external factors into account. For example, people might find that they sleep more on a weekend day compared to a workday. Or that they do more activity when they are at work than when they are at home. Therefore, if EMA is easy to use (we will ask you to rate your experience), it might be a new way to assess behaviours.

Participation

If I choose to participate, what is involved?

Employees who choose to participate will meet with a member of the research team. This meeting will take place at the closest USQ campus (Toowoomba, Ipswich, or Springfield) or at your workplace, at a time that is most convenient for you.

This first meeting will take approximately 30-45 minutes, and we will complete the following activities.

- Researcher will explain the study to you and answer any questions that you might have.
- Should you agree to participate, we will ask you to complete a questionnaire, called a Health Risk Assessment.
- The researcher will download the SEMA app onto your phone and show you how to use the app.

- The researcher will give you two devices that measure posture and movement, called accelerometers. We will show you to put them on and take them off.

After the first meeting we will ask you to do the following for 7-10 days:

- Answer 3-5 SEMA prompts per day (we will agree on times that suit you best in the first visit).
- Wear the accelerometers (please see some more information on the accelerometers below.

After the 10 days, the researcher will contact you and arrange to collect the accelerometer, or you can drop it off at the USQ campus.

Health Risk Assessment
The health risk assessment is a questionnaire comprising of three sections. The first part asks about demographic information like your age and work habits, we will also ask you about your lifestyle behaviours and health status. The second part is a series of questions to determine is you are a morning or evening person. The last part is a series of questions that relate to your sleep quality.

Accelerometers:
ActivPAL accelerometers:

The activPAL device is a thigh-worn inclinometer accelerometer, which continuously records posture and movement (time spent sitting/lying, standing, or stepping). The device will be sealed with a nitrile finger cot and attached to the skin with a transparent film to provide a waterproof barrier. We will ask you to wear this device on your right thigh for 10 days.

Actigraph GT3x accelerometer

This accelerometer is worn on an elastic belt either over or under your clothes. It measures time spent stepping and various intensities of physical activity. We will ask you to wear this device during all waking hours for 10 days.

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, please contact the Research Team (contact details at the top 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

Participants will receive an individual report summarizing their results. Therefore, you will be informed of your current levels of physical activity, sedentary behaviour, and sleep. You will also receive information on your sleep quality. Researchers will provide hints and tips for those who do not meet the current physical activity guidelines (150 – 300 minutes per week).

Risks

There are no anticipated risks beyond normal day-to-day living when participating in this study.

If wearing the accelerometers (around the waist and on the thigh) uncomfortable, you are free to remove them and return to the research team.

A perceived risk could be that people other than the research team could gain access to your data. However, all their results will be confidential. All completed surveys and EMA data will be stored in accordance with USQ's data management policy.

Due to the current COVID pandemic, we are taking the following additional precautions:

- The researcher will contact you the day before your planned meeting to ensure that you have not travelled out of state or country in the past 14 days and confirm that you have no cold / flu / COVID symptoms.
- Your meeting with the researcher will take place in a room that meets the space requirements to accommodate 2 people.
- The researcher will ask you to apply the accelerometers yourself to restrict physical contact between yourself and the researcher.
- The researcher will leave the room when you are completing the survey to limit time spent in the same room.

- Participants will be asked to place the accelerometers in the envelope provided and arrange a suitable time to return them to the researcher.
- All accelerometers will be sanitized before and after use.

Privacy and Confidentiality

All comments and responses will be treated confidentially unless required by law.

Once all data has been collected, each participant will receive an individual report of their results via email. Participants can also request a copy of the final research report, which includes the aggregated findings. Please note, that at no stage will individual participants be identified as each person will receive a unique study identify code. This means all data will be de-identified to ensure privacy and confidentiality.

Please note, the de-identified data will be stored and might be used in future research studies conducted by Dr Tracy Kolbe-Alexander. These data include those obtained from the iSURVEY questions, health risk assessment and accelerometers. All data will be stored in a de-identified manner and *in accordance with 2.5.2 of the "Australian Code for the Responsible Conduct of Research".*

Any data collected as a part of this project will be stored securely as per University of Southern Queensland's Research Data Management policy.

Consent to Participate

The return of the completed health risk assessment questionnaire is accepted as an indication of your consent to participate in this project.

Questions or Further Information about the Project

Please refer to the Research Team Contact Details at the top of the form to have any questions answered or to request further information about this project.

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. Please keep this sheet for your information.

University of Southern Queensland

Consent Form for USQ Research Project

Supplementary File B.2.: Consent form

UNIVERSITY OF SOUTHERN QUEENSLAND AUSTRALIA

Project Details

Title of Project:	**The Feasibility and Validity of Ecological Momentary Assessment to measure physical activity, sedentary behaviour, and sleep in adults**
Human Research Ethics Approval Number:	H19REA056

Research Team Contact Details

Principal Investigator Details
Dr Tracy Kolbe-Alexander
[redacted]

Other Investigator Details
Ms Malebogo Monnaatsie
Email:
[redacted]

Co-Investigator

Prof Stuart Biddle
Email:
[redacted]

Statement of Consent

By signing below, you are indicating that you:

• Have read and understood the information document regarding this project.	☐Yes / ☐No
• Have had any questions answered to your satisfaction.	☐Yes / ☐No
• Understand that if you have any additional questions, you can contact the research team.	☐Yes / ☐No
• Are over 18 years of age.	☐Yes / ☐No
• Understand that any data collected may be used in future research activities	☐Yes / ☐No
• Agree to participate in the project.	☐Yes / ☐No

Participant Name	
Participant Signature	
Date	

Please return this sheet to a Research Team member prior to undertaking the questionnaire.

Supplementary File B.3.: Participant Checklist

The Feasibility and Validity of Ecological Momentary Assessment to measure physical activity and sedentary behaviour in adults

Checklist

Name	
Participant Code	
Type of work	
Shift *(please circle)*	Night only Rotational Day shift only
Telephone number	
Email Address	

Accelerometer Data: ActivPAL

Number	Date Given	Date Collected	Download Date

Accelerometer Data: Actigraph

Number	Date Given	Date Collected	Download Date

Measurements:

Measure	Completed
Weight	
Height	

Waist	
Survey completed	
Results report	

The Feasibility of Ecological Momentary Assessment to measure physical activity, sedentary behaviour, and sleep in adults

Shifts

Day	Weekday	Work hours
1	M Tu W Th Fri Sa Su	
2	M Tu W Th Fri Sa Su	
3	M Tu W Th Fri Sa Su	
4	M Tu W Th Fri Sa Su	
5	M Tu W Th Fri Sa Su	
6	M Tu W Th Fri Sa Su	
7	M Tu W Th Fri Sa Su	
8	M Tu W Th Fri Sa Su	
9	M Tu W Th Fri Sa Su	
10	M Tu W Th Fri Sa Su	
11	M Tu W Th Fri Sa Su	
12	M Tu W Th Fri Sa Su	

Supplementary File B.4.

Office Use Only:
Participant Code: ____________

Health Risk Appraisal

SURVEY

Section A: Socio-demographic and health information

1. What is your date of birth?		
Day:	Month	Year

2. What is your gender?	
☐ Male	☐ Female

3. What is your marital status? *(Tick only one box)*					
Never married	Married	Single	Divorced / separated	Widow/ widower	Living with partner
☐	☐	☐	☐	☐	☐

3. Do you work shifts?	
☐ Yes	☐ No

4. In general how much does your work schedule interfere with the sort of things you <u>would like to do</u> in your <u>leisure time</u> (e.g. sport activities, hobbies, etc.)?		
Not at All	Somewhat	Very much
☐	☐	☐

5. In general how much does your work schedule interfere with the <u>domestic things you have to do</u> in your time off work (e.g. domestic tasks, looking after children, etc.)?		
Not at All	Somewhat	Very much
☐	☐	☐

6. Over the past 12 months, how many days of annual leave have you taken altogether (not due to illness)?
Number of Days:

7. How many ***days*** of sick leave have you taken altogether over the past 12 months?
Number of Days:

8. How would you describe your general health? *(Tick only one box)*				
Excellent ☐	Good ☐	Average ☐	Poor ☐	Very Poor ☐

9. How tall are you?
(meters/centimetres)

10. How much do you weigh?
(kilograms)

11. What is your waist circumference?
(centimetres)

12. Please choose the option that best describes how you feel about your current weight.	
☐	I am happy with my weight
☐	I am not happy with my weight but have no intention of trying to lose or gain weight any time soon.
☐	I would like to change my weight (gain weight) and start within the next 6 months
☐	I would like to change my weight (lose weight) and start within the next 6 months

13. What is your blood pressure?
/
☐ Don't know

14. Has a doctor or a healthcare professional told you that you currently have any of the following illnesses?

	Yes	No	Don't Know
High Blood Pressure	☐	☐	☐
Heart disease (chest pain, angina, shortness of breath, heart attack)	☐	☐	☐
High blood cholesterol	☐	☐	☐
Diabetes	☐	☐	☐
Emphysema / asthma / bronchitis	☐	☐	☐
Cancer	☐	☐	☐
Arthritis / rheumatism	☐	☐	☐
Foot / knee / hip problems	☐	☐	☐
Back pain / problems	☐	☐	☐
Chronic headaches or migraines	☐	☐	☐
Digestive problems such as inflammatory bowel disease	☐	☐	☐
Other, please specify	☐	☐	☐

15. Do you currently smoke tobacco products (cigarettes / cigars / pipe)?

No (non-smoker)	Ex-smoker	Yes
☐	☐	☐

16. Please choose the option that best describes your smoking habits. *(only answer this question if you are a current smoker)*	
☐	I have NO intention of stopping smoking
☐	I would like to stop smoking, but not right now

☐	I would like to quit smoking within the next 6 months
☐	I am currently trying to stop smoking

17. How many servings of <u>vegetables</u> do you *usually* eat per day (1 serving = 1 cup of fresh vegetables or ½ cup of cooked vegetables)?
Servings / day

18. How many servings of <u>fruit</u> do you *usually* eat per day?
Servings / day

19. Which of the statements below best describes your eating habits?	
☐	I eat mainly unhealthy food
☐	I eat approximately equal amounts of health and unhealthy foods
☐	I eat mainly healthy food, but sometimes eat unhealthy food as well.
☐	I eat unhealthy foods occasionally or not at all

20. Are you satisfied with your eating habits?	
☐	Yes, I am
☐	No, and I intend to adopt healthier eating habits within the next 6 months
☐	No, but I don't want to change my eating habits.

21. Do you participate in physical activity during your leisure time?	
☐ Yes	☐ No

22. If yes, how much time on average, do you spend doing physical activity per week?	
Hours	Minutes

23. How does you work schedule influence your leisure time physical activity? (only if shift worker)	
☐	I am **more** physically active during my leisure time when I work night shifts.
☐	I am **less** physically active during my leisure time when I work night shifts.
☐	There is no change in my physical activity habits

24. What would best describe how you feel about your levels of physical activity?	
☐	I am happy with my current levels of physical activity.

☐	I know I should be more physically active, but do not plan to start anytime soon.
☐	I would like to become more physically active and plan to increase my levels of physical activity within the next 6 months.

25. Does your work involve <u>mostly</u> sitting or standing still, **OR** walking for very short periods (less than 10 minutes)?	
☐	Mostly Sitting
☐	Mostly Standing Still
☐	Mostly walking for very short periods
☐	Mostly doing moderate / vigorous activity
☐	None of the above

Supplementary B.5. EMA advertisement

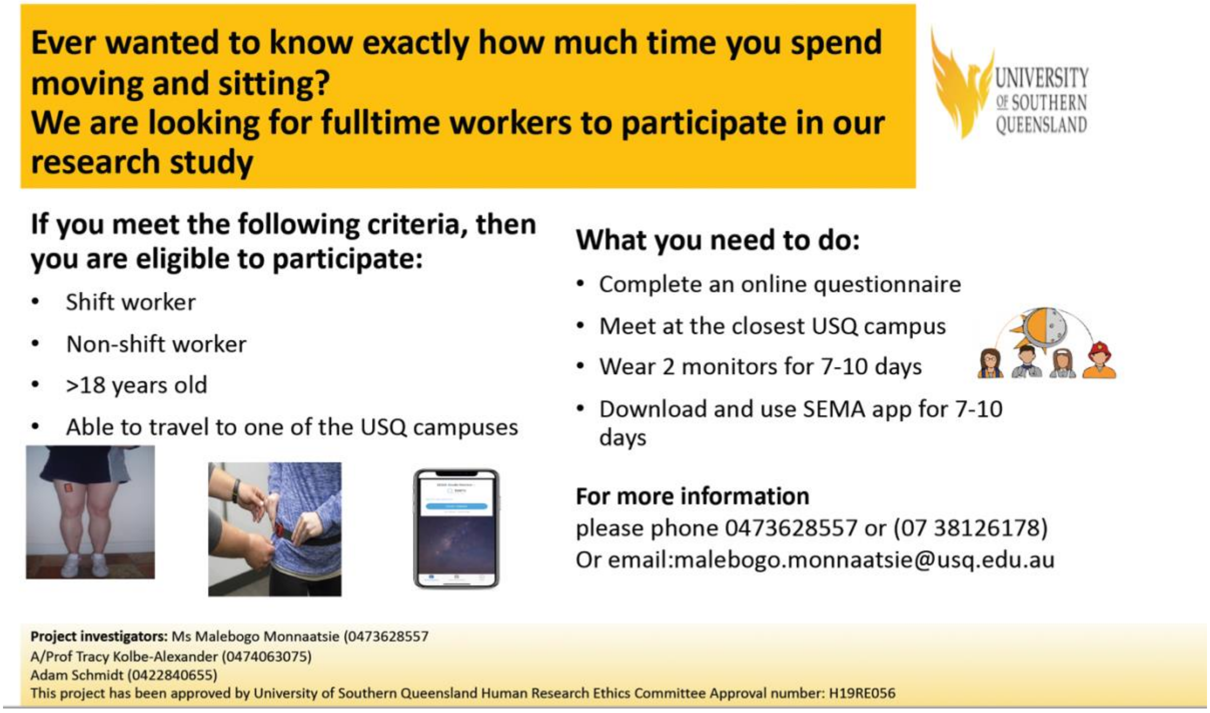


Table B.1. EMA reported activities by occupation group [n (%)]

Survey question	Total *(N=120)*	SW-T *(N=51)*	SW-S *(N=18)*	NSW-S *(N=51)*
Watching TV	365* (8.0)	140 (7.2)	69 (9.1)	156 (8.3)
Using phone/computer	461 (10.1)	136 (6.9)	81 (10.7)	244 (13.0)
Eating/drinking	262 (5.7)	105 (5.4)	35 (4.6)	122 (6.5)
Physical activity/exercise	171* (3.7)	43 (2.2)	39 (5.2)	89 (4.8)
Work duties	750 (16.4)	311 (21.0)	70 (9.2)	269 (14.4)
Socialising	137 (3.0)	58 (3.0)	16 (2.1)	63 (3.4)
Sleeping	141 (3.1)	68 (3.5)	31 (4.1)	42 (2.2)
Caring for children	48 (1.0)	18 (0.9)	4 (0.1)	26 (1.4)
Chores	231 (5.0)	78 (4.0)	36 (4.8)	117 (6.3)
Travelling	223 (4.9)	98 (5.0)	45 (5.9)	80 (4.3)
Others	166 (3.6)	84 (4.3)	30 (4.0)	52 (2.8)

Legend: SW-T: shift workers with tailored EMA prompts, SW-S: shift workers who received standardized prompts, NSW-S: non-shift workers with standardised prompts. Differences with Kruskal Wallis test between the groups are statistically significant represented with * ($p<0.05$).

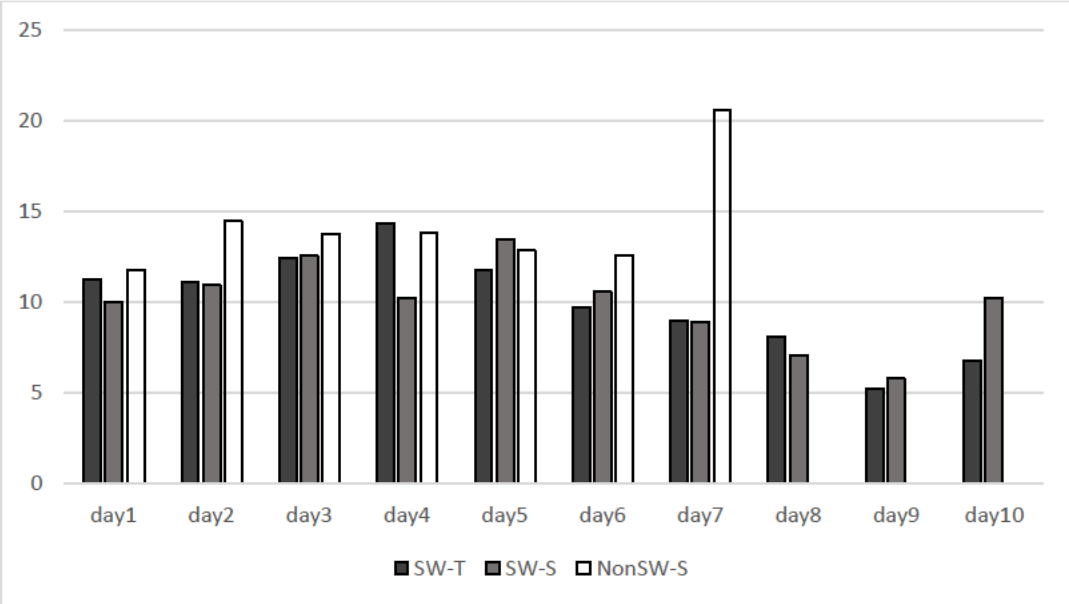


Figure B.1. Comparison of workers EMA prompt responses by days SW-T: shift workers with tailored EMA prompts, SW-S: shift workers who received standardized prompts, NSW-S: non-shift workers with standardised prompts.

Appendix C

EMA Validity

Table C.1. EMA compliance rate and overall accelerometer data in workers

Variable	SW-T (n=51)	NSW-S (n=51)	p-value
Accelerometry (Actigraph)			
Valid wear time (%)	46.6	46.5	0.95
MVPA (%)	3.1	3.8	0.75
LPA (%)	33.9	29.8	0.04*
Sedentary time (%)	62.4	65.2	0.09
MVPA (min/wk.)	217.7 (117.0)	234.0 (209.0)	0.08
EMA			
Completed prompts (%)	63.6	67.6	0.19
Missed prompts (%)	36.1	32.4	0.08
Response time min)	0.41	0.34	0.26

Legend: MVPA: Moderate-to-Vigorous Physical Activity, LPA: Light Physical Activity, SW-T: Shift workers who received tailored EMA prompts, NSW-S: Non-shift workers who received standardized EMA prompts

Note: Kruskal-Wallis's test was used to test differences between the groups for EMA and accelerometer data, statistically significant represented with * ($p<0.05$).

Table C.2. Results from regression analysis predicting accelerometer-derived steps and vector magnitude (CPM) 15 minutes before EMA prompt showing differences between SW-T and

NSW-S

	EMA reported activities (CPM)		**EMA reported activities (Steps)**		**EMA reported sitting (CPM)**		**EMA reported sitting (Steps)**	
	b	*95% CI*	*b*	*95% CI*	*b*	*95% CI*	*b*	*95% CI*
Intercept	66.6	ref	0.53	ref	277.8	ref	3.4	ref
SW-T	35.5	-14.2,85.7	0.40	-0.51,1.30	50.7	-5.2, 106.7	0.64	-0.35,1.6

Legend: SW-T: shift workers who received tailored EMA prompts, CPM: Counts per minute, b: Beta, 95% CI: 95% Confidence Intervals.

Note: Reference group: Non-shift workers

Appendix D

Supplementary file D.1.

University of Southern Queensland

Consent Form for USQ Research Project

Project Details

Title of Project:	**Feasibility and efficacy of a text messaging intervention to improve physical activity in shift workers: a pilot randomized trial and process evaluation**
Human Research Ethics Approval Number:	**H22REA021**

Research Team Contact Details

Principal Investigator Details
Ms. Malebogo Monnaatsie
Email:
[redacted]

Other Investigator Details
Ass Prof Tracy Kolbe-Alexander
[redacted]

Co-Investigator
Prof Stuart Biddle
[redacted]

Statement of Consent

By signing below, you are indicating that you:

• Have read the information sheet regarding this project and aware of the topics to be discussed in the focus group.	☐Yes / ☐No
• Understand that if you have any additional questions, you can contact the research team.	☐Yes / ☐No
• Aware that you are not obliged to answer any question, but that you do so at your own free will.	☐Yes / ☐No
• Understand that all data will be kept confidential and that the research team will not share the data containing your personal information with anyone outside the team or with your employer.	☐Yes / ☐No
• Agree to have the focus group recorded so it can be transcribed after the focus group is held. Aware that you have the right to edit the transcript of the Focus Group once it has been completed.	☐Yes / ☐No
• Agree to participate in the Focus group discussion.	☐Yes / ☐No

Participant Name	
Participant Signature	
Date	

Supplementary file D.2.

University of Southern Queensland

Consent Form for USQ Research Project

Project Details

Title of Project:	**Feasibility and efficacy of a text messaging intervention to improve physical activity in shift workers: a pilot randomized trial and process evaluation**
Human Research Ethics Approval Number:	**H22REA021**

Research Team Contact Details

Principal Investigator Details
Ms. Malebogo Monnaatsie
Email:
[redacted]

Other Investigator Details
Ass Prof Tracy Kolbe-Alexander
[redacted]

Co-Investigator
Prof Stuart Biddle
[redacted]

Statement of Consent

By signing below, you are indicating that you:

• Have understood the information document regarding this project.	☐Yes / ☐No
• Have had any questions answered to your satisfaction.	☐Yes / ☐No
• Understand that if you have any additional questions, you can contact the research team.	☐Yes / ☐No
• Understand that all data will be kept confidential and that the research team will not share the data containing personal information with anyone outside the team or with your employer.	☐Yes / ☐No
• Are over 18 years of age.	☐Yes / ☐No
• Understand that any data collected may be used in future research activities	☐Yes / ☐No
• Agree to participate in the project.	☐Yes / ☐No

Participant Name	
Participant Signature	
Date	

Supplementary file D.3.

Office Use Only:
Participant Code: ________ ______

Socio-demographic and health information

SURVEY

1. What is your date of birth?		
Day:	Month	Year

2. What is your gender?	
☐ Male	☐ Female

3. What is your marital status? *(Tick only one box)*					
Never married ☐	Married ☐	Single ☐	Divorced / separated ☐	Widow/ widower ☐	Living with partner ☐

4. In general how much does your work schedule interfere with the sort of things you <u>would like to do</u> in your <u>leisure time</u> (e.g. sport activities, hobbies, etc.)?		
Not at All ☐	Somewhat ☐	Very much ☐

5. In general how much does your work schedule interfere with the <u>domestic things you have to do</u> in your time off work (e.g. domestic tasks, looking after children, etc.)?		
Not at All ☐	Somewhat ☐	Very much ☐

6. Over the past 12 months, how many days of annual leave have you taken altogether (not due to illness)?
Number of Days:

7. How many <u>*days*</u> of sick leave have you taken altogether over the past 12 months?
Number of Days:

12. Please choose the option that best describes how you feel about your current weight.	
☐	I am happy with my weight
☐	I am not happy with my weight but have no intention of trying to lose or gain weight any time soon.
☐	I would like to change my weight (gain weight) and start within the next 6 months
☐	I would like to change my weight (lose weight) and start within the next 6 months

8. How would you describe your general health? *(Tick only one box)*				
Excellent	Good	Average	Poor	Very Poor
☐	☐	☐	☐	☐

9. How tall are you?
(meters/centimetres)

10. How much do you weigh?
(kilograms)

11. What is your waist circumference?
(centimetres)

13. Has a doctor or a healthcare professional told you that you currently have any of the following illnesses?			
	Yes	No	Don't Know
High Blood Pressure	☐	☐	☐
Heart disease (chest pain, angina, shortness of breath, heart attack)	☐	☐	☐
High blood cholesterol	☐	☐	☐
Diabetes	☐	☐	☐
Emphysema / asthma / bronchitis	☐	☐	☐
Cancer	☐	☐	☐
Arthritis / rheumatism	☐	☐	☐
Foot / knee / hip problems	☐	☐	☐
Back pain / problems	☐	☐	☐
Chronic headaches or migraines	☐	☐	☐
Digestive problems such as inflammatory bowel disease	☐	☐	☐
Other, please specify	☐	☐	☐

14. Do you currently smoke tobacco products (cigarettes / cigars / pipe)?		
No (Non-smoker)	Ex-smoker	Yes
☐	☐	☐

15. Please choose the option that best describes your smoking habits. *(only answer this question if you are a current smoker)*	
☐	I have NO intention of stopping smoking
☐	I would like to stop smoking, but not right now
☐	I would like to quit smoking within the next 6 months
☐	I am currently trying to stop smoking

17. How many servings of <u>fruit</u> do you *usually* eat per day?
Servings / day

18. Which of the statements below best describes your eating habits?	
☐	I eat mainly unhealthy food
☐	I eat approximately equal amounts of health and unhealthy foods
☐	I eat mainly healthy food, but sometimes eat unhealthy food as well.
☐	I eat unhealthy foods occasionally or not at all

19. Are you satisfied with your eating habits?	
☐	Yes, I am
☐	No, and I intend to adopt healthier eating habits within the next 6 months
☐	No, but I don't want to change my eating habits.

20. Do you participate in physical activity during your leisure time?	
☐ Yes	☐ No

21. If yes, how much time on average, do you spend doing physical activity per week?	
Hours	Minutes

16. How many servings of <u>vegetables</u> do you *usually* eat per day (1 serving = 1 cup of fresh vegetables or ½ cup of cooked vegetables)?
Servings / day

22. How does you work schedule influence your leisure time physical activity?	
☐	I am **more** physically active during my leisure time when I work night shifts.
☐	I am **less** physically active during my leisure time when I work night shifts.
☐	There is no change in my physical activity habits

24. What would best describe how you feel about your levels of physical activity?	
☐	I am happy with my current levels of physical activity.
☐	I know I should be more physically active, but do not plan to start anytime soon.
☐	I would like to become more physically active and plan to increase my levels of physical activity within the next 6 months.

25. Does your work involve <u>mostly</u> sitting or standing still, **OR** walking for very short periods (less than 10 minutes)?	
☐	Mostly Sitting
☐	Mostly Standing Still
☐	Mostly walking for very short periods
☐	Mostly doing moderate / vigorous activity
☐	None of the above

Sleep Quality

The following questions relate to your usual sleep habits during the past month ***only***.
Your answers should indicate the most accurate reply for the ***majority*** of days and nights in the past month.

1. During the **past month**, when have you usually gone to bed?
Usual bedtime:

2. During the **past month**, how long does it usually take you to fall asleep at night?
Number of Minutes:

3. During the **past month**, what time have you usually gotten up in the morning?

Usual get up time:

4. During the **past month**, how many hours of actual sleep did you get at night? (This may be different than the number of hours you spend in bed.)
Hours of sleep per night:

5. *For each of the following questions, select the best response. Please answer ALL questions.*
During the past month, how often have you had trouble sleeping because you….

	Not during the past month	Less than once a week	Once or twice a week	Three or more times a week
Cannot get to sleep within 30 minutes				
Wake up in the middle of the night or early morning				
Have to get up to use the bathroom				
Cannot breathe comfortably				
Cough or snore loudly				
Feel too cold				
Feel too hot				
Had bad dreams				
Have pain				
Other: (please describe) ________________				
How often during the past month have you had trouble sleeping because of this?				

6. During the past month, how would you rate your sleep quality overall?			
☐ Very good	☐ Fairly good	☐ Fairly bad	☐ Very bad

7. During the past month, how often have you taken medicine (prescribed or 'over the counter') to help you sleep?			
☐ Not during the past month	☐ Less than once a week	☐ Once or twice a week	☐ Three or more times per week

8. During the past month, how often have you had trouble staying awake while driving, eating meals, or engaging in social activity?			
☐ Not during the past month	☐ Less than once a week	☐ Once or twice a week	☐ Three or more times per week

9. During the past month, how much of a problem has it been for you to keep up enough enthusiasm to get things done?			
☐ No Problem at all	☐ Only a very slight problem	☐ Somewhat of a problem	☐ A very big problem

10. Do you have a bed partner or roommate?			
☐ No bed partner or roommate	☐ Partner / roommate in other room	☐ Partner / roommate in same room, but not same bed	☐ Partner in same bed

11. If you have a roommate or bed partner, ask him or her how often in the past month have you had....					
	Not during the past month	Less than once a week	Once or twice a week	Three or more times a week	Don't know
Loud snoring					
Long pauses between breaths while asleep					
Legs twitching or jerking while you sleep					
Episodes of disorientation or confusion during sleep					
Other restlessness while you sleep: (please describe) ______					
How often during the past month have you had trouble sleeping because of this?					

Supplementary file D.4.: Global Physical Activity Questionnaire (GPAQ)

Physical Activity Questions			
I am going to ask you about the time you spend doing different types of physical activity in a typical week. Please answer these questions even if you do not consider yourself to be a physically active person. Think first about the time you spend doing work. Think of work as the things that you have to do such as paid or unpaid work, study/training, household chores, harvesting food/crops, fishing or hunting for food, seeking employment. In answering the questions 'vigorous-intensity activities' are activities that require hard physical effort and cause large increases in breathing or heart rate, 'moderate-intensity activities' are activities that require moderate physical effort and cause small increases in breathing or heart rate.			
Work			
Q1	Does your work involve vigorous-intensity activity that causes large increases in breathing or heart rate like carrying or lifting heavy loads, digging or construction work for at least 10 minutes continuously?	Yes / No If No go to Q4	
Q2	In a typical week, on how many days do you do vigorous- intensity activities as part of your work?	Days	
Q3	How much time do you spend doing vigorous-intensity activities at work on a typical day?	Hours	Mins
Q4	Does your work involve moderate-intensity activity, that causes small increases in breathing or heart rate such as brisk	Yes / No If No go to Q7	

	walking [or carrying light loads] for at least 10 minutes continuously?		
Q5	In a typical week, on how many days do you do moderate- intensity activities as part of your work?	Days	
Q6	How much time do you spend doing moderate-intensity activities at work on a typical day?	Hours	Mins
Travel to and from places			
The next questions exclude the physical activities at work that you have already mentioned. Now I would like to ask you about the usual way you travel to and from places. For example, to work, for shopping, to market, to place of worship.			
Q7	Do you walk or use a bicycle (pedal cycle) for at least 10 minutes continuously to get to and from places?	Yes / No If No go to Q10	
Q8	In a typical week, on how many days do you walk or bicycle for at least 10 minutes continuously to get to and from places?	Days	
Q9	How much time do you spend walking or bicycling for travel on a typical day?	Hours	Mins
Recreational activities			
The next questions exclude the work and transport activities that you have already mentioned. Now I would like to ask you about sports, fitness and recreational activities (leisure).			
Q10	Do you do any vigorous-intensity sports, fitness or recreational (leisure) activities that cause large increases in breathing or	Yes / No If No go to Q13	

	heart rate like [running or football] for at least 10 minutes continuously?		
Q11	In a typical week, on how many days do you do vigorous- intensity sports, fitness or recreational (leisure) activities?	Days	
Q12	How much time do you spend doing vigorous-intensity sports, fitness or recreational activities on a typical day?	Hours	Mins
Q13	Do you do any moderate-intensity sports, fitness or recreational (leisure) activities that cause a small increase in breathing or heart rate such as brisk walking, [cycling, swimming, volleyball] for at least 10 minutes continuously?	Yes / No If No go to Q16	
Q14	In a typical week, on how many days do you do moderate- intensity sports, fitness or recreational (leisure) activities?	Days	
Q15	How much time do you spend doing moderate-intensity sports, fitness or recreational (leisure) activities on a typical day?	Hours	Mins
Sedentary behaviour			
The following question is about sitting or reclining at work, at home, getting to and from places, or with friends including time spent sitting at a desk, sitting with friends, traveling in car, bus, train, reading, playing cards or watching television, but do not include time spent sleeping			
Q16	How much time do you usually spend sitting or reclining on a typical day?	Hours	Mins

Well-being

Please respond to each item by marking one box per row, regarding how you felt in the last two weeks.		All the time	Most of the time	More than half the time	Less than half the time	Some of the time	At no time
WHO1	I have felt cheerful in good spirits.						
WHO2	I have felt calm and relaxed.						
WHO3	I have felt active and vigorous.						
WHO4	I woke up feeling fresh and rested.						
WHO5	My daily life has been filled with things that interest me.						

Supplementary File D.5.

Intervention advertisement sheet

Health promotion programme in shift workers

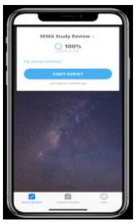
Are you a shift worker interested in becoming more physically active?

What’s involved?

- You will get a free physical activity program and learn ab physical
  activity guidelines
- Find out about your physical activity and sleep quality.
- Receive the activity tracker (picture on the right) after the program.

Who is involved?
If you meet the following criteria, then you are eligible to participate:

- Full time shift worker at Debswan
- >18 years old
- Own a smart mobile phone



What you need to do:

- Complete questionnaires
- Meet at your workplace for 5 visits
- Wear an activity monitor for 16 days during the two shift cycles

Please email/call or text Malebogo Monnaatsie to register your interest in this initiative. Phone +267 72285305 Or email: malebogo.monnaatsie@usq.edu.au/ monnaatsiem@ub.ac.bw.

Supplementary table D.1.

The feasibility of a text-messaging intervention promoting physical activity in shift workers: a process evaluation

Exit online survey

The following survey items addressing the implementation, context and mechanisms of action will be used:

Process evaluation component	Survey items
Reach	Why did you take part in th program
Adoption	Overall, how beneficial do you think the program has been to you so far? How would you rate the text messages? How would you rate the *SEMA*^{3} app? How would you rate the discussions with the researcher on the program? (Answer with 1=no benefit, 5= neutral &; 10= extremely beneficial)
Implementation	Did the program meet your expectations? Did you experience any barriers to participation in the program? If you answered yes to the last question, please give details about any barriers: Do you have any other comments about the health promotion program? (Maybe positive or negative factors).
Maintenance	I will continue to be physically active even after the program (answer: yes, uncertain, no) Would you recommend this type of program to other shift workers?

Supplementary File D.6.

The feasibility of a text-messaging intervention promoting physical activity in shift workers: a process evaluation

Interview guide questions

1. Why did you participate in the program?
2. How has this intervention influenced your physical activity or exercise habits?
3. Which factors influenced your physical activity habits while on the intervention?
4. What were the most helpful and the least helpful components of the intervention?
5. How did you like the physical activity information provided?
6. What was your experiences about the text messages?
   -Follow up; what are some of the things you find most valuable/useful for you? And what things have you found not find valuable/useful?
7. Can you tell me about your experiences of using the SEMA app?
8. How has the program influenced your sleep habits?
9. How has the program influenced your sitting habits?
10. On the scale of 1-10, where 1 is not at all, and 10 is extremely confident. How competent do you feel to carry on being physically active after the programme has ended?
11. Have you used the *Mi* band you received as an incentive after the program? And has it played a role in your PA, sitting and sleeping?
12. Would you recommend this type of intervention for other people doing shift work who want to increase the amount of physical activity they do – why/why not?

Supplementary table D.2.

	Content	Action planning component	Notes
1	*Based on your physical activity measured the past weeks, your average moderate physical activity is _____ minutes. The highest steps recorded were _____ and this was during shift ________and lowest ______ on a __________.* *Cadence, which is the number of steps per minute simply means the speed of walking. Your results shows that only ___ minutes of the steps were moderate intensity (>100 cadence).* *The average sitting time recorded was _ h and __ h spent standing.*	Assess	
2	*Physical activity is important to help prevent diseases and increase your energy levels thus reducing fatigue. The public health guideline is at least 150-300 minutes of moderate activity intensity per week.* *Moderate intensity is any activity that produce sweat and heavy breathing like a brisk walk. When doing vigorous activity, it will be difficult to talk. This comes to about 30-60 mins 5 times per week.* *A walking cadence of 100 steps per minute translate to moderate physical activity.* *Prolonged sitting and standing are also risk factors for impaired health. Shorter periods of standing can be beneficial since it allows breaks in prolonged sitting but standing for long in the same posture can be risk for low back pain.* *So, the aim is to break long periods of standing and sitting by doing some activities like stretching.*	Advise	
3	*Now let us agree on a physical activity goal for the next month. When we create a goal, we want it to be clear and realistic. An example will be to increase your walking speed during work hours and go to gym or jogs after work or on day offs.*	Agree	

	What is a realistic goal for you to improve your moderate physical activity? *On a scale of 0-10, where 0 is not at all confident or sure and 10 is extremely confident or sure.*	
4	*To reach this goal, let's make a plan. What days do you plan to exercise? What time of the day do you think you can get to be active/ do leisure time activities, considering all your day shifts, afternoon shifts, night shifts and even day offs schedule?* *How many minutes per session?* *In the long term, after the program what is your physical activity goal?*	Agree
5	*Now we are going to come up with tips to help you achieve your goal.* *If you are not able to reach the goal, you can invite family member or friend to help with accountability. Let's identify people that can provide that support______*	Assist
6	*There can be other challenges that might stop you from reaching your goal. Can you think of something that you think will be a barrier stopping you from achieving your goal?* Suggest ways on how to overcome the chosen barrier.	Assist
7	*During the second cycle we will ask you to wear the device that you were wearing on the thigh again to compare if there will be an improvement.*	Arrange

Supplementary Table D.3.

Feasibility and efficacy of a text messaging intervention to improve physical activity in shift workers: a pilot randomized trial and process evaluation

Examples of text-messages

First text message: Well-done on starting the shift work intervention! Your daily average
MVPA was ** minutes and your goal is to reach *** minutes per day.
Have a great week!

COM-B behaviour change and techniques	**Text messages examples**
Psychological capability Describe psychological benefits of walking and physical activity.	Physical activity can help you manage stress and feel less tired. Once you become active, you're likely to have more energy than before. You may not be able to walk 30 minutes a day every day but every little bit counts. Start small the minutes will add up! Why not aim for a weekend walk? A 30-minute walk is about 3500 steps! :) Going for a walk is a great stress reliever! Get stepping to keep your heart healthy!
Social opportunity Encourage participants that they may share the information and walks with other workers and family	Today is a great day for a walk! Have you tried walking with a friend or family member? You might want to walk more today. Want to suggest a walking meeting with a co-worker?
Physical opportunity Physical environment cues to engage in physical activity	Keep on finding opportunities to walk more! Go to the mall and walk! Physical activity doesn't have to happen in gyms only, try walking around your home or workplace. Try walk during a work break, walking can be done anywhere.

Automatic motivation Increasing the desire to walk	Remember your goal is to walk an average of **** minutes per day. How about an early morning walk? Keeping on clocking up those steps. You are on track for achieving your goal of **** minutes per day! How about adding an evening walk to your day? Walking and talking can be a fun activity. Think of someone you know who might want to join you for a “walk and talk”.
Reflective Motivation Setting goals on increasing steps and believing that engaging in walks will improve their wellbeing	Great job! You’re working hard to meet your goals. Now try increasing your time to meet next week’s goal. You are doing great! You can do it again, park further away in parking lots to walk more!