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How Does Occupational Lifting Affect Ambulatory Blood Pressure, Relative Aerobic Workload and Level of Physical Activity?

Mathilde Baumann[1,], Martine Mejding Poulsen[1], Ole Steen Mortensen[1,2], Michael Hecht Olsen[3,4] and Mette Korshøj PhD[1]

[1]Department of Occupational and Social Medicine, University Hospital Holbæk, Denmark;
[2]Department of Public Health, Section of Social Medicine, University of Copenhagen, Denmark;
[3]Department of Internal Medicine 1, Holbæk Hospital, Denmark;
[4]Department of Regional Health Research, University of Southern Denmark, Denmark

[*]Author to whom correspondence should be addressed. e-mail: melars@regionsjaelland.dk

Abstract

Introduction: Occupational physical activity (OPA), including occupational lifting (OL), seems to increase the risk of cardiovascular disease (CVD). Knowledge about the association between OL and risk of CVD is sparse, but repeated OL is assumed to result in prolonged raised blood pressure and heart rate (HR) eventually augmenting the risk of CVD. To disentangle parts of the mechanisms behind the raised 24-hour ambulatory blood pressure measurement (24h-ABPM), by exposure to OL, this study aimed to explore the acute differences in 24h-ABPM, relative aerobic workload (RAW) and OPA across workdays with and without OL, and secondary to assess the feasibility and rater agreement of direct field observations of the frequency and load of occupational lifting.

Methods: This controlled cross-over study investigates associations between moderate to high OL and 24h-ABPM, RAW in per cent of heart rate reserve (%HRR) and level of OPA. This included 2x24h monitoring of 24h-ABPM (Spacelabs 90217), PA (Axivity) and HR (Actiheart), comprising a workday containing OL and a workday without. The frequency and burden of OL were directly observed in field. The data were time synchronized and processed in the Acti4 software. Differences across workdays with and without OL in 24h-ABPM, RAW and OPA were evaluated using repeated 2 × 2 mixed-models among 60 blue-collar workers in Denmark.. Exposure to OL was estimated by direct manual field observation, registering burden and frequency of OL. Interrater reliability tests were performed across 15 participants representing 7 occupational groups. Interclass correlation coefficient (ICC) estimates of total burden lifted and frequency of lifts were calculated, based on a mean-rating (k = 2), absolute-agreement, 2 way mixed-effects model, indicating the raters as fixed effects.

Results: OL led to non-significant increases in ABPM during work-time (systolic Δ1.79 mmHg, 95%CI −4.49–8.08, diastolic Δ0.43 mmHg, 95%CI −0.80–1.65), and on 24-hours basis (systolic Δ1.96 mmHg, 95%CI −3.80–7.72, diastolic Δ0.53 mmHg, 95%CI −3.12–4.18), significant increases in RAW during work (Δ7.74 %HRR, 95%CI 3.57–11.91) as well as a raised level of OPA (Δ4156.88 steps, 95%CI 1898.83–6414.93, Δ−0.67 hours of sitting time, 95%CI −1.25–0.10, Δ−0.52 hours of standing time, 95%CI −1.03–0.01, Δ0.48 hours of walking time, 95%CI 0.18–0.78). ICC estimates were 0.998 (95% CI 0.995–0.999) for total burden lifted and 0.992 (95% CI 0.975–0.997) for frequency of lift.

Discussion: OL increased both intensity and volume of OPA among blue-collar workers, which supposedly to contributes to an augmented risk of CVD. Although this study finds hazardous acute effects, further investigations are needed to evaluate the long-term effects of OL on ABPM, HR and volume of OPA, also effects of cumulative exposure to OL would be relevant to investigate.

Conclusion: OL significantly raised the intensity and volume of OPA. Direct field observation of occupational lifting showed an excellent interrater reliability.

Keywords: Hypertension; Work environment; physical activity paradox, technical measurements; manual work

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What's Important About This Paper?

High occupational physical activity (OPA), including occupational lifting (OL), increases the risk of cardiovascular disease (CVD). To understand the mechanism of this association, this study investigated associations between OL and ambulatory blood pressure (ABP) as well as relative aerobic workload (RAW) and physical activity (PA) among 60 blue-collar workers in Denmark with technical measurements of outcome and direct observation of exposure. OL significantly raised the intensity and volume of the OPA, but was not associated with statistically significant increases in ABP.

Introduction

Occupational physical activity (OPA), including occupational lifting (OL), is believed to increase the risk of cardiovascular disease (CVD) in contrast to leisure time physical activity, called "the physical activity paradox"(Clays *et al.*, 2012; Petersen *et al.*, 2012; Holtermann *et al.*, 2018; Korshøj *et al.*, 2015; Cillekens *et al.*, 2022; Feinberg *et al.*, 2022). CVD is the leading cause of death worldwide (Roth *et al.*, 2018), thus, it is of uttermost importance to identify and characterize potential occupational risk factors for CVD. Yet, the background for the relation between OPA and adverse CVD outcomes is not fully understood, and it seems that harmful effects depend on the type and level of OPA, as well as i.e. sex and socioeconomic background (Petersen *et al.*, 2012; Dalene *et al.*, 2021; Li *et al.*, 2021). Also, the majority of the studies investigating the associations between physical activity (PA) and CVD are limited by self-reported exposure estimates (Dalene *et al.*, 2021; Li *et al.*, 2021; Quinn, Yorio, *et al.*, 2021), increasing the risk of reporting bias (Korshøj *et al.*, 2020), thus, more valid,technical measures and observationsshould be preferred (Koch *et al.*, 2016; Cillekens *et al.*, 2022). Six proposed hypotheses for "the physical activity paradox" have been posed (Holtermann *et al.*, 2018), two of them stating hypothesis of harmful effects of OL, being elevated 24-hour blood pressure (BP) and heart rate (HR) following OL (Clays *et al.*, 2012; Korshøj *et al.*, 2015; Holtermann *et al.*, 2021; Korshøj *et al.*, 2020), and insufficient recovery. However to investigate the association of OL, BP and HR, reliable measures of OL are needed.

Heavy lifting per se entails acute elevation in BP and HR, due to vasoconstriction resulting in increased peripheral circuit resistance (MacDougall *et al.*, 1985; Sukhova *et al.*, 1999). In the long term, this causes rises in ambulatory blood pressure (ABP) (Clays *et al.*, 2012), which may increase the risk of inflammation inside the vessels and therefore risk for hypertension (Glagov *et al.*, 1988; Chobanian *et al.*, 2003). High ABP and hypertension are the leading risk factors for several CVDs including stroke, coronary artery disease and atrial fibrillation (Hardy *et al.*, 2015; Campbell and White 2017), and likewise resting HR is an independent predictor of CVD morbidity or fatal events (Zhang *et al.*, 2016).

Interestingly, weight lifting for recreational purposes is not related to an increased CVD risk or mortality (Williams *et al.*, 2007; Cornelissen *et al.*, 2011). OL, on the other hand, often exhibits a high frequency and duration, inhibiting sufficient restitution which can easier be obtained in a leisure context. Mainly blue-collar workers report exposure to OL (Sixth European Working Condition Survey 2015; Arbejde og Helbred 2018) and may be exposed to OL throughout the majority of their work time. Thus, it is hypothesized that the lack of restitution between bouts of OPA including OL, increases ABP, which may explain some of the contrasting effects of lifting on the risk of CVD (Cornelissen *et al.*, 2011; Clays *et al.*, 2012; Holtermann *et al.*, 2018; Quinn, Kline, et al., 2021; Cillekens *et al.*, 2022).

To disentangle parts of the mechanisms behind the raised 24-hour ABP proposed by exposure to OL, this study aimed to explore the acute differences in ABP, relative aerobic workload (RAW) and OPA with and without OL among 60 blue-collar workers in Denmark, and secondary to estimate the interrater reliability of observed burden and frequency of lifts.

Materials and methods

Study design

This controlled cross-over study was set from December 2019 to May 2022 among 60 blue-collar workers, and two separate 24-hour measurements of ABP, HR and PA were collected on a workday including OL and a workday without OL respectively, separated by a washout-period of minimally 48 hours (Mach *et al.*, 2005). Field observations were performed during a whole workday for each participant while performing his or her ordinary work tasks including OL.

Participants and recruitment

Due to the COVID-19 pandemic, the data collection was performed in two rounds. The first round of recruitment was carried out in 2018 with help from a Danish consultancy agency for farming, VKST (www.VKST.dk), which contacted pig farmers in the region of Zealand and presented the overall aim of the project.

Interested pig farmers and their relevant staff were invited to an information meeting and baseline measurements. Measurements were performed on this group from December 2019 to march 2020. The second round of recruitment was carried out from September 2021 until April 2022, by a researcher contacting a wide range of companies with employed blue-collar workers with possible lifting tasks in the region of Zealand in Denmark. Measurements were performed on the second group from September 2021 to May 2022.

Inclusion and exclusion criteria

Participant inclusion criteria included being aged 18–65 years and full-time employed (≥26 hours/week). Workers were excluded by pregnancy, allergy to bandages, use of a pacemaker, physical impairments such as shoulder disorders, medical treatment for hypertension, and CVD of any kind. The exclusion of participants with recognized CVD was based on the intention of this study to investigate the basic physiological mechanisms on healthy adults without bias from the use of medicine or diagnosis.

Ethical consideration

The study protocol was reviewed and approved by the Independent Ethics Committee (IEC) in Region Zealand (Journal number SJ-792) and the data protection authorities (REG-082-2019). Participation followed the Helsinki declaration (General Assembly of the World Medical, 2014) and no payment or remuneration was given. The participants were informed of the aim, methods, and implications of the study before signing informed consent. Participation involved no risk other than the possible discomfort of wearing the devices. However, participants showing an office BP of ≥160 systolic and/or ≥100 mmHg diastolic BP were advised to seek their general physician and further monitoring was cancelled.

Data collection

Data included baseline measurements followed by 2x24-hours technical measurement of ABP, HR and PA. Participants were measured continually for 24 hours and to fill in a paper diary stating the time at work, the time in bed and the time of any periods spent without monitors. Based on the diary, the 24 hours of measurements were divided into time domains of work, leisure and bedtime for each participant for each measuring day. The order of the two measuring days (with/without OL) was alone determined by the employers.

Assessment of exposure

Exposure to OL was registered by direct manual observation in a scheme (supplementary file S1) by one of the three researchers during the participant´s working hours on the workday including OL. The researcher bringing a scale along and whenever possible weighing every single lifted object. When not able to weigh the objects, the researcher would estimate the weight of the lifted object in consultation with the participant; all of the participants were skilled in handling exactly those objects with only little variation in their respective job functions, which made them experts in the handled objects. All lifts ≥0.05 kg, no matter the distance or time the object was handled, were registered–as long as the object was raised from the floor or any other surface by the participant. Shared lifts, where a participant would lift together with a colleague, were registered as one lift and the total burden of the lifted object would be reduced by 50%. Pulling or pushing an object, even a heavy one for example a pig, would not count as a lift. When off work, the participant would go home continuing the diurnal measurements but with no further observation of lifted objects, since any lifted objects, the rest of the day wouldn't categorize as OL. Based on the total registration of lifts it was possible to determine the frequency of lifting and the total burden of OL, besides from the individual weight of all lifted objects, during that workday for each participant. During the workday without OL, the participant would beforehand have received thorough instructions on not to lift any heavy objects during this workday, since the sum of all lifted objects, including minor ones, should not exceed 300 kg during work time that day. The work tasks on days without OL were within the same production line as those on the OL day, however tasks included use of assistive devices or a colleague performing the OL. The researchers observing did not receive any formal training in how to observe OL, since the occupational areas were so diverse and the companies recruited by fly and with short notice. But the procedure was discussed and agreed on internally among the researchers before every part of the field work, as well as ongoing interrater reliability tests in field were carried out initially for every new job function with OL.

Assessment of outcome

The primary outcome was ABP, which is known to have a higher prognostic value than office BP, as ABP can reveal day-variation and the hemodynamic response to stressors (Hansen *et al.*, 2007; Aung and Htay 2019). Thus, it is important to use 24-hours measures of BP in order to capture the cumulative repeated exposures of the cardiovascular system to hemodynamic forces when exposed to OL. ABP was measured by oscillometry as prescribed by the European Society of Hypertension (Stergiou *et al.*, 2018) using Spacelabs 90217 (Spacelabs Healthcare, Washington, U.S.A, www.spacelabshealthcare.com), a valid portable monitor worn at the waist with a tube connected to a cuff around the left upper-arm (Baumgart and Kamp 1998).

The Spacelabs monitor was initialized with the Spacelabs Healthcare 2017 software (Sentinel v10.5.0.8939) to record the participant´s ABP automatically every 20 minutes during the 24 hours. During measurement, the participants were instructed in keeping still and to stop talking. Failed measurements were automatically followed by a single new attempt of measurement after three minutes. Moreover, the participants were instructed on how to handle and remove the Spacelabs monitor during bathing.

HR was measured as a secondary outcome with an Actiheart monitor (CamNtech, Cambridgeshire, UK, www.camntech.com) mounted with Ag/AgCl pre-gelled electrodes (Ambu blue sensor VL-00-S/25, Ambu A/S, Ballerup, Denmark) at the validated position at the apex of the sternum with the wire horizontal to the left lateral intercostal (Brage *et al.*, 2005). Actiheart measures the raw electrocardiographic signals continuously with a sensitivity of 0.25 mV and calculates the HR from the R peaks in the QRS complex of the electrocardiogram. Actihearts were initialized and data was downloaded using the Actiheart Software (version 4.0.116). HR data were filtered and physiological outliers (< 30 and > 220 beats/min) were excluded (McArdle *et al.*, 2010). Only HR measurements of more than 4 hours of duration within the separate time domains of work, leisure and bedtime and with < 50% beat error were included in the statistical analysis (Skotte *et al.*, 2014; Gupta *et al.*, 2015). HR reserve (HRR) was defined as the difference between the estimated 24-hours maximal HR (HRmax), defined by the Tanaka equation (Tanaka *et al.*, 2001) and minimum HR (HRmin), defined as the tenth lowest recorded HR value during bed-time (Brage *et al.*, 2004), ($HRR = HRmax - HRmin$) (Karvonen *et al.*, 1957). RAW in percentage of heart rate reserve (%HRR), was calculated as $RAW = \frac{HRmean\ during\ work\ -\ HRmin}{HRR} \times 100\%$. RAW is well documented to provide a measure of the physiological cardiorespiratory strain on the body depending on the work demands and cardiorespiratory fitness of the participant (Ilmarinen 2001) and is on a group level comparable to % oxygen consumption (Astrand and Rodahl 1986). Also, RAW in %HRR correlates highly with % oxygen reserve, at the same time being both easier and cheaper collectable, and is therefore, the preferred measure for RAW and thus the intensity of the PA performed (Wu and Wang 2002).

The additional outcome of PA was technically measured by Axivity (Axivity, Newcastle, UK, www.axivity.com); a triaxial accelerometer taped directly on the skin using double-sided adhesive tape (3M, Hair-Set, St. Paul, Minnesota, USA) and a waterproof film (OpSite Flexifix, Smith & Nephew, London, England). One accelerometer was placed at 1) the upper part of the back at T1-T2 level, below processus spinosus, and another accelerometer was placed at 2) the front of the right thigh midway between the patella and crista illaca. Axivity was initialized and data was using Axivity Software Open movement version V1.0.0.30. Axivity recordings were only included in the statistical analyses if the specific time domain had a duration of at least 4 hours per day (Gupta *et al.*, 2015). All further data analyses and time synchronization were performed in the validated custom-made Acti4 software (Skotte *et al.*, 2014), which derives the duration and frequency of lying, sitting, standing (body posture) as well as stair climbing, running, biking and walking (i.e. PA) (Stemland *et al.*, 2015).

Assessment of covariates

Baseline measurements, collected initially to the diurnal measures, included a structured interview on medical history, lifestyle and working conditions as well as measurements of anthropometrics. Resting systolic and diastolic BP and resting HR were measured on the left arm three consecutive times after 10 min of sitting (Omron Healthcare). During measuring, the participant was asked to relax, not to speak and to sit upright. The lowest measured BP was registered as the office BP. Body mass index (BMI) was calculated using the equation $BMI = \frac{bodyweigt\ (kg)}{body\ height\ (m^2)}$ (Canoy 2008). Body mass (kg) and fat percentage (%) were measured by a bioimpedance (BC545N, TANITA). Body height (m) was measured shoeless on a mobile stadiometer (Seca 213).

Statistical analyses

The primary null hypothesis was that OL does not affect ABP during work. Secondly, we hypothesized that RAW and PA during work were not affected by OL. Additional analyses of ABP, RAW and PA during leisure and sleep were made, as well as 24-hour-effect on ABP.

A power calculation showed that an expected increase in systolic ABP during work of 4 mmHg (Siegelova and Fiser 2008) would take 50 participants each of the two measurement days to show significance at a level of 0.05%.

All statistical analyses were performed in SAS statistical software for Windows (version 9.4) (SAS Institute, Cary, NS, US). Descriptive data were reported by mean and standard deviation (SD). The difference in ABP, RAW and PA, during days with and without OL was estimated by the use of repeated measures 2x2 linear mixed-models analysis. Classification of the day (with/without OL) was the fixed factor and each participant was inserted as random effect in the model. Statistical estimates of mean differences, standard error (SE) of the mean, and 95% confidence intervals (CI) during days with and without OL were reported in unadjusted models, spilt by time domain. Moreover, keeping the cross-over design in mind, and the assumption that none of the confounding factors would change between the diurnal measurements, no adjustment to the statistical models was made. To quantify the magnitude of associations between the burden of OL (kg) and ABP and RAW during work, these associations were investigated in unadjusted linear regressions.

Interrater reliability tests were performed on 15 participants representing 7 occupational areas. Two observers at the same place would observe one participant at the time. The interrater reliability measuring burden (kg) and frequency (number of lifts) was analyzed by i) the percent agreement, calculated by division of the two raters observations of total lifted burden (kg) and total frequency of lifting, and ii) the intraclass correlation coefficient (ICC), estimated in SPSS version 28.0.0.0, in a two way mixed model, indicating the raters as fixed effects (k=2), and with absolute agreement type to estimate the differences between the raters (Karstad *et al.*, 2018). The observations from two raters were compared within the same time window.

Results

Flow of participants and data

Contact was established with 16 pig farms and 69 companies in the region of Zealand, Denmark. Four farms and nine companies agreed to offer participation, and an information meeting was set up within each company. Each company supplied between two to six participants. Many of the companies which did not participate expressed practical or ethical difficulties in receiving the researchers or in planning OL-free workdays for their employees. A total of 60 participants completed baseline measurements and questionnaires, representing 10 different occupational areas, being pig farming, carpentry, landscape gardening, cake factory, juice factory, paint store, laundry, warehouse, hospital kitchen and hospital depository. Seven participants were excluded due to health issues, withdrawn consent, lack of contact or layoff; resulting in 53 participants completing baseline measurements and diurnal measurements (Figure 1).

Unfortunately, the 50 complete datasets, estimated in the power calculations were not reached in all time domains, due to technical errors in the equipment, user errors when setting up the equipment or lack of compliance or imprecise measurements. For instance, Axivity had difficulties in categorizing the participant's movements at times, which occasionally gave us imprecise measurements and periods of invalid data. Also, walking/moving while Spacelabs was measuring would cause missing ABP-recordings. The technical errors consisted of for example poor electrode contact of the Actiheart monitor to the participant's skin (e.g. because of sweating), unreliable battery or intern flaws on some devices, giving fewer and inconsistent data. Also, many participants unconsciously and repeatedly touched the Actiheart-wire outside their clothes resulting in this losing contact with the electrodes on the skin. In some cases, the participants even removed their device, most often their ABP-monitor at night. Since the ABP was measured automatically every 20th minutes and the humming sound couldn´t be turned off, some experienced discomfort during sleep. Hence, only 42–52 complete measurements in each time domain. I.e. work-, leisure- and bed-time, were included in the statistical analyses in each category instead of 53 (Figure 1).

Characteristics of the study population

Although only workers without known hypertension were included, only 71.7% were normotensive at baseline (office BP), defined as <140/<90 mmHg; here one must keep in mind that white coat hypertension can account for up to 30–40% of patients with elevated office BP (Williams *et al.*, 2019). Almost all of the participants had a 5-day working week of 37 hours, and all of them working solely day hours (figure 1).

Analyses of outcome

Slightly larger ABP was seen on OL days compared to non-OL days (Δ = ABP during day with OL − ABP during day without OL); during work (systolic Δ1.79 mmHg, 95%CI −4.49 to 8.08, diastolic Δ0.43 mmHg, 95%CI −0.80 to 1.65) and leisure (systolic Δ1.12 mmHg, 95%CI −5.08 to 7.31) (Table 1). Also, 24-hour ABP was larger on OL days (systolic Δ1.96 mmHg, 95%CI −3.80 to 7.72, diastolic Δ0.53 mmHg, 95%CI −3.12 to 4.18). During leisure time the mean diastolic ABP however, was larger for non-OL days (diastolic Δ-0.38 mmHg, 95%CI −4.12 to 3.36) and the same applied for bed-time ABP (systolic Δ −1.80 mmHg, 95%CI −7.28 to 3.67, diastolic Δ −0.68 mmHg, 95%CI −4.62 to 3.27). However, none of the ABP-results reached statistical significance.

Observations showed that the average total burden of the OL was 3853.8 kg per workday (SD 2535.2 kg), and the mean number of lifts during a workday was 1404.1 lifts (SD 1945.4), both illustrating a considerable variation between the participants regarding both total burden of OL, frequency of lifting and average burden per lifted items (Table 2). When analyzing the linear association between ABP, during work at the day with OL, and the total burden of OL, we found a nonsignificant positive association (systolic β 0.001

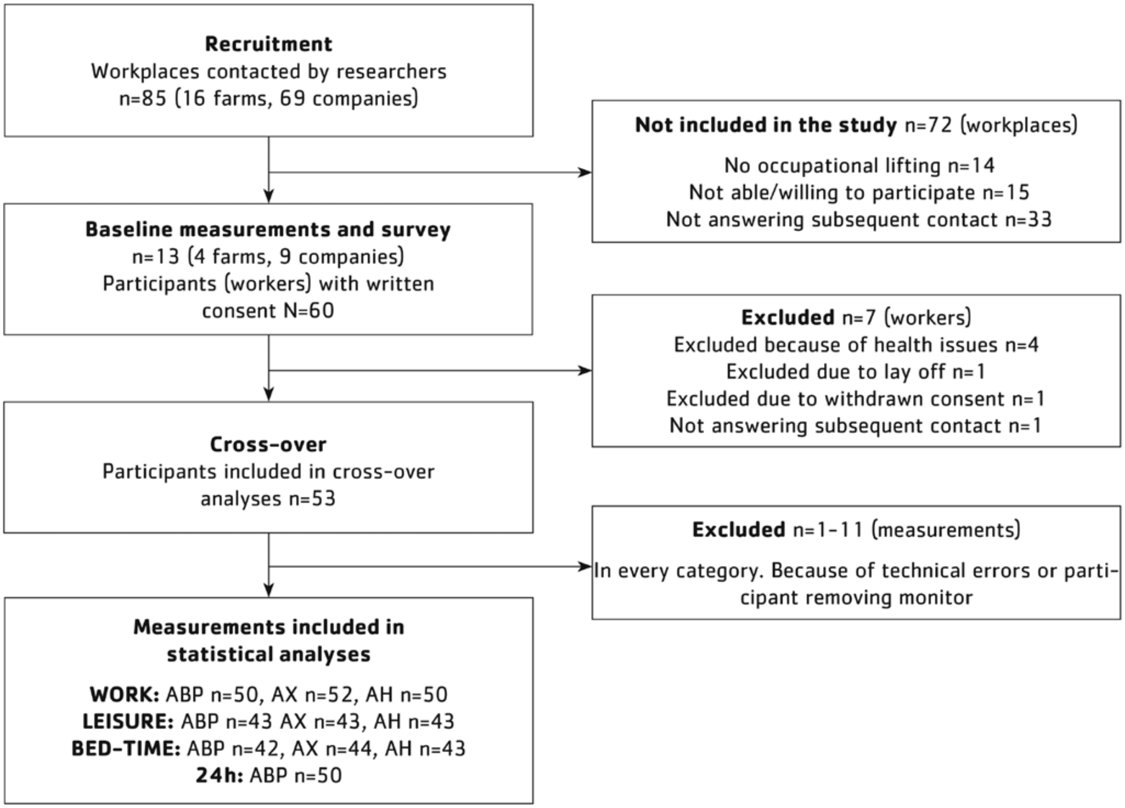

Figure 1. Flow chart of the study population. ABP ambulatory blood pressure, AX Axivity, AH Actiheart.

Table 1. Ambulatory blood pressure (ABP). Group means and differences between days with and without occupational lifting.

	+LIFT Mean	-LIFT Mean	Δ	SE	95% CI
Work					
Systolic ABP (mmHg) *n* = 50	132.47	130.68	1.79	3.16	–4.49 to 8.08
Diastolic ABP (mmHg) *n* = 50	84.59	84.16	0.43	0.63	–0.80 to 1.65
Leisure					
Systolic ABP (mmHg) *n* = 43	128.00	126.89	1.12	3.11	–5.08 to 7.31
Diastolic ABP (mmHg) *n* = 43	78.84	79.22	–0.38	1.88	–4.12 to 3.36
Bed-time					
Systolic ABP (mmHg) *n* = 42	106.65	108.46	–1.80	2.75	–7.28 to 3.67
Diastolic ABP (mmHg) *n* = 42	62.42	63.10	–0.68	1.98	–4.62 to 3.27
24 h					
Systolic ABP (mmHg) *n* = 50	124.38	122.43	1.96	2.90	–3.80 to 7.72
Diastolic ABP (mmHg) *n* = 50	76.55	76.02	0.53	1.84	–3.12 to 4.18

+*LIFT* diurnal measurement on a workday with occupational lifting, –*LIFT* diurnal measurement on a workday without occupational lifting *ABP* ambulatory blood pressure, *Δ* delta (+*LIFT minus -LIFT)*, *SE* standard error, *95% CI* 95% confidence interval

Table 2. Descriptive information of the study population, N=60.

Category	Mean	SD	%[n]
Age (years)	40.8	13.44	
Sex (% female)			45% [27]
BMI (kg/m²)	25.4	5.86	
BMI ≥ 30 kg/m²			16.7% [10]
Fat%	26.5	9.34	
Smoking (%daily/regularly)			30.5% [18]
Office systolic blood pressure (mmHg)	130.4	16.3	
Office diastolic blood pressure (mmHg)	81.7	11.1	
Hypertensive at health check (>140/90 mmHg)			28.3% [17]
Resting heart rate at health check (bpm)	75.0	12.7	
Born outside Denmark			23.7% [14]
Education (% that had a medium length secondary education, i.e. ≥3 years of secondary education)			45.6% [26]
Job seniority in current occupation (years)	13.3	12.7	
Self-rated health (%good or above)			37.3% [22]
Self-rated fitness (%above average)			30.6% [18]
Self-reported occupational physical activity			
Mostly standing and walking			11.9% [7]
Mostly standing and walking with occupational lifting			72.9% [43]
Pushing and pulling during work (% ≥50% of working hours)			23.7% [14]
Carrying and lifting during work (% ≥50% of working hours)			49.2% [29]
Arms raised during work (≥50% of working hours)			55.9% [33]
Bended/twisted back during work (≥50% of working hours)			15.3% [9]
Self-reported most frequent lifting burden at work			
<3 kg			23.7% [14]
3–10 kg			33.9% [20]
11–29 kg			35.4% [15]
30–49 kg			13.6% [8]
≥50 kg			3.4% [2]
Leisure time physical activity			
Inactive, light physical activity <2 hours/week			8.5% [5]
Light physical activity 2-4 hours/week			16.9% [10]
Light physical activity >4 hours/week or moderate physical activity 2-4 hours/week			61.0% [36]
Moderate to vigorous physical activity >4 hours/week			13.6% [8]
Occupational lifting (by observation on days with OL)			
Total burden of lifted objects, during days with OL (kg)	3853.8	2535.2	
Total number of lifts, during days with OL	1404.1	1945.4	
Average burden per lifted items, during days with OL (kg)	9.39	8.97	
Interrater reliability test			
Number of participants included in IR test (percentage of participants included in analysis)			15 (29%)
Number of companies where IR test were carried out (percentage of companies represented)			7 (70%)
Duration of IR test observation (min)	18.67	13.00	
Total burden lifted while performing IR test	294.43	224.66	
Total frequency of lifts while performing the IR test	142.33	150.10	
Agreement in total burden lifted (%)	97.93	13.28	
Difference in total lifted burden (kg)	11.78	13.53	
Difference in frequency of lifts (%)	88.07	49.55	
Difference in frequency of lifts (number of lifts)	12.13	20.28	

BMI Body Mass Index; *bpm* beats per minute.

mmHg/kg, 95%CI −0.001 to 0.003, diastolic β 0.001 mmHg/kg, 95%CI −0.0004 to 0.002) (Figure 2). A positive, but also nonsignificant, association between the burden of OL and RAW during work-time with OL likewise indicated that every extra kg lifted increased RAW by 0.001 %HRR (β 0.001 %HRR/kg, 95% CI −0.0003 to 0.003). ICC estimates and their 95%CI were 0.998 (95%CI 0.995 to 0.999) for total burden lifted and 0.992 (95%CI 0.975 to 0.997) for frequency of lift.

Exposure to OL significantly increased RAW during work time (Δ7.74 %HRR, 95%CI 3.75 to 11.91) (Table 3) which reflects an increased intensity of OPA. During leisure- and bedtime, nonsignificant positive differences were seen for RAW (leisure Δ0.77 %HRR, %95CI −2.28 to 3.81, bed-time Δ0.15 %HRR, 95%CI −1.82 to 2.12) (Table 3).

OL significantly increased the volume of OPA (Table 3) in terms of less work time spent sitting and standing and more work time spent walking than during non-OL days (Δ4156.88 steps, 95%CI 1898.83–6414.93, Δ-0.67 hours of sitting time, 95%CI −1.25 to −0.10, Δ-0.52 hours of standing time, 95%CI −1.03 to −0.01, Δ0.48 hours of walking time, 95%CI 0.18 to 0.78). During leisure, only minor differences in the volume of PA were seen with for example more steps following non-OL-days (Δ-455.83 steps, 95%CI −1498.25 to 586.59). During bedtime, OL non-significantly increased the time spent lying (Δ-0.43 hours lying, 95%CI −0.17 to 1.02).

Interrater reliabilty test

During observation it was possible to follow the participants through all their job tasks, as well as to follow each company´s guidelines; such as wearing uniform, warm clothes, performing handwash frequently, safety shoes. Observing and registering all lifts manually on paper turned out to be feasible, but demanding at times, e.g., when the participants were lifting quickly and repeatedly. When the observer had to go to the restroom or take a break, the participant paused the OL meanwhile. As the participants from the same company performed similar OL, a good representation of the OL would be assumed to be covered by the IR test (Table 2).

The analysis of the % agreement between the raters observations of OL burden showed a high agreement (97.93% SD 13.28), also supported by the SD of the rather low differences in the observed OL burden being 13.53 kg (Table 2). Also a high agreement in frequency of OL (88.07%, SD 49.55) was seen and supported by the low mean level of difference in frequency of OL (12.13 lifts, SD 20.28); although the SD points towards some variation of the mean of frequency of OL (Table 2).

The high agreement between the raters is also shown by the ICC estimates of 0.998 (95%CI 0.995 to 0.999) for total burden of OL and 0.992 (95%CI 0.975 to 0.997) for OL frequency (Table 4).

Discussion

Main findings

This cross-over study found significantly increased RAW and volume of OPA as well as nonsignificantly raised ABP during work time and on 24-hours basis, on days including OL (Table 1, 3).

Overall we found it feasible to observe the participants and to manually record their individual OL in matter of frequency and burden per item. The ICC estimates indicated an excellent agreement (Koo and Li 2016) between the raters´ observation of total burden lifted and frequency of lifts, underpining the overall interpretation of the feasibility of recording OL by observation as good.

Previously, associations between OL, ABP, HR and volume of OPA have, to the best of our knowledge, not been assessed in parallel with direct observation of the burden of OL. Yet, three previous studies have investigated associations between OL and BP; Clays and colleagues (2012) found that self-reported exposure to high vs. low OL significantly increased ABP. Korshøj and colleagues (2020) found that self-reported exposure to OL increased BP among workers aged ≥50 years and especially among workers using an anti-hypertensive medication, and another study by Korshøj and colleagues (2021) found that self-reported exposure to OL seemed to increase the risk for hypertension, but showed no effect of OL on BP. Thus, the few previous studies on associations between OL and BP indicate that OL hazardously affects BP and thereby risk for CVD, which is in line with the results from this study.

The reported magnitude of difference in RAW, between OL-days and non-OL-days, is clinically significant since it has earlier been shown that each 10% increase in RAW increases the risk of acute myocardial infarction among men by 18% (Krause *et al.*, 2015).

Consideration of possible mechanisms and explanations

Increases in BP during lifting are explained by the constriction of vessels due to contracting muscle fibres surrounding them, the elevated HR, and the pressor reflex, decreasing the diameter in the peripheral resistance arteries, which in turn increases peripheral circuit resistance and BP (MacDougall *et al.*, 1985; Sukhova *et al.*, 1999). In addition, HR will rise during lifting due to the increased activation of muscle fibres needing

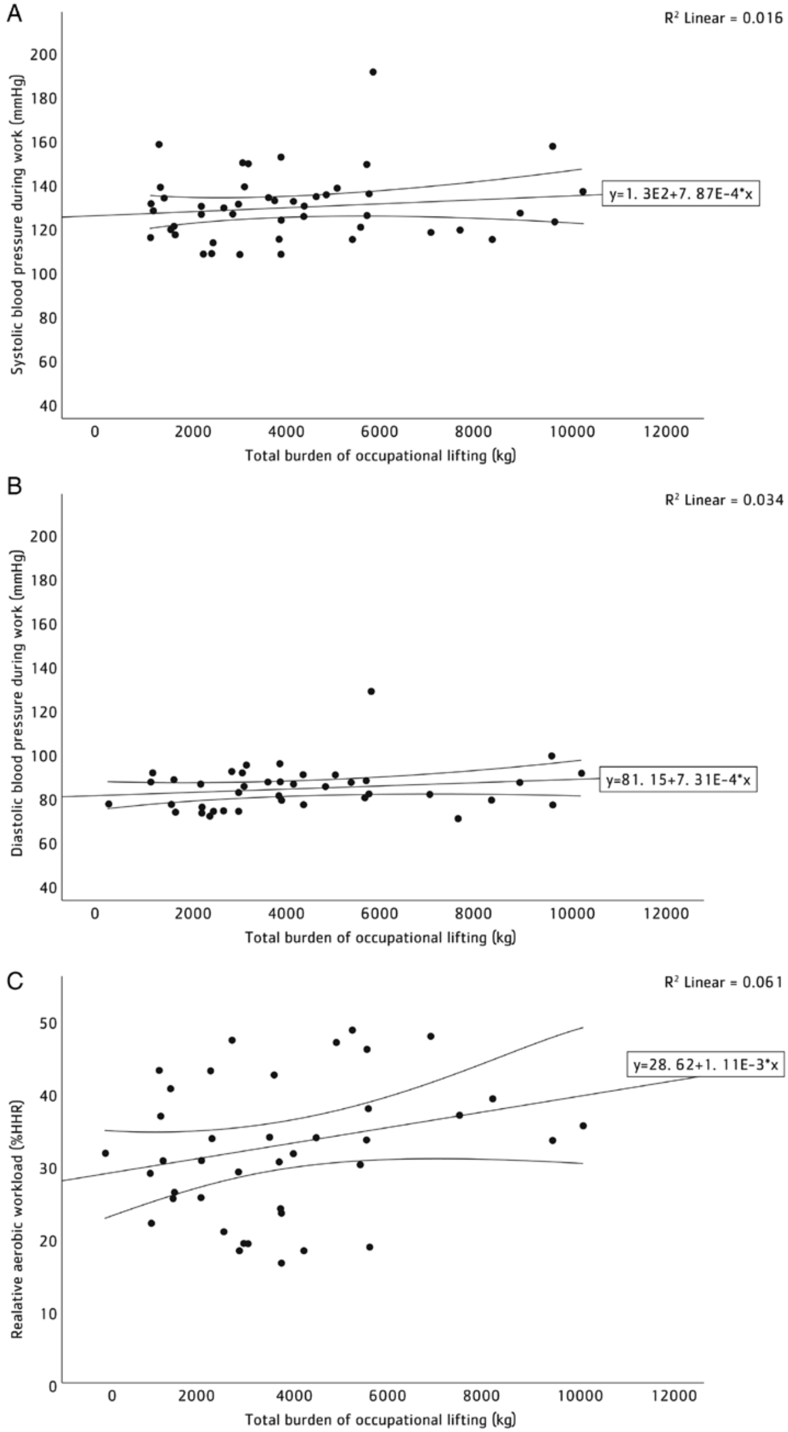

Figure 2. Associations, all statistically non-significant, between the total burden of occupational lifting and A. systolic ambulatory blood pressure during work, B. ambulatory diastolic blood pressure during work, and C. relative aerobic workload during work. *%HRR* percentage of heart rate reserve.

Table 3. Relative aerobic workload and accelerometer parameters stratified in days with and without occupational lifting. Mean during days with and without occupational lifting, differences between days, standard error and 95% confidence intervals.

	+LIFT Mean	–LIFT Mean	Δ	SE	95% CI
Work					
RAW (%HRR), *n* = 50	33.22	25.48	7.74	2.10	3.57 to 11.91
Sitting time (hours/workday), *n* = 52	1.40	2.08	-0.67	0.29	–1.25 to –0.10
Standing time (hours/workday), *n* = 52	2.56	3.07	–0.52	0.26	–1.03 to –0.01
Walking time (hours/workday), *n* = 52	1.71	1.23	0.48	0.15	0.18 to 0.78
Steps, *n* = 52	12894.49	8737.61	4156.88	1137.10	1898.83 to 6414.93
Leisure					
RAW (%HRR), *n* = 43	21.47	20.71	0.77	1.53	–2.28 to 3.81
Sitting time (hours in leisure), *n* = 43	3.61	3.68	–0.07	0.33	–0.72 to 0.59
Standing time (hours in leisure), *n* = 43	0.95	1.05	–0.11	0.13	–0.36 to 0.15
Walking time (hours in leisure), *n* = 43	0.43	0.49	–0.06	0.08	–0.22 to 0.09
Lying time (hours in leisure), *n* = 43	0.87	0.86	0.01	0.26	–0.51 to 0.53
Steps *n* = 43	2958.57	3414.40	–455.83	523.83	–1498.25 to 586.59
Bed-time					
RAW (%HRR), n=43	12.78	12.63	0.15	0.99	–1.82 to 2.12
Lying time (hours in bed), *n* = 44	7.50	7.07	0.43	0.30	–0.17 to 1.02

+LIFT diurnal measurement on a workday with occupational lifting, *–LIFT* diurnal measurement on a workday without occupational lifting *RAW* relative aerobic workload *%HRR* percentage of heart rate reserve, *Δ* delta (+LIFT minus –LIFT), *SE* standard error, *95% CI* 95% confidence interval.

Table 4. Interrater reliability test estimates and their and their 95%confidence intervals.

	ICC	95% confidence interval	*P* value
Total burden lifted	0.998	0.995–0.999	<0.001
Frequency of lifts	0.992	0.975–0.997	<0.001

more oxygen as a higher amount of the muscle is activated. The finding of a likewise, but minor, increase in RAW during leisure- and bedtime, though not statistically significant, points towards not only an acute effect from OL on the cardiovascular system but also a subacute one, or a so-called spill-over effect from work. Thus, because some workers perform OL for several hours per day, many days per week, sufficient restitution between the bouts of cardiovascular strain might be difficult to achieve (Clays *et al.*, 2012; Holtermann *et al.*, 2018). This is in line with a recent study (Quinn *et al.*, 2021), whose results indicated that a full workday of OPA was associated with higher 24-hour HR and diastolic BP. In the long term, an elevated HR and BP will induce shear stress on the arterial wall, increasing the risk of inflammation, hypertension, and eventually CVD (Glagov *et al.*, 1988; Chobanian *et al.*, 2003; Krause *et al.*, 2015; Olsen *et al.*, 2016).

In our study the spectrum of different occupational areas and work tasks was broad, and so was the type of OL. We investigated blue-collar workers from 10 different occupation areas, all of them with their particular patterns of OL, PA and handling goods/animals, i.e. a warehouse worker would typically lift many lighter objects repeatedly and frequently throughout the day, while a carpenter typically would lift fewer objects less uniformly and predictably during the day, but with a significantly bigger weight per unit. Because of the relatively small sample size, it was not possible to stratify the results on occupational area, but one could speculate that the cardiovascular responses to OL could differ depending on the OL pattern.

Strengths and limitations

The major strength of this study is the measurement of technical 24-hours ABP, HR and PA. Measurement of ABP has been shown to provide more reliable and accurate estimates of BP than office measurements, and ABP has the advantage of being able to be split into time domains (Hansen *et al.*, 2007; Stergiou *et al.*, 2018). The assessment of OL by direct observation bypasses previous concerns about reporting bias (Stock *et al.*, 2005; Korshøj *et al.*, 2020). There might, however, exist variations in the estimation of the burden of OL, since the researchers performing the observation were not trained before the observation and the different occupational areas were relatively many with a lot of different lifted objects. However, the most frequent and heavy items were weighed by the researchers in field. ICC estimates indicated an excellent agreement (Koo and Li 2016) between the raters' observation of total burden lifted and frequency of lifts. Also, it should be noticed that the precise burden of OL was not crucial for the findings in this study, as the main exposure was either +OL or −OL. In addition, observations of days without OL would strengthen the certainty of differences in HR and OPA due to OL and not because of differences in work tasks. Furthermore, future studies should consider collecting data on pushing and pulling as well, as these activities are believed to increase blood pressure by the same pathway as OL.

The repeated 24-hour measurements on the same participant ensure a high internal validity of the ABP, HR, and PA and the collection during normal workdays guarantees a high external validity of exposure. We aimed to collect complete measurements on at least 50 participants with comparable work tasks of OL. However, the difficulties in recruiting participants and companies and the economical frame and time available, allowed us to include only 60 participants from many different occupational areas. Several of the participants experienced challenges in wearing the device, especially at night, which led to an exclusion of their measurements during periods of not-worn. On top of this, we faced technical errors on our measuring devices leaving even fewer measurements reliable for analyses. All in all, we managed to meet our power calculations in some of the analyses (during work time and for 24h-ABP), but not all (Figure 1, Tables 1 and 3).

Considering confounders, we did not adjust for diet, due to the cross-over design, where one should only adjust for confounders known to differ between time points of data collection and to acutely affect the ABP. Diet has no immediate effect on BP with the possible exception of salt, caffeine or other stimulants, and in a future study, these factors as well as psychosocial stressors at home/work and quality and length of sleep could be considered a relevant confounder to include. Also, a selection bias should be considered in this study since the inclusion criteria for participants were purposely restrictive in order to establish frontline evidence. This makes the study prone to healthy worker bias which could have diluted the results somehow (Cillekens *et al.*, 2022).

We cannot securely reject an observational bias as it is possible that the fact that the participants being aware of the observation, could influence the participants OL performance

Impact of results

These results may contribute to the overall apprehension of the link and the underlying physiological mechanisms between high OPA and CVD. OL may infer an impact on worker health since approximately 31% of the Danish workforce and 32% of the European workers report exposure to OL regularly (≥25% of their working hours) (Sixth European Working Condition Survey 2015; Arbejde og Helbred 2018). Hence, investigating these associations could reveal a potential for the prevention of cardiovascular damage and in the long run CVD among almost one-third of the Danish workforce by contributing to the groundwork of evidence for future recommendations and rehabilitation of elevated BP concerning OL.

So far, no precautionary principles exist regarding OL concerning cardiovascular health, as seen in sports (Williams *et al.*, 2007). In modern society, it is of uttermost importance to prevent and rehabilitate to uphold labour capacity in an ageing workforce facing the increasing prevalence of CVD in a still workable age (Koch *et al.*, 2016).

Concluding Remarks

The results of this study indicate that moderate to high OL increase OPA intensity, by significantly increasing RAW during working hours, and non-significantly increasing ABP during working hours and 24 hours, to a magnitude clinically relevant at population level and thus potentially contributing to the risk of CVD. The volume of PA was significantly higher during work with OL than without. Direct observation of OL turned out to be feasible and the interrater reliability test showed an excellent interrater reliability of total burden lifted and frequency of lifts.

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Conflict of interest declaration

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Data Availability

Data is available upon reasonable request to Mette Korshøj alongside approval by the regional data-protection agency of Region Zealand, Denmark. Other materials are available upon request to Mette Korshøj.´

Supplementary Data

Supplementary data are available at *Annals of Work Exposures and Health* online.

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