PLOS ONE

RESEARCH ARTICLE

Is high aerobic workload at work associated with leisure time physical activity and sedentary behaviour among blue-collar workers? A compositional data analysis based on accelerometer data

Charlotte Lund Rasmussen[1,2]*, **Javier Palarea-Albaladejo**[3], **Mette Korshøj**[1], **Nidhi Gupta**[1], **Kirsten Nabe-Nielsen**[1,2], **Andreas Holtermann**[1,4], **Marie Birk Jørgensen**[5]

1 National Research Centre for the Working Environment, Copenhagen, Denmark, **2** Section of Social Medicine, Department of Public Health, University of Copenhagen, Copenhagen, Denmark, **3** Biomathematics and Statistics Scotland, Edinburgh, United Kingdom, **4** Department of Sports Science and Clinical Biomechanics, University of Southern Denmark, Odense, Denmark, **5** Department of Forensic Science, University of Copenhagen, Copenhagen, Denmark

* CLR@nrcwe.dk

Citation: Lund Rasmussen C, Palarea-Albaladejo J, Korshøj M, Gupta N, Nabe-Nielsen K, Holtermann A, et al. (2019) Is high aerobic workload at work associated with leisure time physical activity and sedentary behaviour among blue-collar workers? A compositional data analysis based on accelerometer data. PLoS ONE 14(6): e0217024. https://doi.org/10.1371/journal.pone.0217024

Editor: Kathryn L. Weston, Teesside University/Qatar Metabolic Institute, UNITED KINGDOM

Received: January 25, 2019

Accepted: April 30, 2019

Published: June 6, 2019

Data Availability Statement: We are unable to make an anonymized dataset publicly available given legal restrictions. The dataset contains both sensitive information and information which can be used to identify the study participants. These rules are based on the Data Protection Act, imposed by The Danish Data Protection Agency. An English translation of the Data Protection Act can be found on the official website for The Danish Data Protection Agency (https://www.datatilsynet.dk/

Abstract

Objective

This study aimed to investigate the hypothesized negative association between duration of work time spent at a high relative aerobic workload and leisure time movement behaviours among blue-collar workers.

Methods

This was a cross-sectional study based on heart rate and accelerometer data from 803 blue-collar workers (447 men and 356 women). Relative aerobic workload was measured as percentage of heart rate reserve during work (%HRR). Leisure time movement behaviours were expressed in terms of leisure time spent in sedentary and active behaviours in uninterrupted bouts (i.e. <10 min, ≥10–30 min and >30 min). Compositional regression and isotemporal substitution models were used to assess the association between the predominance of work time spent at ≥40%HRR and leisure time spent in sedentary and active bouts. All analyses were stratified by sex.

Results

For men, there was no statistically significant association between the predominance of work time spent at ≥40%HRR and leisure time movement behaviours. Among women, the predominance of ≥40%HRR at work was negatively associated with relative leisure time spent in ≥10 min bouts of active behaviour ($\hat{\beta}$ = -0.21, p = 0.02) and a theoretical 15 min reallocation of work time from <40%HRR to ≥40%HRR was estimated to decrease active behaviour by 6 min during leisure time.

english/legislation/). Data are available from the Danish National Archives (https://www.sa.dk/en/k/about-us) upon request. Requests may be sent to Kim Winding (KMW@nfa.dk) or Lisbeth Nielsen (LNI@nfa.dk).

Funding: The work was supported by a grant from the Danish government (Satspulje) and by The Danish Working Environment Research Fund (grant number 20175100213). J. Palarea-Albaladejo was partly supported by the Scottish Government's Rural and Environment Science and Analytical Services Division (RESAS) and by the Spanish Ministry of Economy and Competitiveness under the project CODA-RETOS MTM2015-65016-C2-1(2)-R.

Competing interests: The authors have declared that no competing interests exist.

Conclusion

Our result highlights the need for considering work-related barriers for an active leisure time in high-risk populations. Longitudinal studies are warranted to disentangle the relationship between physically demanding work characteristics and leisure time movement behaviours in such populations.

Introduction

Workers with high aerobic workloads have increased risk of cardiovascular disease and all-cause mortality [1–4]. The physiological mechanism is likely related to the characteristics of physically demanding job tasks which involve activities such as heavy lifting, pushing and pulling [2,5]. Performing such strenuous activities over prolonged time periods (e.g. 8 hours/5 days a week) imposes a high circulatory strain and subsequent risk of cardiovascular impairments [6–9]. Accordingly, for an 8-hour workday having a relative aerobic workload of 30–40% is considered a high aerobic workload [10,11]. High cardiorespiratory fitness could protect against these detrimental effects by reducing the relative aerobic workload when performing physically demanding job tasks [12–14].

Leisure time physical activity is typically performed in short bouts of high-intensity activities followed by adequate time for recovery and is found to enhance cardiorespiratory fitness [15]. In contrast, occupational physical activities are often performed without sufficient recovery, thereby not resulting in enhanced cardiorespiratory fitness [16,17]. In fact, hours of continuous physically demanding work each day is likely to cause fatigue [18]. Consequently, workers within manual jobs are likely to spent leisure time being sedentary instead of engaging in high-intensity activities[19,20]. Accordingly, we hypothesized high aerobic workload to be a barrier for performing bouts of health-enhancing physical activities and to increase the need for prolonged periods of sedentary leisure time. Given the accumulating evidence on health impairments associated with long, uninterrupted periods of sedentary behaviour and lack of bouted physical activities, such leisure time movement pattern could have severe health impact in an already high-risk population [21–25].

To our knowledge, no study has assessed the association between high aerobic workload and leisure time movement behaviours using device-based measurements and only two studies have investigated such association, both using self-reported measurements of leisure time physical activities [26,27]. However, self-reported measures of physical activities can be biased [28]. For example, individuals with higher cardiorespiratory fitness have been found to over-report physical activity levels more than those with lower cardiorespiratory fitness [29]. Accordingly, device-based measurements of physical activity have been recommended [28]. Moreover, time spent on physical activities at work and leisure time defines mutually exclusive and exhaustive parts of daily time awake. Consequently, these times are not independent of each other and, rather than analysing them in isolation, it is recommended to target all activities synergistically [30]. Proportions of daily time spent in each behaviour represent so-called compositional data for which dedicated statistical methodology has been developed [31,32]. Recently, this methodology has been successfully introduced in physical activity research [30,33,34]. Accordingly, the aim of our study was to investigate the association between device-based measured high aerobic workload at work and leisure time movement behaviours in a group of blue-collar workers, using compositional data analysis.

Materials and methods

Study design, study population and data collection

This study was based on cross-sectional data from the Danish Physical ACTivity cohort with Objective measurements (DPhacto) [35] and the New Method for Objective Measurements of Physical Activity in Daily Living (NOMAD) study [36]. The data collection and procedures in the two studies were identical, enabling merging of the two datasets.

The study population consisted of blue-collar workers from Danish companies within transportation, cleaning, manufacturing, construction, road maintenance, garbage disposal, assembly, mobile plant operator, and health services [35,36]. Eligible workers were employed for at least 20 hours/week; between 18–65 years old; had a blue-collar job; and given voluntary consent to participate. Workers were excluded if they were pregnant, had fever on the day of testing or allergy to adhesives.

Data were collected over four consecutive days and included a health check, questionnaire, and accelerometer and heart rate measurements over 24 hours a day [35,36]. Data collection and procedures have been described previously [35,36]. In short, eligible workers were invited to complete a questionnaire and to participate in a health check, consisting of anthropometric measurements and a physical health examination. Participants were asked to wear accelerometers and heart rate monitors for a minimum of two consecutive workdays and to complete a diary reporting time at work, time in bed and non-wear time. Daily work hours and leisure time were defined from the participants' diary information.

Only workers with at least one day of valid device-based measurements were included. A valid day consisted of having both a) heart rate measurement of $\geq$4 hours or 75% of the individual's average work time and b) accelerometer measurement of $\geq$4 hours or 75% of the individual's average leisure time awake. Time in bed at night was excluded from the analyses. Fig 1 shows the flow chart of the study population. A total of 1200 blue-collar workers participated in the baseline questionnaire and/or health check. Of these, 37 were excluded because they were managers, students, on holiday, pregnant or for unknown reasons; 186 did not have heart rate and/or accelerometer data; and 174 did not fulfil the criterion of having one valid day of device-based measurements. Thus, a total of 803 blue-collar workers (447 men and 356 women) were included in the analyses.

Ethical considerations

The DPhacto and NOMAD studies were approved by the local Ethics Committee of the Capital region of Denmark (file number H-2-2012-011[35] and file number H-2-2011-047 [36], respectively). Both studies were conducted according to the Helsinki declaration and all data were anonymized in relation to individuals and workplaces.

Measurements

Measurement of relative aerobic workload. Heart rate was measured using Actiheart (Camntech, Cambridge, United Kingdom), placed at the chest at one of the two standardized positions [37], consisting of two electrodes connected by a short lead attached to the skin by two standard electrocardiography pads (Ambu, Blue sensor VL-00-S/25) [38]. Data were downloaded in the Actiheart software (version 4.0.100) [39] and analysed by a custom-made MATLAB program Acti4 (The National Research Centre for the Working Environment, Denmark and The Federal Institute for Occupational Safety and Health, Germany (BAuA))[40].

Heart rate data were filtered and checked for errors according to an earlier described protocol [41]. In brief, inter-beat intervals corresponding to $<$36 or $>$200 beats/min were

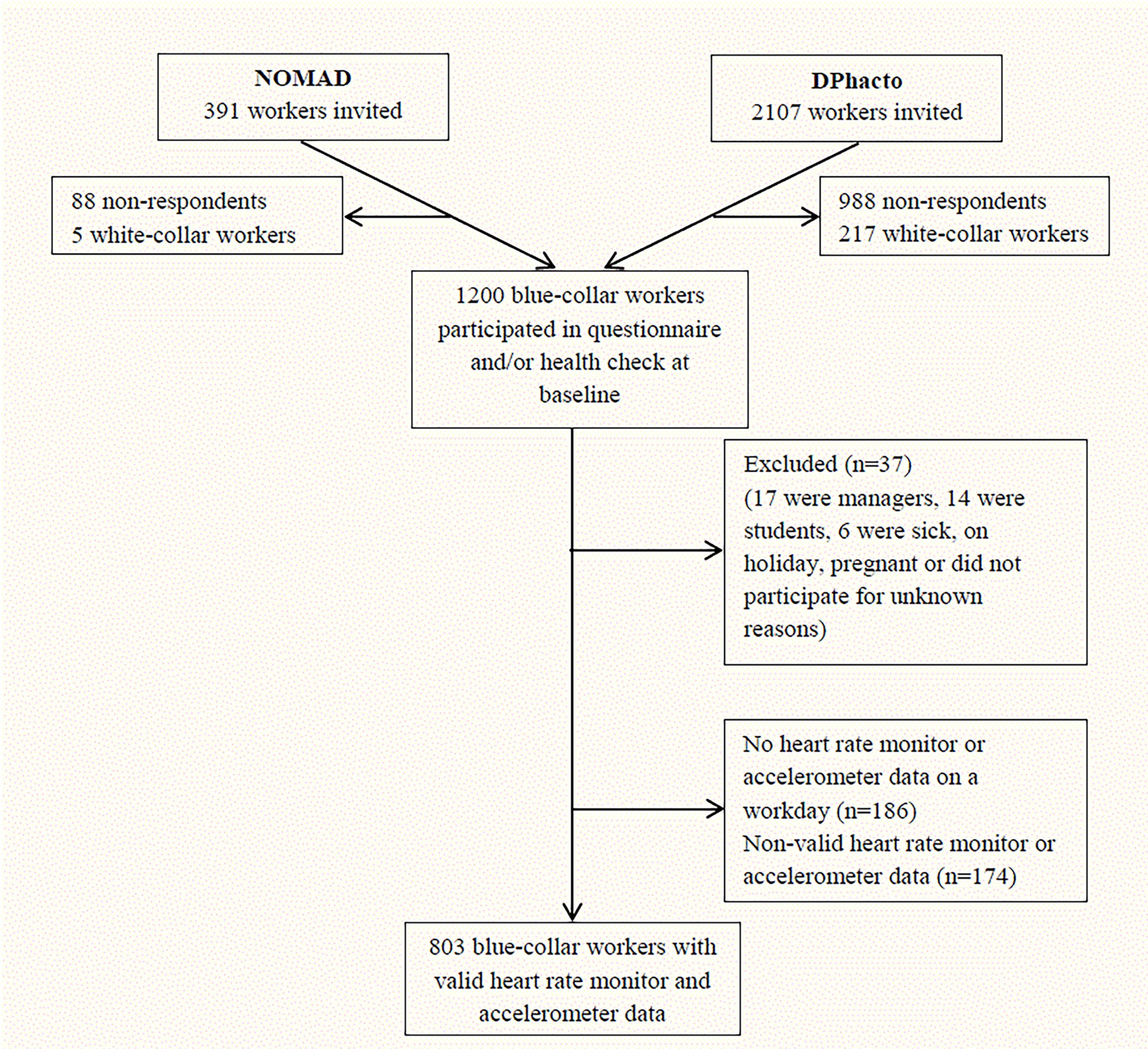

Fig 1. Flowchart of participants in the NOMAD and DPhacto study included in the current paper.

https://doi.org/10.1371/journal.pone.0217024.g001

considered as physiological outliers and excluded [41]. Moreover, heart rate measurements including > 50% beat error were excluded. Relative aerobic workload was estimated based on the heart rate reserve (%HRR), which is a well-established estimate of the aerobic workload on the body depending on the work demand and the individual's cardiorespiratory fitness [42]. Heart rate reserve was defined as the difference between estimated maximal heart rate (HR_{max}) and sleeping heart rate (SHR) ($HRR = HR_{max}-SHR$) for each worker [43]. HR_{max} was determined by the Tanaka equation [44] and SHR was defined as the minimum heart rate of an average of ten beats/min during time in bed at night [45]. The mean relative aerobic workload was then calculated as the percentage of estimated HRR (mean heart rate during work / $HRR^{*}100$ = %HRR). Generally, for an 8-hour workday having a HRR of 30–40% is considered a high aerobic load [10,11]. Thus, we defined high aerobic workload as work hours spent with ≥40%HRR.

Accelerometer measurements of leisure time physical activity and sedentary behaviour. Leisure time movement behaviours were assessed using data from one tri-axial ActiGraph GT3X+ accelerometer (Actigraph, Florida, U.S.A). The accelerometer was placed on the right thigh using double-sided adhesive tape (3 M, Hair-Set, St. Paul, Minnesota, USA) and Fixomull (Fixomull BSN medical GmbH, Hamburg, Germany) [46]. Accelerometer data were downloaded using Actilife Software version 5.5 [47] and analysed using the Acti4 program. The Acti4 program enables identification of physical activity types and postures (i.e. cycling, stair climbing, running, walking, standing, sitting and lying) with high sensitivity and specificity using angles from the accelerometer axis and standard deviation of mean acceleration [40,48]. Sedentary behaviour during leisure time was defined as time spent sitting and/or lying. Leisure time spent active was defined as time spent standing, walking, stair climbing, running or cycling.

Temporal patterns of physical activities and sedentary behaviour during leisure time were measured and quantified using exposure variation analyses (EVA). EVA enabled identification of uninterrupted periods of different durations of specific activities and sedentary behaviour. The temporal patterns of sedentary behaviour were expressed as average leisure time spent in short (<10 min), moderate (≥10–30 min) and prolonged (>30 min) uninterrupted periods (minutes/day). Active behaviour was expressed as average leisure time spent in short (<10 min) or moderate (≥10 min) uninterrupted periods (minutes/day). The chosen temporal patterns comply with recommendations from the American Physical Activity Guidelines 2018 based on current evidence on sedentary and active behaviour bout lengths to avoid health impairments [21–25].

Covariates. Sex and age of the workers were determined from each worker's unique Danish civil registration number (CPR-number). Body Mass Index (BMI) was calculated as body mass in (kg) divided by height (m) squared (kg/m^2). Information about prescribed heart or lung medicine intake as obtained by the question: *"Do you take prescribed medication for heart or lung diseases?"*. Job seniority was determined by the question: *"For how long have you had the kind of occupation that you have now?"*. Information on shift work was assessed using the question: *"At which time of the day do you usually work in your main occupation?"* with 3 response categories; fixed day work; night/varying working hours with night; and other. The variable was dichotomised into workers with fixed day work and workers with no-fixed day work (including shift work and other).

Statistical analyses

Compositional regression analysis was used to estimate the association between %HRR at work and leisure time movement behaviours. All analyses were performed in R version 1.1.3 [49], using the *compositions* [50], *robCompositions* [51] and *zCompositions* [52] packages.

Each worker's average daily time use was conceptualized as consisting of two compositions i.e. work and leisure time. Daily work period was treated as a 2-part composition, consisting of time spent at <40%HRR and ≥40%HRR. Leisure time was treated as a 5-part composition, consisting of time spent on prolonged sedentary bouts (i.e. >30 min), moderate sedentary bouts (i.e. ≥10–30 min), short sedentary bouts (i.e. <10 min), short active bouts (i.e. <10 min) and moderate active bouts (i.e. ≥10 min). Six workers had zero leisure time spent in moderate active bouts and one worker had zero leisure time spent in moderate sedentary bouts. These zero observations were assumed to be due to limited sampling and treated as missing data. They were imputed by expected values using the log-ratio Expectation-

Maximization (EM) algorithm based on the information in the covariance structure of the observed data set [53].

Compositional descriptive statistics. Compositional geometric means were calculated for the %HRR and leisure time compositions to describe the central tendency of the data [31,32]. They were obtained by computing the geometric mean of each individual part of the respective compositions and then normalising (closing) these vectors of geometric means to be expressed in units relative to the workers' average daily work and leisure time (i.e. 442 min and 519 min, respectively). The pair-wise variation matrix and total variance of the leisure time composition were calculated as compositional summaries of data variability [31,32]. The pair-wise variation matrix indicates the co-dependence between the parts of the leisure time composition in terms of proportionality, with values close to 0 indicating that two parts are highly co-dependent. The total variance was decomposed into contributions from each part of the leisure time composition.

Isometric log-ratio (ilr) coordinates and compositional linear regression. A detailed description of the compositional multivariate linear regression and isotemporal substitution methods has been reported previously [54]. In short, the %HRR and leisure time compositions were represented using isometric log-ratio (*ilr*) coordinates. For the 2-part work composition, one ilr-coordinate expressed the relative importance (or predominance) of work time spent with $\geq$40% HRR relative to work time spent with $<$40%HRR. For the leisure time composition, we used so-called pivot ilr coordinates, by which all the relative information of the first part of the composition (with respect to the geometric mean of the remaining parts) is included in the first ilr-coordinate [55]. The parts were then sequentially rearranged to place each leisure time movement behaviour bout at the first position once and the corresponding ilr-coordinate sets were computed. In this way, the relative importance of each part was sequentially represented in the first ilr-coordinate of a set for subsequent statistical significance testing through regression analysis.

The strength and direction of the associations between the predominance of work time at $\geq$40%HRR and leisure time movement behaviour bouts were estimated using compositional multivariate linear regression models. In all models, the ilr-coordinate for the workers' %HRR composition was given as the exposure variable and the set of ilr-coordinates of the workers' leisure time composition defined the outcome variables. Five regression models were then fitted, each one isolating the relative importance of one of the leisure time movement behaviour bouts with respect to the others in the first ilr-coordinate (denoted by ilr_1) as described above.

Studies have shown men and women to differ in work tasks and leisure time behaviours [56,57]. In line with this, we have previously found differences in work and leisure time physical activities within the same study population as in the current study [54]. Thus, all analyses were stratified by sex. Based on literature and theoretical considerations of potential confounders, models were adjusted for age [17,20], average work hours [58] and heart or lung medicine intake (reference group = none). Average total work hours was calculated using the logarithm of the geometric mean of time spent on each part of the %HRR composition multiplied by $\sqrt{D} = \sqrt{2}$ [59]. Regression beta-coefficients and standard errors were estimated for the five regression models. For each model, 2-sided Wald test p-values were used to determine if the predominance of %HRR was statistically significantly associated with the predominance of the leisure time movement behaviour bout represented by the first ilr-coordinate, based a 5% significance threshold. The assumptions of normality and homoscedasticity of the residuals were assessed for all models by visual inspection of plots of residuals versus predicted values and quantile-quantile plots.

Compositional isotemporal substitution models. Compositional isotemporal substitution models were used to estimate the potential effect of reallocating work time spent with

<40%HRR to ≥40%HRR, following the methods described in Dumuid et al. (2017) and Lund Rasmussen et al. (2018). This analysis was performed in three steps. Firstly, an expected leisure time composition was estimated based on the workers' average %HRR composition. Secondly, a new %HRR composition was constructed by reallocating time spent with <40%HRR to ≥40%HRR from 15 min to 60 min in 15-min increases. Thirdly, expected changes in the leisure time composition were derived by taking the inverse ilr-transformation of the leisure time movement behaviour ilr-coordinates estimated by the reference baseline and new %HRR compositions and then calculating change in leisure time movement behaviours. Quantile-based bootstrap 95% confidence intervals [60,61] of the expected changes in the LTPA composition were estimated based on 1000 bootstrap resamples generated at random by sampling from the original dataset with replacement.

Results

Study population

Table 1 shows the baseline characteristics of the study population, stratified by sex. Among men, the average age was 43.9 (SD = 10.8) years; average BMI was 27.0 kg/m^2 (SD = 4.3); 64% were smokers; 8% used prescribed heart or lung medicine; and the majority worked within manufacturing (69%). Among women, the average age was 46.8 (SD = 8.6) years; average BMI was 27.1 kg/m^2 (SD = 5.4); 67% were smokers; 9% used prescribed heart or lung medicine; and most of the women worked in manufacturing (50%).

Compositional descriptive statistics

Compositional geometric means (CGMs) of the %HRR and leisure time compositions stratified by sex are presented in Table 2. Both men and women spent the majority of their work time at <40%HRR (90% and 89% time, respectively). The average distribution of leisure time spent in sedentary and active bouts were similar for men and women.

Table 3 displays the variation matrix of the leisure time composition for men and women. For both sexes, the strongest association was observed between short sedentary bouts and short active bouts during leisure time (log-ratio variances $\tau = 0.11$ and $\tau = 0.11$, respectively). Moreover, for both men and women the moderate active bouts category was the main contributor to the total variation (56% and 42%, respectively), indicating that leisure time spent on moderate active bouts varied considerably.

Compositional multivariate linear regression analyses

For men, we found no statistically significant association between the predominance of work time spent with ≥40%HRR and of any type of leisure time movement behaviour bouts (Table 4; $p > 0.05$ in all cases). For women, relative work time spent with ≥40%HRR was positively associated with the predominance of short sedentary bouts ($\hat{\beta} = 0.09$, p = 0.02) and negatively associated with the predominance of moderate active bouts ($\hat{\beta} = -0.21$, p = 0.02) in the leisure time composition. Note that the total work time term was not statistically significant in any model (p-values ranging from 0.15 to 0.89). This suggests that the association between work and leisure time movement behaviours was driven by relative and not absolute times.

Compositional isotemporal substitution analyses

Among women, reallocating 15 min to work time spent with ≥40%HRR was associated with an expected increase in short sedentary bouts of 1 min and a decrease in moderate active bouts of 6 min during leisure time (Table 5). Among men, the largest expected change associated

Table 1. Baseline characteristics of the study population, stratified by sex.

Variables	Men (n = 447)				Women (n = 356)			
	N	%	Mean (SD)	Range	N	%	Mean (SD)	Range
Age in years	447	100	43.9 (10.8)	[18.0;68.0]	356	100	46.8 (8.6)	[21.0;68.0]
Seniority in years	428	96	13.9 (10.9)	[0.0; 45.0]	336	94	13.0 (10.1)	[0.1; 48.0]
Overall health (1–5)[A]	437	98	2.2 (0.6)	[1.0; 5.0]	349	98	2.3 (0.7)	[1.0; 5.0]
BMI in kg/m^2	439	98	27.0 (4.3)	[18.9;45.1]	352	99	27.1 (5.4)	[16.2;43.8]
Aerobic capacity (ml O2/min/kg)	353	79	33.7 (9.0)	[13.9;66.9]	251	71	29.9 (8.5)	[13.6; 68.9]
Alcohol consumption (units/week)	443	99	4.8 (6.2)	[0.0; 40.0]	350	98	1.8 (2.5)	[0.0; 18.0]
Days with valid heart rate monitor measurements	447	100	2.4 (0.9)	[1.0; 5.0]	356	100	2.4 (0.9)	[1.0; 5.0]
Days with valid accelerometer measurements	447	100	2.7 (1.0)	[1.0; 5.0]	356	100	2.5 (0.9)	[1.0; 5.0]
Cohort								
NOMAD	101	23			89	25		
DPhacto	346	77			267	75		
Fixed day job	341	76			279	78		
Skilled workers	227	51			119	33		
Smokers	288	64			237	67		
Prescribed heart or lung medicine intake	34	8			32	9		
Working sector								
Cleaning	18	4			126	35		
Manufacturing	311	69			178	50		
Transportation	55	12			2	1		
Health Service	0	0			16	5		
Assemblers	2	1			28	7		
Construction	26	6			0	0		
Garbage Collectors	16	4			0	0		
Mobile Plant Operators	6	1			0	0		
Other[B]	13	3			9	2		

BMI = body mass index. SD = standard deviation.

[A]High scores indicate higher self-reported heath.

[B]Includes general office clerks and other elementary workers.

https://doi.org/10.1371/journal.pone.0217024.t001

with reallocating 15 min to work time spent with ≥40%HRR was found for long sedentary bouts of an increase of 2 min. However, this was not statistically significant (Table 4; p = 0.45).

Discussion

In this cross-sectional study, we investigated the association between work time spent at high relative aerobic workload, expressed as ≥40%HRR, and movement behaviours during waking leisure time among blue-collar men and women. For an average female worker, reallocating 15 min of work time with <40%HRR to work time with ≥40%HRR was associated with an increase in relative leisure time spent in short sedentary bouts of 1 min and a decrease in moderate active bouts of 6 min. We found no associations among men.

Our finding of a negative association between relative aerobic workload and leisure time activities among women is in line with observations from other cross-sectional studies using device-based measurements [62,63]. One study among 20 female cleaners observed that those with an average relative aerobic workload of ≥25%HRR during work time did not engage in high-intensity physical activities during leisure [62]. Another study assessed the association

Table 2. Compositional geometric mean (CGM) for percentage heart rate reserve at work (%HRR) and leisure time movement behaviour bouts (in minutes/day and %), stratified by sex.

	Men (n = 447)		Women (n = 356)	
%HRR at work (CGM)				
	Min./day	*%*	*Min./day*	*%*
<40%HRR	400	90	396	89
≥40%HRR	42	10	46	11
Leisure time bouts (CGM)				
	Min./day	*%*	*Min./day*	*%*
SB ≥30 min	162	31	143	27
SB ≥10–30 min	115	22	102	20
SB<10 min	66	13	66	13
Active<10 min	84	18	96	19
Active≥10 min	82	16	111	22

Active = standing, walking, running, stair climbing, and cycling. CGM = compositional geometric mean. % HRR = percentage heart rate reserve. SB = sedentary behaviour (sitting and lying). Time-use of %HRR was closed to the workers' average daily work hours (442 minutes). Time-use of leisure time composition was closed to workers' average daily leisure time (519 minutes).

https://doi.org/10.1371/journal.pone.0217024.t002

between workloads at work and leisure time activities derived from METs based on measurements from SenseWear mini armbands among 303 workers (of which 113 were women) [63]. The authors reported that occupational groups with high aerobic workloads at work (mean of 32% VO_{2max}) performed the lowest amount of high physical activity at leisure time compared with occupational groups with low- and moderate-aerobic workloads at work (mean of 16% VO_{2max} and 20% VO_{2max}, respectively) [63]. Finally, our current findings are in line with our previous study in which the association between occupational and leisure time movement behaviours was investigated using CoDA based on the same study population [54]; here we observed that increasing work time walking by 15 min was associated a decrease in leisure

Table 3. Compositional variation matrix for leisure time spent on movement behaviour bouts, stratified by sex.

	Men (n = 447)						Women (n = 356)					
	SB >30 min	**SB ≥10–30 min**	**SB <10 min**	**Active <10 min**	**Active ≥10 min**	**Var-clr (%)**	**SB ≥30 min**	**SB ≥10–30 min**	**SB <10 min**	**Active <10 min**	**Active ≥10 min**	**Var-clr (%)**
SB >30 min	0.00					0.47 (23)	0.00					0.49 (24)
SB ≥10–30 min	0.68	0.00				0.15 (8)	1.12	0.00				0.42 (21)
SB <10 min	0.81	0.24	0.00			0.15 (8)	0.84	0.62	0.00			0.15 (8)
Active <10 min	0.67	0.21	0.11	0.00		0.10 (5)	0.73	0.53	0.11	0.00		0.10 (5)
Active ≥10 min	2.23	1.73	1.64	1.57	0.00	1.14 (56)	1.77	1.79	1.23	1.17	0.00	0.85 (42)
Total var						2.01 (100)						2.01 (100)

Active = standing, walking, running, stair climbing, and cycling. SB = sedentary behaviour (sitting and lying). Total var = total variance of the composition. Var-clr (%) = absolute and percentage (%) contribution of each part to the total variance. Values close to 0 indicate that two parts are nearly proportional (highly co-dependent) and thus, their log-ratio is nearly constant.

https://doi.org/10.1371/journal.pone.0217024.t003

Table 4. Compositional regression analysis estimates: association between leisure time movement behaviour bouts and work time percentage heart rate reserve (%HRR) compositions, stratified by sex.

Variable	$\hat{\beta}$	SE	P-value
Men (n = 447)			
ilr_1(SB ≥30 min)	0.12	0.09	0.19
ilr_1(SB ≥10–30 min)	0.01	0.05	0.92
ilr_1(SB <10 min)	0.04	0.05	0.45
ilr_1(Active<10 min)	0.01	0.04	0.86
ilr_1(Active≥10 min)	-0.14	0.14	0.32
Women (n = 356)			
ilr_1(SB ≥30 min)	-0.004	0.07	0.95
ilr_1(SB ≥10–30 min)	0.01	0.07	0.93
ilr_1(SB <10 min)	0.09*	0.04	0.02
ilr_1(Active<10 min)	0.05	0.03	0.09
ilr_1(Active≥10 min)	-0.21*	0.09	0.02

Active = standing, walking, running, stair climbing, and cycling. %HRR = percentage heart rate reserve. SB = sedentary behaviour (sitting and lying).ilr_1 = first ilr-coordinate, representing the relative importance of a leisure time movement behaviour bout (indicated in parenthesis) with respect to the others. $\hat{\beta}$ = beta-coefficient of the ilr-coordinate of the %HRR composition. Regression models adjusted for age, prescribed heart or lung medicine and average work hours.

*p-value <0.05.

https://doi.org/10.1371/journal.pone.0217024.t004

time standing of 7 min among women. Taken together, these findings indicate that women with high aerobic workloads are less likely to have an active leisure time, compared with women with low aerobic workloads.

Table 5. Expected change in leisure time movement behaviours bouts associated with reallocating of work time (in minutes) from heart rate reserve (%HRR) below 40% to above 40%, stratified by sex.

Leisure time behaviour	SB>30 min			SB ≥10–30 min			SB<10 min			Active<10 min			Active≥10 min		
	Min	95% CI	Δ	Min	95% CI	Δ	Min	95% CI	Δ	Min	95% CI	Δ	Min	95% CI	Δ
Men (n = 447)															
Ref. %HRR comp.	96	[35; 219]		106	[47; 213]		64	[30; 116]		72	[36; 153]		87	[20; 221]	
+15 min ≥40%HRR	98	[37; 215]	2	106	[50; 206]	0	64	[32; 115]	0	71	[38; 149]	-1	87	[21; 201]	0
+30 min ≥40%HRR	100	[39; 212]	4	107	[52; 201]	1	65	[33; 112]	1	69	[40; 146]	-3	87	[22; 186]	0
+45 min ≥40%HRR	102	[42; 207]	6	107	[54; 197]	1	65	[34; 112]	1	68	[42; 145]	-4	88	[22; 174]	1
+60 min ≥40%HRR	103	[44; 204]	7	107	[56; 194]	1	66	[36; 111]	2	67	[44; 143]	-5	88	[23; 165]	0
Women (n = 356)															
Ref. %HRR comp.	92	[44; 320]		92	[33; 215]		63	[27; 114]		96	[48;146]		144	[39; 234]	
+15 min ≥40%HRR	92	[44; 314]	0	92	[33; 210]	0	64*	[27; 114]	1	97	[49; 145]	1	138*	[41; 232]	-6
+30 min ≥40%HRR	92	[46; 307]	0	92	[34; 204]	0	65*	[28; 112]	2	97	[50; 144]	1	133*	[41; 228]	-11
+45 min ≥40%HRR	91	[47; 305]	-1	91	[35; 202]	-1	66*	[28; 112]	3	98	[51; 144]	2	128*	[41; 224]	-16
+60 min ≥40%HRR	91	[48; 300]	-1	91	[35; 202]	-1	66*	[29; 111]	3	98	[52; 143]	2	125*	[42; 222]	-19

Active = standing, walking, running, stair climbing, and cycling. HRR = heart rate reserve. SB = sedentary behaviour (sitting and lying). Models adjusted for age, prescribed heart or lung medicine and average daily work hours. 95% CI = bootstrap 95% confidence interval for the expected LTPA.

*p-value <0.05. Reference %HRR comp. is the worker's average %HRR composition.

https://doi.org/10.1371/journal.pone.0217024.t005

The expected changes in leisure time of 6 min decreased accumulated time spent in active bouts and 1 min increased accumulated time spent in sedentary bouts among women might seem small. However, replacing 10 min of sedentary time with equal amounts of moderate to vigorous physical activity has been found to lower risk of cardiovascular disease by 12% in a general population [64]. Additionally, replacing 10 min sedentary time with moderate physical activity and vigorous physical activity has shown reduction in risk of metabolic syndrome with 8% and 58%, respectively [65]. Indeed, as little as 1 min replacement of sedentary time with any activity (light, moderate or vigorous) has shown to lower the odds for having metabolic syndrome [65]. Moreover, this group of women were predominantly sedentary during leisure time (Table 2), overweight and with low cardiorespiratory fitness levels (Table 1) and thereby already at increased risk of cardiovascular disease and all-cause mortality [66,67]. Consequently, any decrease in health-enhancing physical activities could have severe health implications for this high-risk population of women.

Among men, we found no association between %HRR at work and leisure time movement behaviours. This result contradicts those of two previous studies. In the first study, the authors observed that high relative aerobic workload of HRR >33% predicted a lower leisure time physical activities during a 4-year follow-up (OR = 0.56, 95% CI = [0.44–0.70]) among 1,891 men from various occupations [26]. Nevertheless, this finding was based on a heterogeneous study population in terms of socioeconomic position and occupation, which could bias the results given that both factors are highly associated with physical job demands and leisure time physical activities [19]. The second study used device-based heart rate measurements over 3–4 days among 42 male construction workers [27]. The authors observed that workers with the highest amount of work time with HRR above 33% had the lowest amount of leisure time spent in high ranges of %HRR, suggesting low levels of moderate to vigorous leisure time physical activities. However, this study did not technically measure physical activities, which limits the comparability with the current results.

Practical implications

For men and women we observed an average of 42–46 minutes/day of activities ≥40%HRR but low amounts of leisure time physical activities, which is in line with other studies among blue-collar workers [18]. Thus, if not considering if activities are performed at work or leisure, this suggests that the workers are meeting the physical activity guidelines of 150 min of moderate-to-vigorous physical activities per week [21]. However, accumulating evidence indicate that while leisure time physical activities have beneficial health effects, occupational physical activities are likely to have detrimental health effects [1,3,7,9]. Accordingly, interventions addressing health among manual workers should aim at increasing health-enhancing leisure time physical activities and not rely solely on total daily physical activities levels. Unfortunately, such interventions appear to fail in reaching inactive population groups at greatest risk of health impairments [68]. For improving the effect of targeted health interventions, knowledge about determinants for healthy leisure time-use are essential. While several studies have investigated individual determinants for leisure time physical activities [58], little research has been conducted on the effects of physical demands at work on leisure time movement behaviours. However, we argue that a holistic approach considering behaviours both at work and leisure time, like one based on compositional methodology, is required to identify healthy time-use patterns and corresponding determinants among high-risk populations. Furthermore, we suggest that health practitioners and policymakers focus on how work and leisure time activity patterns might impact each other when promoting physical activity guidelines and interventions.

Strength and limitations

The use of device-based measurements of aerobic workload and leisure time movement behaviours is a strength of this study by limiting misclassification error [28]. The use of exposure variation analyses of leisure time movement behaviours enabled a detailed insight into patterns of active and sedentary bouts. Moreover, the negative association between high aerobic workload at work and active bouts ≥10 min among women supports that exposure variation analyses provided important information beyond that available from data on total time spent in activity categories. Finally, the use of compositional data analysis was a methodological strength which facilitated assessment of the association between relative work time spent with high %HRR and relative leisure time spent on sedentary and active bouts, taking potential interactions between leisure time movement behaviours categories into account. This methodology considerably adds to the field of occupational and public health and physical activity research by enabling research on time-use combinations of physical activities at work and leisure time and health outcomes [69].

The cross-sectional design was a limitation as we cannot rule out an inverse association between low levels of leisure time physical activities and relative aerobic workload. For example, it is plausible that workers performing more leisure time physical activities have higher cardiorespiratory fitness levels and thus, reduced relative aerobic workloads. In this study, we chose not to analyse the pattern of work time spent with uninterrupted periods of high aerobic workload. Consequently, only mean time spent with high %HRR during work time was considered in our analyses. This could be considered a limitation, as different time distribution within %HRR ranges and exertion/rest periods could affect levels of fatigue and thereby leisure time movement behaviours differently [70]. Although the use of EVA enabled detailed insights into leisure time movement patterns, we did not assess the sequences of periods, for instance whether a long, uninterrupted sedentary period was always followed by a short bout of activity. We suggest future studies to potential determinants and health effects of such leisure time movement behaviour sequences. The cut-points for bout-duration and definition set for interrupting a bout were based on current evidence on associations between behaviour bout lengths and health (21–25). Nevertheless, research on this topic is limited and thus the chosen cut-points were not based on solid scientific ground. Finally, the workers in this study had low variation in %HRR during work hours and leisure time physical activities bouts, which could attenuate the strength of the investigated association [71]. Accordingly, the uncertainty of the estimated associations was relatively high given the high standard errors and wide 95% CI.

Conclusion

In this study we found that a theoretical reallocation of 15 min of work time from <40%HRR to work time spent with ≥40%HRR was associated with a decrease in relative leisure time spent in active bouts of 6 min for the average working women. This finding is of particular concern given that these women were mainly sedentary and consequently, even a few minutes of decrease in active leisure time is likely to impose health impairments. Nevertheless, the result should be interpreted with caution given the relatively high uncertainty in the estimated association. Moreover, our hypothesis of high aerobic workload as a barrier for performing health-enhancing leisure time physical activities was not supported among men.

Acknowledgments

The authors would like to thank the DPhacto and NOMAD research groups and personnel who contributed to the data collection.

Author Contributions

Conceptualization: Charlotte Lund Rasmussen.

Formal analysis: Charlotte Lund Rasmussen, Javier Palarea-Albaladejo.

Funding acquisition: Charlotte Lund Rasmussen.

Investigation: Charlotte Lund Rasmussen.

Methodology: Charlotte Lund Rasmussen.

Project administration: Andreas Holtermann, Marie Birk Jørgensen.

Supervision: Kirsten Nabe-Nielsen, Andreas Holtermann, Marie Birk Jørgensen.

Writing – original draft: Charlotte Lund Rasmussen.

Writing – review & editing: Charlotte Lund Rasmussen, Javier Palarea-Albaladejo, Mette Korshøj, Nidhi Gupta, Kirsten Nabe-Nielsen, Andreas Holtermann, Marie Birk Jørgensen.

References

1. Coenen P, Huysmans MA, Holtermann A, Krause N, van Mechelen W, Straker LM, et al. Do highly physically active workers die early? A systematic review with meta-analysis of data from 193 696 participants. Br J Sports Med. 2018; https://doi.org/10.1136/bjsports-2017-098540 PMID: 29760168
2. Krause N, Brand RJ, Arah OA, Kauhanen J. Occupational physical activity and 20-year incidence of acute myocardial infarction: results from the Kuopio Ischemic Heart Disease Risk Factor Study. Scand J Work Environ Health. 2015; 41: 124–139. https://doi.org/10.5271/sjweh.3476 PMID: 25599524
3. Ferrario MM, Roncaioli M, Veronesi G, Holtermann A, Clays E, Borchini R, et al. Differing associations for sport versus occupational physical activity and cardiovascular risk. Heart. 2018; heartjnl-2017–312594. https://doi.org/10.1136/heartjnl-2017-312594 PMID: 29440185
4. Li J, Loerbroks A, Angerer P. Physical activity and risk of cardiovascular disease: what does the new epidemiological evidence show? Curr Opin Cardiol. 2013; 28: 575–583. https://doi.org/10.1097/HCO.0b013e328364289c PMID: 23928923
5. Karlqvist L, Leijon O, Härenstam A. Physical demands in working life and individual physical capacity. Eur J Appl Physiol. 2003; 89: 536–547. https://doi.org/10.1007/s00421-003-0832-4 PMID: 12728324
6. Allesøe K, Holtermann A, Aadahl M, Thomsen JF, Hundrup YA, Søgaard K. High occupational physical activity and risk of ischaemic heart disease in women: The interplay with physical activity during leisure time. Eur J Prev Cardiolog. 2015; 22: 1601–1608. https://doi.org/10.1177/2047487314554866 PMID: 25311002
7. Clays E, Bacquer DD, Herck KV, Backer GD, Kittel F, Holtermann A. Occupational and leisure time physical activity in contrasting relation to ambulatory blood pressure. BMC Public Health. 2012; 12: 1002. https://doi.org/10.1186/1471-2458-12-1002 PMID: 23164344
8. Hu G-C, Chien K-L, Hsieh S-F, Chen C-Y, Tsai W-H, Su T-C. Occupational versus leisure-time physical activity in reducing cardiovascular risks and mortality among ethnic Chinese adults in Taiwan. Asia Pac J Public Health. 2014; 26: 604–613. https://doi.org/10.1177/1010539512471966 PMID: 23343645
9. Holtermann A, Mortensen OS, Burr H, Søgaard K, Gyntelberg F, Suadicani P. Physical demands at work, physical fitness, and 30-year ischaemic heart disease and all-cause mortality in the Copenhagen Male Study. Scand J Work Environ Health. 2010; 36: 357–365. PMID: 20352174
10. Åstrand P-O, Rodahl K, Dahl HA, Stromme SB. Textbook of Work Physiology. Maidenhead, UK: McGraw-Hill Book Company; 1986.
11. Wu H-C, Hsu W-H, Chen T. Complete recovery time after exhaustion in high-intensity work. Ergonomics. 2005; 48: 668–679. https://doi.org/10.1080/00140130500070871 PMID: 16087501
12. Hu G, Jousilahti P, Borodulin K, Barengo NC, Lakka TA, Nissinen A, et al. Occupational, commuting and leisure-time physical activity in relation to coronary heart disease among middle-aged Finnish men and women. Atherosclerosis. 2007; 194: 490–497. https://doi.org/10.1016/j.atherosclerosis.2006.08.051 PMID: 16979645
13. Krause N. Physical activity and cardiovascular mortality–disentangling the roles of work, fitness, and leisure. Scandinavian Journal of Work, Environment & Health. 2010; 36: 349–355. https://doi.org/10.5271/sjweh.3077

14. Clays E, Lidegaard M, De Bacquer D, Van Herck K, De Backer G, Kittel F, et al. The combined relationship of occupational and leisure-time physical activity with all-cause mortality among men, accounting for physical fitness. Am J Epidemiol. 2014; 179: 559–566. https://doi.org/10.1093/aje/kwt294 PMID: 24305575
15. McArdle WD. Exercise physiology, energy, nutrition and human performance. 6. ed. Baltimore, MD: Lippincott, Williams & Wilkins; 2007.
16. Howley ET. Type of activity: resistance, aerobic and leisure versus occupational physical activity. Med Sci Sports Exerc. 2001; 33: S364–369; discussion S419-420. PMID: 11427761
17. Savinainen M, Nygård C-H, Ilmarinen J. A 16-year follow-up study of physical capacity in relation to perceived workload among ageing employees. Ergonomics. 2004; 47: 1087–1102. https://doi.org/10.1080/00140130410001686357 PMID: 15370865
18. Arias OE, Caban-Martinez AJ, Umukoro PE, Okechukwu CA, Dennerlein JT. Physical activity levels at work and outside of work among commercial construction workers. J Occup Environ Med. 2015; 57: 73–78. https://doi.org/10.1097/JOM.0000000000000303 PMID: 25563543
19. Beenackers MA, Kamphuis CB, Giskes K, Brug J, Kunst AE, Burdorf A, et al. Socioeconomic inequalities in occupational, leisure-time, and transport related physical activity among European adults: A systematic review. Int J Behav Nutr Phys Act. 2012; no pagination. https://doi.org/10.1186/1479-5868-9-116 PMID: 22992350
20. Bláfoss R, Micheletti JK, Sundstrup E, Jakobsen MD, Bay H, Andersen LL. Is fatigue after work a barrier for leisure-time physical activity? Cross-sectional study among 10,000 adults from the general working population. Scand J Public Health. 2018; 1403494818765894. https://doi.org/10.1177/1403494818765894 PMID: 29609495
21. Physical Activity Guidelines Advisory Committee Scientific Report. 2018 Physical Activity Guidelines Advisory Committee [Internet]. Washington, DC: U.S. Department of Health and Human Services; 2018. Available: https://health.gov/paguidelines/second-edition/report.aspx
22. Loprinzi PD, Cardinal BJ. Association between biologic outcomes and objectively measured physical activity accumulated in $\geq$ 10-minute bouts and <10-minute bouts. Am J Health Promot. 2013; 27: 143–151. https://doi.org/10.4278/ajhp.110916-QUAN-348 PMID: 23286590
23. Carson V, Wong SL, Winkler E, Healy GN, Colley RC, Tremblay MS. Patterns of sedentary time and cardiometabolic risk among Canadian adults. Preventive Medicine. 2014; 65: 23–27. https://doi.org/10.1016/j.ypmed.2014.04.005 PMID: 24732719
24. Wolff-Hughes DL, Fitzhugh EC, Bassett DR, Churilla JR. Total Activity Counts and Bouted Minutes of Moderate-to-Vigorous Physical Activity: Relationships With Cardiometabolic Biomarkers Using 2003–2006 NHANES. J Phys Act Health. 2015; 12: 694–700. https://doi.org/10.1123/jpah.2013-0463 PMID: 25109602
25. Vasankari V, Husu P, Vähä-Ypyä H, Suni J, Tokola K, Halonen J, et al. Association of objectively measured sedentary behaviour and physical activity with cardiovascular disease risk. Eur J Prev Cardiol. 2017; 24: 1311–1318. https://doi.org/10.1177/2047487317711048 PMID: 28530126
26. Wang A, Arah OA, Kauhanen J, Krause N. Effects of leisure-time and occupational physical activities on 20-year incidence of acute myocardial infarction: mediation and interaction. Scand J Work Environ Health. 2016; 42: 423–434. https://doi.org/10.5271/sjweh.3580 PMID: 27367151
27. Lunde L-K, Koch M, Veiersted KB, Moen G-H, Wærsted M, Knardahl S. Heavy Physical Work: Cardiovascular Load in Male Construction Workers. Int J Environ Res Public Health. 2016; 13: 356. https://doi.org/10.3390/ijerph13040356 PMID: 27023574
28. Prince SA, Adamo KB, Hamel ME, Hardt J, Gorber SC, Tremblay M. A comparison of direct versus self-report measures for assessing physical activity in adults: a systematic review. Int J Behav Nutr Phys Act. 2008; 5: 56. https://doi.org/10.1186/1479-5868-5-56 PMID: 18990237
29. Tomaz SA, Lambert EV, Karpul D, Kolbe-Alexander TL. Cardiovascular fitness is associated with bias between self-reported and objectively measured physical activity. European Journal of Sport Science. 2016; 16: 149–157. https://doi.org/10.1080/17461391.2014.987323 PMID: 25537282
30. Chastin SFM, Palarea-Albaladejo J, Dontje ML, Skelton DA. Combined Effects of Time Spent in Physical Activity, Sedentary Behaviors and Sleep on Obesity and Cardio-Metabolic Health Markers: A Novel Compositional Data Analysis Approach. PLOS ONE. 2015; 10: e0139984. https://doi.org/10.1371/journal.pone.0139984 PMID: 26461112
31. Aitchson J. The statistical analysis of compositional data. 1986.
32. Pawlowsky-Glahn V, Egozcue JJ, Tolosana-Delgado R. Modeling and Analysis of Compositional Data. John Wiley & Sons; 2015.
33. Štefelová N, Dygrýn J, Hron K, Gába A, Rubín L, Palarea-Albaladejo J. Robust Compositional Analysis of Physical Activity and Sedentary Behaviour Data. Int J Environ Res Public Health. 2018; 15. https://doi.org/10.3390/ijerph15102248 PMID: 30322203

34. Gupta N, Dumuid D, Korshøj M, Jørgensen MB, Søgaard K, Holtermann A. Is Daily Composition of Movement Behaviors Related to Blood Pressure in Working Adults? Med Sci Sports Exerc. 2018; 50: 2150–2155. https://doi.org/10.1249/MSS.0000000000001680 PMID: 30222689

35. Jørgensen MB, Korshøj M, Lagersted-Olsen J, Villumsen M, Mortensen OS, Skotte J, et al. Physical activities at work and risk of musculoskeletal pain and its consequences: protocol for a study with objective field measures among blue-collar workers. BMC musculoskeletal disorders. 2013; 14: 1. https://doi.org/10.1186/1471-2474-14-1

36. Gupta N, Jensen BS, Søgaard K, Carneiro IG, Christiansen CS, Hanisch C, et al. Face Validity of the Single Work Ability Item: Comparison with Objectively Measured Heart Rate Reserve over Several Days. Int J Environ Res Public Health. 2014; 11: 5333–5348. https://doi.org/10.3390/ijerph110505333 PMID: 24840350

37. Brage S, Brage N, Ekelund U, Luan J, Franks PW, Froberg K, et al. Effect of combined movement and heart rate monitor placement on physical activity estimates during treadmill locomotion and free-living. Eur J Appl Physiol. 2006; 96: 517–524. https://doi.org/10.1007/s00421-005-0112-6 PMID: 16344938

38. Brage S, Brage N, Franks PW, Ekelund U, Wareham NJ. Reliability and validity of the combined heart rate and movement sensor Actiheart. Eur J Clin Nutr. 2005; 59: 561–570. https://doi.org/10.1038/sj.ejcn.1602118 PMID: 15714212

39. CamNtech Ltd. CamNtech [Internet]. Upper Pendrill Court, Ermine Street North, Papworth Everard, Cambridge CB23 3UY: CamNtech; Available: https://www.camntech.com/

40. Skotte J, Korshøj M, Kristiansen J, Hanisch C, Holtermann A. Detection of physical activity types using triaxial accelerometers. J Phys Act Health. 2014; 11: 76–84. https://doi.org/10.1123/jpah.2011-0347 PMID: 23249722

41. Kristiansen J, Korshøj M, Skotte JH, Jespersen T, Søgaard K, Mortensen OS, et al. Comparison of two systems for long-term heart rate variability monitoring in free-living conditions—a pilot study. Biomed Eng Online. 2011; 10: 27. https://doi.org/10.1186/1475-925X-10-27 PMID: 21481282

42. Ilmarinen J. Job design for the aged with regard to decline in their maximal aerobic capacity: Part I—Guidelines for the practitioner. International Journal of Industrial Ergonomics. 1992; 10: 53–63. https://doi.org/10.1016/S1572-347X(00)80014-2

43. Karvonen MJ, Kentala E, Mustala O. The effects of training on heart rate. Ann Med Exper Fenn. 1957; 35: 1–459.

44. Tanaka H, Monahan KD, Seals DR. Age-predicted maximal heart rate revisited. J Am Coll Cardiol. 2001; 37: 153–156. PMID: 11153730

45. Brage S, Brage N, Franks PW, Ekelund U, Wong M-Y, Andersen LB, et al. Branched equation modeling of simultaneous accelerometry and heart rate monitoring improves estimate of directly measured physical activity energy expenditure. J Appl Physiol. 2004; 96: 343–351. https://doi.org/10.1152/japplphysiol.00703.2003 PMID: 12972441

46. Lagersted-Olsen J, Thomsen BL, Holtermann A, Søgaard K, Jørgensen MB. Does objectively measured daily duration of forward bending predict development and aggravation of low-back pain? A prospective study. Scandinavian Journal of Work, Environment & Health. 2016; 42: 528–537. https://doi.org/10.5271/sjweh.3591 PMID: 27606607

47. ActiGraph. Software | ActiGraph [Internet]. Available: http://actigraphcorp.com/support/software/

48. Stemland I, Ingebrigtsen J, Christiansen CS, Jensen BR, Hanisch C, Skotte J, et al. Validity of the Acti4 method for detection of physical activity types in free-living settings: comparison with video analysis. Ergonomics. 2015; 58: 953–965. https://doi.org/10.1080/00140139.2014.998724 PMID: 25588819

49. R Core Team. R: A language and environment for statistical computing. [Internet]. Vienna, Austria: R Foundation for Statistical Computing; 2017. Available: https://www.R-project.org/

50. van den Boogaart KG, Tolosana-Delgado R. "compositions": A unified R package to analyze compositional data. Computers & Geosciences. 2008; 34: 320–338. https://doi.org/10.1016/j.cageo.2006.11.017

51. Templ M, Hron K, Filzmoser P. robCompositions: An R-package for Robust Statistical Analysis of Compositional Data. In: Pawlowsky-Glahn V, Buccianti Aeditors. Compositional Data Analysis. John Wiley & Sons, Ltd; 2011. pp. 341–355. https://doi.org/10.1002/9781119976462.ch25

52. Palarea-Albaladejo J, Martín-Fernández JA. zCompositions—R package for multivariate imputation of left-censored data under a compositional approach. Chemometrics and Intelligent Laboratory Systems. 2015; 143: 85–96. https://doi.org/10.1016/j.chemolab.2015.02.019

53. Palarea-Albaladejo J, Martín-Fernández JA. A modified EM alr-algorithm for replacing rounded zeros in compositional data sets. Computers and Geosciences. 2008; 34: 902–917. https://doi.org/10.1016/j.cageo.2007.09.015

54. Lund Rasmussen C, Palarea-Albaladejo J, Bauman A, Gupta N, Nabe-Nielsen K, Jørgensen MB, et al. Does Physically Demanding Work Hinder a Physically Active Lifestyle in Low Socioeconomic Workers? A Compositional Data Analysis Based on Accelerometer Data. International Journal of Environmental Research and Public Health. 2018; 15: 1306. https://doi.org/10.3390/ijerph15071306 PMID: 29933644
55. Hron K, Filzmoser P, Thompson K. Linear regression with compositional explanatory variables. Journal of Applied Statistics. 2012; 39: 1115–1128. https://doi.org/10.1080/02664763.2011.644268
56. Eng A, t Mannetje A, McLean D, Ellison-Loschmann L, Cheng S, Pearce N. Gender differences in occupational exposure patterns. Occup Environ Med. 2011; 68: 888–894. https://doi.org/10.1136/oem.2010.064097 PMID: 21486991
57. Chu AHY, Moy FM. Associations of occupational, transportation, household and leisure-time physical activity patterns with metabolic risk factors among middle-aged adults in a middle-income country. Preventive Medicine. 2013; 57: S14–S17. https://doi.org/10.1016/j.ypmed.2012.12.011 PMID: 23276774
58. Bauman AE, Reis RS, Sallis JF, Wells JC, Loos RJ, Martin BW. Correlates of physical activity: why are some people physically active and others not? The Lancet. 2012; 380: 258–271. https://doi.org/10.1016/S0140-6736(12)60735-1
59. Vera Pawlowsky-Glahn, Egozcue Juan José, Lovell David. Tools for compositional data with a total. Statistical Modelling. 2015; 15: 175–190. https://doi.org/10.1177/1471082X14535526
60. Efron B, Tibshirani RJ. An introduction to the bootstrap. New York: Chapmann & Hall; 2003.
61. Palarea-Albaladejo J, Martín-Fernández JA, Olea RA. A bootstrap estimation scheme for chemical compositional data with nondetects. Journal of Chemometrics. 2014; 28: 585–599. https://doi.org/10.1002/cem.2621
62. Korshøj M, Krustrup P, Jespersen T, Søgaard K, Skotte JH, Holtermann A. A 24-h assessment of physical activity and cardio-respiratory fitness among female hospital cleaners: A pilot study. Ergonomics. 2013; 56: 935–943. https://doi.org/10.1080/00140139.2013.782427 PMID: 23586528
63. Brighenti-Zogg S, Mundwiler J, Schüpbach U, Dieterle T, Wolfer DP, Leuppi JD, et al. Physical Workload and Work Capacity across Occupational Groups. PLoS ONE. 2016; 11: e0154073. https://doi.org/10.1371/journal.pone.0154073 PMID: 27136206
64. Wellburn S, Ryan CG, Azevedo LB, Ells L, Martin DJ, Atkinson G, et al. Displacing Sedentary Time: Association with Cardiovascular Disease Prevalence. Med Sci Sports Exerc. 2016; 48: 641–647. https://doi.org/10.1249/MSS.0000000000000816 PMID: 26559454
65. Ekblom-Bak E, Ekblom Ö, Bergström G, Börjesson M. Isotemporal substitution of sedentary time by physical activity of different intensities and bout lengths, and its associations with metabolic risk. Eur J Prev Cardiol. 2016; 23: 967–974. https://doi.org/10.1177/2047487315619734 PMID: 26635358
66. Sofi F, Capalbo A, Cesari F, Abbate R, Gensini GF. Physical activity during leisure time and primary prevention of coronary heart disease: an updated meta-analysis of cohort studies. Eur J Cardiovasc Prev Rehabil. 2008; 15: 247–257. https://doi.org/10.1097/HJR.0b013e3282f232ac PMID: 18525378
67. Fletcher GF, Landolfo C, Niebauer J, Ozemek C, Arena R, Lavie CJ. Promoting Physical Activity and Exercise: JACC Health Promotion Series. Journal of the American College of Cardiology. 2018; 72: 1622–1639. https://doi.org/10.1016/j.jacc.2018.08.2141 PMID: 30261965
68. Ball K. Traversing myths and mountains: addressing socioeconomic inequities in the promotion of nutrition and physical activity behaviours. Int J Behav Nutr Phys Act. 2015; 12: 142. https://doi.org/10.1186/s12966-015-0303-4 PMID: 26572225
69. Pedišić Ž, Dumuid D, S. Olds T. Integrating sleep, sedentary behaviour, and physical activity research in the emerging field of time-use epidemiology: definitions, concepts, statistical methods, theoretical framework, and future directions. Kinesiology: International journal of fundamental and applied kinesiology. 2017; 49: 252–269.
70. Mathiassen SE. Diversity and variation in biomechanical exposure: what is it, and why would we like to know? Appl Ergon. 2006; 37: 419–427. https://doi.org/10.1016/j.apergo.2006.04.006 PMID: 16764816
71. Riazi AM. The Routledge Encyclopedia of Research Methods in Applied Linguistics. Routledge; 2016.