Master's thesis

NTNU
Norwegian University of Science and Technology
Faculty of Medicine and Health Sciences
Department of Neuromedicine and Movement Science

Fredrik Klæboe Lohne

Association between physical capacity and occupational physical activity measured by accelerometers and heart rate monitors

Master's thesis in Physical Activity and Health; Movement Science
Supervisor: Øystein Wiggen
Co-supervisor: Svein Ove Tjøsvoll & Marius Steiro Fimland
May 2021

NTNU
Kunnskap for en bedre verden

SINTEF

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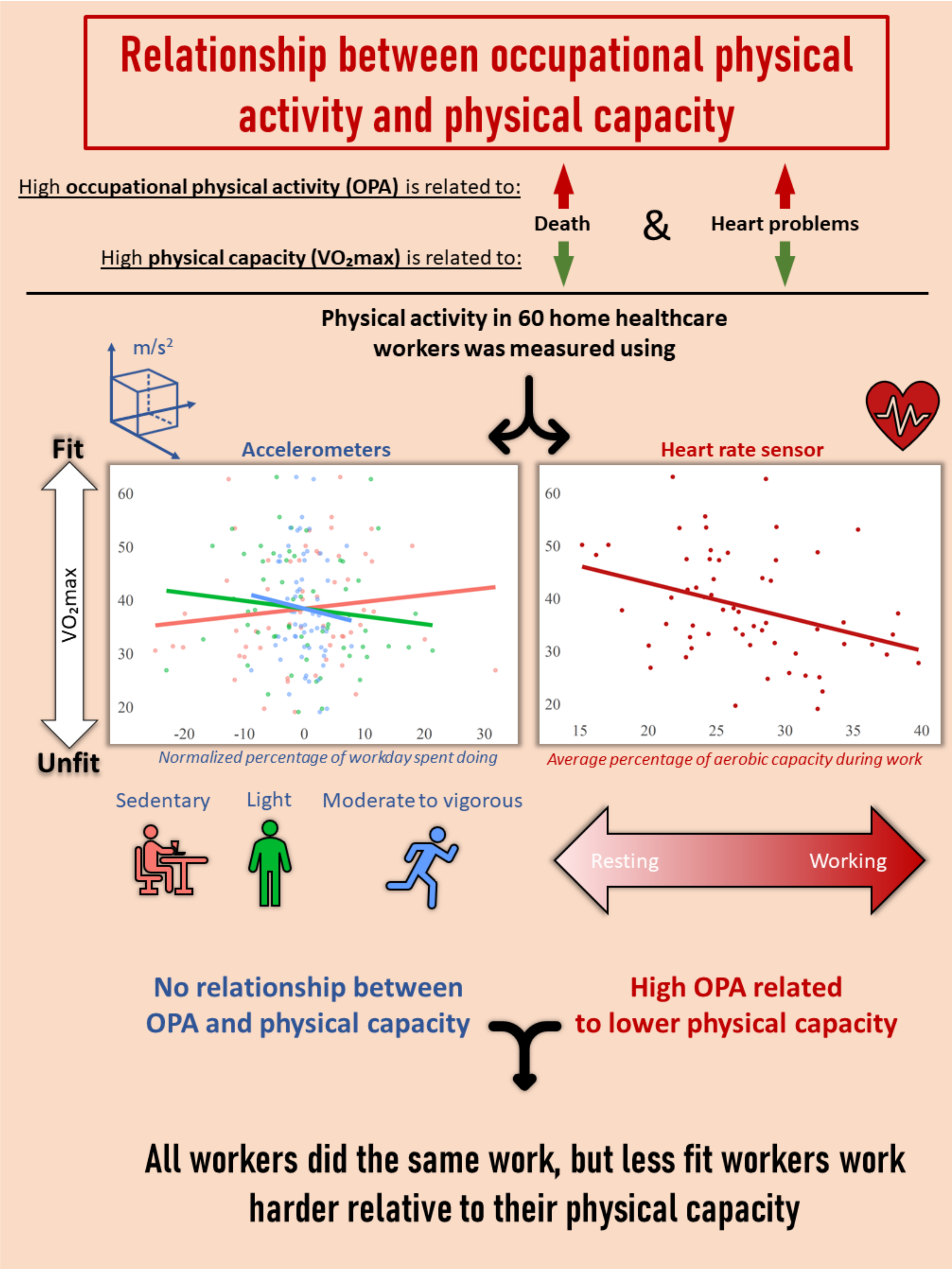
Abbreviations (In alphabetical order):

BMI	=	Body Mass Index
CoDA	=	Compositional Data Analysis
ECG	=	Electrocardiography
HR	=	Heart Rate
HRR	=	Heart Rate Reserve
LIPA	=	Light Intensity Physical Activity
LTPA	=	Leisure Time Physical Activity
MVPA	=	Moderate to Vigorous Physical Activity
OPA	=	Occupational Physical Activity
PA	=	Physical Activity
SB	=	Sedentary behavior


Relationship between occupational physical activity and physical capacity
High occupational physical activity (OPA) is related to:
High physical capacity (VO₂max) is related to:
Death
&
Heart problems
Physical activity in 60 home healthcare workers was measured using
m/s²
Fit
Unfit
VO₂max
Accelerometers
Heart rate sensor
60
50
40
30
20
-20
-10
0
10
20
30
15
25
35
Normalized percentage of workday spent doing
Average percentage of aerobic capacity during work
Sedentary
Light
Moderate to vigorous
Resting
Working
No relationship between OPA and physical capacity
High OPA related to lower physical capacity
All workers did the same work, but less fit workers work harder relative to their physical capacity

Abstract

Introduction

Recent studies have demonstrated a negative health outcome from occupational physical activity (OPA). Thus, the aim of this study was to investigate the relationship between objectively measured OPA and physical capacity.

Methods

This population based cross-sectional observational study used accelerometers (Axivity AX3) and heart rate sensors (Firstbeat Bodyguard 2) to measure OPA on 2-6 days. Accelerometer data was analyzed as percentage of workday spent in sedentary behavior (SB), light intensity physical activity (LIPA) and moderate to vigorous physical activity (MVPA). Heart rate data was assessed as mean %heart rate reserve ($\%HRR_{mean}$) and $\%HRR_{max}$. An Ekblom-bak test estimated the physical capacity. 72 nurses and caregivers participated in the measurements. Multiple regression analysis with gender and age as covariates was used to check for association. Results were reported as beta-coefficient (β) and [95% confidence interval]

Results

60 participants were included in the analysis. No association was found between physical capacity and time spent in SB (β=-0.028, [-0.25 to 0.19]), LIPA (β=0.011, [-0.25 to 0.27]), nor MVPA (β=0.288, [-0.49 to 1.06]). When measuring OPA using %HRR, a negative association was found between $\%HRR_{mean}$ (β= -0.601, [-0.97 to -0.23]), and $\%HRR_{max}$ (β= -0.404, [-0.64 to -0.16]).

Conclusion

No association between accelerometer assessed OPA and physical capacity, but a negative association using heart rate sensor data. These results therefore suggest that all workers do the same amount of work. However, workers with low physical capacity works harder relative to their physical capacity. This is in line with previous studies assessing this relationship.

Keywords: Occupational physical activity; Physical capacity; Occupational health, physical activity paradox

Abstrakt

Introduksjon

Nylige studier har funnet en negativ helse effekt av fysisk aktivitet på arbeidsplassen (FAA). Målet med denne studien var dermed å undersøke forholdet mellom FAA og fysisk kapasitet.

Metode

Dette populasjonsbaserte tverrsnitt studie brukte akselerometer (Axivity AX3) og hjerterate monitor (firstbeat bodyguard 2) til å måle FAA på 2-6 dager. Akselerometer data ble analysert som prosentandel av arbeidsdagen i stillesittende, lett fysisk aktivitet (LFA) og moderat til høy fysisk aktivitet (MHFA). Hjerterate data ble analysert som gjennomsnittlig %hjerterate reserve (%$HRR_{gjennomsnitt}$) og %$HRR_{maksimal}$. En Ekblom-Bak test ble brukt til å estimere den fysiske kapasiteten til deltakerne. 72 sykepleiere og hjelpepleiere var med i målingene. Multippel regresjonsanalyse, med alder og kjønn som kovariater ble brukt for å sjekke for assosiasjon. Resultater ble rapportert som beta-koeffisient (β) og [95% konfidensintervall]

Resultater

60 deltakere var med i den endelige analysen. Det var ingen assosiasjoner mellom fysisk kapasitet og tid i stillesittende (β=0.028, [-0.25 to 0.19]), LFA (β=0.011, [-0.25 to 0.27]) eller MHFA (β=0.288, [-0.49 to 1.06]) målt med akselerometer. FAA målt som %HRR var negativt assosiert med fysisk kapasitet for både %$HRR_{gjennomsnitt}$ (β= -0.601, [-0.97 to -0.23]) og %$HRR_{makimal}$ (β= -0.404, [-0.64 to -0.16]).

Konklusjon

Ingen assosiasjon mellom akselerometer målt FAA og fysisk kapasitet, men en negativ assosiasjon målt med hjerterate sensor. Dette tyder på at alle arbeiderne gjør like mye arbeid, men de med lav fysisk kapasitet jobber hardere, relativt til deres fysiske kapasitet. Disse resultatene blir støttet av tidligere studier.

Nøkkelord: Arbeidsplass fysisk aktivitet, fysisk kapasitet, arbeidshelse, fysisk aktivitet paradox

Acknowledgement

I would first like to thank my main supervisor, Øystein Wiggen. He has been a great support through the writing process, giving great advice on how to improve my writing and always done so with such positivity. Further, he has been an anchor, in the best kind of way, in holding me in my place, when I have tried to stray away from the task, he has kept my focus on the thesis.

Further, I would like to thank my co-supervisors Ph. d candidate Svein Ove Tjøsvoll and prof. Marius Steiro Fimland. Svein Ove was a great leader in the data collection process, he always had comprehensive answers to my questions when I was uncertain. Marius had great insight on how to present data and asked the right questions to get me thinking if what I did was correct. Furthermore, I would like to thank the entire SINTEF team working on the "GoldiCare" project for great discussions during our digital meetings.

Lastly, I would like to thank my closest. My girlfriend who kept my spirits high and helped me disconnect after long days of work. Also, my parents who still do not quite understand what I study, yet they support me, nonetheless.

Contents

1 Background

There are well documented effects of leisure time physical activity (LTPA) being beneficial for health (1-4). In contrast, the positive health benefits of LTPA cannot be found for occupational physical activity (OPA). On the contrary, OPA seems to have a negative effect on health when compared to LTPA (5-9). This has been termed the "physical activity (PA) paradox". LTPA is generally characterized by voluntary, short duration PA, with a high degree of dynamicity and intensity. In contrast, OPA is characterized by low intensity PA over a longer duration and with little recovery time. Additionally, it involves more static muscular loading and monotonous and awkward working positions (10, 11). Hence, one proposed mechanism to the PA paradox is that the physical demand of OPA may not allow for increasing nor maintaining physical capacity (11). Physical capacity (VO_2max; $mL \cdot kg^{-1} \cdot min^{-1}$) is the ability of the cardiovascular and respiratory system to supply oxygen to the working skeletal muscles and for the muscle to use that oxygen to produce energy for movement (12). Low physical capacity has been found to be a good predictor of several negative health outcomes, like cardiovascular disease events (13), sudden cardiac death (14), and all-cause mortality (15, 16). Moderate to vigorous physical activity (MVPA) during leisure time has been found to improve physical capacity (17-19). MVPA intensity is equivalent to approximately 40-85% of the max physical capacity and is usually performed over short periods of time (20), followed by ample recovery time. A systematic review by Swain and Franklin (2006) found no lower intensity threshold for improving physical capacity. However, vigorous (>60% of max physical capacity) showed clearly to be superior compared to lower intensity levels (21). In contrast, the average OPA intensity of blue-collar occupations is approximately 30% (22, 23) for periods closer to 8 hours, followed by repetition the day after, not allowing for recovery. Additionally, high fatigue from OPA is related to more time spent in sedentary behavior (SB), sitting or lying, during leisure time (24). SB is associated with lower physical capacity (18), increased mortality (25) and increased risk of cardiometabolic diseases (26). Another factor that may play into the PA paradox is the increased 24-hour heart rate (HR) from OPA (11, 27, 28). A low 24-hour average HR independently from OPA, LTPA and physical capacity decreases risk of all-cause mortality (29). Further, a high physical capacity is associated with a lower resting HR, leading to a lower 24-hour average HR (11, 29). PA will increase the HR both during and shortly after, however LTPA causes a downregulation of HR subsequently to PA and leads to decreased nighttime HR (27). In contrast, OPA has been found to be associated with increased HR during the following night (27, 28). Furthermore, during LTPA, the HR will be raised for a limited time, as it is generally performed in shorter bouts. Whilst OPA, which generally includes standing and walking, raises the HR above resting level for several hours at a time.

The recently updated 2020 WHO guidelines on PA and SB recommends 150-300 minutes of moderate intensity PA, or 75-150 minutes of vigorous PA per week for adults (4). Previous guidelines have not had domain specific recommendations, therefore, for the 2020 update, an umbrella review was conducted on the health effects of OPA (30). This review concluded that high OPA was beneficial for coronary heart disease and several types of cancer, but unfavorable for all-cause mortality in men, mental health, osteoarthritis, and sleep. Because of these inconclusive results, the new recommendations for PA do not differentiate between OPA and LTPA (4). This may be problematic as workers are led to believe they fulfill the PA requirements from OPA, and therefore do not need to participate in additional PA during leisure time. This may exasperate the supposedly negative effects of OPA (9). The umbrella review also concluded that the evidence base for these findings were of very low to moderate quality, and therefore called for higher quality research in this area (30). Measurements of OPA have mostly used self-reports. In a systematic review investigating the validity of questionnaires compared to objective measures of PA, the international physical activity questionnaire which is the most validated PA questionnaire (31), overestimated PA by 84% average (32). In a separate study the questionnaire also underreported moderate PA, while overreporting high PA at work (33). This indicates a need for more use of objective measurements. A commonly used objective measure in more recent research has been accelerometers (18, 34, 35). A strength of using accelerometers is the ability to identify specific movements and behaviors and can therefore to a certain degree assess the type of PA. However, a weakness of accelerometers is recording the intensity, or cardiorespiratory strain. Loaded activity, such as carrying heavy objects will be recorded as walking, whilst the total physiological strain may be much higher. Hence, an alternative solution in assessing OPA is a measure of HR (36). As the body uses musculature to perform work, the HR rises. This work could be in the form of walking or lifting, the more demanding the task, the higher the HR response is. An often-used method is expressing the HR as heart rate reserve (HRR). It conveys the HR as a percentage of the range between maximal HR and resting HR. Therefore, HRR can be used as a proxy for the percentage of physical capacity, as they are highly correlated (37). It may also seem that the relative strain on the cardiorespiratory system, as measured using %HRR, is more strongly related to the adverse effects of OPA, compared to using absolute measures, such as accelerometers (38). Thus, assessing the cardiorespiratory strain by HR measures, in addition to assessing the physical strain by accelerometers, allows for a more complete analysis of OPA. To our knowledge, this type of analysis has not been conducted in a working population.

Few studies have assessed the association between OPA and physical capacity using objective measures. Only two studies have been identified using HR data, one using accelerometers and one using a SenseWear mini armband that combines accelerometers with heat readings to approximate a PA level. In studies using HR as an OPA measure, Merkus et al. (2019) found no significant association (23). Whilst Stevens et al. (2020) used HR monitors and demonstrated a significant negative association between OPA and physical capacity (22). Ketels at al. (2020), used accelerometers, and found a positive association between time in (SB) during work and physical capacity. However they found no association between time spent doing MVPA nor light intensity physical activity (LIPA) (18). Mundwiler et al. (2017) assessed the association between OPA and physical capacity using SenseWear mini. They found no association between neither low, moderate nor high OPA and physical capacity (17).

OPA characteristics can be vastly different between occupations, while an office worker mostly sits during the day, a cleaner will be walking around most of the day, while a construction worker may carry heavy loads and manually handle tools. A population which includes all these types of working tasks is the homecare health worker. A large portion of the working day is spent driving to patient houses, sometimes walking over longer distances. Caring for patients often include manually handling by lifting and shifting them. In addition, the work may put them in awkward positions, as they must work around the patients. The homecare worker population has been scarcely studied and the OPA has to our knowledge never been objectively assessed.

Thus, recent studies indicate a negative effect on health from OPA, however the mechanisms are still unclear. Further, the relationship between OPA and physical capacity can give a good indication on how health is affected by OPA. Hence, the aim of this study was to objectively measure OPA, using accelerometers and HR monitors and investigate if there is an association between physical capacity and OPA. Our hypothesis is that there is a negative association between OPA and physical capacity.

2 Methods

2.1 General

The data collection for this observational study was conducted in Trondheim, Norway, in October to December 2020. The collection was conducted during the Covid-19 pandemic. Researchers therefore used facemasks when closer than 1 meter to the participants and all equipment was washed using alcohol-based sanitizer between each participant. All participants read and signed a consent form, informing them of their rights in accordance with the Helsinki Declaration. This study is part of project “GoldiCare which has been approved by the regional committee for medical and health research in Norway.

2.1.1 Participants and exclusion criteria

99 homecare workers from three institutions with a ≥50% job position were asked to participate. Participants were excluded from doing the physical capacity test if they were pregnant, had any physical challenges which hindered normal PA, or a fever the last week or during testing. For recording physical behavior, the only exclusion criterion was an allergy to adhesives. Further, to be included in final analysis, they had to have at least two workdays of at least four hours in duration, with both HR and accelerometer data.

2.2 Measurements and equipment

2.2.1 Questionnaires, anthropometric measurements, and activity diary

A self-administered questionnaire was filled out detailing sociodemographic factors such as sex, age, marital status, living situation, highest completed education, work situation, sick leave, musculoskeletal pain, smoking status, fatigue, and workplace well-being. The questionnaire also asked about PA and exertion. Further, height and weight were measured using a wall mounted SECA 206 measuring tape (SECA Medical Measuring Systems and Scales, Birmingham, UK) and bodyweight scale, respectively. During the data collection period, they filled out an activity diary recording start of workday, end of workday, wake up time, sleep time, and time of doing a reference jump. They also informed about when not wearing sensors and days of not working.

2.2.2 Exposure variable; physical strain

Physical behavior was recorded using five triaxial Axivity AX3 (Newcastle upon Tyne, UK) accelerometers. They were attached to the dominant side of the participants, using medical tape.

One 5 cm below the head of fibula on the lateral side of the calf. One on the front of the thigh on the muscle belly of rectus femoris, 10 cm above the proximal part of the patella. One on the lateral side of the hip, 10 cm below the iliac crest. One on the upper back with the upper part of the accelerometer at the level of T1/T2. Lastly one was placed 3 cm below the deltoid insertion on the humerus. The accelerometers were set to record at 25 Hz at ± 8g, for 6 days. Accelerometers were synchronized by participants performing a reference jump. This was conducted every morning during the data collection, by the participant standing still for 15 seconds, then a single jump, then stand still for 15 seconds.

2.2.3 Exposure variable; cardiorespiratory strain

HR variability was recorded during the 6 days of testing using a portable ECG device, Firstbeat bodyguard 2 (Firstbeat Technologies Ltd., Jyväskylä, Finland). It is a two lead ECG, with one electrode connected under the collarbone on the right-hand side, and one on the ribcage on the left-hand side. It records HR variability with a resolution of 1 millisecond and has been validated against standard clinical ECG (39). It had to be removed for activities in water, such as showering and swimming. The participants were responsible for reattaching the sensor and changing the electrodes (Arbo H92SG) afterwards, they were instructed on how to do this.

2.2.4 Outcome variable; Physical capacity

An Ekblom-Bak test (40) using an ergometer bike, Monark 839E and Monark 939E (Monark AB, Varberg, Sweden), was conducted to estimate physical capacity, measured as VO_2max. It uses the HR difference between two physical exertion levels, gauged by the Borg scale, to calculate an estimated VO_2max. It has been validated for adult populations and has a high correlation with measured physical capacity (40). The HR for the Ekblom-Bak test was measured using “Polar H10” and “Garmin HRM-dual” HR sensor belt.

2.3 Data processing and analysis

2.3.1 Processing of accelerometer data

The data was downloaded using Axivity software (AX3-GUI, OmGui software) and processed using custom MATLAB software, Acti4, developed by the National Research Centre for the Working Environment, Copenhagen, Denmark and Department of Work and Health, Federal Institute for Occupational Safety and Health, Berlin, Germany (35). Acti4 is designed to use the triaxial accelerometer signal to identify physical behaviors: sitting, lying, standing, walking, moving (standing with small movements), running, cycling, walking in stairs, and rowing. It also separates the day into categories: leisure time, sleep time and working hours. The different periods are identified by the activity diary. Accelerometer data was then processed into three categories of intensity; SB defined as sitting or lying, LIPA defined as walking slowly (<100 steps/minute), standing and moving, whilst MVPA defined as walking fast (≥100 steps/minute), running, cycling and stair walking. Rowing was checked for amount of time during work, and only two short bouts were identified, and therefore not included. To check that the recorded data added up to the total work time, the total time for all behaviors was added and divided by the duration of work time, if the result was under 90%, the working day was removed. For analysis, the percentage of time spent in SB, LIPA and MVPA was calculated by dividing the time spent in each category by the total time at work.

2.3.2 ECG data processing

The HR variability was downloaded from the Firstbeat bodyguard 2 using the software Firstbeat Uploader. The inter-beat interval data was then processed in acti4 (cf. 2.3.1). Intervals that deviated more than 15% from the neighboring intervals or contained higher than 50% error rate was discarded. %HRR (equation. 1) was used to assess the cardiorespiratory strain.

Equation 1: $\%HRR = \frac{HRwork - HR_{min}}{HR_{max} - HR_{min}} \times 100\%$

"HR_{max}" variable was calculated using $208 - 0.7 * age$ (41). The "HR_{min}" variable was identified by averaging the lowest HR from each night of sleep, for every participant. This method was chosen to identify an approximate resting HR, whilst minimizing the risk of falsely low or high values. The HR data was analyzed as $\%HRR_{max}$ which was based on the average of the highest recorded HR during the workdays. Similarly, $\%HRR_{mean}$, was the average HR of all workdays.

2.3.3 Covariates

Gender and age were determined from questionnaire. Age was continuous, gender was dichotomous, male or female. Body mass index (BMI, kg/m^2) was assessed as continuous. Self-perceived health was used as categorical and ranged from 1 = "poor", 2 = "not that good", 3 = "good" and 4 = "very good".

2.3.4 Statistical analysis

Analysis was conducted in R version 4.0.3 (R Core Team, Vienna, Austria) (42), using the packages "Tidyverse" (43), "car" (44) and "psych" (45). Three regression models were used to analyze the association between physical capacity and OPA. First an unadjusted linear regression analysis between physical capacity and each OPA variable, $\%HRR_{mean}$ and $\%HRR_{max}$ and percent of SB, LIPA and MVPA at work. A second model was adjusted for both gender and age and finally, the fully adjusted model included the variables age, gender, BMI, and self-perceived health. The second model, controlling for age and gender, was regarded as the main analysis, whilst the fully adjusted was regarded as an experimental analysis. All independent variables that were included in the model were checked for multicollinearity visually and by variance inflation factor. These covariates were identified based on previous studies and own theoretical assumptions. The adjusted models were conducted regardless of significance of the unadjusted model. The level of significance was set to $\alpha = 0.05$ for all tests. The data was normally distributed, thus linear models were used. Results from regression analysis are presented as estimate (β; beta-coefficient) and p-value or 95% confidence interval.

3 Results

3.1 Demographics

60 participants were included in the final analysis (figure 1). These were mostly women (68.3%) and highly educated (71.7%). Likewise, most had 100% employment (78.3%) and worked in shift (98.3%). The average time spent at work was 456.3 minutes (Standard deviation; SD 30.2), this was based on an average of 3.2 (SD 0.7) working days. Complete information in table 1.

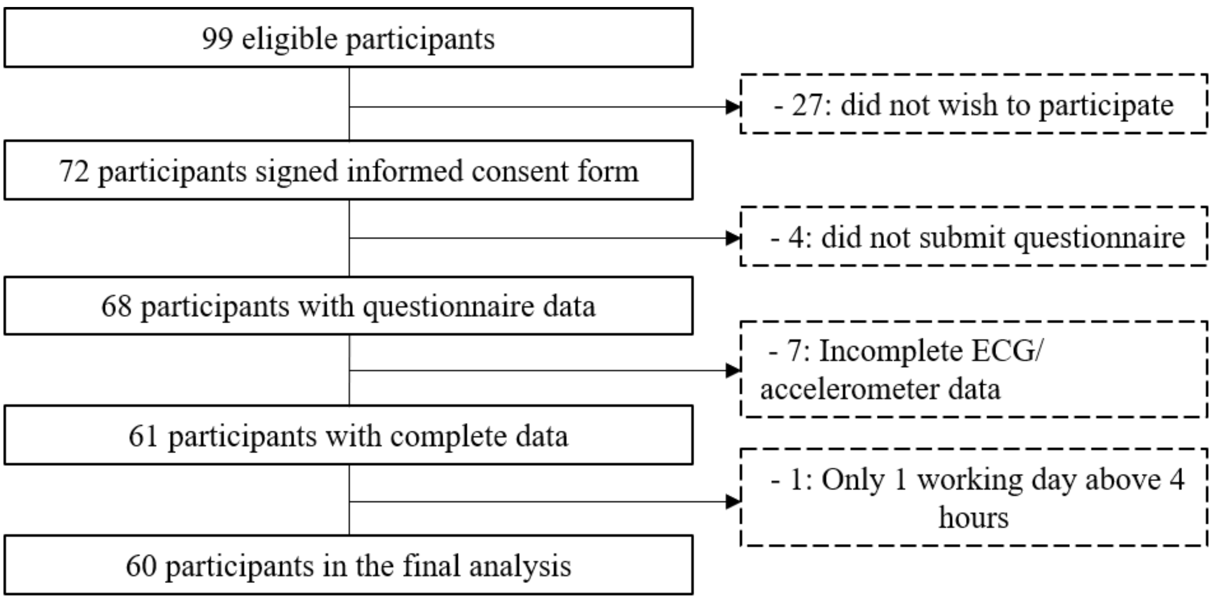


Figure 1: Flow of the participants

Table 1: Demographics of the participants included in the analysis. HRR = Heart rate reserve, SB = sedentary behavior, LIPA = Light intensity physical activity, MVPA = Moderate to vigorous physical activity, and BMI = Body mass index, SD = standard deviation

Demographic Characteristics	**N (%)**	**Mean (SD)**
Age		34.5 (10.1)
Physical capacity (VO_2max)		38.5 (10.3)
BMI		26.4 (4.1)
Sex		
Female	41 (68.3)	
Male	19 (31.7)	
Educational level		
Low (until 3 years in high school)	8 (13.3)	
Medium (Certificate of completed apprenticeship or advanced craft certificate)	9 (15.0)	
High (College/university)	43 (71.7)	
Family status		
Living alone	20 (33.9)	
Living with spouse/partner	30 (49.2)	
Living with other adults	5 (8.5)	
Living with children	5 (8.5)	
Smoking status		
Current smokers	3 (5.0)	
Employment status		
100% employment	47 (78.3)	
<100% & ≥80% employment	11 (18.4)	
<80% employment	2 (3.3)	
Work		
Shift	59 (98.3)	
Day job	1 (1.7)	
Self-reported physical demands (1 = low demands, 4 = high demands)		3.1 (0.4)
Self-perceived health (1 = Poor, 4 = Very Good)		3.1 (0.6)
Workday information	**N (%)**	**Mean (SD)**
Valid workdays		3.2 (0.7)
Work time (min/day)		456.3 (30.2)
Accelerometer-assessed behavior	**N (%)**	**Mean (SD)**
SB work (min/day)		234.4 (53.4)
LIPA work (min/day)		178.4 (41.7)
MVPA (min/day)		43.4 (13.0)
steps at work		5652 (1655.5)
Sleep time (hours/day)		7.9 (0.9)
ECG assessed data		
Average %HRR at work		27.1 (5.6)
Average %HRR_{max} at work		66.6 (8.6)
%HRR SB at work		22.0 (6.7)
%HRR LIPA at work		32.0 (6.0)
%HRR MVPA at work		37.1 (7.0)

3.2 Accelerometer measurements

The unadjusted simple linear model showed no significant association between physical capacity and percentage of workday spent in neither SB (figure 2A; β =0.130, p=0.302), LIPA (figure 2B; β=-0.153, p=0.311) nor MVPA (figure 2C; β =-0.285, p=0.545). It remained non-significant for all models after adjusting for age, gender, BMI, and perceived health (table 2). Further to this finding, no correlation was found between average steps during the workday and physical capacity (β =-0.109, p=0.407). Of the covariates, age, gender, BMI and self-perceived health ("not that good" vs "very good"; No participants answered "poor" on the questionnaire) was significant in all models for every accelerometer-based variable.

Table 2: Results from unadjusted, gender/age adjusted and full adjusted regression analysis. Significant associations in bold. SB = sedentary behavior, LIPA = Light intensity physical activity, MVPA = Moderate to vigorous physical activity, HRR = Heart rate reserve.

	Estimates [95% CI]		
	Unadjusted	Sex/age Adjusted	Full Adjusted
SB	β = 0.126	β = -0.028	β = 0.004
	[-0.13 to 0.38]	[-0.25 to 0.19]	[-0.16 to 0.15]
LIPA	β = -0.146	β = 0.011	β = -0.010
	[-0.45 to 0.16]	[-0.25 to 0.27]	[-0.19 to 0.17]
MVPA	β = -0.288	β = 0.288	β = 0.174
	[-1.20 to 0.62]	[-0.49 to 1.06]	[-0.40 to 0.75]
$\%HRR_{mean}$	**β = -0.745**	**β = -0.601**	β = -0.147
	[-1.54 to -0.01]	**[-0.97 to -0.23]**	[-0.52 to 0.22]
$\%HRR_{max}$	**β = -0.520**	**β = -0.404**	**β = -0.286**
	[-0.80 to -0.24]	**[-0.64 to -0.16]**	**[-0.48 to -0.08]**

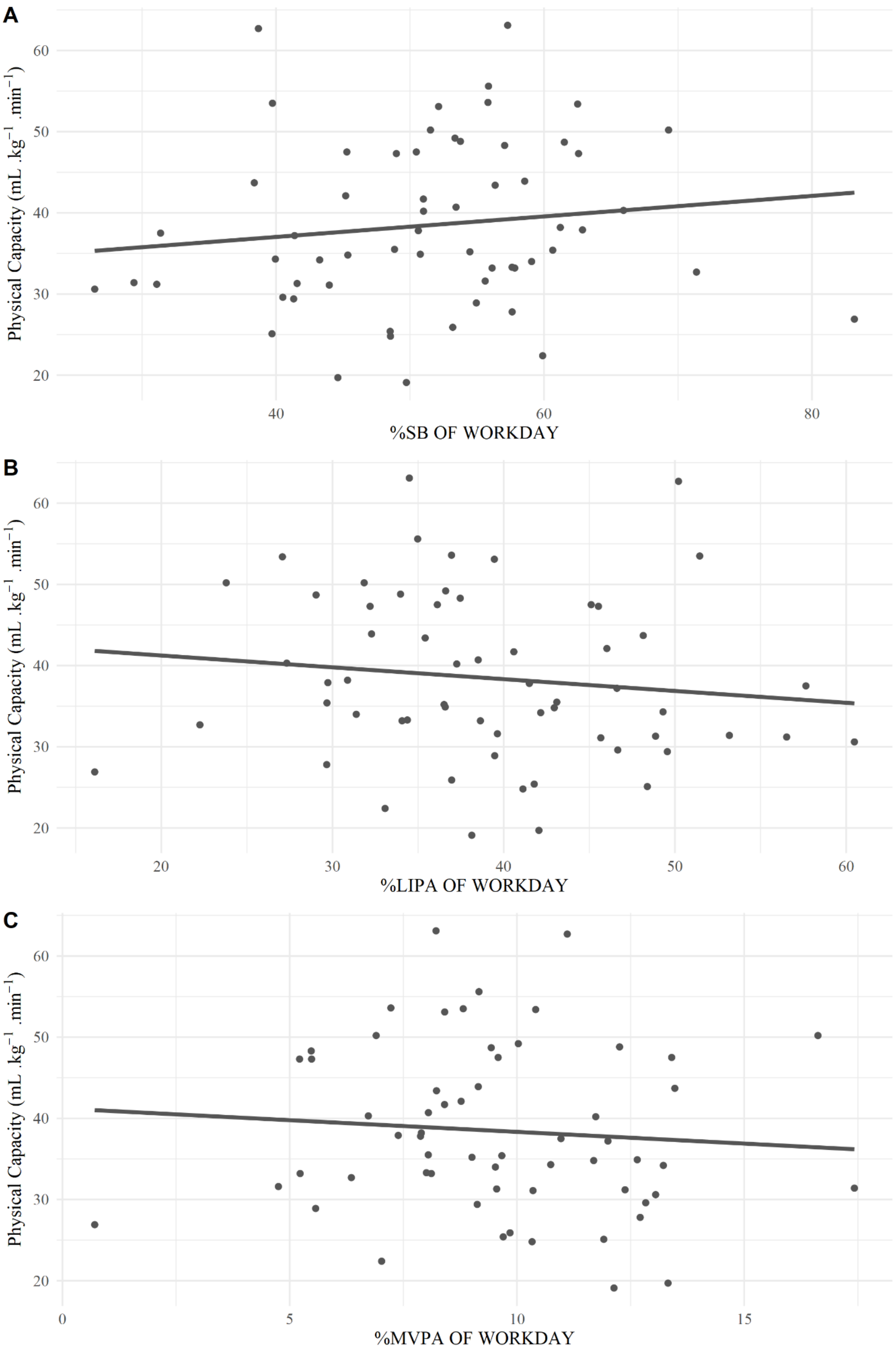


Figure 2: Scatterplot between physical capacity and % of workday spent in A: sedentary behavior (SB) B: light intensity physical activity (LIPA) and C: moderate to vigorous physical activity (MVPA).

3.3 ECG measurements

There was a significant negative association between physical capacity and $\%HRR_{mean}$ at work for the unadjusted model (figure 3A; $\beta = -0.745$, $p = 0.003$) and the gender and age adjusted (β = -0.-601, $p = 0.002$). However, the fully adjusted model resulted in a non-significant correlation ($\beta = -0.147$, $p = 0.430$) (table 2). Whilst $\%HRR_{max}$ at work had a significant negative correlation with physical capacity for the unadjusted (figure 3B; $\beta = -0.520$, $p < 0.001$), gender and age adjusted ($\beta = -0.404$, $p = 0.001$) and fully adjusted model ($\beta = -0.286$, $p = 0.007$) (table 2). The covariates, gender, age, and BMI were significant for all models. Self-perceived health ("not that good" vs "very good") was only significant for $\%HRR_{mean}$.

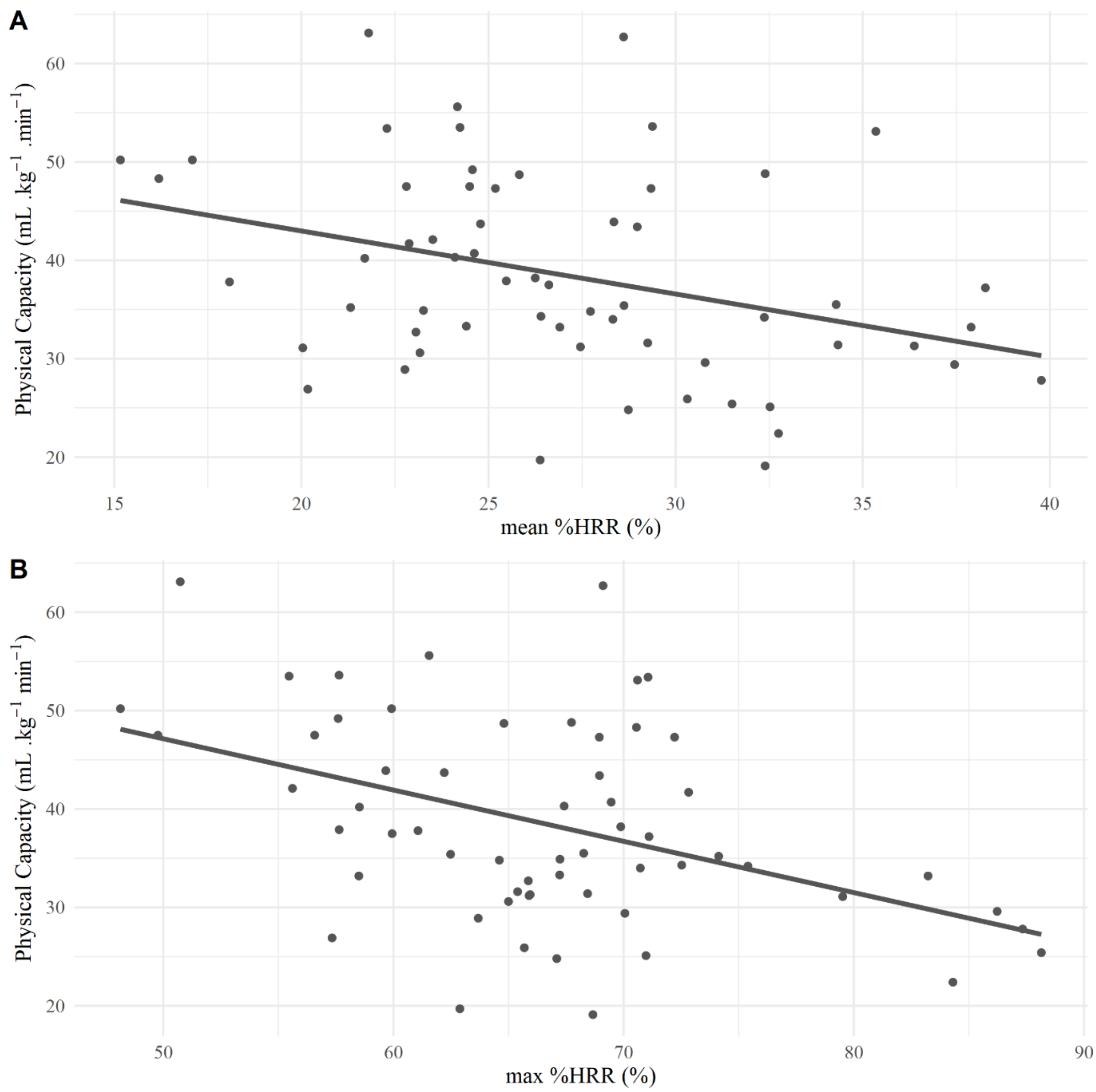


Figure 3: Scatterplot between physical capacity and A: mean %Heart rate reserve (%HRR) and B: max %HRR.

3.4 Composition of workday

Visualization of the composition of the workday in time spent in SB, light, moderate, and vigorous OPA, as measured with accelerometer versus ECG device (figure 4). Sedentary time was more prevalent measured with accelerometer (51.3%) than ECG (28.4%). Comparatively, light intensity was more prevalent when measured with ECG (59.5%) than with accelerometer (39.1%). Further, little time was spent in either moderate (accelerometer: 8.3% vs ECG: 11.4%) or vigorous (accelerometer: 1.2% vs ECG: 0.7%).

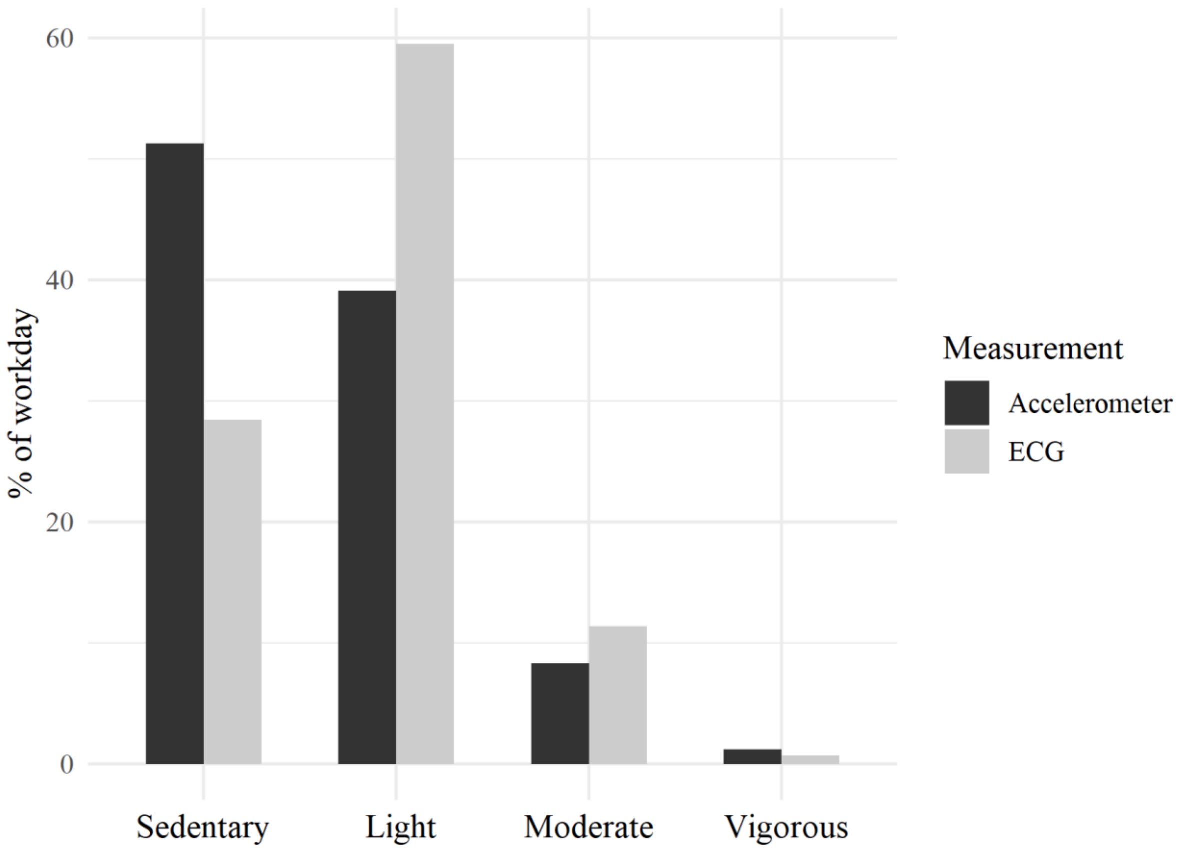


Figure 4: Bar plot comparing accelerometer and electrocardiography (ECG) assessed physical activity. Sedentary = <20% Heart rate reserve (%HRR) and sitting and lying, Light = 20-39% HRR and moving, standing, walking slowly, Moderate = 40-59% HRR and walking fast and cycling, Vigorous = >60% HRR and running and stair walking

4 Discussion

The results from this study indicate there is no association between physical capacity and physical strain from work, as measured using accelerometers. However, cardiorespiratory strain from OPA, as measured using %HRR, is negatively associated with physical capacity. This indicates that all workers, regardless of their physical capacity, do the same amount of work. Yet workers with higher physical capacity works at a lower relative cardiorespiratory strain. This is to our knowledge the first study to assess OPA using both accelerometers and HR monitors. Whilst previous studies have used these independently, combining them can give a more nuanced perspective of the OPA in the homecare sector. Further, it may offer more nuance to how the results from these types of studies are interpreted.

4.1 Previous research

A significant negative association between physical capacity and cardiorespiratory strain as measured with ECG was in line with our hypothesis. However, no significant associations between physical capacity and physical strain as measured with accelerometers was not in line with our hypothesis. Nonetheless, our results are in line with what has been previously demonstrated of the PA paradox, regarding the observation that higher levels of OPA seems not to be associated with increased levels of physical capacity. In contrast the positive relationship between LTPA and physical capacity is established in previous literature (17, 18, 21, 25). Furthermore, it is in line with previous studies objectively assessing the association between OPA and physical capacity. One study from Switzerland on 303 manual and non-manual laborers, found no association between physical capacity and any OPA categories using a SenseWear mini armband for seven days. In contrast they found LTPA at a vigorous level to be positively associated with physical capacity (17). Further, Ketels et al. (2020) used the same Axivity accelerometers as used in the current study. They found similar results where neither MVPA, LIPA nor standing during work had an association with physical capacity in 309 participants working in the service and production sector. However, more time spent in SB was associated with higher physical capacity. In contrast, MVPA during leisure time was associated with increased physical capacity whilst SB during leisure time was associated with lower physical capacity. Ketels et al. utilized a compositional data analysis (CoDA) and was able to investigate the reallocation of time spent in one behavior to another. This analysis found reallocating 10 minutes of MVPA to SB during work lead to increased physical capacity, and vice versa (18). As for the %HRR analysis, these results are in disagreement with a Norwegian study from 2019 by Merkus et al. (23). They found no significant correlation between percentage of time spent above 33%HRR at work and physical capacity in 64 health care workers. Whilst this is not the same variable as used in the current study, Stevens et al. (2020) utilized $\%HRR_{mean}$, $\%HRR_{max}$ and percentage of time above 30%HRR, and found similar results for all three variables (22). Further, in agreement with the current study, Stevens et al. did find a significant negative association between both $\%HRR_{mean}$ and $\%HRR_{max}$ and physical capacity in 497 workers from both administration and manual work (22). The finding of significant association between OPA and cardiorespiratory strain, a relative measure, is supported by the finding of Krause et al. (2015). They assessed OPA in working men by interview and calculated it both as relative to the workers physical capacity and absolute. They found the relative measures to have a stronger association to acute myocardial infarction, compared to absolute measures. Thus, based on the previous research, the findings from this study are mostly in line with what has previously been found. However, never have these factors been analyzed together, in the same population and time window using objective measures. When considering the findings from these previous studies, caution should be used when comparing them to the results in the current study, as professions can have vastly different characteristics and patterns of OPA, and even homecare may have different patterns compared to other professions within healthcare.

4.2 Implications

The results from the current study, indicates that regardless of physical capacity, the workers do the same amount of work. However, the workers with lower physical capacity seem to work at a higher relative cardiorespiratory strain. Therefore, these results show the importance of having and maintaining a high physical capacity for workers, as the work does not scale to the individual physical capacity. Leading to the workers with low physical capacity experiencing higher relative cardiorespiratory strain, which may increase mortality (29) and risk of cardiovascular disease (36). Further, increasing average %HRR at work by 10% has shown to increase the nighttime HR by 4,4 beats/minute (28), thus, increasing mortality (29). One of the possible reasons such scaling is not taking place may be the scheduling of the work. Every employee gets a list of patients to care for. These lists are supposed to be evenly distributed regarding work demands. Thus, workers complete the list they are given, which entails approximately the same amount of work. Further, this group had little time spent in vigorous PA, (figure 4) which is considered necessary for improving the physical capacity (21). This indicates, as has previously been hypothesized, that the OPA performed is not of high enough intensity for improving the physical capacity (11). Therefore, LTPA at high intensity may be very important for this population, as LTPA at higher intensity has shown to have good protective properties for the negative effects caused by OPA (9). Further, no association between physical capacity and physical strain, but for cardiorespiratory strain, may indicate that healthcare workers do a lot of manual handling with patients. Sitting work, whilst helping patients, would not be identified as PA by the accelerometers, but would be registered as heightened HR. Similarly, standing whilst shifting and handling patients would be registered by the accelerometers as LIPA, whilst the ECG may record this type of activity as much higher. This may be further indicated by the difference between time spent in SB and LIPA as measured with accelerometer vs ECG (figure 4). However, this difference can be due to factors inherent to the workplace not related to OPA. The psychosocial stressors at work, such as busy work schedule, work tasks, driving between patients houses, or doing reports with colleagues, could lead to heightened HR, not owing to PA.

4.2.1 Practical implications

These results demonstrate that this setup, using both accelerometers and ECG, can be used by employers and researchers to assess the physiological strain of employees. This can be crucial as high workload is associated with early voluntary retirement (46) and increased risk of cardiovascular disease (36) and mortality (29). By utilizing these sensors, one could potentially identify parts of the working day that are the most detrimental to the health of the employees. Further, the results of this study may put the use of accelerometers for measuring OPA in question, as it does not seem to register the important factors that are related to physical capacity. This could be due to accelerometers being an absolute measure since it does not consider the individual physical capacity as a relative measure, such as ECG does. However, whilst ECG may register more of the PA, such as lifting and handling patients, it cannot differentiate between an elevated HR due to PA or psychosocial stress factors. Further, ECG cannot differentiate between different modes of physical behavior, such as running, cycling, walking, and sitting. Thus, accelerometers can be a good tool to measure PA, if one is aware of the limitations. Whilst not a focus in the current study, accelerometers can be used in measuring specific bodily movements. Investigating specific anthropometric positions, such as kneeling, arms raised above a certain level and trunk inclination, could be used to identify workers that are at a higher risk of musculoskeletal pain. This could further be utilized to extend the working life of workers, by limiting such behavior. Thus, whilst ECG and accelerometers have both strengths and weaknesses, they complement each other well, and give valid and reliable information about the entire complicated composition of OPA.

4.2.2 Goldilocks principle

A proposed solution to OPA not seeming to be of the right intensity or length to improve physical capacity is the “Goldilocks principle” (47). The aim of this principle is making OPA “just right”. The characteristics of OPA should therefore not be of too little intensity, nor too long in duration to not allow for increasing the physical capacity. There is however uncertainty about what is “just right”. A suggested intervention is to include OPA at an intensity of >60% HRR for 10 minutes each working day (48, 49). Further, one third of the working day should be spent doing each of these physical behaviors; sitting, standing and being active (48). This has been shown to be feasible in an industrial setting and have good effects on health and pain (48). Similar interventions have been shown to be feasible in childcare as well (50). Nevertheless, responsibilities of homecare, involving caring for sick and elderly people, may not be as compatible with this type of intervention as other occupations. Hence, feasibility studies should be conducted before integration. Alternatively, previous studies, in addition to our results indicate a need to scale work to the individuals (22). Such a scaling in homecare could include patients that comprise a lot of hard work could be handled by workers with higher physical capacity, as the cardiorespiratory strain is not as high for these workers. This could potentially increase the working life longevity (46) and improve the health of the workers (29, 36). Outside of the workplace, increased participation in LTPA should be a focus as it has shown to be protective against both mortality and cardiovascular disease for populations with high OPA (9). In addition, health promoting programs should be focused on workers with low physical capacity, as to improve their ability to perform the work needed, without the negative health consequences associated with it.

4.3 Strengths and limitations

The biggest strength of this study is the combination of two objective measurement methods; accelerometers and HR monitors. This avoids recall bias as is common with questionnaires. It also presents valid data on complete workdays which presents an opportunity to analyze the OPA relative to the total time. This enabled us to get a full picture of the OPA, both cardiorespiratory strain in the form of HR and physical strain in the form of accelerometer data. Further methodological strengths is the use of Acti4 software which identifies activities with high sensitivity and specificity (35). Regarding the calculation of the %HRR, there is yet to be a consensus on how resting HR should be calculated from this type of data, and therefore the %HRR data could potentially be skewed. The way of calculating the resting HR differs between studies, and the author believes an agreement amongst researchers should be reached, as to produce more directly comparable data.

Another limitation is the number of participants, similar studies have had 300-500 participants (17, 18, 22), compared to 60 in the current study. This was mainly an effect of the small time-window for data collection. It may also be an effect of the high demand for the participants to wear up to six sensors on their body for six days. Several participants reported skin irritation from the sensors. Using a population from the same occupation minimizes the risk of confounding by occupation and socioeconomic status. However, the study was conducted on a specific population, nurses and caregivers in homecare. Hence, caution should be used with applying these results to other occupations. Statistically, physical behavior research would benefit from CoDA to control for the time spent doing other activities, this type of analysis was outside the scope of our study but should be performed in the future. Additionally, 6 days, as was the intended recording window may not be long enough to get a proper representation of the true OPA pattern of the workers. In addition, the season may influence the PA levels of this population more than others. They can choose to use active transportation, walking or biking, or drive between patients. Hence, nice weather may influence them to use active transportation more, rather than drive. The collection was conducted during the autumn, and could therefore possibly lead to more SB, compared to summer months, as more people choose to drive. Lastly, the cross-sectional nature of the study does not allow for inferring any causation about the relationship between OPA and physical capacity.

5 Conclusion

The results from the current study shows no association between OPA as measured with accelerometers and physical capacity. However, results showed a negative association between OPA, as measured with ECG, and physical capacity. This indicates that workers with high physical capacity have the same amount of physical strain, however, they work with a lower relative cardiorespiratory strain. This shows the importance of having and maintaining a high physical capacity for workers in physically demanding occupations as the relative cardiorespiratory strain is higher in those with low physical capacity. Further, the level of OPA intensity does not seem to be adequate for improving physical capacity.

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