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Exposure to Upper Arm Elevation During Work Compared to Leisure Among 12 Different Occupations Measured with Triaxial Accelerometers

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Abstract

Regarding prevention of neck and shoulder pain (NSP), unsupported arm elevation is one factor that should be taken into account when performing work risk assessment. Triaxial accelerometers can be used to measure arm elevation over several days but it is not possible to differentiate between supported and unsupported arm elevation from accelerometers only. Supported arm elevation is more likely to exist during sitting than standing. The aim of the study was to evaluate the use of whole workday measurements of arm elevation with accelerometers to assess potentially harmful work exposure of arm elevation, by comparing arm elevation at work with arm elevation during leisure, in a population with diverse work tasks, and to assess how the exposure parameters were modified when upper arm elevation during sitting time was excluded. The participants, 197 workers belonging to 12 occupational groups with diverse work tasks, wore triaxial accelerometers on the dominant arm, hip, and back for 1–4 days to measure arm elevation and periods of sitting. None of the groups were found to have higher exposure to arm elevation during work compared to leisure. Even though some occupations where known to have work tasks that forced them to work with elevated arms to a large extent. A high proportion of arm elevation derived from sitting time, especially so during leisure. When arm elevation during sitting time was excluded from the analysis, arm elevation was significantly higher at work than during leisure among construction workers, garbage collectors, manufacturing workers, and domestic cleaners. Together this illustrates that it is not suitable to use whole workday measurments of arm elevation with accelerometer as a sole information source when assessing the risk for NSP due to arm elevation. Information on body posture can provide relevant contextual information in exposure assessments when it is known that the potential harmful exposure is performed in standing or walking.

Keywords: accelerometer; arm elevation; leisure; musculoskeletal disorders; risk assessment; shoulder load; work

Introduction

Neck and shoulder pain (NSP) are common in the general population (Luime *et al.*, 2004; Palmer and Smedley, 2007). Awkward (e.g. elevated) arm posture is one of several work-related risk factors for NSP (Viikari-Juntura *et al.*, 2001; Christensen and Knardahl, 2010; van Rijn *et al.*, 2010). This can be explained by the induced increase in the intramuscular pressure in the shoulder (Palmerud *et al.*, 2000) and sustained muscle activation in the neck and shoulder muscles (Visser and van Dieën, 2006) when the arms are elevated.

Risk assessments of NSP are often performed by occupational health services (OHS) ergonomists, who often express a need for quick and simple methods for performing proper risk assessments. Currently, assessments of neck and shoulder load are based primarily on interviews or visual observations covering short periods of the workday. Arm elevation is one of the essential risk factors ergonomists assess during upper body work, and arm elevation assessment is included in many systematic risk assessment methods (Takala *et al.*, 2010). At present, such methods assess arm elevation at work using visual observation. However, observations of arm elevation made for only short periods of the workday may be inaccurate (Liv *et al.*, 2012), and self-reports and interviews may be inaccurate and potentially biased (Hansson *et al.*, 2001).

Triaxial accelerometers has been used in research projects to objectively measure arm elevation toward the line of gravity during full workdays (Hansson *et al.*, 2010; Wahlström *et al.*, 2010; Wahlström *et al.*, 2016; Koch *et al.*, 2017). They are often referred to as inclinometers. Assessment of arm elevation using accelerometers has also been shown to be more cost-effective than observations (Trask *et al.*, 2014).

Associations between accelerometric data on upper arm elevation over the whole workday and shoulder disorders have been demonstrated in machinists, car mechanics, house painters, and hairdressers (Svendsen *et al.*, 2004a,b; Hanvold *et al.*, 2015). In addition, associations between neck complaints and accelerometric data on arm elevation over the whole workday have been reported (Nordander *et al.*, 2016). A Swedish research group has suggested that unsupported arm elevation > 60 degrees for more than 10 % of the workday could imply a risk for disorders (Hansson *et al.*, 2016).

Accelerometric data have been shown to be valid in terms of measuring the angle towards the line of gravity, in semi-standardized working tasks (Korshøj *et al.*, 2014; Dahlqvist *et al.*, 2016). However, there might be problems associated with using accelerometric data when assessing the risk for NSP due to arm elevation. Without simultaneous visual observations, it is impossible to determine whether or not periods showing elevated arms involve supported arms. Some situations of high arm elevation can be misjudged as harmful for the shoulder, e.g. when sitting relaxed in a sofa or armchair with arms on an armrest or when sitting with arms behind the neck. If these situations are common, this may introduce bias into the assessment. Based on common sense and experience, we can assume that in many occupations, the arms are probably more often supported during sitting time than in upright position.

At work, the task and the physical design of the workplace will affect how much a worker needs to elevate their arms into constraint postures. During leisure, a person can to a higher degree choose their activities and avoid constraint arm postures. It is therefore most likely that workers that have work tasks that forces them to work with elevated arm will have a higher exposure to upper arm elevation during work than leisure.

In a large Danish study (NOMAD), whole-day measurements, during both work and leisure, with accelerometers positioned on the arm and thigh were made on workers from different occupations. Some of these occupations were known to involve work tasks that forced workers to work with highly elevated arms, while other groups did not have such tasks. From the thigh accelerometer, used in NOMAD, it is possible to measure when the person is sitting or upright (Skotte *et al.*, 2014; Stemland *et al.*, 2015).

It is of interest to explore whether it can be an alternative to exclude periods of arm elevation during sitting to better describe potential harmful arm elevation when measuring over the full workday.

The aim of the study was to evaluate the use of whole workday measurements of arm elevation with accelerometers to assess potentially harmful work exposure of arm elevation, by comparing arm elevation at work with arm elevation during leisure, in a population with diverse work tasks, and to assess how the exposure parameters were modified when upper arm elevation during sitting time was excluded.

Methods

Study design and population

Workers from the cross-sectional Danish study New Method for Objective Measurements of Physical Activity in Daily Living (NOMAD) were chosen for the present investigation (Gupta *et al.*, 2015; Hallman *et al.*, 2015). Occupations with a high prevalence of musculoskeletal disorders and with varying exposures of physical load at work were selected based on Danish surveys and registers. Seven different workplaces were recruited by convenience. At these workplaces construction work, cleaning, garbage collection, manufacturing, assembling, and mobile plant operations were performed and health services were provided. At each workplace as many workers as possible in the production were invited to participate. Diurnal measurements were performed using accelerometers placed on the shoulder, thigh, hip, and trunk of 259 workers. The workers volunteered and the inclusion criteria were as follows: primary work of at least 20 h week^{-1}, age between 18 and 65 years, and informed consent given. The exclusion criteria were as follows: being pregnant, having a fever or reported skin allergy to adhesive tape, which is used for attaching the accelerometers. The recruitment process is explained more in depth in Hallman *et al.* (2015).

The study was approved by the Ethics Committee for the Capital Region of Denmark (journal number H-2-2011-047) and was conducted in accordance with the Declaration of Helsinki.

Occupational groups

The workers were categorized into 12 different occupational groups, depending on their self-reported answer to the question 'What is your present occupation, more precisely?' and on the researchers' observations during the data collection. The resulting descriptions of their respective jobs are as follows:

- *Assemblers* mainly put together small electronic devices and wound coils at a manufacturing company.
- *CAD/CAM (office) workers* were technical assistants, robot programmers, designers, and project planners in the same company as the assemblers.
- *Cleaners (domestic)* worked at an elderly care facility.
- *Cleaners (aircraft)* cleaned aircrafts.
- *Construction workers/paviors* did paving work.
- *Construction workers/outdoor workers* pulled and dug for cables and pipes.
- *Construction workers/machine operators* operated machines like excavators.
- *Construction workers (a combination of the two above)* both pulled and dug for cables and pipes and operated machines.
- *Garbage collectors* manually collected and brought garbage cans to a truck and also drove the truck.
- *Managers and health professionals* were managers, nurses, physiotherapists, administrative personnel, health and safety professionals in an elderly care facility, a manufacturing company and a waste disposal company.
- *Manufacturing workers with form building tasks* constructed forms before molding large products.
- *Manufacturing workers with finishing tasks* polished these large products after molding. These tasks often involved work with highly elevated arms.

The four groups of construction workers worked within the same construction company but were engaged in different work tasks. The two groups consisting of manufacturing workers were from one production site and were engaged in repetitive and physically demanding work tasks. Workers with mixed work tasks and those belonging to groups with fewer than seven participants were excluded.

Data collection

The workers completed a questionnaire including demographic variables. They were also asked to rate their worst pain intensity in the neck and shoulder regions separately on a numeric scale; ratings concerned the previous month. This scale ranged from 0 (no pain) to 9 (worst pain imaginable).

Four triaxial accelerometers (Actigraph GT3X, ActiGraph LLC, FL, USA) were attached to each worker. One was attached to the right upper arm 3 cm below the deltoid insertion, as described by Korshøj *et al.* (2014), and another was attached to the trunk between the processus spinosus T1–T2. The third was placed on the front of the right thigh midway between the iliac crest and the upper line of patella, and the fourth was placed on the hip. Actigraph is a compact water-resistant device (19 × 34 × 45 mm, weight 19 g) that measures triaxial acceleration with a sampling frequency of 30 Hz, a dynamic range of ±6 G (1G = 9.81 m/s^2) and a precision of 12 bits.

The workers were instructed to wear the accelerometers 24 h a day for the following 4 days. They were instructed to

(i) take off the accelerometers if they caused itching or any kind of discomfort; (ii) perform a reference measurement in a upright standing position for 15 s every day; (iii) fill in a short diary everyday concerning their working hours, bedtime, non-wear time, and time of reference measurement.

Data processing

The accelerometric data were processed using the custom-made Acti4 software (Skotte *et al.*, 2014). Data from the accelerometers on the thigh and trunk were used to identify periods when the workers were lying down, sitting, standing, moving (e.g. standing with small movements without regular walking), walking, running, or walking on stairs. Data from the hip accelerometer were used when trunk data were missing. The activities were defined for 2 s periods with a 50% overlap.

Briefly, raw accelerometric data in relation to three axes (x, y, z) were low-pass filtered using a sixth-order Butterworth filter with a cut-off frequency of 2 Hz. The angles (°) of the thigh, hip, trunk, and arm in relation to the line of gravity were then calculated as arccos (Ax/(A^2x + A^2y + A^2z)$^{1/2}$), where Ax, Ay, and Az were the filtered signals for the three axes of the corresponding accelerometer and X axis was the vertical direction. These angles were calibrated against the daily reference measurement. Sitting time was identified when, in relation to the line of gravity, the thigh angle was above 45° and the trunk angle was below 45°. The procedure for identifying activities has been explained previously (Skotte *et al.*, 2014; Gupta *et al.*, 2015) and validated (Stemland *et al.*, 2015). The use of arm accelerometers to measure arm elevation in relation to the line of gravity has been described and validated (Korshøj *et al.*, 2014).

In the final analysis, all time classified as lying down according to the Acti4 algorithm was excluded. A measured day was considered valid if it comprised both objective measurements from hip or trunk, and arm of at least 4 h of work and 4 h of leisure, and 75% of the individual's average working or leisure time. Work and sleep periods was based on self-reports. The leisure time was defined as the waking hours, on each workday, that were not spent working (leisure time = 24 h – sleep time – work time). The average working time (mean) was 6.9 h day^{-1} and the leisure time (mean) was 8.4 h day^{-1}. In total, 12 workers did not fulfill these criteria, leaving 197 workers in the study population. These criteria were used in earlier papers on the same material (Gupta *et al.*, 2015; Hallman *et al.*, 2015). For each worker, the mean value over the valid measured days was calculated for:

1. the 50th, 90th, and 99th percentile of arm elevation during work and leisure
2. percentage of arm elevation at work (time with arm inclination >60° and >90° at work/total time at work)
3. percentage of arm elevation at leisure (time with arm inclination >60° and >90° at leisure/total time at leisure)
4. percentage of arm elevation >60° and >90° at work when arm elevation during sitting time was excluded/total time at work
5. percentage of arm elevation >60° and > 90° at work when arm elevation during sitting time was excluded/total time at leisure.

Statistics

To assess the difference in arm elevation between work and leisure, the logarithm of differences in percentage of time with arm elevation >60° for each occupational group during work was compared to the mean value for all workers during leisure. The differences were calculated using linear mixed models with T-distribution. To account for multiple comparisons, adjustment of the confidence intervals were made with Dunnets post hoc test. These parametric models used the data in an optimal manner (Heller, 2012). A random effect was included for the intercept with each worker as a subject and with a compound-symmetry covariance structure. With this distribution and covariance structure, the residuals for the model were sufficiently normally distributed for the assumptions of the linear mixed model. Age, height, and pain in neck and shoulder were considered to be possible confounders and were adjusted for. The model included occupational groups and pain in neck or shoulder (>4 of pain intensity, on a 0–9-scale) as a fixed class effects, while age and height were continuous fixed variables.

Results

Eighty-six female and 111 male workers were included in the analysis. The details of their occupation and main work tasks are provided in Table 1.

In total, 6629 valid hours (3316 during work and 3312 during leisure) and 1–4 days of arm posture data were analyzed. The total sitting time during work was 1284 h (39%) and during leisure 1794 h (54%). The mean percentage of sitting time during work ranged from about 20% among manufacturing workers to 69% among CAD/CAM workers (Table 2). During leisure, there were fewer differences between the occupational groups regarding percentage of time sitting (range: 43% among aircraft cleaners to 66% among construction workers who were pulling, digging, and driving excavators at work) (Table 2).

Table 1. Number of females (F) and males (M), mean age, height (cm), reported work time (h) (leisure time= 24 h – work time – sleep time) each day among the different occupational groups.

	N		Age	Height	Work time	Leisure time
	F	M	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)
Assemblers	26	3	48 (9)	168 (8)	7.9 (1.0)	9.1 (1.5)
CAD/CAM (office workers)	6	9	47 (7)	175 (6)	8.3 (0.9)	8.0 (1.2)
Cleaners (aircraft cleaning)	11	5	42 (7)	170 (9)	7.4 (1.1)	8.5 (1.5)
Cleaners (domestic cleaning)	9	0	53 (7)	162 (6)	6.4 (0.6)	10.3 (1.3)
Construction outdoor workers (pulling, digging cable and pipe)	0	11	41 (7)	177 (8)	7.9 (0.9)	9.1 (1.3)
Construction workers machine operator (excavator)	0	8	41 (13)	183 (9)	7.6 (1.6)	10.4 (2.2)
Construction workers (combination of the two above)	0	16	40 (18)	178 (8)	7.9 (1.4)	9.4 (1.4)
Construction workers, paviors	0	8	49 (12)	181 (6)	8.5 (0.7)	9.1 (0.7)
Garbage collectors	0	19	45 (7)	183 (7)	5.1 (0.9)	12.9 (1.6)
Managers and health professionals	5	5	47 (9)	175 (11)	7.6 (1.1)	8.9 (1.5)
Manufacturing workers (finishing tasks)	14	22	48 (8)	175 (9)	11.6 (1.7)	6.1 (2.4)
Manufacturing workers (form building tasks)	2	5	37 (10)	176 (10)	12.2 (0.1)	4.9 (0.6)
Social and health care workers	13	0	47 (13)	167 (6)	7.5 (0.8)	9.2 (1.7)
All occupations	86	111	45 (9)	174 (10)	8.3 (2.3)	8.7 (2.5)

Table 2. Distribution of number of days measured, total time (h) measured during work and leisure, and the percentage of the time measured (%) during work and leisure that were defined as sitting time by the Acti4 algorithm.

	Number of days measured (distribution)				Work hours measured / person	Where of sitting %[a]	Leisure hours measured / person	Where of Sitting %[b]
	1	2	3	4	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)
Assemblers	12	11	4	2	14 (7)	50 (19)	18 (10)	52 (15)
CAD/CAM (office workers)	2	12	1	0	15 (4)	69 (11)	17 (5)	50 (19)
Cleaners (aircraft cleaning)	4	10	1	1	15 (7)	57 (5)	17 (7)	43 (13)
Cleaners (domestic cleaning)	0	9	0	0	13 (1)	24 (9)	22 (2)	49 (17)
Construction outdoor workers (pulling, digging cable and pipes)	3	3	5	0	17 (7)	40 (19)	21 (9)	58 (15)
Construction workers machine operator (excavator)	3	9	4	0	13 (7)	61 (10)	18 (9)	66 (14)
Construction workers (combination of the two above)	4	2	2	0	17 (7)	50 (10)	19 (6)	56 (9)
Construction workers, paviors	1	0	7	0	22 (6)	48 (6)	26 (7)	56 (13)
Garbage collectors	14	4	1	0	6 (2)	40 (15)	17 (8)	49 (10)
Managers and health professionals	5	4	0	1	13 (9)	56 (15)	14 (6)	52 (6)
Manufacturing workers (finishing tasks)	11	8	12	5	28 (14)	20 (10)	13 (5)	64 (13)
Manufacturing workers (form building tasks)	3	3	0	1	23 (13)	19 (5)	9.0 (5)	51 (17)
Social and health care workers	7	3	3	0	13 (7)	36 (12)	15 (8)	57 (12)
All workers	69	78	40	10	17 (10)	43 (20)	17 (8)	55 (15)

[a]Percentage of the measured time at work that the workers were sitting.
[b]Percentage of the measured time at leisure that the workers were sitting.

The highest mean exposure to elevated arms during work was observed among construction workers, followed by garbage collectors, and manufacturing workers doing mold building and finishing tasks (percentage of time >60°) (Table 3). The least exposure to elevated arms during work was observed among assemblers.

Table 3. Arm elevation (mean, SD) for the different occupational groups at work and for all workers at leisure time.

	Arm elevation during both sitting and non-sitting					Arm elevation during sitting excluded	
	p50 °	p90 °	P99°	Percentage of time with arm above 60°	Percentage of time with arm above 90°	Percentage of time with arm above 60	Percentage of time with arm above 90°
	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)
Assemblers	16.6 (4.3)	38.3 (6.9)	71.3 (12.5)	2.4 (1.5)	0.4 (0.4)	1.8 (1.5)	0.3 (0.4)
CAD/CAM (office workers)	25.0 (7.4)	41.8 (6.8)	76.7(15.6)	2.4 (1.5)	0.6 (0.4)	0.9 (0.9)	0.1 (0.2)
Cleaners (aircraft cleaning)	26.0 (5.2)	54.7 (8.1)	92.9 (16.5)	7.5 (5.0)	1.2 (0.9)	1.8 (0.4)	0.4 (0.2)
Cleaners (domestic cleaning)	24.8 (4.1)	50.9 (6.6)	89.3 (10.8)	6.0 (2.9)	1.1 (0.6)	5.2 (3.0)	0.9 (0.6)
Construction outdoor workers (pulling, digging cable, and pipes)	29.8 (5.0)	61.5 (10.2)	104 (17.6)	11.9 (5.5)	2.5 (1.4)	6.6 (3.9)	1.6 (1.2)
Construction workers machine operator (excavator)	27.6 (3.5)	63.1(11.1)	114 (27.5)	11.8 (4.7)	2.7 (1.9)	3.6 (1.2)	0.8 (0.3)
Construction workers (combination of the two above)	29.0 (4.4)	62.7 (8.9	101 (11.4)	12.6 (5.1)	2.1 (1.1)	5.5 (2.1)	1.2 (0.7)
Construction workers, paviors	29.2 (6.6)	63.1 (11.5)	107 (25.4)	11.7 (6.7)	3.0 (2.8)	5.2 (3.2)	1.5 (1.4)
Garbage collectors	29.4 (6.3)	57.4 (8.1)	86.3 (9.2)	9.1 (5.3)	1.1 (0.9)	5.1 (2.5)	0.7 (0.5)
Managers and health professionals	19.7 (5.2)	39.8 (5.9)	85.7 (25.8)	2.7 (1.1)	0.8 (0.7)	1.2 (0.6)	0.3 (0.2)
Manufacturing workers (finishing tasks)	22.6 (3.9)	58.6 (9.7)	105 (13.2)	9.8 (5.2)	2.8 (2.7)	8.4 (4.3)	2.5 (2.4)
Manufacturing workers (form building tasks)	22.6 (4.2)	54.4 (9.3)	110 (16.6)	8.3 (3.0)	2.7 (1.3)	7.1 (2.4)	2.4 (1.2)
Social and health care workers	21.9 (4.2)	46.0 (4.3)	86.4 (11.0)	3.8 (1.2)	0.9 (0.4)	2.7 (1.2)	0.7 (0.4)
All occupation groups at work	24.1 (6.5)	52.5 (12.1)	92.4 (20.0)	7.4 (5.5)	1.6 (1.8)	4.4 (3.6)	1.1 (1.4)
			Leisure time				
All occupation groups during leisure	29.0 (7.3)	60.7 (15.8)	104 (23.9)	10.4 (7.2)	2.1 (2.5)	2.3 (1.3)	0.7 (0.5)

During leisure time, the mean exposure to elevated arms >60° was 10.4% compared to 7.4% during work time. When arm elevation during sitting was excluded, arm elevation during leisure was lowered to 2.3% compared to 4.4% during work. Thus, most of the arm elevation during leisure derived from sitting time (Table 3).

None of the occupational groups had higher exposure to arm elevation during work than the mean leisure exposure for all workers, see Fig. 1. Instead, arm elevation was lower at work compared to leisure for assemblers, CAD CAM office workers, managers, and health professionals as well as social and health care workers (Fig. 1). These differences were statistically significant ($P < 0.05$).

In contrast, when arm elevation during sitting was excluded, exposure to arm elevation was significantly higher ($P < 0.05$) during work compared to leisure for domestic cleaners, construction workers, garbage collectors, and manufacturing workers. Arm elevation was significantly lower during work than leisure, when arm elevation during sitting was excluded, among all other occupations, except for aircraft cleaners and social and health care workers.

Discussion

In this study, we evaluated the use of accelerometers to assess potentially harmful exposure of upper arm elevation at work by comparing work exposure with leisure exposure. The workers were from 12 different occupational groups. Some of the groups were known to have work tasks that forced the workers to work with highly elevated arms while other groups did not have such tasks. As a try to better estimate potential harmful arm elevation, the analysis were performed with and without upper arm elevation during sitting in the analysis, as unsupported arm elevation are more likely to occur in standing and walking positions than during sitting. The whole-day accelerometric measurements did not identify any of the occupational groups as having a higher exposure to arm elevation at work compared to leisure. A high proportion for arm elevation derived from sitting time especially so during leisure. In this material, it can be questioned whether this is harmful arm elevation. When sitting time was removed from the analysis, the domestic cleaners, construction workers, garbage collectors, and manufacturing workers were identified as having higher exposure to arm elevation at work compared to leisure. However, the electronics assemblers, CAD CAM office workers, managers, health professionals, and social and health care workers were identified as having somewhat and significant lower exposure to elevated arms during work compared to leisure. Thus, occupation explained more of the difference between work and leisure when arm elevation during sitting time was removed from the analysis.

In a Swedish report (Hansson *et al.*, 2016), a research group proposed that an arm elevation >60° for more than 10.4% of the working day may be considered a risk for shoulder disorders. These recommendations were based on consensus within the research group, which has long experience of doing both whole-workday measurements of arm inclination and medical examinations, among more than 40 occupations. In this study, the construction workers were exposed to arm elevation >60° for 12% of the time. Thus, according to

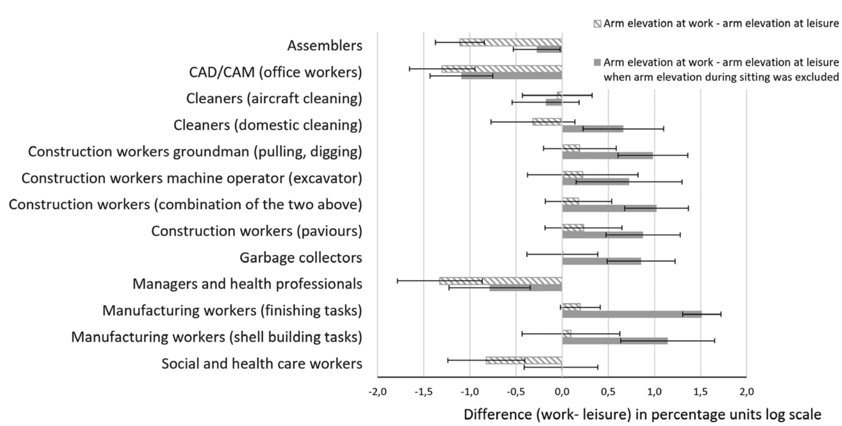

Figure 1. Difference between work and leisure with arm raised above 60°, adjusted for age, height, neck or shoulder pain during total time (bars with stripes) and when arm elevation during sitting excluded (grey bars). Error bars indicate 95 % . Positive values indicate higher duration of arm elevation during work than leisure. Negative values indicate lower duration of arm elevation during work than leisure.

these recommendations, they could 'on average' be considered at risk for developing shoulder disorders. The manufacturing workers doing finishing tasks worked 9.8% of the time with their arms above 60°, and the garbage collectors 9.1%, placing both groups close to this recommended limit. All of these groups are known to have a high prevalence of neck and shoulder disorders. According to statistics from Sweden, construction workers, industrial workers, and garbage collectors belong to the five occupational groups with the highest number of shoulder diagnoses among males, leading to sick leave for more than 14 days (Försäkringskassan, 2011). In summary, this indicates that the proposed recommendation—to consider arm elevation >60° for more than 10% of the working day a risk—would seem to be reasonable. However, in this study, the mean percentage of time with an arm elevated during leisure was as high as 10%. Thus many workers had exposure during leisure, which would imply a risk according to the suggested risk level recommendation. This questions the use of whole workday measurements of arm elevation as a sole information source when assessing the risk for NSP due to arm elevation.

Based on the present data, we cannot explain the high exposure to arm elevation during leisure time. It may be that many workers performed activities involving constrained arm postures and high exposure to arm elevation. However, most of the exposure to arm elevation during leisure occurred during sitting time. We can only speculate that a more probable explanation is that, while sitting and relaxing, people are able to sit with their hands behind the neck (Trask *et al.*, 2013) or to lean for long periods with arms elevated though supported by an armrest or desktop (Hansson *et al.*, 2010). Because arms are supported in these situations, it is likely that they generate a much lower risk for developing pain compared to loaded or unsupported arm elevation. To what extent this can impair the validity of using whole-day accelerometric measurements of arm elevation as a risk indicator for shoulder and neck pain needs to be further investigated. Thus this study indicates that only looking at the results of whole-day accelerometric measurement of arm elevation without knowing more about the context and the person's activities may result in misleading conclusions.

If we assume that arm elevation during sitting is more often supported than during standing, the earlier association between arm elevation and pain that other authors have found based on whole-day measurements might have been stronger if they excluded arm elevation during sitting from their analysis (Svendsen *et al.*, 2004a,b; Hanvold *et al.*, 2015; Nordander *et al.*, 2016). This is particularly true for occupations where the main demanding work tasks are performed in standing or walking positions.

The algorithms used in this study do not allow us to determine whether or not the arm was supported. One alternative for evaluating whether or not the shoulder position is supported could be to make electromyographic (EMG) measures of the shoulder muscles. However, EMG is more complicated for practitioners than using accelerometers, and thus not feasible for assessing the risk of developing musculoskeletal pain in a work situation.

To our knowledge, this is the first time arm elevation during leisure has been presented and the first time whole-workday measurements of arm posture have been reported for aircraft cleaners, garbage collectors, managers, and health professionals, as well as manufacturing workers with finishing or mold building tasks. The exposure data for the domestic cleaners were similar to whole-workday data on 22 hospital cleaners collected in an extended organization where the cleaners performed auxiliary work tasks such as planning, client contacts and conference services (50th percentile: 25° compared to 26° (Unge *et al.*, 2007), 99th percentile: 89° compared to about 90° (Hansson *et al.*, 2010). Assembly workers' exposure was in line with that of 12 female workers assembling thermosets [99th percentile: 72° compared to about 75° (Hansson *et al.*, 2010)]. Social and health care workers' exposure was in line with that of 11 female nursery workers (99th percentile: 86° compared to about 82° [Hansson *et al.*, 2010)]. Construction workers in the present study were highly exposed, but probably not to the same degree as house painters, who have been observed to work 9% of the workday at angles >90° (Svendsen *et al.*, 2005; Heilskov-Hansen *et al.*, 2014).

The difference in arm elevation between work and leisure among the different occupations could be affected by several factors, such as body height, pain, and sex. A short person is likely to elevate his/her arms more than a tall person to reach a distant object. Pain in the neck or shoulder may lead to avoidance and inability to work with elevated arms. However, none or very small differences in arm elevation during work and leisure were found between the crude and the adjusted statistical model for these factors. It was not possible to adjust for sex in the present material, as both sexes were not represented in all occupation groups.

At larger elevation angles, accelerometers have been shown to underestimate the 'true' arm elevation angle. To adjust for this underestimation, a calibration model has been suggested (Jackson *et al.*, 2015). This was not applied in the present study, because it had not been done in earlier studies and it is not likely to affect the difference between work and leisure.

When accelerometers are used to assess angles, the angles are uncertain during very fast movement. However generally, for human movement, this is not considered a significant issue.

The data loss in the present study was mainly due to that data from weekends were excluded, but also due to the criteria that there should be both at least 4 h and at least 75% of the work time and at least 4 h and at least 75% of the leisure time with valid data.

The results of the present study indicate that if accelerometric measurements are to be used as a source of information when performing a work risk assessment, it is essential to combine accelerometric data on arm elevation with other kinds of data indicating whether the captured arm elevation, in that specific context, also induced physical load on the neck or shoulders. If demanding work tasks are performed in standing or walking situations, a second accelerometer capturing when a person is not sitting may provide such valuable information.

Conclusion

In this study, no occupation was identified as having a higher upper arm elevation time during work compared to leisure. Even though some occupations where known to have work tasks that forced them to work with elevated arms to a large extent. This illustrates that it is not suitable to use whole workday measurements of arm elevation with accelerometer as a sole information source when assessing the risk for NSP due to arm elevation.

When arm elevation during sitting time was excluded from the analysis, arm elevation was significantly higher during work compared to leisure among domestic cleaners, construction workers, garbage collectors, and manufacturing workers.

This illustrates that combining measurements of arm elevation with accelerometric data indicating when the person is sitting can provide relevant contextual information in exposure assessments when it is known that the potential harmful exposure is performed in standing or walking.

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