ORIGINAL PAPER

International Journal of Occupational Medicine and Environmental Health 2016;29(2):345–354
http://dx.doi.org/10.13075/ijomeh.1896.00589

SHOULDER GIRDLE MUSCLE ACTIVITY AND FATIGUE IN TRADITIONAL AND IMPROVED DESIGN CARPET WEAVING WORKSTATIONS

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Abstract
Objectives: Work-related musculoskeletal disorders in the neck and shoulder regions are common among carpet weavers. Working for prolonged hours in a static and awkward posture could result in an increased muscle activity and may lead to musculoskeletal disorders. Ergonomic workstation improvements can reduce muscle fatigue and the risk of musculoskeletal disorders. **Material and Methods:** The aim of this study is to assess and to compare upper trapezius and middle deltoid muscle activity in 2 traditional and improved design carpet weaving workstations. These 2 workstations were simulated in a laboratory and 12 women carpet weavers worked for 3 h. Electromyography (EMG) signals were recorded during work in bilateral upper trapezius and bilateral middle deltoid. The root mean square (RMS) and median frequency (MF) values were calculated and used to assess muscle load and fatigue. Repeated measure ANOVA was performed to assess the effect of independent variables on muscular activity and fatigue. The participants were asked to report shoulder region fatigue on the Borg's Category-Ratio scale (Borg CR-10). **Results:** Root mean square values in workstation A are significantly higher than in workstation B. Furthermore, EMG amplitude was higher in bilateral trapezius than in bilateral deltoid. However, muscle fatigue was not observed in any of the workstations. **Conclusions:** The results of the study revealed that muscle load in a traditional workstation was high, but fatigue was not observed. Further studies investigating other muscles involved in carpet weaving tasks are recommended.

Key words:
Muscle activity, Surface electromyography, Muscle fatigue, Carpet weaving, Workstation, Perceived fatigue

This study was fully supported by Urmia University of Medical Science with project No. 91-03-34-760. Project manager: Teimour Allahyari, Ph.D.
This article was extracted from Narges Mortazavi's M.Sc. thesis entitled "The effects of carpet weaving workstations on shoulder muscle fatigue."
Received: January 26, 2015. Accepted: July 14, 2015.
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INTRODUCTION

Hand carpet weaving is a common industry in eastern countries. In more traditional parts of Iran, home-based carpet weaving workshops are still common. Entire families often participate in the process of weaving a carpet. However, occupational health regulations are rarely considered in these particular practices. The prevalence of musculoskeletal disorders among hand carpet weavers is higher than in the general population, with the shoulder region generally being the part which is most impacted (47.8%) [1].

In the process of carpet weaving, weavers work for long periods of time in a static and awkward posture. Working in a stationary and constrained posture is considered an important risk factor for work-related musculoskeletal disorders (WMSDs) [2]. Complaints of pain in the neck and shoulder among women who work in low-load, repetitive and static jobs have been reported in several studies [3,4]. Posture has a considerable influence on muscle load and activity [5]. In fact, activation of neck and shoulder muscles is influenced by a hand task and working posture. During work in 2 different static workstations, change and increase in muscle activation in the neck and shoulder muscles were observed [6]. Changes in electromyography (EMG) amplitude or a shift in the EMG spectrum to lower frequencies are known as an indication of muscle fatigue [7].

Some studies have examined the relationship between workstation, posture, muscle activity, and muscle fatigue. Seghers et al. have shown that electrical activity was different in various workstations and postures; but, they have not observed muscle fatigue [8]. Straker has also reported changes in EMG in 2 different workstations [9]. Luttman analyzed various tasks in an office environment and has found muscular fatigue [7]. Assessing Mean Power Frequency in upper trapezius, during 210 min carpet weaving in traditional workstation showed a significant decrease, but in root mean square (RMS) values no significant changes were observed [10]. A new study that was conducted to compare trapezius muscle activity in 2 proposed workstations for carpet weaving activity suggests that trapezius muscle activity in the workstation designed based on Choobineh et al. [11] recommendations is greater than that in the workstation proposed by authors [12]. However, muscle load and fatigue in a conventional workstation and postures have not been studied.

Using subjective assessment of fatigue by psychophysical rating scales along objective methods is the most common practice in ergonomic studies. Borg's CR-10 rating scale is a usual scale for subjective ratings and has been previously used in numerous studies for fatigue assessment [13,14]. This study, therefore, aimed at contributing to the existing literature by comparing muscular activity and fatigue in shoulder girdle muscles in 2 conventional and adjustable carpet weaving workstations through simulated working conditions.

MATERIAL AND METHODS

Subjects

Twelve right-handed female carpet weavers participated in the current study. Mean age of the participants was 32.5 years (SD = 6.8), mean height was 163.42 cm (SD = 3.67), mean weight was 73.42 kg (SD = 9.26), and mean work experience was 59.17 months (SD = 82.62). All the participants claimed to be in good physical health, without any pain and problems in the neck and shoulder regions.

Ethics

All the participants were apprised of the procedure, purpose, and risk of the research and written informed consent was obtained from each of them prior to the participation. After each working day, according to the study's protocol, the participants' daily wage was paid. This study was approved by the Medical Ethics Committee, Urmia University of Medical Sciences (decision No. 91, of July 23, 2012).

Workstations

Based on investigating on carpet weaving workplaces, the most common workstation among weavers was a low-height vertical loom, weavers sat on the floor in a cross-legged position without any backrest (Photo 1). The improved and ergonomic workstation was designed, as follows: adjustable a vertical loom, in which weavers sat on an adjustable chair with a backrest and armrest (Photo 2). The traditional and improved carpet weaving workstations were simulated in the laboratory.

Task

A quasi-experimental, within-subjects design was applied. According to the study design, each participant did work in workstation A (low-height vertical loom) on the first day and in workstation B (adjustable vertical loom) on the second day. All the participants were asked to work in each workstation for 3 h on 2 separate days. The tasks included routine carpet weaving tasks (knitting, fixating strings, etc.).

Carpet weaving tasks contain 4 groups of repeated tasks. Before starting the study, during the pilot phase, a task analysis of carpet weaving procedure was performed. One weaving cycle consisted of 4 tasks: knotting, picking up the yarn, fixing the yarn and fixing the knots, which took 90%, 2%, 5% and, 3% of the weaving cycle time, respectively. During 1 min, 15–30 wefts were inserted. Therefore, EMG recording was done during the first task. Recording of surface EMG was done 4 times during 3 h of work. Subjective data were collected using Borg's CR-10 scale at the second hour and at the end of work. Borg's CR-10 scale has been suggested to determine perceived exertion such as fatigue, especially in work tests [15].

EMG signal recording

In the pilot study, 6 muscles were tested: bilateral upper trapezius, bilateral mid-deltoid, and bilateral sternocleidomastoid. Our limitation was that only 4 surface electrodes were available. Therefore, due to muscle location

Photo 1. Workstation A: a low height vertical loom and a weaver sitting on the floor in a cross-legged position, without any backrest

Photo 2. Workstation B: a high vertical loom and a weaver sitting on the chair with backrest and armrest

and disturbing the work, bilateral sternocleidomastoid was pretermitted from the study and bilateral upper trapezius and bilateral mid-deltoid were selected.

Myoelectrical signals were recorded simultaneously from 4 muscles by Biometric/Data-link 8 channel surface electromyogram (in this paper, UTL stands for upper trapezius left, UTR for upper trapezius right, MDL for mid-deltoid left, and MDR stands for mid-deltoid right). For recording the signals, 4 surface electrodes (model SX-230 with high impedance ≥ 100 MΩ) were used. Before attaching the electrodes, skin was cleaned with alcohol wipes. The electrode was attached on muscle belly and parallel to the muscle fibers.

Electrode placement for the deltoid was at the point halfway between the lateral aspect of the acromion process and insertion of the deltoid on the deltoid tubercle. The electrode on the upper trapezius muscle was placed at the midpoint between C7 spinous process and the posterior aspect of the acromion process [16]. Also, the ground electrode was placed over styloid process.

At the beginning and end of each working day, a series of maximal voluntary contractions (MVC) were performed. For the upper trapezius, static resistance was arranged by manually fixating the arm with a large enough load to press the shoulder down. For mid-deltoid muscle, in a seated position, with fixated back, the arms were fixated in about 90° position. The bilateral contractions were performed to ensure a balanced force distribution for the trunk [17]. The contractions were repeated 3 times with about 1 min rest between each one. These recordings were used to normalize the EMG amplitudes.

After 5 min of rest, the participant started weaving and EMG was recorded at start of work, end of the first h, second h, and third h. Duration of recording of each signal was 30 s. This procedure was applied for each workstation separately. In order to match data for all the participants, recording was done during the same task of carpet weaving.

Subjective rating scale

Borg's CR-10 scale was developed for rating subjective symptoms from 0 to 10 with the numbers anchored by verbal expressions; i.e., 0 is nothing at all, 5 is strong, and 10 is extremely strong – maximal [15]. This scale was used as a subjective assessment of fatigue in other fatigue-related studies [14,18–20].

During work in each session, at the second h and at the end of work, the participants' self-assessed fatigue in the shoulder girdle was evaluated by the Borg's CR-10 scale.

EMG signal processing

Spectral signals were analyzed and accordingly each raw signal was filtered using the 4th order zero-lag Butterworth band pass filter at 10 Hz and 490 Hz as low and high cutoffs, respectively. Root mean square (RMS) is the applied integrative measure of the EMG amplitude and its dependence on muscular force and fatigue [21]. In 30 s data collection, the EMG data reduced to 0.5 s windows and the means of 60 windows were used to calculate RMS values. The RMS value was calculated for each recording, for each participant: 4 muscles and 4 times. In order to compare the levels of activity in different recording locations and between individuals, the EMG signals were normalized by the signals obtained during maximal voluntary contractions (MVC). Median frequency (MF) is also a measurement of the EMG spectrum calculated by the fast Fourier transformation (FFT).

Statistical analysis

All the RMS and MF values and subjective data were transferred to SPSS software (version 16). Two (workstation) ×2 (muscle type) ×2 (muscle side) ×4 (time) factorial repeated-measure ANOVA was used. Data normality was tested using the Shapiro-Wilk test. Then repeated measure ANOVA was used for analysis of the data. The effects of all variables on the perceived fatigue were determined by the repeated measure ANOVA.

RESULTS

RMS amplitude in relation to workstations, muscle type, side and time

Effects of workstation and muscle type on RMS were significant. Results indicated that mean values of normalized RMS were significantly higher in workstation A than in workstation B ($F(1, 11) = 5.1$, $p < 0.05$). Furthermore, muscle activity was significantly different between trapezius and deltoid and the mean value of normalized RMS was significantly higher in bilateral trapezius than bilateral deltoid ($F(1, 11) = 10.501$, $p < 0.01$). Effects of 2 other variables (muscle side and time) were not significant ($p > 0.05$). Interaction effects between the variables were also not significant (Table 1 and 2).

Median frequency in relation to workstations, muscle type, side and time

Mean and standard deviation of median frequency can be found in Table 3. The results of the repeated ANOVA show no significant difference between the 2 workstations. Also in other variables, a significant difference was not observed (Table 4).

Subjective rating of fatigue in shoulder region

The mean rate of self-reported fatigue in the shoulder region of the Borg's CR-10 scale was 4.5 for workstation A and 4.08 for workstation B (Table 5). For obtaining more results, effect of 2 factors of each workstation and time on self-reported

Table 2. Main and interaction effects of a workstation, muscle type, side and time on normalized RMS by the repeated measure ANOVA

Effects	df	F	p
Main effect			
workstation	1	5.100	0.047
error	11	–	–
muscle type	1	10.501	0.008
error	11	–	–
muscle side	1	0.034	0.857
error	11	–	–
time	3	0.902	0.451
error	33	–	–
Interaction effect			
workstation*muscle type	1	0.489	0.499
error	11	–	–
workstation*muscle side	1	1.229	0.291
error	11	–	–
muscle type*side	1	0.393	0.543
error	11	–	–
workstation*time	3	0.625	0.604
error	33	–	–
muscle type*time	3	1.211	0.312
error	33	–	–
muscle side*time	3	1.728	0.180
error	33	–	–

Error – error component in ANOVA table.
* Interaction effects.
df – degree of freedom; F – Fisher statistics.

Table 1. Normalized muscle activity in 4 muscles in 2 different workstations during 3 h (divided into 4 times)

Time of work	Muscle activity [% RMS] (M±SD)							
	workstation A				workstation B			
	left trapezius	right trapezius	left deltoid	right deltoid	left trapezius	right trapezius	left deltoid	right deltoid
Starting point	35.8±7.3	31.7±5.2	17.3±2.8	18.6±2.1	27.6±4.3	30.9±4.6	11.0±1.4	14.4±4.2
First hour	38.2±7.0	32.4±7.6	21.1±4.0	16.7±2.0	30.9±4.6	24.4±3.8	11.1±1.7	16.8±4.9
Second hour	35.2±5.8	32.6±6.4	17.1±3.0	16.1±1.8	25.1±3.8	26.5±6.3	10.4±1.4	13.4±2.7
Third hour	36.9±7.1	36.5±8.7	16.3±2.3	15.0±1.4	31.1±4.0	28.6±6.5	12.0±1.5	14.4±2.5

RMS – root mean square; M – mean; SD – standard deviation.

Table 3. Median frequency in 4 muscles in 2 different workstations during 3 h (divided into 4 times)

Time of work	Median frequency (M±SD)							
	workstation A				workstation B			
	left trapezius	right trapezius	left deltoid	right deltoid	left trapezius	right trapezius	left deltoid	right deltoid
Starting point	57.7±2.7	54.7±4.3	52.7±4.5	51.5±4.3	57.2±3.3	55.6±2.1	65.9±1.6	56.9±2.0
First hour	59.8±2.2	60.8±2.7	53.7±1.1	58.5±2.4	57.9±3.1	56.6±3.2	58.2±2.7	58.5±2.6
Second hour	59.4±2.4	61.9±3.6	56.6±1.6	56.9±2.1	55.3±3.2	55.6±2.3	61.1±3.9	54.0±2.2
Third hour	58.5±2.5	65.0±3.9	57.9±3.8	57.2±2.4	55.6±3.3	56.3±2.4	60.2±.9.0	52.0±3.2

Abbreviations as in Table 1.

Table 4. Main and interaction effects of a workstation, muscle type, side and time on median frequency by the repeated measure ANOVA

Effects	df	F	p
Main effect			
workstation	1	0.106	0.751
error	11	–	–
muscle type	1	0.362	0.810
error	11	–	–
muscle side	1	0.060	0.857
error	11	–	–
time	3	1.180	0.332
error	33	–	–
Interaction effect			
workstation*muscle type	1	2.852	0.119
error	11	–	–
workstation*muscle side	1	2.434	0.147
error	11	–	–
muscle type*side	1	0.328	0.579
error	11	–	–
workstation*time	3	1.327	0.282
error	33	–	–
muscle type*time	3	0.081	0.970
error	33	–	–
muscle side*time	3	1.146	0.345
error	33	–	–

Abbreviations as in Table 2.

Table 5. Rating of perceived fatigue (Borg CR-10), 2 workstations during 3 h (divided into 2 parts)

Time of work	Rating of perceived fatigue (M±SD)	
	workstation A	workstation B
Second hour	1.750±1.815	1.700±1.400
End of work	4.500±2.300	4.080±1.700

Abbreviations as in Table 1.

Table 6. Main and interaction effects of a workstation and time on subjective fatigue assessment (Borg CR-10 scale), by the repeated measure ANOVA

Effect	df	F	p
Main effects			
workstation	1	0.181	0.679
error	11	–	–
time	1	41.137	0.000
error	11	–	–
Interaction effects			
workstation*time	1	0.851	0.376
error	11	–	–

Abbreviations as in Table 2.

fatigue were analyzed using the repeated measure ANOVA, which showed that time factor had a significant effect on fatigue ($p < 0.001$). However, there was no statistically significant difference between the 2 workstations ($p > 0.05$) (Table 6).

DISCUSSION

Muscular activity and fatigue

Muscle activity was affected by a workstation; this influence was significant in all the tested muscles. Results demonstrated that, in the 4 tested muscles, mean value of RMS in workstation A was higher than that in workstation B (Table 1). Effect of posture and workstation on muscular activity has been shown in several studies [9,22]. An explanation for the low level of muscle activity in workstation B could be the fact that this workstation was more ergonomic and the subjects could customize their seat height. Also, having a back and armrests, could be a possible reason of a decreased shoulder muscle activity in workstation B. The study conducted by Aaras has supported the idea that trapezius muscle activity was significantly reduced when forearm support was provided [23]. In comparison, between the tested muscles, muscular activity in bilateral trapezius was higher than that in bilateral deltoid. Mean value of RMS in the right and left upper trapezius was significantly higher than that in deltoid, indicating that in carpet weaving, shoulder muscle appears to be the most affected one. The study conducted by Choobineh has shown that most of the prevalence of WMSDs in carpet weavers was in the shoulder region [1].

The RMS amplitude and median frequency did not change in respect of times and the effect of time is not significant in the 2 workstations in all muscles. This result means that fatigue was not observed in any of the workstations. Although increasing EMG amplitude and decreasing spectral values used to reflect the fatigue state [24] EMG amplitude parameters like RMS can still obscure in terms of fatigue assessment in dynamic activities. In comparison between amplitude and frequency variables, some researchers have suggested frequency variables, such as MF, and reported the existence of no adequate correlation with torque, and high variations between the participants in terms of EMG amplitude parameters [25,26]. Hence, the frequency analysis or simultaneous analysis of EMG spectrum and amplitude seem to represent methods suitable for the assessment of muscular fatigue.

The previous study on trapezius activity in traditional workstations has not shown any significant RMS increase during the 210 min working, although lower muscle fatigue was related to a reduction in the mean power frequency [10]. In the current study, both amplitude and spectrum parameters were calculated. The results did not show any muscle fatigue occurrence in both workstations. To maintain accurate results, Turville has suggested whole-shift EMG study [27]. Although the whole-shift studies would be more accurate, in the current study there were different limitations to recruiting carpet weavers for 8 h.

Major intramuscular changes, such as muscle blood flow, water fluxes, metabolite contractions and temperatures, occur during high-force and prolonged contraction. These changes cause muscle fatigue during the activity. However, during low-force contractions such as those occurring during carpet weaving, only some hemostatic disorders and subtle physiological changes occur. These fluctuations in long time lead to serious morphological changes in the muscles [28,29]. Therefore, electromyography in repetitive and low-force activity such as carpet weaving just reflected a part of muscle state or possibly failed to record all effects of work. On the other hand, there are some physiological changes that play an important role in muscle fatigue occurrence and that were ignored during electromyographic studies. Consequently, studying other aspects of muscle state would be helpful to reach better results.

Subjective fatigue rating scale

According to the results of Borg scale, there was no significant difference in the self-reported shoulder fatigue between the 2 workstations; but, in the time survey, there was a significant difference between the 2nd hour and the end of work (Table 4). Results of several studies have indicated that the more stressful the activity, the higher the rating of subjective scale selected by the participants. Garg has suggested the mean rating ≤ 3.5 on the Borg's CR-10 scale (between moderate and somewhat hard) as an acceptable level of perceived stress to the shoulder region [16]. Rated values of shoulder muscle fatigue for 3 h of carpet weaving in both workstations were near 4 and moderate. Based on the effect of time on the reported fatigue, it can be suggested that full-shift working in both workstations is stressful and increases the risk of upper-limb musculoskeletal disorders.

Strengths and limitations

The study design (within-subject research design) allowed each participant to have their own control; therefore, participant-to-participant variation was effectively eliminated.

Although this work was an occupational study, the investigation was not performed on the field but in the lab, the main result of which were culture-related problems. Nevertheless, a complete workstation was simulated in the lab and attempts were made to ensure that all environmental conditions were as close as possible to those prevailing in a real carpet weaving workstation.

CONCLUSIONS

Findings of this study indicated that carpet weaving in workstation A resulted in an increased muscular activity. Comparison between the 2 workstations, in workstation B the subjects had better chance to adjust their posture and that is why their muscular activity was lower. Furthermore, muscle activity in bilateral trapezius was significantly higher than that in bilateral deltoid. Muscular fatigue did not occur in any of the workstations. Probably the low-force activities, such as carpet weaving, require more time to cause fatigue. According to these results, a workstation that is suitable for carpet weaving cannot be determined. Further studies investigating other muscles involved during carpet weaving tasks could be helpful to propose an ergonomic workstation.

Results of the Borg's CR-10 rating scale showed similar fatigue ratings in both workstations at the moderate level. As far as time effect on the fatigue rating scale was concerned, it can be concluded that full-shift working in both workstations was stressful, which might result in muscle fatigue.

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