Eur J Appl Physiol (2014) 114:1901–1911
DOI 10.1007/s00421-014-2918-6

ORIGINAL ARTICLE

Sex differences in muscular load among house painters performing identical work tasks

Jacob Meyland · Thomas Heilskov-Hansen · Tine Alkjær · Henrik Koblauch · Sigurd Mikkelsen · Susanne Wulff Svendsen · Jane Frølund Thomsen · Gert-Åke Hansson · Erik B. Simonsen

Received: 22 December 2013 / Accepted: 16 May 2014 / Published online: 7 June 2014

Abstract
Purpose The present study aimed to estimate possible differences in upper body muscular load between male and female house painters performing identical work tasks. Sex-related differences in muscular load may help explain why women, in general, have more musculoskeletal complaints than men.
Methods In a laboratory setting, 16 male and 16 female house painters performed nine standardised work tasks common to house painters. Unilateral electromyography (EMG) recordings were obtained from the supraspinatus muscle by intramuscular electrodes and from the trapezius, extensor and flexor carpi radialis muscles by surface electrodes. Relative muscular loads in %EMG_{max} as well as exerted force in Newton, based on ramp calibrations, were assessed. Sex differences were tested using a mixed model approach.
Results Women worked at about 50 % higher relative muscular loads than men in the supraspinatus and forearm muscles at all percentiles and in all tasks. Women exerted about 30 % less force in the trapezius muscle at the 50th percentile.
Conclusions Female house painters had a higher relative muscular load than their male colleagues without exerting more force. The effects of a higher relative muscular load accumulated over years of work may in part explain why musculoskeletal complaints in the upper body occur more frequently among women than men.

Keywords Electromyography · EMG · Surface EMG · Intramuscular EMG · Force · Upper extremity · Musculoskeletal complaints · Occupational medicine

Communicated by Peter Krustrup.

J. Meyland (✉) · T. Heilskov-Hansen · S. Mikkelsen · J. F. Thomsen
Department of Occupational and Environmental Medicine, Bispebjerg University Hospital, Bispebjerg Bakke 23, 2400 Copenhagen, Denmark
e-mail: jmeyland@gmail.com

T. Alkjær · H. Koblauch · E. B. Simonsen
Department of Neuroscience and Pharmacology, University of Copenhagen, Copenhagen, Denmark

S. W. Svendsen
Danish Ramazzini Centre, Department of Occupational Medicine, Regional Hospital West Jutland–University Research Clinic, Herning, Denmark

G. Hansson
Occupational and Environmental Medicine, Lund University, Lund, Sweden

G. Hansson
Occupational and Environmental Medicine, University and Regional Laboratories Region Scania, Lund, Sweden

Abbreviations

APDF	Amplitude probability distribution function
EMG	Electromyography
EMG_{max}	Maximum EMG amplitude
CI	Confidence interval
MSD	Musculoskeletal disorders
MVC	Maximal voluntary contraction
P10	10 % percentile
P50	50 % percentile
P90	90 % percentile
SD	Standard deviation

Introduction

Musculoskeletal disorders (MSD) affect a large number of people and have important socioeconomic consequences in terms of costs in health care, sickness absence and early retirement (Norlund et al. 2000). Therefore, it is of great importance to understand which factors contribute to the development of MSD.

Several studies have shown that women report musculoskeletal complaints in the upper parts of the body more frequently than men (Bingefors and Isacson 2004; Dahlberg et al. 2004; de Zwart et al. 2001; Hooftman et al. 2004; Wijnhoven et al. 2006), but the causes of this difference are unclear. It could be explained in three different ways: (1) women are exposed to higher relative physical loads than men (Hooftman et al. 2004; Kennedy and Koehoorn 2003; Leijon et al. 2005; Lundberg 2002; Nordander et al. 2008); (2) women are more vulnerable to physical loads than men due to anatomical, physical or other biological differences (de Zwart et al. 2001); (3) women report complaints at a lower threshold than men (Hurley and Adams 2008).

These hypotheses are under investigation in an ongoing epidemiological study focusing on Danish male and female house painters [the Shoulder Hand Arm (SHARM) study]. In Denmark, approximately 1/3 of house painters are women, and male and female house painters are assumed to perform virtually identical work tasks. The purpose of the present part of the SHARM-study was to examine whether there were differences in relative muscular load and exerted force between male and female house painters when they performed identical house painting work tasks under controlled experimental conditions.

Methods

Subjects

The study included 32 right-handed house painters: 16 men [mean (SD): weight 82.4 (12.9) kg, height 182 (6.1) cm, age 25.5 (3.9) years] and 16 women [mean (SD): weight 64.9 (7.1) kg, height 169 (6.2) cm, age 28.3 (6.2) years]. Subjects with previous reports of discomfort in the right shoulder or the right or left arm and/or hand were excluded from the study. The subjects were recruited through the Painters' Union in Denmark. Each subject participated voluntarily in the study and signed an informed consent according to the Helsinki Declaration. The study was approved by the local ethics committee (J. no.: H-3-2011-157).

Electromyography

The descending part of the trapezius muscle was selected as representative of elevation of the shoulder girdle, the supraspinatus muscle as an important abductor at the shoulder joint and clinically relevant as it is often reported to suffer from degenerative alterations of its tendon (Svendsen et al. 2004b). The flexor and extensor radialis muscles were chosen because of the painters' frequent use of dorsiflexion and palmar flexion of the wrist joint.

EMG of the trapezius muscle (descending part) and mm. extensor and flexor carpi radialis on the right side was studied using bipolar silver/silver chloride surface electrodes (Multi Bio Sensors, TX, USA) with a fixed inter-electrode distance of 20 mm. According to Perotto (2005), the electrodes were placed on the trapezius between the neck and the shoulder, on the extensor carpi radialis approximately 5 cm distal to the lateral epicondyle and on the flexor carpi radialis approximately 10 cm distal to the medial epicondyle. Prior to mounting the electrodes, the skin was shaved and cleaned with alcohol. The supraspinatus muscle was recorded by two intramuscular wire electrodes (500 μm diameter, 1,500 μm uninsulated tip, stainless steel) [Spes Medica, Battipaglia (SA), Italy]. The site of insertion was found according to Rudroff (2008). With the subject in prone position, the two wire electrodes were inserted into the supraspinatus muscle, penetrating the trapezius muscle with hypodermic needles. An inter-electrode distance of 20 mm was sought. A reference electrode was placed on the acromion (left side). All electrodes were connected to lightweight pre-amplifiers containing a 10–1,000 Hz band-pass filter and a 16 bit analog/digital converter. The sampling rate was 2,048 Hz. The digitized signals were lead through wires to a small box (120 g) fixed to the subject's right upper arm (MQ16, Marq-Medical, Farum, Denmark) and transmitted wirelessly to a PC using Bluetooth technology. The noise level of the MQ16 system was specified to be less than 3 μV. In the MQ16 system, the signals were pre-amplified and AD converted close to the electrodes to reduce movement artefacts.

The EMG amplitude of each muscle was calibrated to an isometric external force by simultaneously sampling EMG and the signal from a force transducer. A gradually increasing ramp contraction (Jonsson 1978) was performed over 15 s going from absolute relaxation increasing steadily until maximum effort was achieved. An additional period of 5 s was given to make sure that maximal voluntary contraction (MVC) was reached, 30 % MVC was then calculated and the relation between force and EMG was determined by a linear relationship up to 30 % MVC. This was obtained by a least square fit forced through zero (Fig. 1) (Jonsson 1982; Mathiassen 1996).

In all exercises, a force transducer (Hottinger Baldwin Messtechnik, Darmstadt GmbH, Germany), anchored to the floor, was connected in series with a nylon strap applied to the force exerting limb. For the forearm muscles, the subject was seated with the right forearm fixed in a supinated position for flexion and pronated for extension, respectively. The hand was fixed by the nylon strap applied to the distal end of metacarpals 2–5. For the

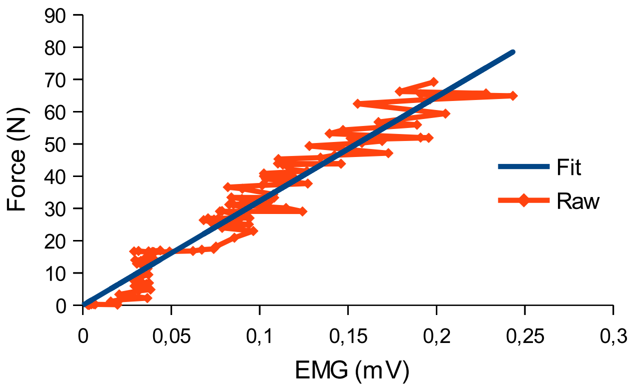

Fig. 1 EMG–force calibration for a typical male subject, here showing the flexor carpi radialis muscle. The recording was performed during a steadily increasing force from 0 % to about 30 % of MVC for 15 s (*EMG* electromyography, *MVC* maximal voluntary contraction)

supraspinatus muscle, the subject was standing with the right arm abducted 45° pressing the loop of the strap firmly outwards/upwards by the back of the hand. For the trapezius muscle, the subject was standing with two nylon straps placed bilaterally on the acromion. The subject was asked to elevate both shoulders while keeping heel contact with the floor. Only the nylon strap on the subject's right side was connected to the force transducer.

Additionally, MVC was measured for the supraspinatus and trapezius muscles with the arm abducted 90° in the frontal plane. The strap was placed just proximal to the elbow. The two forearm muscles were also tested during power grip by use of a hand grip dynamometer (JAMAR, Sammons Preston, Bolingbrook IL, USA). In these two tests, the subjects were given three trials to reach the highest possible force.

For the supraspinatus and trapezius muscles, the mean maximal EMG amplitude was, for both men and women, higher during arm abduction at 90°, than during arm abduction at 45° and shoulder elevation, respectively (Table 1). The maximum EMG amplitude during arm abduction at 90° was, for all subjects, used for normalisation when calculating the relative muscular load (see below) for these muscles.

A subjective measure of the muscular load was obtained immediately after completion of each task by asking the participants to rate perceived exertion using the Borg CR10 scale (Borg 1990; Borg et al. 1987).

Nine work tasks, chosen in collaboration with the Painter's Union in Denmark were investigated. They covered everyday work tasks in the field of house painting and were performed in the order presented: 1: Sanding (by hand), 2: painting (brush), 3: mounting glass-felt, 4: painting wall (roll), 5: painting ceiling (roll), 6: full levelling wall, 7: full levelling ceiling, 8: sanding wall ("Giraffe" dry-wall-sander) and 9: sanding ceiling ("Giraffe" dry-wall-sander) (Fig. 2). The number of square meters in each task was predetermined. The subject had time to prepare the necessary tools for the task. The investigator verbally started the task and the subject signalled when the task was completed. Data was missing from two female subjects in task 9, one due to a technical failure and one being too short to perform the task.

Data processing

Using Matlab R2008b (The MathWorks Inc., USA), EMG data were filtered by a fourth-order Butterworth filter with a band pass of 10–500 Hz for surface electrodes and 30–1,000 Hz for intramuscular measurements. By visual

Table 1 Mean MVC and EMG_{max} of men ($N = 16$) and women ($N = 16$)

	MVC (N)				*P*	EMG_{max} (mV)				*P*
	Men		Women			Men		Women		
	Mean	SD	Mean	SD		Mean	SD	Mean	SD	
M. supraspinatus										
Abd45	109	21	66	15	<0.001	1.40	0.63	1.10	0.56	0.17
Abd90	268	39	176	35	<0.001	1.44	0.66	1.14	0.59	0.19
M. trapezius										
Elevation	467	120	299	137	<0.001	0.72	0.51	0.66	0.45	0.71
Abd90	268	39	176	35	<0.001	0.99	0.59	1.10	0.60	0.60
M. ext. carpi radialis										
Extension	203	56	125	34	<0.001	1.31	0.56	1.00	0.58	0.14
Power grip	500	92	333	42	<0.001	1.00	0.59	0.80	0.46	0.28
M. flex. carpi radialis										
Flexion	230	51	135	42	<0.001	1.36	0.56	1.10	0.40	0.14
Power grip	500	92	333	42	<0.001	0.58	0.18	0.51	0.20	0.27

The *P* values refer to differences (*t* test) between men and women

Fig. 2 The work tasks investigated, from the *top left*: Sanding (by hand); painting (brush); mounting glass felt; painting wall (roll); painting ceiling (roll); full levelling, wall; full levelling, ceiling; sanding wall ("Giraffe" dry-wall-sander); and sanding ceiling ("Giraffe" dry-wall-sander)

inspection of the signals, short periods with high interference or noise were rejected from further analysis. Less than 8 % of the total recording time was excluded. Root mean square amplitudes were calculated for epochs of 125 ms throughout the sampling period. Amplitude probability distribution functions (APDF) (Jonsson 1982) were obtained for each subject, muscle and task. This was performed by sorting an entire measurement period in ascending order, thereby achieving a vector of EMG values wherein the relative position of an EMG value within the vector designated the proportion of the measurement period less or equal to that particular EMG value. Percentiles was used to identify values obtained from the APDF, e.g. the 10 % percentile (p10) designates the EMG value for which 10 % of the measurement period was less or equal. Three percentiles were selected for statistical analysis: The 10 % percentile (p10) the "static load," the 50 % percentile (p50) the median load and the 90 % percentile (p90) the peak load (Jensen et al. 1993; Jonsson 1978) (Fig. 3). Relative muscular load and exerted force were obtained by normalising the EMG amplitudes to EMG_{max} and by expressing the EMG amplitudes in Newton via the EMG-to-force calibrations, respectively.

Statistics

Normality of EMG responses was examined using QQ plots and showed a need for logarithmic transformation. Differences were back-transformed giving results as ratios. Each muscle and percentile level was analysed using a two factor mixed model examining dependences of task, sex and task–sex interaction.

The ratings for perceived physical exertion were analysed for differences between men and women within each task, using an un-paired double-sided t test with unequal variance. Correlations between $\%EMG_{max}$ and Borg CR10 ratings were tested using Pearson's correlation coefficient.

Level of significance was set to 5 %. Statistical analyses were conducted with SAS 9.2 (SAS Institute Inc., Cary, NC, USA).

Results

In all strength measurements, male subjects were significantly stronger than female subjects regarding absolute forces ($P < 0.001$). Men were on average 50–70 % stronger than women in the different measurements of MVC. No statistically significant differences between sexes were found for EMG_{max} ($P = 0.14$), although men had numerically higher mean EMG_{max} than women in 7 out of 8 tests (Table 1).

Total time spent on all nine work tasks varied between subjects from 27 to 47 min with a mean of 36 min. Total work duration did not vary significantly ($P = 0.18$) between men [mean (SD): 34 min 43 s (5 min 25 s)] and women [mean (SD): 37 min 16 s (4 min 58 s)]. The Borg CR10 ratings of perceived exertion showed statistically significant differences between sexes for tasks 5–9 (Fig. 4). In all tasks, women on average rated their physical exertion higher than men did.

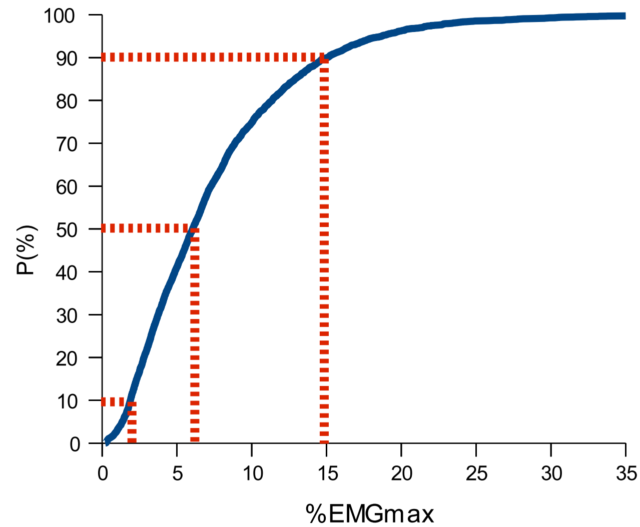

Fig. 3 Example of an APDF curve obtained from the trapezius muscle of a typical subject during task 3. *Dashed lines* show p10, p50 and p90, respectively (*APDF* amplitude probability distribution functions)

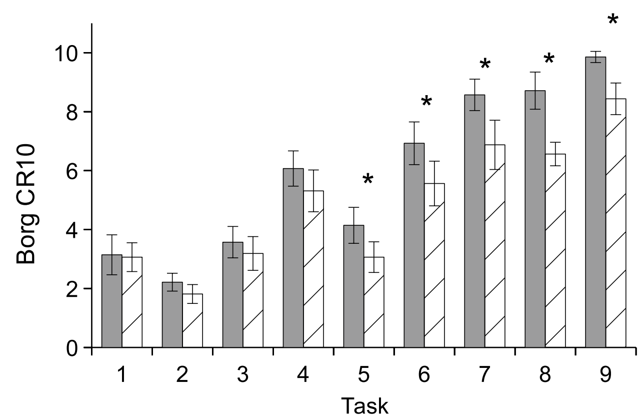

Fig. 4 Borg CR10 scale for perceived physical exertion in nine tasks, females (*grey bars*) and males (*shaded bars*). Mean values and 95 % confidence intervals (indicated by *error bars*). *Asterisks* denote significant differences between sexes

Relative muscular load

Figure 5 depicts the average relative muscular load for each muscle, percentile and task. For all muscles, percentiles and tasks (except for m. trapezius, p10, task 9) women had a higher relative muscular load. For the supraspinatus muscle, average muscular load for p10 was 2.07 $\%EMG_{max}$ for the women and 1.48 $\%EMG_{max}$ for the men, p50 was 8.38 $\%EMG_{max}$ for the women and 5.60 $\%EMG_{max}$ for the men, and p90 was 21.88 $\%EMG_{max}$ for the women

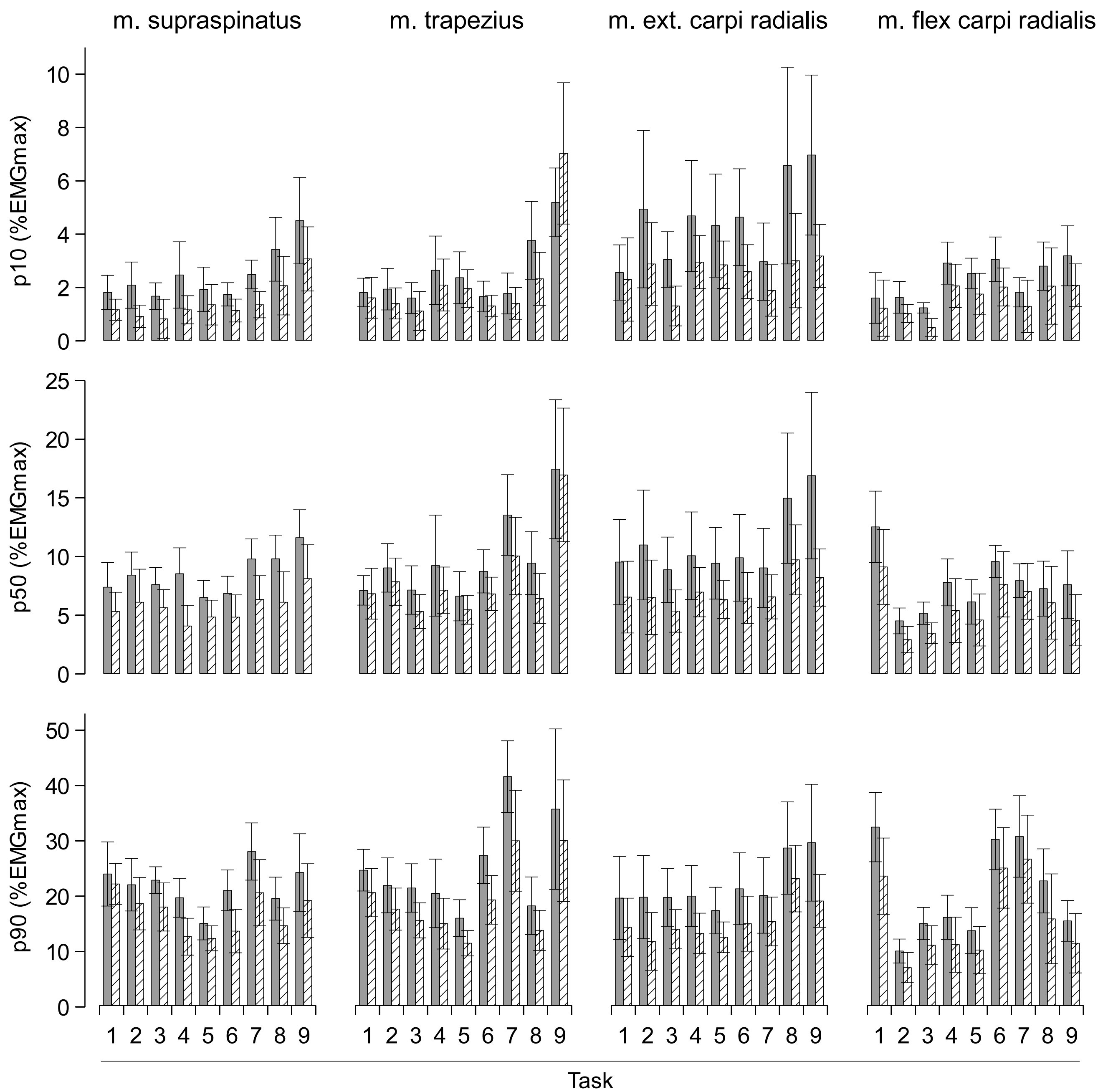

Fig. 5 Relative muscular load in nine tasks, p10 (*top*), p50 (*middle*) and p90 (*bottom*), females ($N = 16$ *grey bars*) and males ($N = 16$ *shaded bars*). Mean values and 95 % confidence intervals (indicated by *error bars*) were calculated on logarithmic data, and retransformed to linear scales for presentation. Tasks are: *1*: Sanding (by hand), *2*: painting (brush), *3*: mounting glass felt, *4*: painting wall (roll), *5*: painting ceiling (roll), *6*: full levelling, wall, *7*: full levelling, ceiling, *8*: sanding wall ("Giraffe" dry-wall- sander), and *9*: sanding ceiling ("Giraffe" dry-wall-sander) [p10, p50 and p90 are the 10th, 50th and 90th percentiles, respectively]. p10, p50 and p90 for the supraspinatus and extensor and flexor carpi radialis muscles showed significant effect of sex adjusted for task

and 17.85 $\%EMG_{max}$ for the men. For the trapezius muscle, average muscular load for p10 was 1.92 $\%EMG_{max}$ for the women and 1.59 $\%EMG_{max}$ for the men, p50 was 9.00 $\%EMG_{max}$ for the women and 6.80 $\%EMG_{max}$ for the men, and p90 was 21.78 $\%EMG_{max}$ for the women and 17.47 $\%EMG_{max}$ for the men. For the extensor carpi radialis muscle, average muscular load for p10 was 4.62 $\%EMG_{max}$ for the women and 2.83 $\%EMG_{max}$ for the men, p50 was 9.86 $\%EMG_{max}$ for the women and 6.50 $\%EMG_{max}$ for the men, and p90 was 19.82 $\%EMG_{max}$ for the women and 14.16 $\%EMG_{max}$ for the men. For the flexor carpi radialis muscle, average muscular load for p10 was 2.51 $\%EMG_{max}$

Table 2 Estimated sex effect on relative muscular loads, adjusted for task

	p10 (%)		p50 (%)		p90 (%)	
	Mean	95 % CI	Mean	95 % CI	Mean	95 % CI
M. supraspinatus	187[a]	131–266	156[a]	118–207	131[a]	109–158
M. trapezius	119	83–171	120	93–155	127	99–162
M. ext. carpi radialis	180[a]	120–270	164[a]	114–237	149[b]	107–207
M. flex. carpi radialis	159[b]	112–225	140[b]	102–193	136[b]	101–183

Load for women ($N = 16$) compared to that of men ($N = 16$), male level being 100 %

[a] $0.001 < P < 0.010$

[b] $0.010 < P < 0.050$

for the women and 1.74 $\%EMG_{max}$ for the men, p50 was 7.57 $\%EMG_{max}$ for the women and 5.36 $\%EMG_{max}$ for the men, and p90 was 15.97 $\%EMG_{max}$ for the women and 11.25 $\%EMG_{max}$ for the men.

The task–sex interaction was found to be insignificant regarding relative muscular load. Leaving only main effects (sex and task) in the model, p10, p50 and p90 for the supraspinatus and extensor and flexor carpi radialis muscles were found to have a significant effect of sex adjusted for task. The trapezius muscle showed an effect in the same direction although not statistically significant. All significant sex effects were due to women being exposed to a higher load than men (Table 2).

Exerted force

Average exerted force for each muscle, percentile and task can be seen in Fig. 6. For the supraspinatus muscle, average exerted force for p10 was 1.68 N for the women and 1.54 N for the men, p50 was 6.70 N for the women and 7.60 N for the men, and p90 was 17.72 N for the women and 23.81 N for the men. For the trapezius muscle, average exerted force for p10 was 7.86 N for the women and 11.08 N for the men, p50 was 36.82 N for the women and 47.21 N for the men, and p90 was 89.14 N for the women and 121.35 N for the men. For the extensor carpi radialis muscle, average exerted force for p10, was 7.92 N for the women and 8.48 N for the men, p50 was 16.91 N for the women and 19.43 N for the men, and p90 was 33.99 N for the women and 42.39 N for the men. For the flexor carpi radialis muscle, average exerted force for p10, was 4.79 N for the women and 4.52 N for the men, p50 was 14.70 N for the women and 13.77 N for the men, and p90 was 30.50 N for the women and 29.29 N for the men.

The task–sex interaction was found to be significant in a single case of p10 of the trapezius muscle ($P = 0.02$), and post hoc analysis showed the difference to be found in task 9 (sanding ceiling with the "Giraffe" dry-wall-sander), which is also visible in Fig. 6.

Leaving only main effects (sex and task) in the model, only p50 of the trapezius muscle was found to be significantly affected by sex adjusted for task. Estimates of sex effects adjusted for task are shown in Table 3, which shows that in the significant case of p50 of the trapezius muscle, women exerted 30 % less force compared with men.

Discussion

In this study, we found that women experienced significantly higher relative muscular loads during house painting tasks than men did. Three of the four muscles investigated, the supraspinatus and extensor and flexor carpi radialis muscles, showed that women experienced a significantly higher relative muscular load in the three EMG parameters: p10, p50 and p90, which furthermore corresponded to the subjective ratings using Borg CR10. Additionally, no significant task–sex interaction was found in terms of relative muscular load. Women were shown to exert a lower p50 of force in trapezius in all tasks as well as a lower p10 in task 9, while the other muscles investigated showed no significant differences between men and women.

Measures of exposure can be assessed by self-reports (Borg and Kaijser 2006; McGorry et al. 2010), observations (Moore and Garg 1995) or technical measurements by, e.g. EMG. Previously, EMG has been used extensively to quantify muscular load during work situations (Hansson et al. 2000, 2009, 2010; Jensen et al. 1993, 1999; Jonsson 1982; Veiersted et al. 1990). Traditionally, EMG is reported in $\%EMG_{max}$ giving a relative muscular load. It is, however, well known, and verified in the present study, that on average men are about 50 % stronger than women (Maughan et al. 1983; Miller et al. 1993) without EMG_{max} in men being correspondingly higher. Therefore, a measure of exerted force was considered relevant for the present study. A linear relationship is in many cases a reasonable description of the relationship between EMG amplitude and force (Staudenmann et al. 2010). However, the relationship between EMG and force is not linear over the full

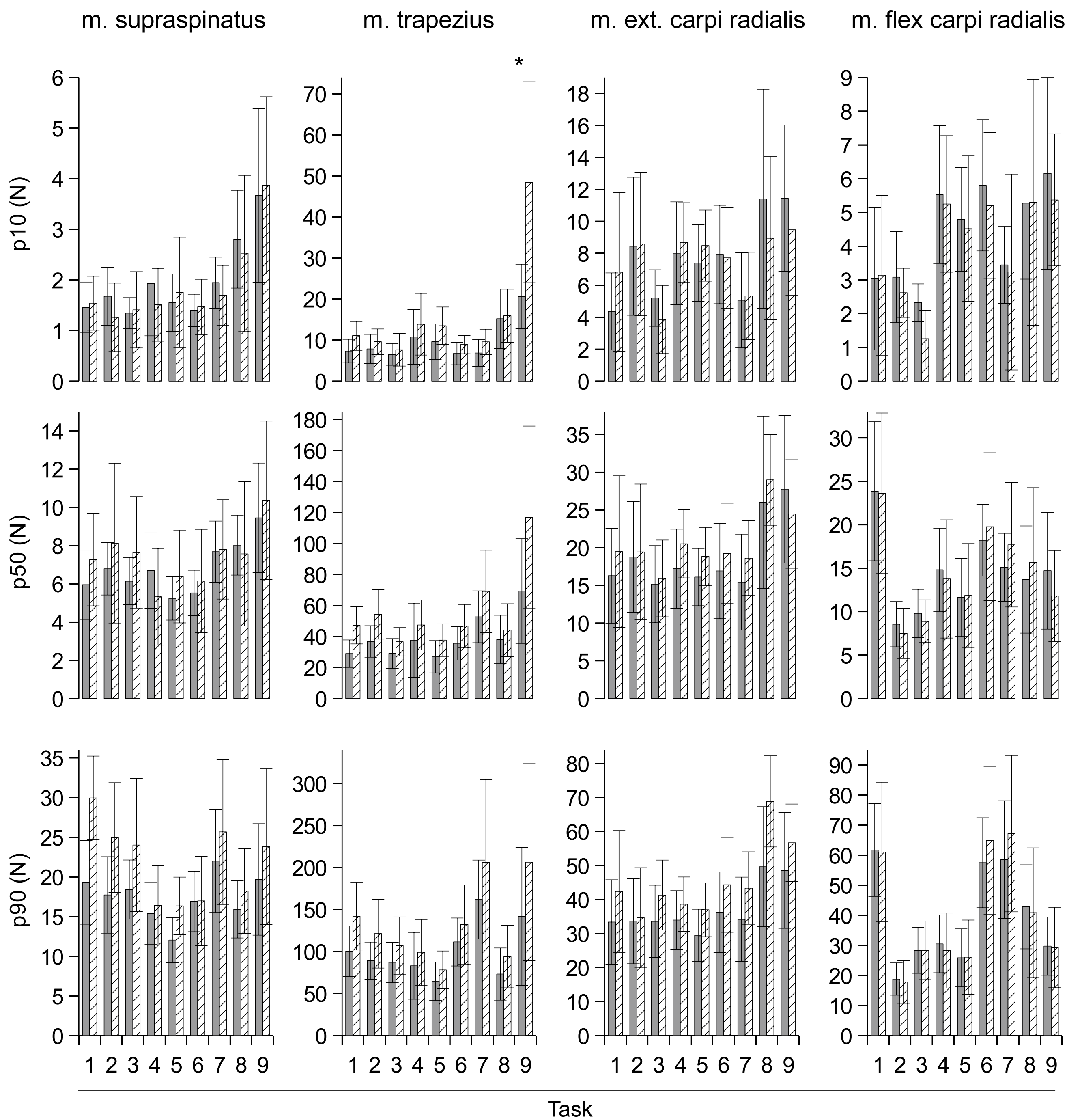

Fig. 6 Exerted force in nine tasks, p10 (*top*), p50 (*middle*) and p90 (*bottom*), females ($N = 16$ *grey bars*) and males ($N = 16$ *shaded bars*). Mean values and 95 % confidence intervals (indicated by *error bars*) were calculated on logarithmic data and retransformed to linear scales for presentation. Tasks are: *1*: Sanding (by hand), *2*: painting (brush), *3*: mounting glass felt, *4*: painting wall (roll), *5*: painting ceiling (roll), *6*: full levelling, wall, *7*: full levelling, ceiling, *8*: sanding wall ("Giraffe" dry-wall-sander), and *9*: sanding ceiling ("Giraffe" dry-wall-sander) [p10, p50 and p90 are the 10th, 50th and 90th percentiles, respectively]. *Asterisk* denotes significant task–sex interaction. P50 of the trapezius muscle showed significant effect of sex adjusted for task

range of force, and therefore, we limited the calibration range to about 30 % of MVC and estimated a linear EMG/force relation for each muscle in each subject. The estimated force should of course be interpreted with caution when the load exceeded 30 % MVC, and the resulting force in Newton should not be taken as a precise measure of the exerted force of the individual muscle, since this is influenced by, e.g. the length of the muscle, contributions from

Table 3 Estimated sex effect of exerted force, adjusted for task

	p10 (%)		p50 (%)		p90 (%)	
	Mean	95 % CI	Mean	95 % CI	Mean	95 % CI
M. supraspinatus	111	78–158	95	70–129	80	62–103
M. trapezius	70	48–101	70[a]	49–99	74	50–108
M. ext. carpi radialis	104	69–158	95	67–136	86	62–121
M. flex. carpi radialis	116	79–171	103	71–148	99	70–141

Force exerted by women ($N = 16$) compared to that of men ($N = 16$), male level being 100 %

[a] $0.010 < P < 0.050$

synergistic muscles, and eccentric and concentric contractions. The external force that is exerted, e.g. on a tool, is even harder to predict from the recorded EMG since this is affected by adjacent muscles and joint geometry. Using EMG normalisation from one contractile condition to another may introduce some disparities. However, a recent review paper (Burden 2010) emphasises that this method is well accepted and is not inferior to other methods, i.e. numerous MVC's at different ROM's, which are considered much more labour intensive.

The role of the supraspinatus muscle is of special interest due to its functional importance for the shoulder joint and the frequent occurrence of shoulder complaints with clinical findings presumed to originate from, e.g. degenerative alterations of the supraspinatus tendon, which are linked to work tasks with arms elevated above 90° (Svendsen et al. 2004a, b; van Rijn et al. 2010; Jensen et al. 1994). Most studies of occupational EMG in the upper extremity have not measured the supraspinatus muscle, probably due to the deep location of the muscle underneath the trapezius muscle. Others have tried to assess muscular load of the supraspinatus muscle by the use of surface electrodes (Waite et al. 2010). The measurement of supraspinatus activity by use of surface electrodes has, however, shown a weak correlation with intramuscular measurements (Waite et al. 2010) stressing the need for examining the supraspinatus muscle by the use of intramuscular electrodes during work. The forearm extensor and flexor muscles as well as the trapezius muscle can all be measured validly by surface electrodes.

This study investigated the work of house painters in a condensed way without pauses between tasks. In comparison with results obtained in whole day recordings, the muscular load measured in the present study will probably be high because this study investigated condensed periods of work. However, this deviation is expected to be equal for men and women.

Several studies have found the Borg CR10 scale of perceived exertion to have a good correlation with physiological responses (Borg et al. 1987; Capodaglio 2001; Pincivero et al. 2004; DiDomenico and Nussbaum 2008). In accordance with previous studies (Borg et al. 1987; Pincivero et al. 2001; Troiano et al. 2008), we found that the Borg CR10 had a linear relationship with relative muscular load. These results indicate that the Borg CR10 scale may be a valid subjective tool to assess sex differences of a given work-related task with respect to relative muscular load.

In several tasks of the present study, it was observed that p10 of relative muscular load was lower, while p90 was higher compared to dentists (Akesson et al. 1997), hairdressers (Chen et al. 2010) and assembly plant employees (Christensen 1986). Thus, the tasks performed by house painters were in these cases of a more diverse and dynamic character.

The highest reported difference between men and women was found by Chen et al. (2010) in a study of barbers and hairdressers. When normalised to EMG_{max}, women had an EMG activity that was 100–200 % higher than men. This could, however, be partly explained by large standard deviations as reported in that particular study.

The differences in relative muscular load found in the present study corroborated the findings of Nordander et al. (2008) in a study of industrial workers, regarding the trapezius and the forearm extensors. Likewise, Won et al. (2009) found that during keyboard typing, women had a higher relative muscular load than men for the trapezius and forearm extensor and flexor muscles, while no differences were found in the exerted force.

The study of keyboard typing by Won et al. (2009) showed that men and women exerted the same force, while a study of postal workers (van der Beek et al. 2000) showed that men exerted greater forces, which was also found in a few cases in the present study. A reasonable explanation is that the more strength demanding the task is, the more apparent the sex difference will be because men are capable of exerting more force if required.

It is interesting that the relative muscular load in the supraspinatus, extensor carpi radialis and flexor carpi radialis muscles was between 30 and 90 % greater in women than in men, considering the fact that these muscles are subject to work-induced MSD (supraspinatus tendinopathy, medial and lateral epicondylitis) (Nordander et al. 2013; van Rijn et al. 2009, 2010). A recent study by Nordander et al. (2013) linked work with a high relative muscular load to the presence of pain and indicated that accumulation of effects caused by a high relative muscular load may be linked to MSD.

The lower exerted force of women found in the trapezius muscle indicates that the work was possibly performed differently by men and women with respect to postures and movements.

There were no significant task–sex interactions with respect to relative muscular load, indicating that sex differences with respect to muscular load were similar across work tasks. However, by differentiating the tasks so that women avoid the most physically challenging tasks, the total daily exposure would be lowered in women. Another way of reducing the difference in relative muscular load could—in theory—be to increase maximal muscle strength of women by strength training. However, it is most unlikely that MVC in female house painters could be increased by 30–90 %, which would be necessary to match the MVC of men. Nevertheless, previous studies have found strength training to be an effective method of reducing pain in other occupational groups (Andersen et al. 2010, 2012).

Conclusions

Female house painters worked at a higher relative muscular load than their male colleagues even though men in some cases exerted more force during work. It is possible that the effects of a higher relative muscular load among female house painters can be accumulated over years contributing to the explanation of why upper body complaints occur more frequently among women. We encourage prospective studies to investigate effects of relative muscular load and exerted force on development of MSD.

Acknowledgments The present study was supported by grants from The Danish Rheumatism Association and The Danish Working Environment Research Fund. The authors wish to thank co-workers at The University Hospital in Lund and Bispebjerg University Hospital, especially student Hatice Yilmaz for assistance during data collection and Jacob Louis Marott for statistical guidance. Also the collaboration of the Painters' Union in Denmark is highly appreciated.

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

References

Akesson I, Hansson GA, Balogh I, Moritz U, Skerfving S (1997) Quantifying work load in neck, shoulders and wrists in female dentists. Int Arch Occup Environ Health 69(6):461–474

Andersen LL, Christensen KB, Holtermann A, Poulsen OM, Sjogaard G, Pedersen MT, Hansen EA (2010) Effect of physical exercise interventions on musculoskeletal pain in all body regions among office workers: a one-year randomized controlled trial. Man Ther 15(1):100–104

Andersen LL, Jakobsen MD, Pedersen MT, Mortensen OS, Sjogaard G, Zebis MK (2012) Effect of specific resistance training on forearm pain and work disability in industrial technicians: cluster randomised controlled trial. BMJ Open 2(1):e000412

Bingefors K, Isacson D (2004) Epidemiology, co-morbidity, and impact on health-related quality of life of self-reported headache and musculoskeletal pain—a gender perspective. Eur J Pain 8(5):435–450

Borg G (1990) Psychophysical scaling with applications in physical work and the perception of exertion. Scand J Work Environ Health 16(Suppl 1):55–58

Borg E, Kaijser L (2006) A comparison between three rating scales for perceived exertion and two different work tests. Scand J Med Sci Sports 16(1):57–69

Borg G, Hassmen P, Lagerstrom M (1987) Perceived exertion related to heart rate and blood lactate during arm and leg exercise. Eur J Appl Physiol Occup Physiol 56(6):679–685

Burden A (2010) How should we normalize electromyograms obtained from healthy participants? What we have learned from over 25 years of research. J Electromyogr Kinesiol 20:1023–1035

Capodaglio EM (2001) Comparison between the CR10 Borg's scale and the VAS (visual analogue scale) during an arm-cranking exercise. J Occup Rehabil 11(2):69–74

Chen HC, Chang CM, Liu YP, Chen CY (2010) Ergonomic risk factors for the wrists of hairdressers. Appl Ergon 41(1):98–105

Christensen H (1986) Muscle activity and fatigue in the shoulder muscles of assembly-plant employees. Scand J Work Environ Health 12(6):582–587

Dahlberg R, Karlqvist L, Bildt C, Nykvist K (2004) Do work technique and musculoskeletal symptoms differ between men and women performing the same type of work tasks? Appl Ergon 35(6):521–529

de Zwart BC, Frings-Dresen MH, Kilbom A (2001) Gender differences in upper extremity musculoskeletal complaints in the working population. Int Arch Occup Environ Health 74(1):21–30

DiDomenico A, Nussbaum MA (2008) Interactive effects of physical and mental workload on subjective workload assessment. Int J Ind Ergon 38(11–12):977–983

Hansson GA, Balogh I, Ohlsson K, Palsson B, Rylander L, Skerfving S (2000) Impact of physical exposure on neck and upper limb disorders in female workers. Appl Ergon 31(3):301–310

Hansson GA, Balogh I, Ohlsson K, Granqvist L, Nordander C, Arvidsson I, Akesson I, Unge J, Rittner R, Stromberg U, Skerfving S (2009) Physical workload in various types of work: Part I. Wrist and forearm. Int J Ind Ergon 39(1):221–233

Hansson GA, Balogh I, Ohlsson K, Granqvist L, Nordander C, Arvidsson I, Akesson I, Unge J, Rittner R, Stromberg U, Skerfving S (2010) Physical workload in various types of work: Part II. Neck, shoulder and upper arm. Int J Ind Ergon 40(3):267–281

Hooftman WE, van Poppel MN, van der Beek AJ, Bongers PM, van Mechelen W (2004) Gender differences in the relations between work-related physical and psychosocial risk factors and musculoskeletal complaints. Scand J Work Environ Health 30(4):261–278

Hurley RW, Adams MC (2008) Sex, gender, and pain: an overview of a complex field. Anesth Analg 107(1):309–317

Jensen BR, Schibye B, Sogaard K, Simonsen EB, Sjogaard G (1993) Shoulder muscle load and muscle fatigue among industrial sewing-machine operators. Eur J Appl Physiol Occup Physiol 67(5):467–475

Jensen BR, Jorgensen K, Sjogaard G (1994) The effect of prolonged isometric contractions on muscle fluid balance. Eur J Appl Physiol Occup Physiol 69(5):439–444

Jensen C, Finsen L, Hansen K, Christensen H (1999) Upper trapezius muscle activity patterns during repetitive manual material handling and work with a computer mouse. J Electromyogr Kinesiol 9(5):317–325

Jonsson B (1978) Quantitative electromyographic evaluation of muscular load during work. Scand J Rehabil Med Suppl 6:69–74

Jonsson B (1982) Measurement and evaluation of local muscular strain in the shoulder during constrained work. J Hum Ergol 11(1):73–88

Kennedy SM, Koehoorn M (2003) Exposure assessment in epidemiology: does gender matter? Am J Ind Med 44(6):576–583
Leijon O, Bernmark E, Karlqvist L, Harenstam A (2005) Awkward work postures: association with occupational gender segregation. Am J Ind Med 47(5):381–393
Lundberg U (2002) Psychophysiology of work: stress, gender, endocrine response, and work-related upper extremity disorders. Am J Ind Med 41(5):383–392
Mathiassen SE (1996) The statistical confidence of load estimates based on ramp calibration of upper trapezius EMG. J Electromyogr Kinesiol 6(1):59–65
Maughan RJ, Watson JS, Weir J (1983) Strength and cross-sectional area of human skeletal muscle. J Physiol 338:37–49
McGorry RW, Lin JH, Dempsey PG, Casey JS (2010) Accuracy of the Borg CR10 scale for estimating grip forces associated with hand tool tasks. J Occup Environ Hyg 7(5):298–306
Miller AEJ, Macdougall JD, Tarnopolsky MA, Sale DG (1993) Gender differences in strength and muscle-fiber characteristics. Eur J Appl Physiol Occup Physiol 66(3):254–262
Moore JS, Garg A (1995) The strain index: a proposed method to analyze jobs for risk of distal upper extremity disorders. Am Ind Hyg Assoc J 56(5):443–458
Nordander C, Ohlsson K, Balogh I, Hansson GA, Axmon A, Persson R, Skerfving S (2008) Gender differences in workers with identical repetitive industrial tasks: exposure and musculoskeletal disorders. Int Arch Occup Environ Health 81(8):939–947
Nordander C, Ohlsson K, Akesson I, Arvidsson I, Balogh I, Hansson GA, Stromberg U, Rittner R, Skerfving S (2013) Exposure-response relationships in work-related musculoskeletal disorders in elbows and hands—a synthesis of group-level data on exposure and response obtained using uniform methods of data collection. Appl Ergon 44(2):241–253
Norlund A, Palsson B, Ohlsson K, Skerfving S (2000) Economic consequences of occupational disorders in women with repetitive industrial work. Eur J Public Health 10(2):127–132
Perotto A (2005) Anatomical guide for the electromyographer: the limbs and trunk. Charles C Thomas, Springfield
Pincivero DM, Coelho AJ, Campy RM, Salfetnikov Y, Bright A (2001) The effects of voluntary contraction intensity and gender on perceived exertion during isokinetic quadriceps exercise. Eur J Appl Physiol 84(3):221–226
Pincivero DM, Coelho AJ, Campy RM (2004) Gender differences in perceived exertion during fatiguing knee extensions. Med Sci Sports Exerc 36(1):109–117
Rudroff T (2008) Kinesiological fine wire EMG, 1st edn. Noraxon U.S.A., Inc., Scottsdale
Staudenmann D, Roeleveld K, Stegeman DF, van Dieen JH (2010) Methodological aspects of SEMG recordings for force estimation—a tutorial and review. J Electromyogr Kinesiol 20(3):375–387
Svendsen SW, Bonde JP, Mathiassen SE, Stengaard-Pedersen K, Frich LH (2004a) Work related shoulder disorders: quantitative exposure-response relations with reference to arm posture. Occup Environ Med 61(10):844–853
Svendsen SW, Gelineck J, Mathiassen SE, Bonde JP, Frich LH, Stengaard-Pedersen K, Egund N (2004b) Work above shoulder level and degenerative alterations of the rotator cuff tendons: a magnetic resonance imaging study. Arthritis Rheum 50(10):3314–3322
Troiano A, Naddeo F, Sosso E, Camarota G, Merletti R, Mesin L (2008) Assessment of force and fatigue in isometric contractions of the upper trapezius muscle by surface EMG signal and perceived exertion scale. Gait Posture 28(2):179–186
van der Beek AJ, Kluver BD, Frings-Dresen MH, Hoozemans MJ (2000) Gender differences in exerted forces and physiological load during pushing and pulling of wheeled cages by postal workers. Ergonomics 43(2):269–281
van Rijn RM, Huisstede BM, Koes BW, Burdorf A (2009) Associations between work-related factors and specific disorders at the elbow: a systematic literature review. Rheumatology 48(5):528–536
van Rijn RM, Huisstede BM, Koes BW, Burdorf A (2010) Associations between work-related factors and specific disorders of the shoulder—a systematic review of the literature. Scand J Work Environ Health 36(3):189–201
Veiersted KB, Westgaard RH, Andersen P (1990) Pattern of muscle-activity during stereotyped work and its relation to muscle pain. Int Arch Occup Environ Health 62(1):31–41
Waite DL, Brookham RL, Dickerson CR (2010) On the suitability of using surface electrode placements to estimate muscle activity of the rotator cuff as recorded by intramuscular electrodes. J Electromyogr Kinesiol 20(5):903–911
Wijnhoven HA, de Vet HC, Picavet HS (2006) Prevalence of musculoskeletal disorders is systematically higher in women than in men. Clin J Pain 22(8):717–724
Won EJ, Johnson PW, Punnett L, Dennerlein JT (2009) Upper extremity biomechanics in computer tasks differ by gender. J Electromyogr Kinesiol 19(3):428–436