

1 **Occupational and leisure-time physical activity and workload among**  
2 **construction workers - A Randomized Control Study**

3 Gram B<sup>1</sup>, Westgate K<sup>2</sup>, Karstad K<sup>3</sup>, Holtermann A<sup>3</sup>, Sjøgaard K<sup>4</sup>, Brage S<sup>2</sup>, Sjøgaard G<sup>4</sup>  
4

5 1 Institute of Regional Health Research/Centre Southwest Jutland, University of Southern Denmark, Denmark.

6 2 Medical Research Council Epidemiology Unit, Institute of Metabolic Science, Cambridge, England, UK

7 3National Research Centre for the Working Environment, Copenhagen, Denmark.

8 4 Institute of Sports Science and Clinical Biomechanics, University of Southern Denmark, Odense, Denmark.  
9

10  
11  
12  
13 Corresponding author:

14 Bibi Gram,

15 Institute of Regional Health Research/Centre Southwest Jutland, University of Southern Denmark

16 Telephone number: +45 30 66 36 90

17 E-mail1: bgram@health.sdu.dk

18 E-mail2: Bibi.Valgerdur.Gram@rsyd.dk  
19

20

## Occupational and leisure-time physical activity and workload among construction workers – A Randomized Control Study

### Abstract

**Background:** There is a lack of quantification of occupational physical activity (OPA) and leisure time physical-activity (LTPA) among construction workers.

**Objectives:** To describe physical activity energy expenditure (PAEE), physical workload, and the effect of a PA-intervention among construction workers.

**Methods:** Sixty-seven Construction workers self-reported their PA, had PA assessed directly (PAEE), and observed OPA using the tool 'Posture, Activity, Tolls and Handling'. The PA-intervention (PA;n=29,Controls;n=24) included 3x20-min training/week for 12 weeks.

**Results:** Baseline median OPA was 5036 MET-min/week and LTPA 2842 MET-min/week,  $p < 0.01$ . OPA directly recorded was (mean  $\pm$ SE):  $56.6 \pm 3.2$  J/kg/min and LTPA was:  $35.7 \pm 2.2$  J/kg/min ( $p < 0.001$ ). Manual material handling was performed for  $\geq 25\%$  of working time by more than 50% of the participants. Post intervention, the training group reduced overall PAEE compared to the control group but not specifically during work.

**Conclusions:** OPA was within the maximum recommended level of 1/3 proposed in consensus guidelines but did not decrease with PA-intervention.

**Key words:** Workplace physical activity program, Physical Fitness, Occupational Health

## Occupational and leisure-time physical activity and workload among construction workers – A Randomized Control Study

### Abstract

Background: There is a lack of quantification of occupational physical activity (OPA) and leisure time physical-activity (LTPA) among construction workers.

Objectives: To describe physical activity energy expenditure (PAEE), physical workload, and the effect of a PA-intervention among construction workers.

Methods: Sixty-seven Construction workers self-reported their PA, had PA assessed directly (PAEE), and observed OPA using the tool 'Posture, Activity, Tolls and Handling'. The PA-intervention (Intervention;n=29, Controls;n=24) included 3x20-min training/week for 12 weeks.

Results: Baseline median OPA was 5036 MET-min/week and LTPA 2842 MET-min/week,  $p<0.01$ . OPA directly recorded was (mean  $\pm$ SE): 56.6 $\pm$ 3.2 J/kg/min and LTPA was: 35.7 $\pm$ 2.2 J/kg/min ( $p<0.001$ ). Manual material handling was performed for  $\geq 25\%$  of working time by more than 50% of the participants. Post intervention, the training group reduced overall PAEE compared to the control group but not specifically during work.

Conclusions: OPA was within the maximum recommended level of 1/3 proposed in consensus guidelines but did not decrease with PA-intervention.

Key words: Workplace physical activity program, Physical Fitness, Occupational Health

**Commented [F1]:** TO THE EDITOR:

We have added an abstract in this document but please note that we additionally have upload the abstract in a specific file

## Introduction

Unlike the health benefits associated with physical activity during leisure-time, high levels of occupational physical activity including mechanical musculoskeletal strain during awkward postures and manual material handling are associated with increased long term sickness absence.<sup>1-3</sup> Therefore, establishing maximum permissible intensity levels, proposed in International Labor Organization consensus guidelines in 1971, is an important step to improve occupational health.<sup>4</sup> Physically demanding jobs can result in negative health and economic related consequences for employees and may also be detrimental for the company and society at large.<sup>5,6</sup>

Physically demanding work may require certain level cardio-respiratory fitness and leisure-time physical activity may be a means of maintaining or improving fitness level.<sup>7</sup> Inactive lifestyles are associated with elevated cardiovascular risk among the general population but evidence suggests that moderate and high levels of leisure-time physical activity may be especially important among employees with moderate and high levels of occupational physical activity compared to employees in sedentary work.<sup>8-11</sup> We have previously shown that Danish construction workers have a significantly lower value of maximum oxygen uptake (VO<sub>2</sub> max) compared to a representative group of employees in Denmark.<sup>12</sup> Since low aerobic capacity implies increased relative load during work, the current study was conceptualized to examine how occupational and leisure physical activity patterns are related to VO<sub>2</sub> max. The aim of this study was to describe physical activity and strain at work and at leisure-time among construction workers. Furthermore, we investigated how an individually tailored physical activity intervention changed the level of physical activity at work and during leisure time. We hypothesized: 1) that high mechanical strain in construction work results in a metabolic load exceeding the permissible intensity levels proposed in consensus guidelines as  $\frac{1}{3}$  of the maximum capacity of the workers and 2) that a work site exercise program to increase fitness will reduce the relative metabolic load during work.

**Commented [F2]:** TO THE EDITOR:  
We have now added a reference for this statement

## **Methods**

This study analysed secondary outcome variables from a randomized controlled trial. The physical activity intervention has been reported elsewhere.<sup>12</sup> In short, the intervention included 12 weeks of a one-hour individually tailored aerobic and strength training session per week for workers in physically strenuous jobs.<sup>12</sup>

Sixty-seven construction workers were recruited from three construction industry workplaces in Denmark. Eligibility criteria required participants to have physically demanding tasks including high peak loads and work more than or equal to 20 hours per week. After baseline measurements, construction workers were stratified by age and individually randomized (1:1) into an intervention or a control group. Participants completed pre and post intervention health exams that included a sub-maximal fitness test and assessment of physical activity.<sup>13</sup> Physical activity was objectively measured and self-reported for seven days pre-randomization and seven days post- intervention. To estimate mechanical strain, a subgroup was randomly selected and observed during work. These observations were completed in conjunction with the post-test. Written informed consent was obtained from all participants before enrollment in the study. The Regional Scientific Ethical Committee for Southern Denmark approved the study protocol (No 20090058) and the study was registered in [www.clinicaltrials.com](http://www.clinicaltrials.com) (number NCT01007669).

### ***Cardio-respiratory fitness:***

Maximal oxygen uptake was estimated from the relationship between sub-maximal workload and heart rate (HR) obtained during an one-point sub-max test on a cycle ergometer (Monark 874E, Monark Exercise AB, Sweden) and using the Astrand nomogram with  $\text{VO}_2\text{max}$  corrected for age.<sup>14</sup> The test started with a load of 80 watt (1.0 kg) and at a cadence of 80 rpm. During the first two minutes, the load was adjusted based on measured HR; if HR was below 120 beats per minute (bpm) during the first two minutes 0.5 kg was added, and further weight was added at three and four minutes to attain a stable HR between 120-170 bpm if necessary. The test was terminated when HR was stable for one minute at the target level.

### ***Direct physical activity assessment:***

Physical activity energy expenditure (PAEE) and physical activity intensity were estimated using a combined heart rate and accelerometry sensor (Actiheart, CamNtech, Papworth, UK), worn for seven days after the pre and post-intervention health exams. The sensor was attached to participant's chest via two ECG electrodes and the individuals were instructed to change the electrodes as needed.<sup>15</sup> The device continuously measured HR and acceleration component along the body's longitudinal axis (ACC) with epoch duration of one minute. HR data were pre-processed using Gaussian Process Regression utilizing a custom-written JAVA program on a MySQL database.<sup>16</sup> An estimation of activity energy expenditure in J/kg/min and proportion of time spent at different intensity levels was obtained using branched equation modeling for combining the ACC with the individually calibrated HR component using HR response parameters from the fitness test.<sup>17, 18</sup> Pre- and post-intervention calibrations were performed using the pre and post fitness tests, respectively. This branched modelling approach has been shown to yield valid estimates of activity energy expenditure during both laboratory and free-living conditions.<sup>18-21</sup> In this study we separately analysed the changes in HR and ACC in the intervention group since the intervention had an effect on maximum oxygen uptake. In other words, the participants in the intervention group demonstrated a lower HR when working on the same absolute power output. Prolonged periods of no movement and non-physiological HR, patterns were inferred as non-wear and those time periods were excluded from physical activity time-series analysis. Analyses of direct activity data was performed in terms of number of hours per participant in a multi-level model. Only participants with a minimum of 48 hours of wear data were included in the statistical analyses. Data were categorized into physical activity intensity categories defined as multiples of individualized resting metabolic rate: fraction of time spent in <1 MET, 1-1.25 MET, 1.25-1.5 MET, 1.5-1.75 MET, 1.75-2.0 MET, 2.0-2.25 MET, 2.25-2.5 MET, 2.5-2.75 MET, 2.75-3.0 MET, 3.0-3.5 MET, 3.5-4.0 MET, 4.0-4.5 MET, 4.5-5.0 MET, 5.0-6.0 MET, 6.0-7.0 MET, 7.0-8.0 MET, 8.0-9.0 MET, 9.0-10 MET, 10.0-11 MET. Additionally three broad MET-categories were defined as "sedentary" (1-1.5 MET), "light" (1.5-3.0 MET), and "moderate-vigorous" (>3.0 MET).<sup>22</sup>

**Commented [F3]:** TO THE EDITOR: Please note that we have added a recent reference which documents the validity of our objective exposure instrument during free-living against isotopic measurements of human energy expenditure.

We also analyzed the HR data and ACC data in raw forms (i.e. not translated to activity energy) to identify if cardiovascular load or movement changed between the intervention and control group.

Non-sleep data were analyzed for the seven days period and summed across different categories: 1) total time awake (7-23), 2) weekdays (Monday-Friday), and 3) weekends (Saturday-Sunday). Additionally, data were summed separately for working hours (Monday-Friday, hours 7-15) and leisure-time (Monday-Friday, hours 15-23 + Saturday-Sunday, hours 7-23). Furthermore, we analyzed data summed 24 hours a day for seven days.

***Self-reported physical activity and occupational workload:***

International Physical Activity Questionnaire (IPAQ)

Participants completed the long form of the International Physical Activity Questionnaire (IPAQ) at the health exams to evaluate four domains of physical activity (occupational, transport, domestic/gardening, and leisure).<sup>23</sup> Transport, domestic/gardening, and leisure physical activities were classified as leisure-time physical activity. For each participant, physical activity was categorized as occupational or leisure-time and converted according to official scoring protocol and guidelines into MET-min/week as outcome measures.<sup>24</sup>

Workload questionnaire

Ten questions from the FINALE questionnaire regarding mechanical workload and perceived exertion were administered when participants were monitored with the HR and ACC sensor.<sup>25</sup> Questions included: 1) Did your work last week involve manual material handling? Response categories were: a) Almost all the time, b) 75% of the time, c) 50% of the time, d) 25% of the time, and e) Seldom or Never. If manual material handling was performed the next question was: 2) How many kg did you handle? Response categories were: a) 5 kg or less, b) 6-10 kg, c) 11-15 kg, d) 16-20 kg, e) 21-25 kg, and f) more than 25 kg. The same questions were repeated with 'material handling' substituted by 'pushing/pulling', 'carrying', and 'lifting', respectively. There was one question on perceived physical exertion: On a scale from 6 to 20 (6 being very easy and 20 being the hardest possible), how did you

perceive your level of exertion last week?<sup>26</sup> Participants were asked whether they worked with the back bent-double, bent or twisted, with one or both arms above shoulder height, and/or in kneeling postures. Lastly, they were asked to what extent their job induced increased respiratory rate. Response categories were a) Almost all the time, b) 75% of the time, c) 50% of the time, d) 25% of the time, and e) Seldom or Never. The question and answer categories can be seen in Table 1.

**Table 1** Questionnaire regarding work postures and cardio-respiratory work load with five reply categories. Only one category had to be chosen for each question.

**Commented [F4]:** TO THE EDITOR:  
A Table has been added to present the questions and answer choices more informative

Did you last week in your job work	Almost all the time	75% of the time	50% of the time	25% of the time	Seldom or never
...with your back bent-double?					
...with your back bent or twisted?					
...with one or both arms above shoulder height?					
...in kneeling postures?					
...with increased respiratory rate?					

**Observation of occupational postures and movement:**

The observational ‘Posture, Activity, Tools and Handling’ (PATH) instrument was used to observe mechanical strain of occupational postures and movement with a subgroup of participants selected randomly at two of the workplaces referred in this study.<sup>27</sup> We observed arm, trunk and leg postures and the amount of walking. Observations were performed at the construction site without advance notice. Registrations were recorded once per minute and participants were observed for periods of five - 43 consecutive minutes. The number of observation periods ranged from one to four per participant, with several PATH behaviors noted within each observation period. The summed number of PATH behaviors ranged from 40 to 120 per participant.

### *Statistical analyses*

Descriptive statistics for direct measures and questionnaire data were calculated as means and standard deviation (SD) or as 25, 50 and 75 percentiles. Differences in physical activity were calculated as means with standard error (SE) and 95% confidence intervals (95% CI). Analyses of physical activity intensity using HR and ACC data were assessed as medians with interquartile range (IQR) at baseline. Measures of physical activity energy expenditure determined from HR and ACC activity data (person-hours) during periods of working- and leisure-time, were performed using ANOVA repeated measures, with random effects on the individual level. Analyses of changes from baseline to post-intervention were performed by analyses of covariance (ANCOVA) with the baseline value as covariate.

In post-hoc analyses, paired t-tests were used to estimate significant differences within groups. Results were considered statistically significant if the 2-tailed P-value was  $<0.05$ . Stata version SE12 was used for all analyses (StataCorp LP, College Station, Texas).

### **Results**

Sixty one participants at baseline wore the combined HR and ACC monitor. Five participants had difficulties scheduling appointment times for direct measurements at baseline and one participant withdrew from the study. In addition, one device failed to record any information during the observation period and seven participants had less than 48 hours wear time. Sufficient information ( $> 48$ hours of wear) on combined HR and ACC with individual calibration of HR was available for 53 participants. Five of these 53 participants did not complete the bike test. In these cases we used the average HR response of all remaining participants' bike tests as calibration but anchored their values at individual sleeping HR. In total, we analyzed 7,577 person-hours recordings on combined HR and ACC, collected from 53 participants of which 5,049 person-hours were non-sleep observations (Figure 1).

Sixty-two participants completed the occupational exposure questionnaire. Postures and movement observations were performed with 16 participants, from two of the three workplaces. Observed employees performed outdoor work tasks (n=6) and indoors work tasks (n=10). The 16 participants included in the observational study did not statistically differ in their BMI (P=0.08),  $VO_2$ max (P=0.17),

or age ( $P=0.053$ ) from the rest of participants. Insufficient baseline measurements from the ACC and HR devices prevented a comparison to PAEE.

### ***Directly monitored physical activity***

#### Baseline

PAEE estimates are shown in Table 2. Approximately 60% of average weekly PAEE was during working hours, accounting for 36% (40/112h) of non-sleep time. During working hours and using Mondays as reference for comparison ( $59.4\pm 3.6$  J/kg/min), we found no difference in physical activity Monday through Thursday but a lower physical activity on Fridays ( $\Delta$  mean  $\pm$ SE:  $-12.2\pm 2.1$  J/kg/min) ( $p<0.001$ ). Furthermore, there was significantly less leisure-time physical activity on Tuesdays ( $P<0.05$ ), Wednesdays ( $P<0.02$ ), and Sundays ( $P<0.02$ ) compared to Mondays (Figure 2). The mean PAEE across the 24-hour day was:  $31.3\pm 1.7$  J/kg/min.

Figure 3 shows the distribution of physical activity intensity as the median percentage of work time and leisure-time. During work hours the median fraction of time spent at 1-1.25 MET was 10%. During leisure-time, the median fraction of time was 45%. Participants spent most work time in the “light” (1.5-3.0 MET) category (88%, IQR: 2-97 %,  $P<0.001$ ), compared to “sedentary” (2%, IQR: 0-13 %) and “moderate-vigorous” (2%, IQR: 0-10 %) categories. This average intensity at work was corresponding to 1.8 MET. Similarly, the majority of leisure-time was in the “light” category (72%, IQR: 47-90%), followed “sedentary” (20%, IQR: 3-50 %,  $P<0.001$ ) and “moderate-vigorous” categories (0%, IQR: 0-2 %,  $P<0.001$ ). There was a statistically significant difference in median time spent in “light” activity intensity: 83% vs. 72% ( $P<0.001$ ) between work hours and leisure-time. Correspondingly, significant differences were seen in work vs. leisure-time physical activity hours in the “sedentary” category (1.7% vs. 20%,  $P<0.001$ ), respectively, and in “moderate-vigorous” activity (1.7% vs. 0% respectively,  $P<0.001$ ).

Figure 1 Flowchart – ACC + HR measurements

**Table 2** Physical Activity Energy Expenditure estimated from combined movement and heart rate sensing at baseline

Variable	Exercise + Control (n)			Exercise group(n)	Control group (n)	P value
	Mean $\pm$ SE (n)	CI (95%)	P value	Mean $\pm$ SE (n)	Mean $\pm$ SE (n)	
Whole period	42.9 $\pm$ 2.3 (53)	38.4-47.5		44.2 $\pm$ 2.7 (29)	41.3 $\pm$ 3.9 (24)	NS
Weekdays	45.9 $\pm$ 2.5 (53)	41.0-50.9	0.00*	46.9 $\pm$ 2.8 (29)	44.7 $\pm$ 4.5 (24)	NS
Weekend	34.0 $\pm$ 2.2 (49)	29.6-39.3		34.2 $\pm$ 2.9 (27)	33.6 $\pm$ 3.5 (22)	NS
Work hours	56.6 $\pm$ 3.2 (53)	50.3-62.9	0.00*	54.6 $\pm$ 3.2 (29)	59.0 $\pm$ 6.0 (24)	0.001 <sup>#</sup>
Leisure-time	35.7 $\pm$ 2.2 (53)	31.5-40.1		38.2 $\pm$ 3.1 (29)	32.9 $\pm$ 3.0 (24)	0.013 <sup>#</sup>

Values are means (J/kg/min) $\pm$ SE, non-sleep PAEE (hour of day <7am - <=23pm). Differences are estimated as the difference between means with 95% confidence intervals (95% CI), based on ANOVA repeated measures random effects model.

\*: significant difference between weekdays and weekends and between work hours and leisure-time.

<sup>#</sup>: significant difference between groups

Whole period: Monday – Sunday (7-23)

Weekdays: Monday - Friday, weekends: Saturday and Sunday.

Working hours: 7-15 on weekdays, leisure-time: 15-23 on weekdays and 7-23 on weekends.

**Figure 2** Physical Activity Energy Expenditure for each day of the week

Footnotes to figure 2: The PAEE is presented as mean values, the bars indicating  $\pm$ SE.

**Figure 3** Physical activity intensity distributions during work and leisure time

Footnotes to figure 3: The fraction of time spent on “small range” MET-categories plotted against the mean value for each category. The fraction of time is presented as median value and the bars indicate 25 and 75 percentiles, respective.

#### Post-intervention

In spite of the randomization after baseline monitoring, there were significant differences between the groups with respect to baseline physical activity during work hours and at leisure (Table 2). Estimates of change in directly monitored physical activity from baseline to post- intervention are shown in Table 3.

These latter results include participants who completed both baseline and post-intervention measurements and had sufficient combined HR and ACC information (n=31). Analyses on drop-out-rate between the participants included in baseline analysis and post-intervention did not show differences between the groups (p=0.35). Fifty-eight participants wore the ACC+HR monitor post intervention. However, 19 participants did not provide sufficient data for inclusion in the analyses (Figure 1). Paired analyses within each group showed significant reduction in physical activity in the intervention group for the whole period summarized, weekdays, and leisure time but not during weekends and work hours. There were no significant changes in the controls. In group-by-time analyses, the intervention group decreased their weekday and leisure time physical activity more compared to controls (Table 3). Separate analyses on net HR (bpm) above sleeping HR changed among the intervention compared with the control group during the whole period:  $\Delta -4.7 \pm 1.6$  bpm ( $P < 0.02$ ); weekdays  $\Delta -4.9 \pm 1.7$  bpm ( $P < 0.02$ ); leisure-time  $\Delta -3.7 \pm 1.7$  bpm ( $P < 0.05$ ), but not during work hours  $\Delta -4.8 \pm 2.6$  bpm ( $P = 0.07$ ) or during weekends;  $\Delta 3.1 \pm 3.1$  bpm ( $P > 0.33$ ). Analyses on trunk acceleration ( $\text{m/sec}^2$ ) showed significant reduction in body movement in the intervention group compared to the control group (whole period:  $\Delta -0.06 \pm 0.02$ ,  $\text{m/sec}^2$ ,  $P < 0.02$ ; weekdays:  $\Delta -0.07 \pm 0.02$   $\text{m/sec}^2$ ,  $P < 0.04$ ; leisure:  $\Delta -0.07 \pm 0.03$   $\text{m/sec}^2$ ,  $p < 0.02$ ) but the difference was not significant for work hours ( $\Delta -0.05 \pm 0.03$   $\text{m/sec}^2$ ,  $p = 0.11$ ) and weekends ( $\Delta -0.0002 \pm 0.03$   $\text{m/sec}^2$ ,  $P = 0.99$ ).

**Table 3** Changes in Physical Activity Energy Expenditure estimated from combined movement and heart rate sensing for each study group from baseline to post 12 weeks intervention.

Variable	Exercise group	Control group	Exercise group	Control group	Difference	
	Baseline (n=14)	Baseline (n=17)	Post-pre (n=14)	Post-pre (n=17)	Exercise vs. Control (n=31)	
	Mean $\pm$ SD	Mean $\pm$ SD	Mean $\pm$ SE	Mean $\pm$ SE	Mean $\pm$ SE	95 % CI
Whole period	44.1 $\pm$ 17.5	38.7 $\pm$ 19.2*	-9.8 $\pm$ 16.8	5.8 $\pm$ 12.9	-12.8 $\pm$ 4.2 <sup>#</sup>	-21.3 to -4.2
Weekdays	47.2 $\pm$ 18.1	42.4 $\pm$ 21.5	-10 $\pm$ 16.8	5.1 $\pm$ 14.2	-12.6 $\pm$ 4.0 <sup>#</sup>	-20.8 to -4.3
Weekend	29.9 $\pm$ 14.9	26.3 $\pm$ 17.1	-2.4 $\pm$ 20.0	-0.2 $\pm$ 26.5	0.4 $\pm$ 7.6	-15.2 to 16.1
Work hours	56.1 $\pm$ 19.2	55.2 $\pm$ 28.9	-7.2 $\pm$ 16.2	-1.0 $\pm$ 24.2	-5.9 $\pm$ 6.6	-19.5 to 7.6
Leisure-time	37.5 $\pm$ 19.6	30.7 $\pm$ 14.2*	-11.4 $\pm$ 18.1	5.8 $\pm$ 18.6	-12.8 $\pm$ 5.1 <sup>#</sup>	-23.2 to -2.4

Values are means (J/kg/min) $\pm$ SE (SD in baseline values), non-sleep PAEE (hour of day <7am - <=23pm). Differences are estimated as the difference between means with 95% confidence intervals (95% CI), based on the 1-factor analysis of covariance (ANCOVA) with the level at baseline applied as a covariate. Only showing estimates on participants who completed both baseline and post measurements.

\*: significant difference at baseline between groups

<sup>#</sup>: significant difference in change with intervention between groups

Whole period: Monday-Sunday 7-23. Weekdays: Monday - Friday, weekends: Saturday and Sunday.

Working hours: 7-15 on weekdays, leisure-time: 15-23 on weekdays and 7-23 on weekends

### ***Self-reported physical activity and occupational workload***

#### **Baseline**

Perceived physical exertion at work averaged 11.1 $\pm$ 0.4 with no difference between intervention and control group. For each of the manual material handling tasks of pushing/pulling, carrying and lifting, more than 90% of the participants reported these activities, and they were performed for  $\geq$  25% of working time by 50%, 57%, and 52% of the participants, respectively. Data on specific workloads are shown in Table 4. Working posture of the back was reported to be bent-double by 75% and bent or twisted by 89% of the participants, and this was true for  $\geq$ 25% of working time for 38% (bent-double)

and 53% (bent or twisted) of the participants. Seventy two per cent of the participants reported work with the arm above shoulder and 20% of the participants did so for  $\geq 25\%$  of the work time. Additionally, kneeling postures were reported by 82% of the participants, and this was true for  $\geq 25\%$  of the working time for 45% of the participants. Among 45% of the participants, the respiratory rate was increased  $\geq 25\%$  of the working time (intervention group: 56%, control group 35%).

According to the IPAQ questionnaire, roughly two thirds of total physical activity is reported as occupational physical activity (6570, IQR 2970;9930 MET-min/week), and roughly one third as leisure-time physical activity ( 3871, IQR 2221;5154 MET-min/week). This difference in occupational and leisure-time activity was significant ( $p < 0.01$ ). Assuming 40 hours' work per week, self-reported activity at work corresponds to a mean activity intensity of approx. 2.7 MET which is roughly 50% higher than the directly overall measured values of work of 1.8 MET (see above).

#### Post-intervention

After the intervention, self-reported physical activity and occupational workload remained unchanged in both groups. Data on specific workloads at follow-up are shown in Table 4. The distribution of frequencies in different categories of work postures did not vary significantly from baseline measurements.

**Table 4** Percentage of participants reporting specific workloads in kg, handled  $\geq 25\%$  during working time of pushing/pulling, carrying, and lifting

<b>Baseline</b>							
	<b>Load handled</b>	<b>Pushing/pulling</b>		<b>Lifting</b>		<b>Carrying</b>	
		Ex (n=26)	C (n=25)	Ex (n=26)	C (n=26)	Ex (n=26)	C (n=26)
	$\geq 10$ kg	58%	52%	54%	54%	42%	42%
	$\geq 20$ kg	27%	24%	27%	12%	19%	12%
	$\geq 25$ kg	15%	20%	12%	8%	8%	4%
<b>Post intervention</b>							
		Ex (n=28)	C (n=23)	Ex (=29)	C (n=23)	Ex (n=29)	C (n=23)
	$\geq 10$ kg	68%	61%	62%	65%	55%	23%
	$\geq 20$ kg	18%	17%	17%	7%	17%	9%
	$\geq 25$ kg	18%	9%	14%	7%	3%	0%

Ex: exercise group, C: control group

Values are percentage of the participants reporting the specific work tasks.

### ***Observations of posture and movement***

Postures and movements observed at work showed that the employees 59% of the daily working time (approximately 4.7 hours) were standing and 21% of the time (approximately 1.7 hours) were moving. Thus the employees were working in upright position bearing their own weight approximately 80% of their time. Observed postures in percent of worktime were for the back 19% bent, 12% bent-double, 1% twisted, and 3%, bent and twisted. In addition, 9% of the worktime was performed with one or two arms above shoulder height, and 6 % in kneeling posture.

## Discussion

We found rather modest metabolic workload based on self-reported and direct measures of physical activity for construction workers in this study. Leisure time physical activity was significantly lower than occupational physical activity, resulting in an overall low physical activity level in terms of metabolic load. In contrast, physical exposure at work was heavy in terms of mechanical strain from manual material handling.

Directly measured physical activity for the week was 31.3J/kg/min (across all 24 hours of the day) or approximately 45kJ/kg/24 hours. The InterAct Consortium used similar methods to quantify PAEE in 591 healthy middle-aged European men and reported a mean PAEE of 44 kJ/kg/24 hours, a result in line with the present study.<sup>28</sup> However, it is important to note that InterAct study participants had a variety of occupations, and more than 40% self-reported having “sedentary occupations”.

Analyses of time spent in different physical activity categories showed that most work and leisure time was spent on light physical activity (i.e. 1.5-3MET).<sup>22</sup> However, care must be taken when interpreting the measurements from the sensor as an indicator of total cardiovascular work exposure. Piezo-electric accelerometers do not register activity during static muscle work, as no time-varying acceleration occurs, although muscle metabolism is increased during such activity. Further, even when handling heavy loads increases HR, this may only last for a few seconds requiring beat-to-beat resolution monitoring detect this increase. Even with this methodology it would be difficult to document an increase in HR related to strenuous postures and handling of heavy loads; registration of body postures using multiple accelerometers sensitive to gravity may be required for a more comprehensive assessment of such exposures. It is indeed challenging to choose the appropriate, clinically relevant, valid and responsive measurement for physical activity since the term physical activity is multidimensional.<sup>29</sup>

The average directly assessed physical activity intensity at work was approximately 57 J/min/kg (Table 2) or 1.8 MET. Results on VO<sub>2</sub>max among this study population are previously published showing a mean value of VO<sub>2</sub>max corresponding to 2.3±0.5 (l/min).<sup>12</sup> The estimated relative workload at baseline during an 8-hour work day was  $27/79 = 34\%$  (“HR during work time above sleeping HR from the

present study” divided by the previously published “maximum HR above a resting value of 70 bpm for this group.<sup>10)</sup> This is consistent with the maximum permissible intensity level of 33% proposed in consensus guidelines.<sup>4</sup>

Measuring physical activity during work is important, as majority of adults spend many hours a day at work and activity recommendations correspond to overall physical activity. In this randomized control trial, the participants wore the combined HR and ACC sensor for 7 days pre and post-intervention. The direct measurements showed reduced physical activity after a 12-week physical exercise program (1 hour/week) in the intervention group compared to controls. Lower physical activity measured by combined HR and ACC may be a result of a lower HR with unchanged physical activity, due to an improved physical capacity as a result of the intervention, although this should be accounted for some extent by the individual calibration procedure at both pre- and post-assessment. Interestingly, estimating HR and ACC separately showed no significant decreases in HR or in trunk accelerations in the intervention group compared to controls after the intervention when distinguished between work and leisure. Since we have previously reported an increase in aerobic capacity in the intervention group, these findings may due to leisure activities being performed more efficiently while work activity may be similarly more effective since HR and ACC measures were unchanged due to higher productivity. This is in agreement with our earlier findings of unchanged productivity although these workers spent one hour physical exercise training per week during working time.<sup>30</sup> The lack of comparable level at baseline within the work-time and leisure-time domains makes it challenging to assess the real effect of the intervention. However, within-group estimates showed only significant reduction in physical activity in the intervention group. According to self-report measurements there were no changes in mechanical workload and perceived exertion; thus, the increased individual capacity may have influenced the relative workload. The time of the post-measurements of directly measured physical activity may also have influenced the negative results since the measurements were conducted a week after the intervention ended and it cannot be excluded the possibility that the construction workers in the intervention group relaxed more than usual during that first week after a relatively hard intervention program.

To evaluate the possible health enhancing or deteriorating effects of physical activity at work, all domains of activity should be considered and evaluated relative to the recommendation during the later years adopted by many national health authorities.<sup>31</sup> In addition, specifically for the occupational domain physical activity assessment should ideally include not only a characterization of the metabolic load but also measurements of the mechanical strains on the musculoskeletal system, e.g. EMG. Biomechanical measures may assess the mechanical strain and have documented considerable physical exposure among construction workers.<sup>32,33</sup> High mechanical strains may in contrast to the health enhancing physical activity cause musculoskeletal disorders and other aspects of deteriorated health.

In conclusion, the original hypothesis that high mechanical strain in construction work results in a metabolic load exceeding the permissible intensity levels was rejected since the metabolic load at work did not exceed 1/3 of the maximum capacity of the workers in spite of a high mechanical strain at work. Our second hypothesis, that a work site exercise program increasing fitness reduces the relative metabolic load during work, was also rejected since the exercise intervention did not further decrease the rather light metabolic load during work. Furthermore, the physical activity level at leisure-time was lower than occupational physical activity among construction workers; this was also not increased with the intervention. The low total physical activity level may in fact be responsible for the low metabolic capacity among these workers, and since their work involves exposure to strenuous mechanical workload that may be harmful to their health, general lifestyle counseling and provision of worksite training schemes should be considered for this occupational group.

### **Acknowledgments**

The authors would like to thank engineer Shadi Samir Chreiteh, Institute of Sports Science and Clinical Biomechanics, University of Southern Denmark for technical support. This study was supported by a grant from the Danish Working Environment Research Foundation and the Ministry of Culture Committee on Sports Research, Denmark.

**Commented [F5]:** TO THE EDITOR:  
We have now rephrased this sentence

### **Funding source**

This study is part of the FINALE programme supported by a grant (16-2006-04) from the Danish Working Environment Research Foundation and the Ministry of Culture Committee on Sports Research, Denmark. This study is registered in [www.clinicaltrials.com](http://www.clinicaltrials.com) (number NCT01007669).

Conflict of interest: The authors declare that they have no conflict of interest

### **References**

1. Leino-Arjas P, Solovieva S, Riihimäki H, Kirjonen J, Telama R. Leisure time physical activity and strenuousness of work as predictors of physical functioning: a 28 year follow up of a cohort of industrial employees. *Occupational and Environmental Medicine* 2004;61(12):1032-8.
2. Krause N, Brand RJ, Kaplan GA, Kauhanen J, Malla S, Tuomainen T-P et al. Occupational physical activity, energy expenditure and 11-year progression of carotid atherosclerosis. *Scandinavian journal of work, environment & health* 2007;33(6):405-24.
3. Holtermann A, Hansen JV, Burr H, Sjøgaard K, Sjøgaard G. The health paradox of occupational and leisure-time physical activity. *British journal of sports medicine* 2012;46(4):291-5.
4. Bonjer F. Energy expenditure In: Parmeggiani L, editor. *Encyclopedia of Occupational Health and Safety*. Geneva: International Labour Organisation; 1971. p 458-60.
5. Mantyselka PT, Kumpusalo EA, Ahonen RS, Takala JK. Direct and indirect costs of managing patients with musculoskeletal pain-challenge for health care. *Eur J Pain* 2002;6(2):141-8.
6. Bevan S, Quadrello T, McGee R, Mahdon M, Vavrosky A, Barham L. Fit for work? *Musculoskeletal Disorders in the European Workforce*. 2009.
7. Holtermann A, Mortensen OS, Burr H, Sjøgaard 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. *Scandinavian journal of work, environment & health* 2010;36(5):357-65.

8. Telford RD. Low physical activity and obesity: causes of chronic disease or simply predictors? *Medicine and science in sports and exercise* 2007;39(8):1233-40.
9. Lee IM, Shiroma EJ, Lobelo F, Puska P, Blair SN, Katzmarzyk PT. Effect of physical inactivity on major non-communicable diseases worldwide: an analysis of burden of disease and life expectancy. *Lancet* 2012;380(9838):219-29.
10. Holtermann A, Mortensen OS, Sogaard K, Gyntelberg F, Suadicani P. Risk factors for ischaemic heart disease mortality among men with different occupational physical demands. A 30-year prospective cohort study. *BMJ Open* 2012;2(1).
11. Blair SN, Kohl HW, 3rd, Paffenbarger RS, Jr., Clark DG, Cooper KH, Gibbons LW. Physical fitness and all-cause mortality. A prospective study of healthy men and women. *JAMA : the journal of the American Medical Association* 1989;262(17):2395-401.
12. Gram B, Holtermann A, Sogaard K, Sjogaard G. Effect of individualized worksite exercise training on aerobic capacity and muscle strength among construction workers--a randomized controlled intervention study. *Scandinavian journal of work, environment & health* 2012;38(5):467-75.
13. Astrand PO, Ryhming I. A nomogram for calculation of aerobic capacity (physical fitness) from pulse rate during sub-maximal work. *Journal of applied physiology (Bethesda, Md : 1985)* 1954;7(2):218-21.
14. Astrand I. Aerobic work capacity in men and women with special reference to age. *Acta physiologica Scandinavica Supplementum* 1960;49(169):1-92.
15. Brage S, Brage N, Franks PW, Ekelund U, Wareham NJ. Reliability and validity of the combined heart rate and movement sensor Actiheart. *European journal of clinical nutrition* 2005;59(4):561-70.
16. Stegle O, Fallert SV, MacKay DJ, Brage S. Gaussian process robust regression for noisy heart rate data. *IEEE transactions on bio-medical engineering* 2008;55(9):2143-51.
17. Brage S, Ekelund U, Brage N, Hennings MA, Froberg K, Franks PW et al. Hierarchy of individual calibration levels for heart rate and accelerometry to measure physical activity. *Journal of applied physiology (Bethesda, Md : 1985)* 2007;103(2):682-92.
18. Brage S, Brage N, Franks PW, Ekelund U, Wong MY, Andersen LB et al. Branched equation modeling of simultaneous accelerometry and heart rate monitoring improves estimate of directly measured

physical activity energy expenditure. *Journal of applied physiology* (Bethesda, Md : 1985) 2004;96(1):343-51.

19. Thompson D, Batterham AM, Bock S, Robson C, Stokes K. Assessment of low-to-moderate intensity physical activity thermogenesis in young adults using synchronized heart rate and accelerometry with branched-equation modeling. *The Journal of nutrition* 2006;136(4):1037-42.

20. Strath SJ, Brage S, Ekelund U. Integration of physiological and accelerometer data to improve physical activity assessment. *Medicine and science in sports and exercise* 2005;37(11 Suppl):S563-71.

21. Brage S, Westgate K, Franks PW, Stegle O, Wright A, Ekelund U et al. Estimation of Free-Living Energy Expenditure by Heart Rate and Movement Sensing: A Doubly-Labelled Water Study. *PloS one* 2015;10(9):e0137206.

22. Ainsworth BE, Haskell WL, Whitt MC, Irwin ML, Swartz AM, Strath SJ et al. Compendium of physical activities: an update of activity codes and MET intensities. *Medicine and science in sports and exercise* 2000;32(9 Suppl):S498-504.

23. Craig CL, Marshall AL, Sjostrom M, Bauman AE, Booth ML, Ainsworth BE et al. International physical activity questionnaire: 12-country reliability and validity. *Medicine and science in sports and exercise* 2003;35(8):1381-95.

24. The\_IPAQ\_group. International Physical Activity Questionnaire, [www.ipaq.ki.se](http://www.ipaq.ki.se) 2014. Available from: URL: [www.ipaq.ki.se](http://www.ipaq.ki.se)

25. Holtermann A, Jorgensen MB, Gram B, Christensen JR, Faber A, Overgaard K et al. Worksite interventions for preventing physical deterioration among employees in job-groups with high physical work demands: background, design and conceptual model of FINALE. *BMC public health* 2010;10:120.

26. Borg G. Perceived exertion as an indicator of somatic stress. *Scandinavian journal of rehabilitation medicine* 1970;2(2):92-8.

27. Buchholz B, Paquet V, Punnett L, Lee D, Moir S. PATH: a work sampling-based approach to ergonomic job analysis for construction and other non-repetitive work. *Applied ergonomics* 1996;27(3):177-87.

28. Peters T, Brage S, Westgate K, Franks PW, Gradmark A, Tormo Diaz MJ et al. Validity of a short questionnaire to assess physical activity in 10 European countries. *European journal of epidemiology* 2012;27(1):15-25.
29. Bussmann JB, van den Berg-Emons RJ. To total amount of activity..... and beyond: perspectives on measuring physical behavior. *Frontiers in psychology* 2013;4:463.
30. Gram B, Holtermann A, Bultmann U, Sjogaard G, Sogaard K. Does an exercise intervention improving aerobic capacity among construction workers also improve musculoskeletal pain, work ability, productivity, perceived physical exertion, and sick leave?: a randomized controlled trial. *Journal of occupational and environmental medicine / American College of Occupational and Environmental Medicine* 2012;54(12):1520-6.
31. Garber CE, Blissmer B, Deschenes MR, Franklin BA, Lamonte MJ, Lee IM et al. American College of Sports Medicine position stand. Quantity and quality of exercise for developing and maintaining cardiorespiratory, musculoskeletal, and neuromotor fitness in apparently healthy adults: guidance for prescribing exercise. *Medicine and science in sports and exercise* 2011;43(7):1334-59.
32. Tak S, Buchholz B, Punnett L, Moir S, Paquet V, Fulmer S et al. Physical ergonomic hazards in highway tunnel construction: overview from the Construction Occupational Health Program. *Applied ergonomics* 2011;42(5):665-71.
33. Hartmann B, Fleischer AG. Physical load exposure at construction sites. *Scandinavian journal of work, environment & health* 2005;31 Suppl 2:88-95.

## **Occupational and leisure-time physical activity and workload among construction workers – A Randomized Control Study**

### Abstract

**Background:** There is a lack of quantification of occupational physical activity (OPA) and leisure time physical-activity (LTPA) among construction workers.

**Objectives:** To describe physical activity energy expenditure (PAEE), physical workload, and the effect of a PA-intervention among construction workers.

**Methods:** Sixty-seven Construction workers self-reported their PA, had PA assessed directly (PAEE), and observed OPA using the tool ‘Posture, Activity, Tolls and Handling’. The PA-intervention (Intervention;n=29, Controls;n=24) included 3x20-min training/week for 12 weeks.

**Results:** Baseline median OPA was 5036 MET-min/week and LTPA 2842 MET-min/week,  $p<0.01$ . OPA directly recorded was (mean  $\pm$ SE):  $56.6\pm 3.2$  J/kg/min and LTPA was:  $35.7\pm 2.2$  J/kg/min ( $p<0.001$ ). Manual material handling was performed for  $\geq 25\%$  of working time by more than 50% of the participants. Post intervention, the training group reduced overall PAEE compared to the control group but not specifically during work.

**Conclusions:** OPA was within the maximum recommended level of 1/3 proposed in consensus guidelines but did not decrease with PA-intervention.

**Key words:** Workplace physical activity program, Physical Fitness, Occupational Health

## **Introduction**

Unlike the health benefits associated with physical activity during leisure-time, high levels of occupational physical activity including mechanical musculoskeletal strain during awkward postures and manual material handling are associated with increased long term sickness absence.<sup>1-3</sup> Therefore, establishing maximum permissible intensity levels, proposed in International Labor Organization consensus guidelines in 1971, is an important step to improve occupational health.<sup>4</sup> Physically demanding jobs can result in negative health and economic related consequences for employees and may also be detrimental for the company and society at large.<sup>5,6</sup>

Physically demanding work may require certain level cardio-respiratory fitness and leisure-time physical activity may be a means of maintaining or improving fitness level.<sup>7</sup> Inactive lifestyles are associated with elevated cardiovascular risk among the general population but evidence suggests that moderate and high levels of leisure-time physical activity may be especially important among employees with moderate and high levels of occupational physical activity compared to employees in sedentary work.<sup>8-11</sup> We have previously shown that Danish construction workers have a significantly lower value of maximum oxygen uptake ( $\text{VO}_2 \text{ max}$ ) compared to a representative group of employees in Denmark.<sup>12</sup> Since low aerobic capacity implies increased relative load during work, the current study was conceptualized to examine how occupational and leisure physical activity patterns are related to  $\text{VO}_2 \text{ max}$ . The aim of this study was to describe physical activity and strain at work and at leisure-time among construction workers. Furthermore, we investigated how an individually tailored physical activity intervention changed the level of physical activity at work and during leisure time. We hypothesized: 1) that high mechanical strain in construction work results in a metabolic load exceeding the permissible intensity levels proposed in consensus guidelines as  $\frac{1}{3}$  of the maximum capacity of the workers and 2) that a work site exercise program to increase fitness will reduce the relative metabolic load during work.

## **Methods**

This study analysed secondary outcome variables from a randomized controlled trial. The physical activity intervention has been reported elsewhere.<sup>12</sup> In short, the intervention included 12 weeks of a one-hour individually tailored aerobic and strength training session per week for workers in physically strenuous jobs.<sup>12</sup>

Sixty-seven construction workers were recruited from three construction industry workplaces in Denmark. Eligibility criteria required participants to have physically demanding tasks including high peak loads and work more than or equal to 20 hours per week. After baseline measurements, construction workers were stratified by age and individually randomized (1:1) into an intervention or a control group. Participants completed pre and post intervention health exams that included a sub-maximal fitness test and assessment of physical activity.<sup>13</sup> Physical activity was objectively measured and self-reported for seven days pre-randomization and seven days post-intervention. To estimate mechanical strain, a subgroup was randomly selected and observed during work. These observations were completed in conjunction with the post-test. Written informed consent was obtained from all participants before enrollment in the study. The Regional Scientific Ethical Committee for Southern Denmark approved the study protocol (No 20090058) and the study was registered in [www.clinicaltrials.com](http://www.clinicaltrials.com) (number NCT01007669).

### ***Cardio-respiratory fitness:***

Maximal oxygen uptake was estimated from the relationship between sub-maximal workload and heart rate (HR) obtained during an one-point sub-max test on a cycle ergometer (Monark 874E, Monark Exercise AB, Sweden) and using the Aastrand nomogram with  $\text{VO}_2\text{max}$  corrected for age.<sup>14</sup> The test started with a load of 80 watt (1.0 kg) and at a cadence of 80 rpm. During the first two minutes, the load was adjusted based on measured HR; if HR was below 120 beats per minute (bpm) during the first two minutes 0.5 kg was added, and further weight was added at three and four minutes to attain a stable HR between 120-170 bpm if necessary. The test was terminated when HR was stable for one minute at the target level.

***Direct physical activity assessment:***

Physical activity energy expenditure (PAEE) and physical activity intensity were estimated using a combined heart rate and accelerometry sensor (Actiheart, CamNtech, Papworth, UK), worn for seven days after the pre and post-intervention health exams. The sensor was attached to participant's chest via two ECG electrodes and the individuals were instructed to change the electrodes as needed.<sup>15</sup> The device continuously measured HR and acceleration component along the body's longitudinal axis (ACC) with epoch duration of one minute. HR data were pre-processed using Gaussian Process Regression utilizing a custom-written JAVA program on a MySQL database.<sup>16</sup> An estimation of activity energy expenditure in J/kg/min and proportion of time spent at different intensity levels was obtained using branched equation modeling for combining the ACC with the individually calibrated HR component using HR response parameters from the fitness test.<sup>17, 18</sup> Pre- and post-intervention calibrations were performed using the pre and post fitness tests, respectively. This branched modelling approach has been shown to yield valid estimates of activity energy expenditure during both laboratory and free-living conditions.<sup>18-21</sup> In this study we separately analysed the changes in HR and ACC in the intervention group since the intervention had an effect on maximum oxygen uptake. In other words, the participants in the intervention group demonstrated a lower HR when working on the same absolute power output. Prolonged periods of no movement and non-physiological HR, patterns were inferred as non-wear and those time periods were excluded from physical activity time-series analysis. Analyses of direct activity data was performed in terms of number of hours per participant in a multi-level model. Only participants with a minimum of 48 hours of wear data were included in the statistical analyses. Data were categorized into physical activity intensity categories defined as multiples of individualized resting metabolic rate: fraction of time spent in <1 MET, 1-1.25 MET, 1.25-1.5 MET, 1.5-1.75 MET, 1.75-2.0 MET, 2.0-2.25 MET, 2.25-2.5 MET, 2.5-2.75 MET, 2.75-3.0 MET, 3.0-3.5 MET, 3.5-4.0 MET, 4.0-4.5 MET, 4.5-5.0 MET, 5.0-6.0 MET, 6.0-7.0 MET, 7.0-8.0 MET, 8.0-9.0 MET, 9.0-10 MET, 10.0-11 MET. Additionally three broad MET-categories were defined as "sedentary" (1-1.5 MET), "light" (1.5-3.0 MET), and "moderate-vigorous" (>3.0 MET).<sup>22</sup>

We also analyzed the HR data and ACC data in raw forms (i.e. not translated to activity energy) to identify if cardiovascular load or movement changed between the intervention and control group.

Non-sleep data were analyzed for the seven days period and summed across different categories: 1) total time awake (7-23), 2) weekdays (Monday-Friday), and 3) weekends (Saturday-Sunday). Additionally, data were summed separately for working hours (Monday-Friday, hours 7-15) and leisure-time (Monday-Friday, hours 15-23 + Saturday-Sunday, hours 7-23). Furthermore, we analyzed data summed 24 hours a day for seven days.

### ***Self-reported physical activity and occupational workload:***

#### International Physical Activity Questionnaire (IPAQ)

Participants completed the long form of the International Physical Activity Questionnaire (IPAQ) at the health exams to evaluate four domains of physical activity (occupational, transport, domestic/gardening, and leisure).<sup>23</sup> Transport, domestic/gardening, and leisure physical activities were classified as leisure-time physical activity. For each participant, physical activity was categorized as occupational or leisure-time and converted according to official scoring protocol and guidelines into MET-min/week as outcome measures.<sup>24</sup>

#### Workload questionnaire

Ten questions from the FINALE questionnaire regarding mechanical workload and perceived exertion were administered when participants were monitored with the HR and ACC sensor.<sup>25</sup> Questions included: 1) Did your work last week involve manual material handling? Response categories were: a) Almost all the time, b) 75% of the time, c) 50% of the time, d) 25% of the time, and e) Seldom or Never. If manual material handling was performed the next question was: 2) How many kg did you handle? Response categories were: a) 5 kg or less, b) 6-10 kg, c) 11-15 kg, d) 16-20 kg, e) 21-25 kg, and f) more than 25 kg. The same questions were repeated with 'material handling' substituted by 'pushing/pulling', 'carrying', and 'lifting', respectively. There was one question on perceived physical exertion: On a scale from 6 to 20 (6 being very easy and 20 being the hardest possible), how did you

perceive your level of exertion last week?<sup>26</sup> Participants were asked whether they worked with the back bent-double, bent or twisted, with one or both arms above shoulder height, and/or in kneeling postures. Lastly, they were asked to what extent their job induced increased respiratory rate. Response categories were a) Almost all the time, b) 75% of the time, c) 50% of the time, d) 25% of the time, and e) Seldom or Never. The question and answer categories can be seen in Table 1.

**Table 1** Questionnaire regarding work postures and cardio-respiratory work load with five reply categories. Only one category had to be chosen for each question.

Did you last week in your job work	Almost all the time	75% of the time	50% of the time	25% of the time	Seldom or never
...with your back bent-double?					
...with your back bent or twisted?					
...with one or both arms above shoulder height?					
...in kneeling postures?					
...with increased respiratory rate?					

***Observation of occupational postures and movement:***

The observational ‘Posture, Activity, Tools and Handling’ (PATH) instrument was used to observe mechanical strain of occupational postures and movement with a subgroup of participants selected randomly at two of the workplaces referred in this study.<sup>27</sup> We observed arm, trunk and leg postures and the amount of walking. Observations were performed at the construction site without advance notice. Registrations were recorded once per minute and participants were observed for periods of five - 43 consecutive minutes. The number of observation periods ranged from one to four per participant, with several PATH behaviors noted within each observation period. The summed number of PATH behaviors ranged from 40 to 120 per participant.

### *Statistical analyses*

Descriptive statistics for direct measures and questionnaire data were calculated as means and standard deviation (SD) or as 25, 50 and 75 percentiles. Differences in physical activity were calculated as means with standard error (SE) and 95% confidence intervals (95% CI). Analyses of physical activity intensity using HR and ACC data were assessed as medians with interquartile range (IQR) at baseline. Measures of physical activity energy expenditure determined from HR and ACC activity data (person-hours) during periods of working- and leisure-time, were performed using ANOVA repeated measures, with random effects on the individual level. Analyses of changes from baseline to post-intervention were performed by analyses of covariance (ANCOVA) with the baseline value as covariate.

In post-hoc analyses, paired t-tests were used to estimate significant differences within groups. Results were considered statistically significant if the 2-tailed P-value was <0.05. Stata version SE12 was used for all analyses (StataCorp LP, College Station, Texas).

### **Results**

Sixty one participants at baseline wore the combined HR and ACC monitor. Five participants had difficulties scheduling appointment times for direct measurements at baseline and one participant withdrew from the study. In addition, one device failed to record any information during the observation period and seven participants had less than 48 hours wear time. Sufficient information (> 48hours of wear) on combined HR and ACC with individual calibration of HR was available for 53 participants. Five of these 53 participants did not complete the bike test. In these cases we used the average HR response of all remaining participants' bike tests as calibration but anchored their values at individual sleeping HR. In total, we analyzed 7,577 person-hours recordings on combined HR and ACC, collected from 53 participants of which 5,049 person-hours were non-sleep observations (Figure 1).

Sixty-two participants completed the occupational exposure questionnaire. Postures and movement observations were performed with 16 participants, from two of the three workplaces. Observed employees performed outdoor work tasks (n=6) and indoors work tasks (n=10). The 16 participants included in the observational study did not statistically differ in their BMI (P=0.08), VO<sub>2</sub>max (P=0.17),

or age ( $P=0.053$ ) from the rest of participants. Insufficient baseline measurements from the ACC and HR devices prevented a comparison to PAEE.

### ***Directly monitored physical activity***

#### Baseline

PAEE estimates are shown in Table 2. Approximately 60% of average weekly PAEE was during working hours, accounting for 36% (40/112h) of non-sleep time. During working hours and using Mondays as reference for comparison ( $59.4\pm 3.6$  J/kg/min), we found no difference in physical activity Monday through Thursday but a lower physical activity on Fridays ( $\Delta$  mean  $\pm$ SE:  $-12.2\pm 2.1$  J/kg/min) ( $p<0.001$ ). Furthermore, there was significantly less leisure-time physical activity on Tuesdays ( $P<0.05$ ), Wednesdays ( $P<0.02$ ), and Sundays ( $P<0.02$ ) compared to Mondays (Figure 2). The mean PAEE across the 24-hour day was:  $31.3\pm 1.7$  J/kg/min.

Figure 3 shows the distribution of physical activity intensity as the median percentage of work time and leisure-time. During work hours the median fraction of time spent at 1-1.25 MET was 10%. During leisure-time, the median fraction of time was 45%. Participants spent most work time in the “light” (1.5-3.0 MET) category (88%, IQR: 2-97 %,  $P<0.001$ ), compared to “sedentary” (2%, IQR: 0-13 %) and “moderate-vigorous” (2%, IQR: 0-10 %) categories. This average intensity at work was corresponding to 1.8 MET. Similarly, the majority of leisure-time was in the “light” category (72%, IQR: 47-90%), followed “sedentary” (20%, IQR: 3-50 %,  $P<0.001$ ) and “moderate-vigorous” categories (0%, IQR: 0-2 %,  $P<0.001$ ). There was a statistically significant difference in median time spent in “light” activity intensity: 83% vs. 72% ( $P<0.001$ ) between work hours and leisure-time. Correspondingly, significant differences were seen in work vs. leisure-time physical activity hours in the “sedentary” category (1.7% vs. 20%,  $P<0.001$ ), respectively, and in “moderate-vigorous” activity (1.7% vs. 0% respectively,  $P<0.001$ ).

Figure 1 Flowchart – ACC + HR measurements

**Table 2** Physical Activity Energy Expenditure estimated from combined movement and heart rate sensing at baseline

Variable	Exercise + Control (n)			Exercise group(n)	Control group (n)	P value
	Mean ±SE (n)	CI (95%)	P value	Mean ±SE (n)	Mean ±SE (n)	
Whole period	42.9±2.3 (53)	38.4-47.5		44.2±2.7 (29)	41.3±3.9 (24)	NS
Weekdays	45.9±2.5 (53)	41.0-50.9	0.00*	46.9±2.8 (29)	44.7±4.5 (24)	NS
Weekend	34.0±2.2 (49)	29.6-39.3		34.2±2.9 (27)	33.6±3.5 (22)	NS
Work hours	56.6±3.2 (53)	50.3-62.9	0.00*	54.6±3.2 (29)	59.0±6.0 (24)	0.001 <sup>#</sup>
Leisure-time	35.7±2.2 (53)	31.5-40.1		38.2±3.1 (29)	32.9±3.0 (24)	0.013 <sup>#</sup>

Values are means (J/kg/min)±SE, non-sleep PAEE (hour of day <7am - <=23pm). Differences are estimated as the difference between means with 95% confidence intervals (95% CI), based on ANOVA repeated measures random effects model.

\*: significant difference between weekdays and weekends and between work hours and leisure-time.

<sup>#</sup>: significant difference between groups

Whole period: Monday – Sunday (7-23)

Weekdays: Monday - Friday, weekends: Saturday and Sunday.

Working hours: 7-15 on weekdays, leisure-time: 15-23 on weekdays and 7-23 on weekends.

**Figure 2** Physical Activity Energy Expenditure for each day of the week

Footnotes to figure 2: The PAEE is presented as mean values, the bars indicating ±SE.

**Figure 3** Physical activity intensity distributions during work and leisure time

Footnotes to figure 3: The fraction of time spent on “small range” MET-categories plotted against the mean value for each category. The fraction of time is presented as median value and the bars indicate 25 and 75 percentiles, respective.

#### Post-intervention

In spite of the randomization after baseline monitoring, there were significant differences between the groups with respect to baseline physical activity during work hours and at leisure (Table 2). Estimates of change in directly monitored physical activity from baseline to post- intervention are shown in Table 3.

These latter results include participants who completed both baseline and post –intervention measurements and had sufficient combined HR and ACC information (n=31). Analyses on drop-out-rate between the participants included in baseline analysis and post-intervention did not show differences between the groups (p=0.35). Fifty-eight participants wore the ACC+HR monitor post intervention. However, 19 participants did not provide sufficient data for inclusion in the analyses (Figure 1). Paired analyses within each group showed significant reduction in physical activity in the intervention group for the whole period summarized, weekdays, and leisure time but not during weekends and work hours. There were no significant changes in the controls. In group-by-time analyses, the intervention group decreased their weekday and leisure time physical activity more compared to controls (Table 3). Separate analyses on net HR (bpm) above sleeping HR changed among the intervention compared with the control group during the whole period:  $\Delta -4.7 \pm 1.6$  bpm (P<0.02); weekdays  $\Delta -4.9 \pm 1.7$  bpm (P<0.02); leisure-time  $\Delta -3.7 \pm 1.7$  bpm (P<0.05), but not during work hours  $\Delta -4.8 \pm 2.6$  bpm (P=0.07) or during weekends;  $\Delta 3.1 \pm 3.1$  bpm (P>0.33). Analyses on trunk acceleration (m/sec<sup>2</sup>) showed significant reduction in body movement in the intervention group compared to the control group (whole period:  $\Delta -0.06 \pm 0.02$ , m/sec<sup>2</sup>, P<0.02; weekdays:  $\Delta -0.07 \pm 0.02$  m/sec<sup>2</sup>, P<0.04; leisure:  $\Delta -0.07 \pm 0.03$  m/sec<sup>2</sup>, p<0.02) but the difference was not significant for work hours ( $\Delta -0.05 \pm 0.03$  m/sec<sup>2</sup>, p=0.11) and weekends ( $\Delta -0.0002 \pm 0.03$  m/sec<sup>2</sup>, P=0.99).

**Table 3** Changes in Physical Activity Energy Expenditure estimated from combined movement and heart rate sensing for each study group from baseline to post 12 weeks intervention.

Variable	Exercise group	Control group	Exercise group	Control group	Difference	
	Baseline (n=14)	Baseline (n=17)	Post-pre (n=14)	Post-pre (n=17)	Exercise vs. Control (n=31)	
	Mean ±SD	Mean ±SD	Mean ±SE	Mean ±SE	Mean ±SE	95 % CI
Whole period	44.1±17.5	38.7±19.2*	-9.8 ±16.8	5.8±12.9	-12.8±4.2 <sup>#</sup>	-21.3 to -4.2
Weekdays	47.2±18.1	42.4±21.5	-10 ±16.8	5.1±14.2	-12.6±4.0 <sup>#</sup>	-20.8 to -4.3
Weekend	29.9±14.9	26.3±17.1	-2.4 ±20.0	-0.2±26.5	0.4±7.6	-15.2 to 16.1
Work hours	56.1±19.2	55.2±28.9	-7.2 ±16.2	-1.0±24.2	-5.9±6.6	-19.5 to 7.6
Leisure-time	37.5±19.6	30.7±14.2*	-11.4±18.1	5.8±18.6	-12.8±5.1 <sup>#</sup>	-23.2 to -2.4

Values are means (J/kg/min)±SE (SD in baseline values), non-sleep PAEE (hour of day <7am - <=23pm). Differences are estimated as the difference between means with 95% confidence intervals (95% CI), based on the 1-factor analysis of covariance (ANCOVA) with the level at baseline applied as a covariate. Only showing estimates on participants who completed both baseline and post measurements.

\*: significant difference at baseline between groups

<sup>#</sup>: significant difference in change with intervention between groups

Whole period: Monday-Sunday 7-23. Weekdays: Monday - Friday, weekends: Saturday and Sunday.

Working hours: 7-15 on weekdays, leisure-time: 15-23 on weekdays and 7-23 on weekends

### ***Self-reported physical activity and occupational workload***

#### Baseline

Perceived physical exertion at work averaged 11.1±0.4 with no difference between intervention and control group. For each of the manual material handling tasks of pushing/pulling, carrying and lifting, more than 90% of the participants reported these activities, and they were performed for ≥ 25% of working time by 50%, 57%, and 52% of the participants, respectively. Data on specific workloads are shown in Table 4. Working posture of the back was reported to be bent-double by 75% and bent or twisted by 89% of the participants, and this was true for ≥25% of working time for 38% (bent-double)

and 53% (bent or twisted) of the participants. Seventy two per cent of the participants reported work with the arm above shoulder and 20% of the participants did so for  $\geq 25\%$  of the work time. Additionally, kneeling postures were reported by 82% of the participants, and this was true for  $\geq 25\%$  of the working time for 45% of the participants. Among 45% of the participants, the respiratory rate was increased  $\geq 25\%$  of the working time (intervention group: 56%, control group 35%).

According to the IPAQ questionnaire, roughly two thirds of total physical activity is reported as occupational physical activity (6570, IQR 2970;9930 MET-min/week), and roughly one third as leisure-time physical activity ( 3871, IQR 2221;5154 MET-min/week). This difference in occupational and leisure-time activity was significant ( $p < 0.01$ ). Assuming 40 hours' work per week, self-reported activity at work corresponds to a mean activity intensity of approx. 2.7 MET which is roughly 50% higher than the directly overall measured values of work of 1.8 MET (see above).

#### Post-intervention

After the intervention, self-reported physical activity and occupational workload remained unchanged in both groups. Data on specific workloads at follow-up are shown in Table 4. The distribution of frequencies in different categories of work postures did not vary significantly from baseline measurements.

**Table 4** Percentage of participants reporting specific workloads in kg, handled  $\geq 25\%$  during working time of pushing/pulling, carrying, and lifting

Baseline							
	Load handled	Pushing/pulling		Lifting		Carrying	
		Ex (n=26)	C (n=25)	Ex (n=26)	C (n=26)	Ex (n=26)	C (n=26)
	$\geq 10$ kg	58%	52%	54%	54%	42%	42%
	$\geq 20$ kg	27%	24%	27%	12%	19%	12%
	$\geq 25$ kg	15%	20%	12%	8%	8%	4%
Post intervention							
		Ex (n=28)	C (n=23)	Ex (=29)	C (n=23)	Ex (n=29)	C (n=23)
	$\geq 10$ kg	68%	61%	62%	65%	55%	23%
	$\geq 20$ kg	18%	17%	17%	7%	17%	9%
	$\geq 25$ kg	18%	9%	14%	7%	3%	0%

Ex: exercise group, C: control group

Values are percentage of the participants reporting the specific work tasks.

### *Observations of posture and movement*

Postures and movements observed at work showed that the employees 59% of the daily working time (approximately 4.7 hours) were standing and 21% of the time (approximately 1.7 hours) were moving. Thus the employees were working in upright position bearing their own weight approximately 80% of their time. Observed postures in percent of worktime were for the back 19% bent, 12% bent-double, 1% twisted, and 3%, bent and twisted. In addition, 9% of the worktime was performed with one or two arms above shoulder height, and 6 % in kneeling posture.

## Discussion

We found rather modest metabolic workload based on self-reported and direct measures of physical activity for construction workers in this study. Leisure time physical activity was significantly lower than occupational physical activity, resulting in an overall low physical activity level in terms of metabolic load. In contrast, physical exposure at work was heavy in terms of mechanical strain from manual material handling.

Directly measured physical activity for the week was 31.3J/kg/min (across all 24 hours of the day) or approximately 45kJ/kg/24 hours. The InterAct Consortium used similar methods to quantify PAEE in 591 healthy middle-aged European men and reported a mean PAEE of 44 kJ/kg/24 hours, a result in line with the present study.<sup>28</sup> However, it is important to note that InterAct study participants had a variety of occupations, and more than 40% self-reported having “sedentary occupations”.

Analyses of time spent in different physical activity categories showed that most work and leisure time was spent on light physical activity (i.e. 1.5-3MET).<sup>22</sup> However, care must be taken when interpreting the measurements from the sensor as an indicator of total cardiovascular work exposure. Piezo-electric accelerometers do not register activity during static muscle work, as no time-varying acceleration occurs, although muscle metabolism is increased during such activity. Further, even when handling heavy loads increases HR, this may only last for a few seconds requiring beat-to-beat resolution monitoring detect this increase. Even with this methodology it would be difficult to document an increase in HR related to strenuous postures and handling of heavy loads; registration of body postures using multiple accelerometers sensitive to gravity may be required for a more comprehensive assessment of such exposures. It is indeed challenging to choose the appropriate, clinically relevant, valid and responsive measurement for physical activity since the term physical activity is multidimensional.<sup>29</sup>

The average directly assessed physical activity intensity at work was approximately 57 J/min/kg (Table 2) or 1.8 MET. Results on VO<sub>2</sub>max among this study population are previously published showing a mean value of VO<sub>2</sub>max corresponding to 2.3±0.5 (l/min).<sup>12</sup> The estimated relative workload at baseline during an 8-hour work day was  $27/79 = 34\%$  (“HR during work time above sleeping HR from the

present study” divided by the previously published “maximum HR above a resting value of 70 bpm for this group.<sup>10)</sup> This is consistent with the maximum permissible intensity level of 33% proposed in consensus guidelines.<sup>4</sup>

Measuring physical activity during work is important, as majority of adults spend many hours a day at work and activity recommendations correspond to overall physical activity. In this randomized control trial, the participants wore the combined HR and ACC sensor for 7 days pre and post-intervention. The direct measurements showed reduced physical activity after a 12-week physical exercise program (1 hour/week) in the intervention group compared to controls. Lower physical activity measured by combined HR and ACC may be a result of a lower HR with unchanged physical activity, due to an improved physical capacity as a result of the intervention, although this should be accounted for some extent by the individual calibration procedure at both pre- and post-assessment. Interestingly, estimating HR and ACC separately showed no significant decreases in HR or in trunk accelerations in the intervention group compared to controls after the intervention when distinguished between work and leisure. Since we have previously reported an increase in aerobic capacity in the intervention group, these findings may be due to leisure activities being performed more efficiently while work activity may be similarly more effective since HR and ACC measures were unchanged due to higher productivity. This is in agreement with our earlier findings of unchanged productivity although these workers spent one hour physical exercise training per week during working time.<sup>30</sup> The lack of comparable level at baseline within the work-time and leisure-time domains makes it challenging to assess the real effect of the intervention. However, within-group estimates showed only significant reduction in physical activity in the intervention group. According to self-report measurements there were no changes in mechanical workload and perceived exertion; thus, the increased individual capacity may have influenced the relative workload. The time of the post-measurements of directly measured physical activity may also have influenced the negative results since the measurements were conducted a week after the intervention ended and it cannot be excluded the possibility that the construction workers in the intervention group relaxed more than usual during that first week after a relatively hard intervention program.

To evaluate the possible health enhancing or deteriorating effects of physical activity at work, all domains of activity should be considered and evaluated relative to the recommendation during the later years adopted by many national health authorities.<sup>31</sup> In addition, specifically for the occupational domain physical activity assessment should ideally include not only a characterization of the metabolic load but also measurements of the mechanical strains on the musculoskeletal system, e.g. EMG. Biomechanical measures may assess the mechanical strain and have documented considerable physical exposure among construction workers.<sup>32, 33</sup> High mechanical strains may in contrast to the health enhancing physical activity cause musculoskeletal disorders and other aspects of deteriorated health.

In conclusion, the original hypothesis that high mechanical strain in construction work results in a metabolic load exceeding the permissible intensity levels was rejected since the metabolic load at work did not exceed 1/3 of the maximum capacity of the workers in spite of a high mechanical strain at work. Our second hypothesis, that a work site exercise program increasing fitness reduces the relative metabolic load during work, was also rejected since the exercise intervention did not further decrease the rather light metabolic load during work. Furthermore, the physical activity level at leisure-time was lower than occupational physical activity among construction workers; this was also not increased with the intervention. The low total physical activity level may in fact be responsible for the low metabolic capacity among these workers, and since their work involves exposure to strenuous mechanical workload that may be harmful to their health, general lifestyle counseling and provision of worksite training schemes should be considered for this occupational group.

### **Acknowledgments**

The authors would like to thank engineer Shadi Samir Chreiteh, Institute of Sports Science and Clinical Biomechanics, University of Southern Denmark for technical support. This study was supported by a grant from the Danish Working Environment Research Foundation and the Ministry of Culture Committee on Sports Research, Denmark.

**Funding source**

This study is part of the FINALE programme supported by a grant (16-2006-04) from the Danish Working Environment Research Foundation and the Ministry of Culture Committee on Sports Research, Denmark. This study is registered in [www.clinicaltrials.com](http://www.clinicaltrials.com) (number NCT01007669).

Conflict of interest: The authors declare that they have no conflict of interest

## References

1. Leino-Arjas P, Solovieva S, Riihimäki H, Kirjonen J, Telama R. Leisure time physical activity and strenuousness of work as predictors of physical functioning: a 28 year follow up of a cohort of industrial employees. *Occupational and Environmental Medicine* 2004;61(12):1032-8.
2. Krause N, Brand RJ, Kaplan GA, Kauhanen J, Malla S, Tuomainen T-P et al. Occupational physical activity, energy expenditure and 11-year progression of carotid atherosclerosis. *Scandinavian journal of work, environment & health* 2007;33(6):405-24.
3. Holtermann A, Hansen JV, Burr H, Sjøgaard K, Sjøgaard G. The health paradox of occupational and leisure-time physical activity. *British journal of sports medicine* 2012;46(4):291-5.
4. Bonjer F. Energy expenditure In: Parmeggiani L, editor. *Encyclopedia of Occupational Health and Safety*. Geneva: International Labour Organisation; 1971. p 458-60.
5. Mantyselka PT, Kumpusalo EA, Ahonen RS, Takala JK. Direct and indirect costs of managing patients with musculoskeletal pain-challenge for health care. *Eur J Pain* 2002;6(2):141-8.
6. Bevan S, Quadrello T, McGee R, Mahdon M, Vavrosky A, Barham L. *Fit for work? Musculoskeletal Disorders in the European Workforce*. 2009.
7. Holtermann A, Mortensen OS, Burr H, Sjøgaard 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. *Scandinavian journal of work, environment & health* 2010;36(5):357-65.
8. Telford RD. Low physical activity and obesity: causes of chronic disease or simply predictors? *Medicine and science in sports and exercise* 2007;39(8):1233-40.
9. Lee IM, Shiroma EJ, Lobelo F, Puska P, Blair SN, Katzmarzyk PT. Effect of physical inactivity on major non-communicable diseases worldwide: an analysis of burden of disease and life expectancy. *Lancet* 2012;380(9838):219-29.
10. Holtermann A, Mortensen OS, Sjøgaard K, Gyntelberg F, Suadicani P. Risk factors for ischaemic heart disease mortality among men with different occupational physical demands. A 30-year prospective cohort study. *BMJ Open* 2012;2(1).
11. Blair SN, Kohl HW, 3rd, Paffenbarger RS, Jr., Clark DG, Cooper KH, Gibbons LW. Physical fitness and all-cause mortality. A prospective study of healthy men and women. *JAMA : the journal of the American Medical Association* 1989;262(17):2395-401.
12. Gram B, Holtermann A, Sogaard K, Sjøgaard G. Effect of individualized worksite exercise training on aerobic capacity and muscle strength among construction workers--a randomized controlled intervention study. *Scandinavian journal of work, environment & health* 2012;38(5):467-75.

13. Astrand PO, Ryhming I. A nomogram for calculation of aerobic capacity (physical fitness) from pulse rate during sub-maximal work. *Journal of applied physiology* (Bethesda, Md : 1985) 1954;7(2):218-21.
14. Astrand I. Aerobic work capacity in men and women with special reference to age. *Acta physiologica Scandinavica Supplementum* 1960;49(169):1-92.
15. Brage S, Brage N, Franks PW, Ekelund U, Wareham NJ. Reliability and validity of the combined heart rate and movement sensor Actiheart. *European journal of clinical nutrition* 2005;59(4):561-70.
16. Stegle O, Fallert SV, MacKay DJ, Brage S. Gaussian process robust regression for noisy heart rate data. *IEEE transactions on bio-medical engineering* 2008;55(9):2143-51.
17. Brage S, Ekelund U, Brage N, Hennings MA, Froberg K, Franks PW et al. Hierarchy of individual calibration levels for heart rate and accelerometry to measure physical activity. *Journal of applied physiology* (Bethesda, Md : 1985) 2007;103(2):682-92.
18. Brage S, Brage N, Franks PW, Ekelund U, Wong MY, Andersen LB et al. Branched equation modeling of simultaneous accelerometry and heart rate monitoring improves estimate of directly measured physical activity energy expenditure. *Journal of applied physiology* (Bethesda, Md : 1985) 2004;96(1):343-51.
19. Thompson D, Batterham AM, Bock S, Robson C, Stokes K. Assessment of low-to-moderate intensity physical activity thermogenesis in young adults using synchronized heart rate and accelerometry with branched-equation modeling. *The Journal of nutrition* 2006;136(4):1037-42.
20. Strath SJ, Brage S, Ekelund U. Integration of physiological and accelerometer data to improve physical activity assessment. *Medicine and science in sports and exercise* 2005;37(11 Suppl):S563-71.
21. Brage S, Westgate K, Franks PW, Stegle O, Wright A, Ekelund U et al. Estimation of Free-Living Energy Expenditure by Heart Rate and Movement Sensing: A Doubly-Labelled Water Study. *PLoS one* 2015;10(9):e0137206.
22. Ainsworth BE, Haskell WL, Whitt MC, Irwin ML, Swartz AM, Strath SJ et al. Compendium of physical activities: an update of activity codes and MET intensities. *Medicine and science in sports and exercise* 2000;32(9 Suppl):S498-504.
23. Craig CL, Marshall AL, Sjoström M, Bauman AE, Booth ML, Ainsworth BE et al. International physical activity questionnaire: 12-country reliability and validity. *Medicine and science in sports and exercise* 2003;35(8):1381-95.
24. The\_IPAQ\_group. International Physical Activity Questionnaire, [www.ipaq.ki.se](http://www.ipaq.ki.se) 2014. Available from: URL: [www.ipaq.ki.se](http://www.ipaq.ki.se)

25. Holtermann A, Jorgensen MB, Gram B, Christensen JR, Faber A, Overgaard K et al. Worksite interventions for preventing physical deterioration among employees in job-groups with high physical work demands: background, design and conceptual model of FINALE. *BMC public health* 2010;10:120.
26. Borg G. Perceived exertion as an indicator of somatic stress. *Scandinavian journal of rehabilitation medicine* 1970;2(2):92-8.
27. Buchholz B, Paquet V, Punnett L, Lee D, Moir S. PATH: a work sampling-based approach to ergonomic job analysis for construction and other non-repetitive work. *Applied ergonomics* 1996;27(3):177-87.
28. Peters T, Brage S, Westgate K, Franks PW, Gradmark A, Tormo Diaz MJ et al. Validity of a short questionnaire to assess physical activity in 10 European countries. *European journal of epidemiology* 2012;27(1):15-25.
29. Bussmann JB, van den Berg-Emons RJ. To total amount of activity..... and beyond: perspectives on measuring physical behavior. *Frontiers in psychology* 2013;4:463.
30. Gram B, Holtermann A, Bultmann U, Sjogaard G, Sogaard K. Does an exercise intervention improving aerobic capacity among construction workers also improve musculoskeletal pain, work ability, productivity, perceived physical exertion, and sick leave?: a randomized controlled trial. *Journal of occupational and environmental medicine / American College of Occupational and Environmental Medicine* 2012;54(12):1520-6.
31. Garber CE, Blissmer B, Deschenes MR, Franklin BA, Lamonte MJ, Lee IM et al. American College of Sports Medicine position stand. Quantity and quality of exercise for developing and maintaining cardiorespiratory, musculoskeletal, and neuromotor fitness in apparently healthy adults: guidance for prescribing exercise. *Medicine and science in sports and exercise* 2011;43(7):1334-59.
32. Tak S, Buchholz B, Punnett L, Moir S, Paquet V, Fulmer S et al. Physical ergonomic hazards in highway tunnel construction: overview from the Construction Occupational Health Program. *Applied ergonomics* 2011;42(5):665-71.
33. Hartmann B, Fleischer AG. Physical load exposure at construction sites. *Scandinavian journal of work, environment & health* 2005;31 Suppl 2:88-95.

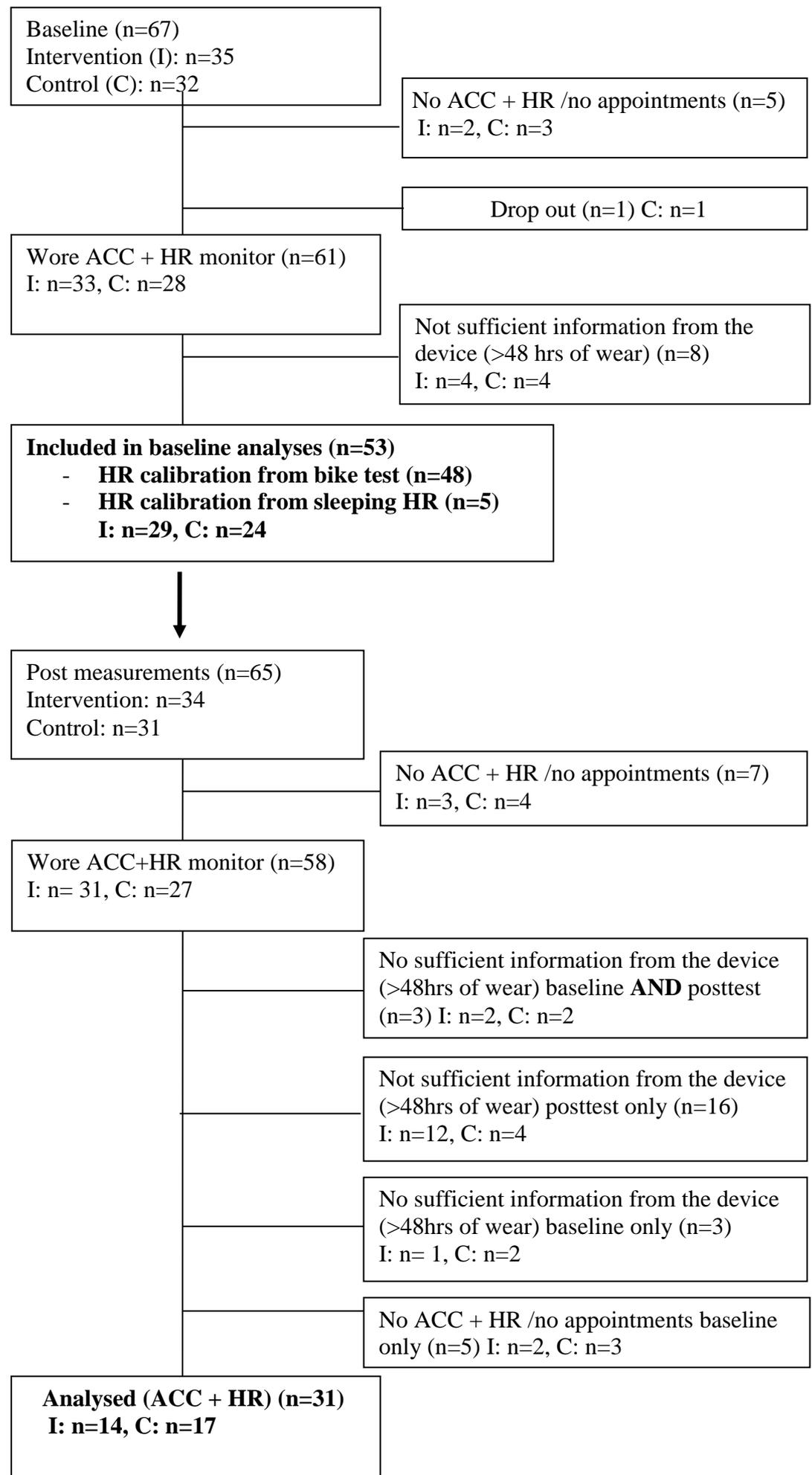
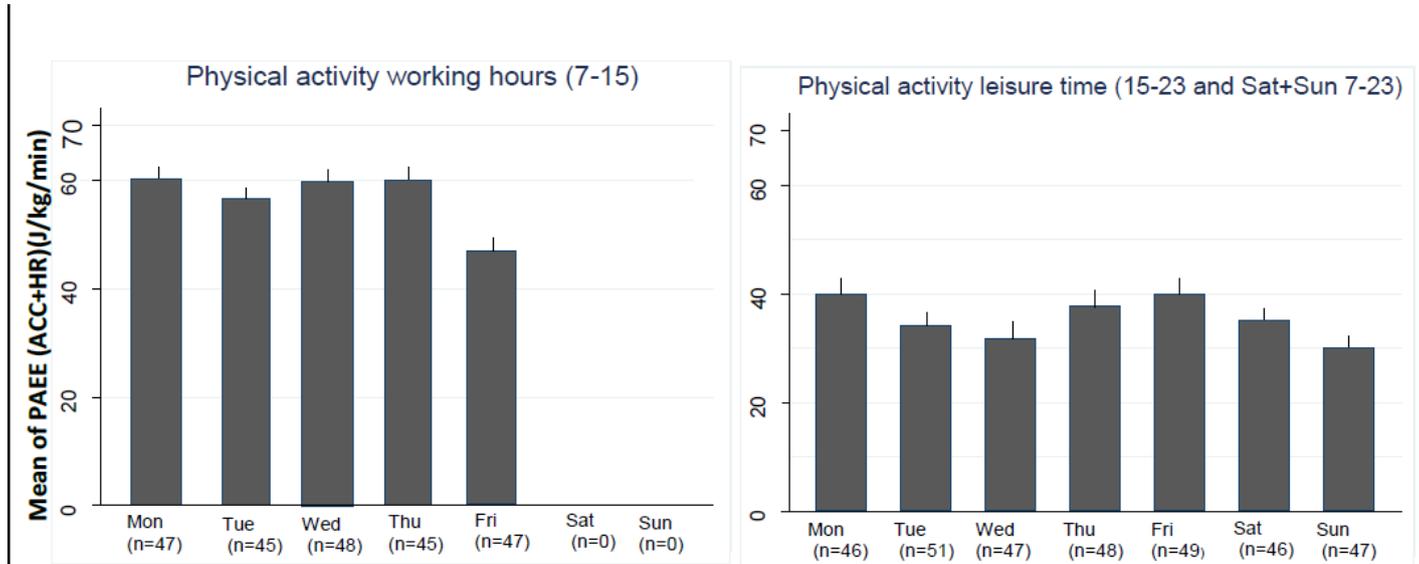
**Figure 1 Flowcart - ACC and HR measurements**

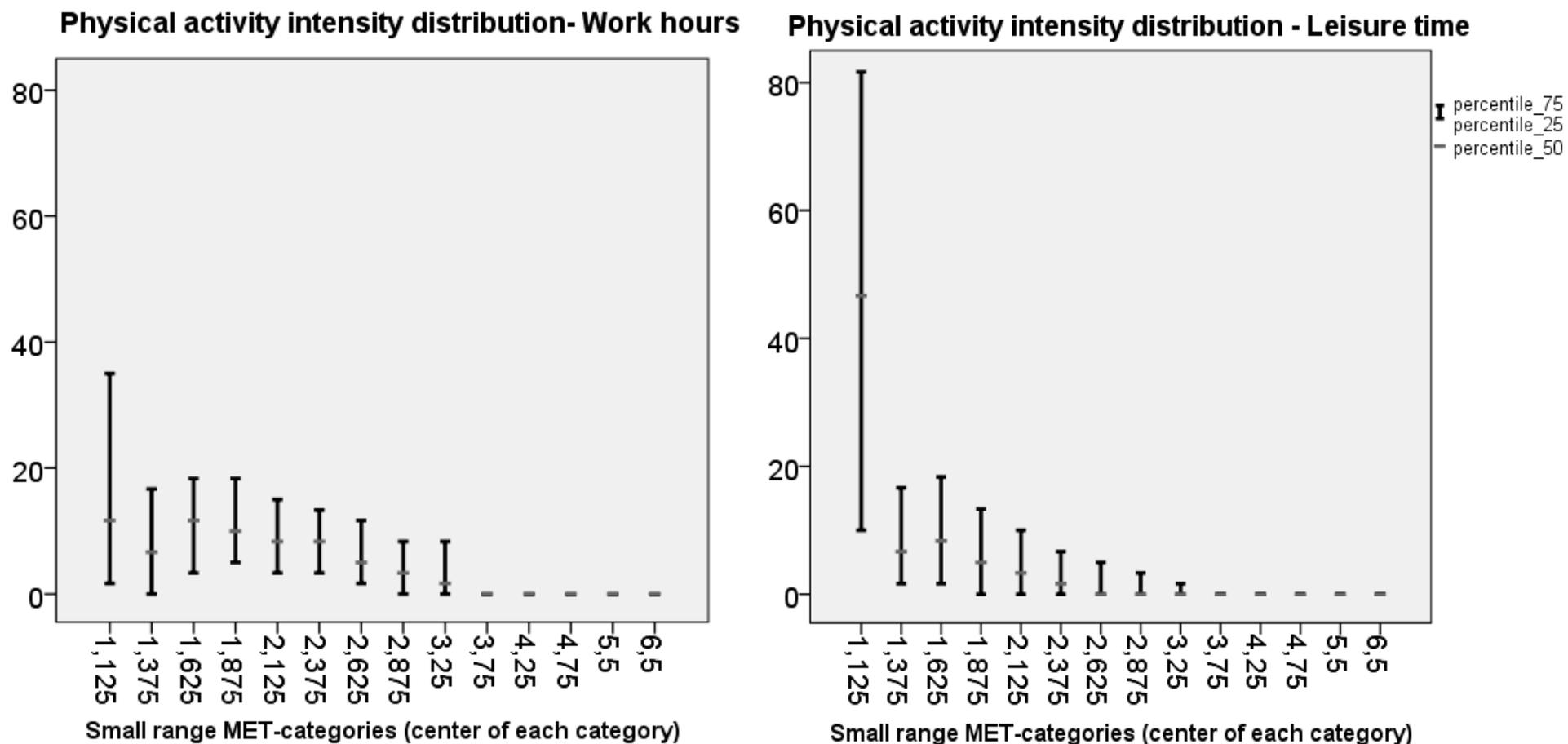
Figure 2

**Figure 2 Physical activity energy Expenditure for each day of the week**

The PAEE are presented as mean values, the bars indicating  $\pm$ SE

Figure 3

**Figure 3 Physical activity intensity distributions during work and leisure time**



The fraction of time spent on “small range” MET-categories plotted against the mean value for each category. The fraction of time is presented as median value and the bars indicate 25 and 75 percentiles, respectively.