ORIGINAL PAPER

International Journal of Occupational Medicine and Environmental Health 2019;32(4):537–552
https://doi.org/10.13075/ijomeh.1896.01387

SHOULDER GIRDLE MUSCLE ACTIVITY AND FATIGUE DURING AUTOMOBILE CHASSIS REPAIR

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Abstract
Objectives: The objective of this study was to assess the postures that were commonly used in automobile chassis repair operations, and to evaluate shoulder girdle muscle fatigue for different combinations of the weight of hand-tools. **Material and Methods:** Two right muscles, including upper trapezius (UT) and middle deltoid (MD), were selected. Surface electromyography (SEMG) and a perceived level of discomfort (PLD) were used to assess the degree of shoulder girdle fatigue. Fifteen healthy young male subjects from the Northwestern Polytechnical University participated in the test. The test consisted of assuming 4 different postures and maintaining each of them for 60 s. The 4 postures varied in terms of dumbbell weights, standing for the hand-tools weight: W1 was 0.48 kg and W2 was 0.75 kg; the 4 shoulder postures were shoulder flexions of 150°, 120°, 90°, and 60°, combined with an included elbow angle of 180°, 150°, 120° and 90°, respectively. The experimental sequences were randomly selected. The signals of SEMG and the values of PLD in the shoulder girdle were recorded in 60 s. All subjects completed the whole test. The repeated measure analysis of variance (ANOVA) was performed to ascertain differences between dumbbell weight (0.48 kg and 0.75 kg) and shoulder postures (150°/180°, 120°/150°, 90°/120° and 60°/90°). The Friedman test was utilized to determine the significant differences for UT(PLD) and MD(PLD) on shoulder postures. Spearman's correlation was used to analyze the relationship between the subjective and objective measurements. **Results:** Significant correlational relationships existed between the UT percentage of the maximal voluntary electrical activation (%MVE) and UT(PLD) ($r = 0.459$, $p < 0.01$), between MD(%MVE) and MD(PLD) ($r = 0.821$, $p < 0.01$). The results showed that SEMG and PLD of the 4 postures under analysis differed significantly ($p < 0.05$). **Conclusions:** It was indicated that posture T4 (shoulder forward flexion 60° and included elbow angle 90°) resulted in the lowest fatigue, both in terms of the objective measure and the subjective perception, which meant that this posture was more ergonomic. Int J Occup Med Environ Health. 2019;32(4):537–52

Key words:
muscle activity, surface electromyography, muscle fatigue, perceived level of discomfort, automobile chassis repair, shoulder postures

INTRODUCTION

Although mass production in the automobile industry has been automated, repair work must be tailored to customers' requirements, and manual tasks in some assignments are still essential. It is necessary for automobile workers to adopt different working postures during a typical day. There are many poor working postures which involve a substantial static load. Work-related musculoskeletal disorders (MSDs) in the shoulder girdle are common among automobile mechanics. It is said that overhead work is a dangerous factor, contributing to shoulder disorders. However, eliminating overhead work tasks is not

Funding: this study was supported by the Ministry of Science and Technology of the People's Republic of China (grant No. 2017YFB1104205 entitled "Development and demonstration application of 3D printing innovation and entrepreneurship cloud platform," grant manager: Prof. Jianjie Chu) and by the Ministry of Education of the Peoples's Republic of China (grant No. B13044 entitled "Research on Industrial design and ergonomics," grant manager: Prof. Suihuai Yu).
Received: September 26, 2018. Accepted: April 11, 2019.
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always possible [1]. It was reported that in an automotive plant, shoulder injuries were the most frequently treated disorder among those working injuries [2].

Musculoskeletal disorders are an umbrella term used to describe different kinds of inflammatory and degenerative diseases and disorders which can lead to pain and functional impairments of the shoulders, elbows and so on [3]. As regards maintenance workers, MSDs weaken their ability to work and cut down their overall working life expectancy [4]. Due to static tension, a work posture involving elevated tools may expedite degeneration of shoulder tendons through circulation impairment [5]. Their constrained working postures, occupational trauma and a point of mild fatigue are prevalent.

Research has shown that fatigue increases the risk of injury to the joint because it creates an increased muscle activation and variations in kinematics that result in increased joint loading [6,7]. In car assembly, ergonomics problems were 3 times the quality deficiencies as common for the work tasks compared with the other tasks [8]. Precautions for various kinds of MSDs are fundamental in ergonomics. However, the way to reduce the harmful effects relating to the height to which the arms may be elevated, the time range and weights of the hands in a theoretical result still remain unclear [9]. The muscle load has been measured by several investigators using surface electromyography (SEMG) for analyzing muscular activity of the shoulder [1,2,10].

Some previous studies have examined shoulder postures. Garg et al. [1] studied the arm up and down for different exertion times. Mehta and Agnew [11] studied the muscle fatigability between the mental workload and the physical workload during repetitive shoulder work. Luger et al. [12] suggested that task variation could be a potential intervention for MSDs. Corben et al. [13] examined muscle fatigue after fast-pitch softball performances to provide an assessment of performance demand. These studies, however, were all focused on dynamic aspects.

Assuming a stationary and constrained working posture is considered an important risk factor for work-related musculoskeletal disorders [8]. Muscle imbalance, defined as the predominance of one of the synergist pairs of muscles during a movement [14], has become an important topic in the etiology of many musculoskeletal disorders [15]. This study analyzed the problem of shoulder fatigue from a static perspective. The authors' objective was to investigate shoulder muscle fatigue in the automobile chassis repair process by simulating various working postures, and to evaluate shoulder girdle fatigue for different experimental combinations, with the aim to provide some guidance for automobile chassis repair operations. Experimental combinations included various weights of hand-tools and shoulder postures that are commonly found in automobile chassis repair operations. Both the objective (SEMG) and subjective measures (the perceived level of discomfort – PLD) were used to assess the degree of shoulder girdle muscle activity and fatigue.

MATERIAL AND METHODS

Subjects

The characteristic of automobile repair workers is predominantly male workforce [16]. Fifteen healthy males (aged [M±SD] 29.3±2.8 years [range: 23–31 years], weight [M±SD] 76.2±13.4 kg [range: 56–95 kg]) were recruited from the Northwestern Polytechnical University. Their associated descriptive statistics values were recorded as mean ± standard deviations. All the subjects were required to wear waistcoats for the test in order to get the accurate data and to facilitate fixing the surface electrodes. The anthropometric characteristics are listed in Table 1, along with the following information: the subjects' metrics, including height, body mass, body mass index (BMI), shoulder height, upper arm length, lower arm length, hand length (from the wrist to the center of hand grip), the active shoulder

Table 1. Demographic and anthropometric data for the 15 male subjects from the Northwestern Polytechnical University, Xian, China, taking part in the study on shoulder girdle muscle activity and fatigue during automobile chassis repair in 13 July 2017 – 9 August 2017

Variable	M±SD	Range
Age [years]	29.3±2.8	23–35
Body mass [kg]	72.6±12.4	56–95
Body mass index (BMI)	23.7±3.9	18.8–31.4
Height [mm]	1 750±49.9	1 660–1 860
Shoulder height [mm]	1 472±55.4	1 410–1 620
Arm length [mm]		
upper	304±18.0	280–340
lower	286±17.2	250–310
Hand length (wrist to the center of grip) [mm]	108±6.8	100–120
Shoulder flexion range of motion		
HR = 0°, IEA = 180°	154.1±4.1	148–162
HR = 0°, IEA = 150°	148.8±5.9	137–157
HR = 45°, IEA = 180°	143.5±7.3	124–150
HR = 90°, IEA = 180°	142.9±5.2	135–150
Grip strength [kg]	41.1±8.1	30–58.8

HR – shoulder horizontal rotation; IEA – included elbow angle.

flexion range of motion, and grip strength. All the subjects were right-side dominant. They all claimed to be in good physical health, and none of them had any previous history of upper-limb pain or any cardiovascular disorder. They were asked not to perform any exercise 24 h prior to the measurement. The subjects performed their tasks in a standing position. All the subjects had previously completed a training phase, and thus were not unaccustomed to lifting tasks.

Ethics

All the subjects signed informed consent forms and obtained a verbal interpretation of the research protocol. After the test, they received some presents as compensation. This study was approved by the local Research Ethics Committee and was implemented according to the Declaration of Helsinki, as revised in 2013.

Surface electromyography

Surface electromyography, as a method non-invasive to the subjects during the test, was suitable for performing measurements in the occupational setting, enabling the recording of myoelectrical signals and a minimal restraint of the subjects. The electromyographic activity could be considered a neuromuscular response to match the biomechanical requirements [16]. It is one of the most effective tools and provides distinct feasibilities to get seasonable information, highly relevant from several ergonomic perspectives [17]. In addition, SEMG is one of the reliable methods applied to quantify muscle fatigue levels and physical exposure [18–20]. Surface electromyography signal information can be used in several ways, depending on the analyzed questions. Both biomechanics (forces and torques) and physiology (muscle activation and fatigue) had some ergonomic relevance.

The myoelectric signals, containing important information with regard to the timing of muscles, recorded as electromyogram SEMG, could explain the force/SEMG signal relationship and represent the SEMG signal as the fatigue index [21]. The frequency of the SEMG signal includes information about the muscle fiber activation patterns [22–24]. In order to analyze the amplitude, the currently rectified signals or root mean squared (RMS) values were used [25]. The root mean squared values and electrical activity, or spectral parameters such as mean power frequency (MPF), were calculated on the basis of the raw SEMG data. The RMS were used as an integrative measure of the SEMG amplitude, and its dependence on muscular force and fatigue [16,23]. It was reported that increasing RMS values were accompanied with an advancing fatigue [26]. The RMS and MPF values were calculated separately for each record and subject.

Experimental design

Apparatus

A MP150 16 multi-channel physiological recorder (BIOPAC MP150 systems, USA), along with disposable surface electrodes, silver/silver-chloride and software (AcqKnowledge 4.2.1), were used for recording the measurements and processing the SEMG signals amplified, band-pass filtered (10–500 Hz). Data were acquired at a sampling frequency of 1000 Hz.

Subject positioning

A 1.2×2.4 m plastic board printed automotive chassis was hung over the head, to be used to simulate the automobile chassis and the posture of automobile repair operators working underneath an automobile and using a vehicle lift. Performing work under an automobile standing on the floor was excluded from this study. The subjects stood on the ground. Two different weights and dumbbells were used to exert an upward force of either 0.48 kg/190 mm or 0.75 kg/150 mm. Each subject was instructed to touch the bottom of the printed automobile chassis plastic board with a dumbbell in his right hand, and the plastic board was adjusted up and down to match the subject's desired posture. A manual goniometer was used to measure the shoulder and elbow angles. The subject was also verbally encouraged to maintain an upright posture and to keep the shoulder and elbow angles steady. Grip strength was measured with a grip dynamometer.

Test procedure

Muscle fatigue needs to be executed several times throughout the work. Such a procedure should not be applied under actual repair conditions, as the measuring strongly obstructs the work routine and reduces the performance capacity. Therefore, in occupational studies indirect fatigue measurements using electromyography are preferred [16]. It is obviously possible to control the posture under laboratory conditions. The postures can be kept stationary at a decided level, and a change in each SEMG can be attributed to a change in the fatigue posture of the muscle. Under the actual working conditions, however, the posture is determined by the practical conditions of the performed operation and cannot be decided by the researchers. In general, it is not feasible to determine whether a given SEMG variation results from a change in the posture or the fatigue state.

The experiment was performed in a controlled laboratory at the Northwestern Polytechnical University. The indoor temperature was 23±2°C, and the relative humidity was 45–60%. During the test, a repeated-measure design was used for the effects of muscle activity (i.e., SEMG measures). However, SEMG of the trapezius has often been applied to assess total shoulder muscle load [2,10,27–29]. At the same time, the deltoid muscle has been widely used to study shoulder muscle load [30–33]. Muscle activity was monitored for the upper trapezius (UT) and the middle deltoid (MD), as overhead work is reportedly primarily

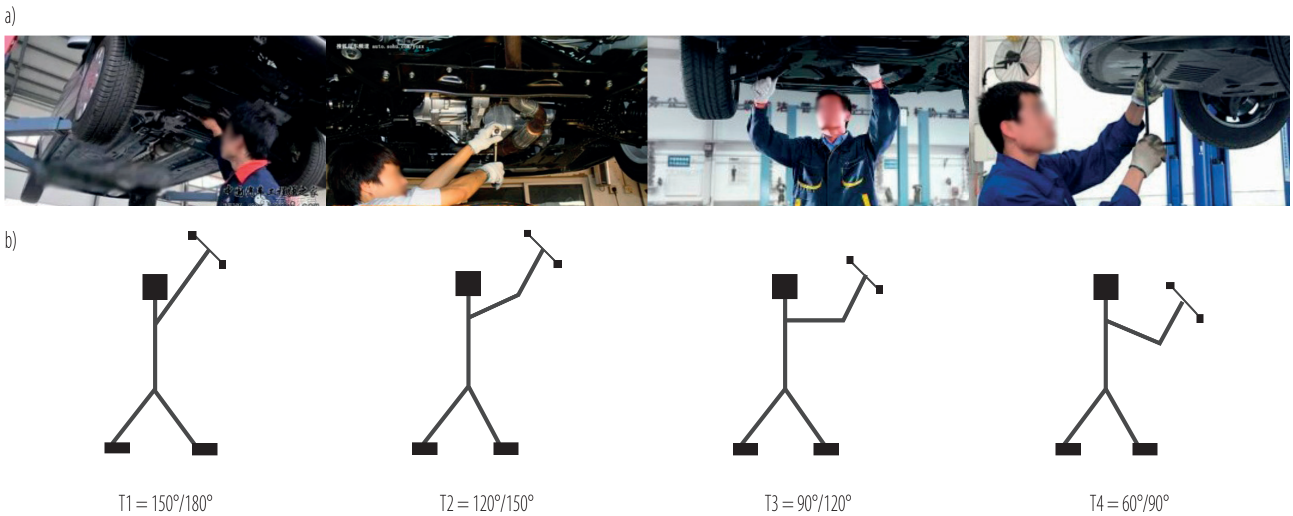


Figure 1. The shoulder postures (degrees) tested in the study on shoulder girdle muscle activity and fatigue during automobile chassis repair in 2017: a) actual operation in automobile chassis repair, b) 4 operation posture

supported by these muscles [1]. In this study, the right UT and MD muscles were selected to be tested.

Before electrode positioning, the skin should be shaved and cleaned with alcohol so as to reduce resistance and ensure good signal transmission. The electrode on the UT muscle was placed at the mid-point between the C7 spinous process and the posterior aspect of the acromion process [1]. The MD electrode was placed over the belly of the muscle, which is approximately one-fourth of the distance down from the acromion to the lateral epicondyle of the humerus [2].

During automobile chassis repair, several different postures were assumed. The common maintenance posture of the automobile chassis is shown in Figure 1a. Four shoulder postures were selected in this test, i.e., 150°/180° (T1) (shoulder forward flexion 150° and included elbow angle 180°), 120°/150° (T2), 90°/120° (T3), and 60°/90° (T4) (Figure 1b). Two weights (0.48 kg and 0.75 kg), representing hand-tool weights, were used several times for carrying and attaching in the automotive disassembly overhead postures. The 2 different dumbbell weights were chosen in order to simulate hand-tool weights which are commonly used by automobile repair workers, to emulate plausible work tasks, and to avoid generating muscle strain during the experimental session.

Before the experiment, the subjects were asked to maintain the postures until they were no longer able to keep their arms up, and the individual times were recorded. The tests indicated that the trial was terminated at 1 min to provide more consistent data for the statistical analysis. Prior to the trials, the subjects accomplished 6 standardized muscle-specific maximum voluntary isometric contractions (MVC) measurements.

For the UT muscle, the subjects were asked to lay prone, with their arms abducted to 90° and their thumbs facing their head, while they were pushing in the same direction against resistance [30]. For the MD muscle, the subjects, with their arms abducted to 90° and thumbs facing forwards, were pushing upwards against resistance [30]. For each muscle, a minimum of 3 MVCs were used for collecting the MVCs, and each test lasted 5 s. Mathiassen et al. [34] suggested that the highest peak value obtained from 3 successive MVCs should be chosen as the maximum. Another paper [35] reported that researchers also commonly applied an average of the peaks obtained from each successive MVC. The numerous normalization procedures reflect the lack of conformity, which makes comparisons between various research studies challenging [36]. The highest peak value recorded for each muscle was used for normalization procedures in this study.

The study used a test-rest-test protocol, which means 1 min of work at 1 work setting, 5 min of rest, 1 min of work at the other work setting. The subjects were told to hold up the dumbbell (0.48 kg and 0.75 kg, respectively) with their right hand, in a posture of 150°/180° for 1 min, and the rest could be done in the same manner. A minute later, the subjects were asked to rest for 5 min. A 5-min rest period has been proven to be a sufficient rest period, following a localized muscle fatiguing contraction [37]. The test order was subject to block randomization. At the beginning and after each minute of the test, the subjects were asked to rate their PLD on the 2 muscles. Figure 2 shows one of the postures.

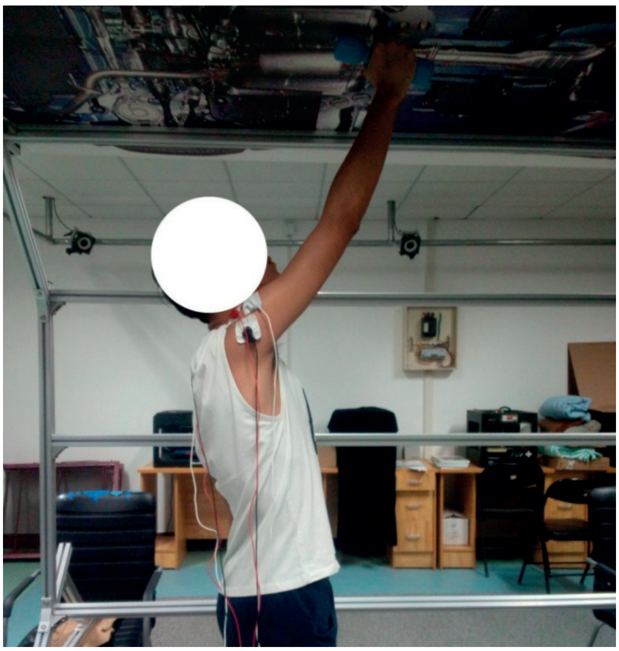


Figure 2. One of the postures tested in the study on shoulder girdle muscle activity and fatigue during automobile chassis repair in 2017

Table 2. The perceived level of discomfort (PLD) scale [38]

Scale	Description
0 pts	not noticeable discomfort
0.5 pt	extremely light discomfort (just noticeable)
1 pt	very light discomfort
2 pts	light discomfort
3 pts	moderate discomfort
4 pts	somewhat high discomfort
5–6 pts	high discomfort
7–9 pts	very high discomfort
10 pts	extremely high discomfort

Perceived level of discomfort

Hagberg et al. [35,36] believed that it was insufficient to merely apply the surface EMG technique to measure shoulder muscle load. The previous research focused on MSD evolution or ergonomic interventions has emphasized the interactions between the objective and subjective fatigue in connection with occupational activities [1,37,38]. In addition, the posture fatigue is influenced by subjective and objective methods. In order to compare the signs of the objective and subjective fatigue, by means of the root mean square, the mean power frequencies and the perceived level of discomfort in the trapezius muscle were tested at different load levels. The perceived level of discomfort was assessed using a modified Borg's perceived level of exertion scale, where 0 stands for no discomfort perceived, and 10 stands for extremely high discomfort [39]. Table 2 shows the scores. The subjects were asked to provide a verbal description of the score on PLD for 2 regions of their shoulders. A PLD poster was hung on the wall in front of the subjects.

Study variables

Independent variables

The study included 2 variables: dumbbell weights and shoulder postures. There were 2 dumbbell weights: 0.48 kg and 0.75 kg, and 4 shoulder postures: 150°/180° (shoulder forward flexion 150° and included elbow angle 180°) (T1), 120°/150° (T2), 90°/120° (T3), and 60°/90° (T4) (Figure 2).

Dependent variables

This study took muscle activation and the perceived level of discomfort as dependent variables. Muscle activation included the root mean square and mean power frequencies. Following the normalization procedure, RMS was replaced by a percentage of the maximal voluntary electrical activation (%MVE).

Statistical analysis

Due to major SEMG differences occurring between individual subjects and muscles, each data type requires SEMG to be calibrated or normalized, in order to be compared and analyzed. The root mean square is the applied integrative measure of the SEMG amplitude, and its dependence on muscular force and fatigue. In order to compare the levels of activity in different recording locations, and between individuals, selected RMS of the trial for each muscle was computed and normalized to the peak magnitude obtained during the muscle specific MVC exertions to comparisons [40].

The most common approach is to refer all muscle activity to an %MVE [36], which is a percentage of the maximal voluntary electrical activation [34]. It should be noted that this is only a linear conversion of the original SEMG amplitude parameter (RMS) [29]. The %MVE value was calculated for each record and subject: 2 muscles and 8 times. The raw signal was differentially amplified at a sampling rate of 1000 Hz, and band-pass filtered (10–500 Hz). All SEMG data were processed off-line with MATLAB, and the RMS and MPF values and subjective data were calculated. Correlations between dependent variables (i.e., UT(%MVE), MD(%MVE), and UT(PLD), MD(PLD)) were further investigated using Spearman's analysis in this study. All the %MVE and MPF values, and PLD data were transferred to SPSS software (version 20). Two (dumbbell weights) × 2 (muscle type) × 4 (posture) factorial repeated-measure ANOVA was used. Data normality was tested using the Shapiro-Wilk test [10].

RESULTS

The mean and standard deviations of %MVE can be found in Table 3. Mauchly's test of sphericity was performed for all normally-distributed data, and the Greenhouse-Geisser correction was used if this assumption was violated. The

Table 3. The mean and standard deviations of dependent variables (the percentage of the maximal voluntary electrical activation, %MVE) in the study on shoulder girdle muscle activity and fatigue during automobile chassis repair in 2017

DV/DW	%MVE (M±SD)			
	T1	T2	T3	T4
UT				
W1	53.07±15.88	43.96±10.11	35.93±7.28	33.99±6.72
W2	57.08±17.56	49.34±15.51	44.18±11.53	40.26±8.83
MD				
W1	53.14±12.37	38.58±8.04	31.11±7.10	17.53±5.12
W2	58.13±12.78	42.46±9.31	35.79±9.78	24.60±7.33

DV – dependent variable; DW – dumbbell weight; MD – middle deltoid; UT – upper trapezius.
W1 – 0.48 kg; W2 – 0.75 kg.
T1 – 150°/180°; T2 – 120°/150°; T3 – 90°/120°; T4 – 60°/90°.

Table 4. The main and interaction effects of weight and shoulder postures on the percentage of the maximal voluntary electrical activation (%MVE) by the repeated measure ANOVA in the study on shoulder girdle muscle activity and fatigue during automobile chassis repair in 2017

Effect	%MVE					
	UT			MD		
	df	F	p	df	F	p
Main effect						
dumbbell weight	1	25.812	**0.000**	1	223.541	**0.000**
error	14	n.d.	n.d.	14	n.d.	n.d.
shoulder postures	1	13.144	0.003	1	104.419	**0.000**
error	14	n.d.	n.d.	14	n.d.	n.d.
Interaction effect						
weight* shoulder postures	1	3.559	0.08	1	0.370	0.553
error	14	n.d.	n.d.	14	n.d.	n.d.

MD – middle deltoid; UT – upper trapezius.
df – degree of freedom; F – Fisher statistics.
Error – error component in the ANOVA table.
* Interaction effects.
n.d. – no data.
Bolded – these values indicate significant differences ($p<0.05$).

significance level was set as 5%. When a significant interaction was found, the simple effects were calculated using the Bonferroni correction for multiple comparisons.

Muscle activity was significantly different between the UT and MD muscles. The mean value of %MVE showed that posture T1 was the highest among the 4 postures, both as regards UT and MD. The effects of dumbbell weights and shoulder postures on %MVE were significant ($p < 0.05$), while the interaction effects between dumbbell weights and shoulder postures were not ($p > 0.05$) (Tables 3 and 4).

The mean and standard deviations of MPF can be found in Table 5. The results of the repeated ANOVA showed no significant differences in the 4 postures and 2 weights ($p > 0.05$). Also as regards the interaction effects between dumbbell weights and shoulder postures, no significant differences were observed ($p > 0.05$) (Table 6).

For non-normal data of PLD, non-parametric tests were employed to analyze the mean PLD. The Friedman test was utilized to determine the significant differences for UT(PLD) and MD(PLD).

Table 8 shows that some significant differences for the muscle activation were found across the shoulder postures. Among these values, for UT(%MVE), there were significant differences on posture T1; for MD(%MVE), the shoulder postures showed significant differences except T2 vs. T3 ($p < 0.05$). However, for UT(MPF), there was no difference except T2 vs. T3 and T2 vs. T4. For MD(MPF), T1 vs. T4, T2 vs. T4 showed a significant difference ($p = 0.006$ and $p = 0.005$). For PLD, shoulder postures showed a significant difference except T1 vs. T2, T2 vs. T3 and T3 vs. T4 on UT(PLD) and MD(PLD).

The results (Table 8) showed that %MVE and PLD of the shoulder postures differed significantly ($p < 0.05$). Most values of MPF ($p > 0.05$) implied that it had no statistical significance, and the results for MPF meant that fatigue was not observed in most of the postures, which could not work as a valid estimator of shoulder muscle fatigue at the low load levels, as indicated in this study.

Table 5. Dependent variables (mean power frequency, MPF) in the study on shoulder girdle muscle activity and fatigue during automobile chassis repair in 2017

DV/DW	MPF [Hz] (M±SD)			
	T1	T2	T3	T4
UT				
W1	104.60±23.16	112.61±18.37	97.45±13.61	96.44±18.94
W2	106.25±31.58	118.05±22.57	110.76±17.11	103.44±17.39
MD				
W1	125.27±21.61	125.81±22.75	114.19±20.07	90.41±15.08
W2	114.12±14.50	111.49±13.31	114.49±27.90	111.74±16.64

T1 – 150°/180°; T2 – 120°/150°; T3 – 90°/120°; T4 – 60°/90°.
Abbreviations as in Table 3.

Table 6. The main and interaction effects of weight and shoulder postures on MPF by the repeated measure ANOVA in the study on shoulder girdle muscle activity and fatigue during automobile chassis repair in 2017

Effect	MPF					
	UT			MD		
	df	F	p	df	F	p
Main effect						
dumbbell weight	1	2.946	0.108	1	0.054	0.819
error	14	n.d.	n.d.	14	n.d.	n.d.
shoulder postures	1	1.687	0.215	1	24.945	0.000
error	14	n.d.	n.d.	14	n.d.	n.d.
Interaction effect						
weight*shoulder postures	1	1.076	0.317	1	11.442	0.004
error	14	n.d.	n.d.	14	n.d.	n.d.

Explanations as in Table 4.

Table 7. The perceived level of discomfort (PLD) in the study on shoulder girdle muscle activity and fatigue during automobile chassis repair in 2017

DV/DW	PLD [pts] (M±SD)			
	T1	T2	T3	T4
UT				
W1	4.13±0.64	4.47±0.51	3.53±0.52	2.20±0.77
W2	5.27±0.70	5.13±0.64	4.07±0.70	2.73±0.70

Table 7. The perceived level of discomfort (PLD) in the study on shoulder girdle muscle activity and fatigue during automobile chassis repair in 2017 – cont.

DV/DW	PLD [pts] (M±SD)			
	T1	T2	T3	T4
MD				
W1	5.67±0.72	3.4±0.51	2.4±0.63	1.0±0.33
W2	6.8±0.68	4.2±0.68	3.13±0.64	2.0±0.53

T1 – 150°/180°; T2 – 120°/150°; T3 – 90°/120°; T4 – 60°/90°
Abbreviations as in Table 3.

Table 8. A comparison between the different shoulder postures in the study on shoulder girdle muscle activity and fatigue during automobile chassis repair in 2017

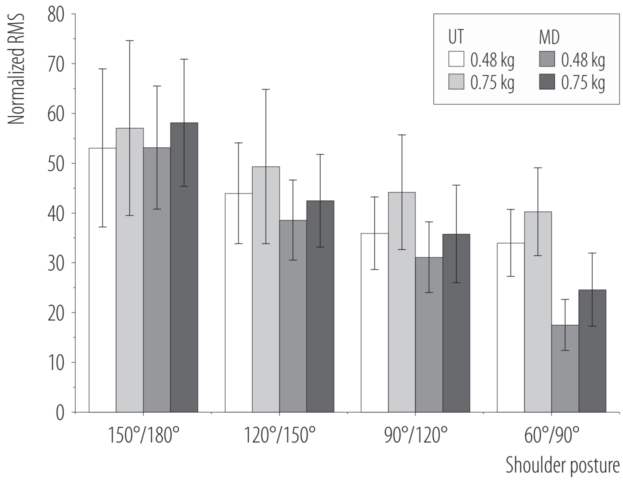
Items	T1 vs. T2	T1 vs. T3	T1 vs. T4	T2 vs. T3	T2 vs. T4	T3 vs. T4
Repeated-measures ANOVA						
UT(%MVE) (B)	**0.047**	**0.019**	**0.015**	0.083	0.100	0.677
MD(%MVE) (B)	**0.000**	**0.000**	**0.000**	0.164	**0.000**	**0.000**
UT(MPF) (B)	0.943	1.000	1.000	**0.020**	**0.018**	1.000
MD(MPF) (B)	1.000	1.000	**0.006**	1.000	**0.005**	0.386
Friedman test						
UT(PLD)	0.463	**0.001**	**0.000**	0.286	**0.000**	0.118
MD(PLD)	0.170	**0.000**	**0.000**	0.286	**0.000**	0.170

%MVE – a percentage of the maximal voluntary electrical activation; B – Bonferroni; MD – middle deltoid; MPF – mean power frequencies; PLD – the perceived level of discomfort; UT – upper trapezius.
T1 – 150°/180°; T2 – 120°/150°; T3 – 90°/120°; T4 – 60°/90°.
Bolded – significant differences ($p < 0.05$).

DISCUSSION

Operational posture is one of the interventions that has been proven to exert a positive impact on the health of automobile mechanics [41]. Because of the complex operating conditions, some activities still force workers to adopt working postures that are harmful to their musculoskeletal system. For the convenience of the study, the authors selected some common postures and hand-tool weights as the objects of analysis. Typical working postures were always selected to be improved or changed as the optimal work handling effect. Reducing the amount of time spent in each poor posture, lightening tool weight and taking ergonomic postures should be taken into consideration with a view to eliminating the influence of poor typical working postures.

The present work focused on muscle activity in 4 shoulder postures and 2 kinds of hand-tool weights simulating the operation of automobile chassis repair during 60 s. The aim was to determine the influence of shoulder girdle activation on the posture, and to better understand which posture and which muscle were the most tiring during automobile chassis repair, by referring to SEMG and the perceived level of discomfort. In this study, shoulder mus-



MD – middle deltoid; UT – upper trapezius.
RMS – root mean squared.

Figure 3. The surface electromyography amplitude on hand-tool weight and shoulder postures in the study on shoulder girdle muscle activity and fatigue during automobile chassis repair in 2017

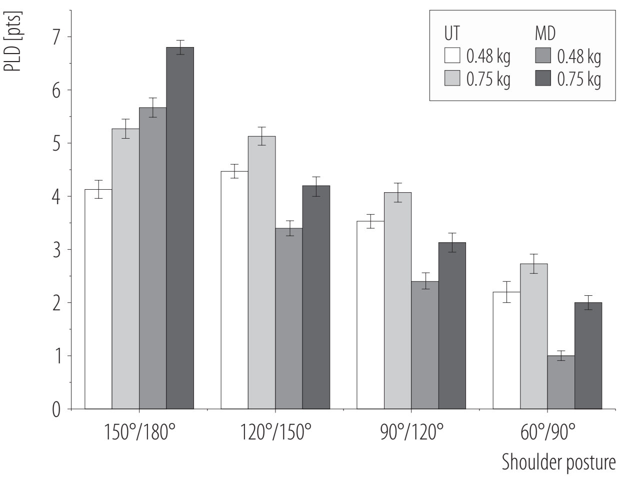
cle fatigue was at low load levels in terms of the relevant objective and subjective measures, and they were not contradictory. It was important to find correlations between the objective and subjective variables to develop a foundation of the objective correlates when muscle fatigue measurements were performed. This influence was significant in all the tested muscles (Figure 3).

The amplitude increase attributable to fatigue can be understood as an increased muscle activation even though a small part of it can be due to the action potential velocity decrease and the psychological factors related muscular activity [29]. The obtained results demonstrated that, in the 2 tested muscles and 2 kinds of hand-tool weights, the mean value of %MVE in posture T1 (shoulder forward flexion 150° and included elbow angle 180°) was higher than in other postures (Figure 3). As to posture T1, the SEMG amplitude of MD was a little higher than that of UT. As to the other 3 postures, the SEMG amplitude of UT was higher than that of MD. This indicated that the shoulder muscle appeared to be the most affected in the automobile chassis repair process. The fatigue evoked an increase in the activation of the muscle. This meant that in posture T1, fatigue was easy to be produced on MD under the same hand-tool weight, while in the other 3 postures, fatigue was easy to be produced on UT (Figure 3).

The dumbbell weight affected the SEMG amplitude, and the heavier the weight, the higher the SEMG amplitude of the muscles. However, it had a little impact on MPF. This result was in agreement with previous research [42]. The dumbbell weight was mainly used to simulate the hand-tool weight at a low load level. Thus, at the lower load levels and static postures, MPF was unfit to act as an estimator of localized muscle fatigue. An explanation for the low level of muscle activity in posture T4 could be the possible condition of a decreased shoulder muscle activity, and this posture was more ergonomic. Briefly speaking, comprehensive measures of the SEMG amplitude, such as RMS, can be employed to explain changes in the SEMG signal caused by muscular fatigue; but not *vice versa*, that is to say, they were not appropriate to decide whether the increase in the SEMG amplitude had resulted from fatigue or other factors [16].

Figure 4 showed that posture T4 resulted in the lowest PLD values. The shoulder postures included in this investigation confirmed the above measurement results. For example, the highest fatigue for posture T1 was significantly greater than those for postures of T2, T3 and T4. One of the reasons was that the first posture would produce higher torque in the shoulder joint than the other 3 postures. The result was identical to %MVE, with some differences between %MVE and PLD (Figures 3 and 4). Figure 3 shows that in posture T1, the UT muscle was only a little higher than for the MD muscle. However, as regards the PLD value, the heavier tool exhibited higher values of PLD, both for the UT and MD muscle.

As regards the subjective and objective measure of fatigue, literature [33] shows that the subjective ratings are more



Abbreviations as in Figure 3.

Figure 4. The perceived level of discomfort (PLD) on hand-tool weight and shoulder postures in the study on shoulder girdle muscle activity and fatigue during automobile chassis repair in 2017

informative than the objective ones. This study also found that the perceived level of discomfort contained more information than surface electromyography. The subjective fatigue degree is shown in Figure 4. However, it was hard to acquire similar information from SEMG. The reason for this inconsistency could be most likely attributable to different experiment designs or the different characteristics of the two muscles. However, most of the results were consistent between the subjective and objective measures, which means that PLD could be used to evaluate some postures when using SEMG does not seem convenient. To analyze the correlations between the objective and subjective variables, Spearman's correlation analysis was used, and the results are shown in Table 9.

It was indicated that there were significant correlations between the subjective ratings and the objective variables. Significant correlation relationships were found to exist between UT(%MVE) and UT(PLD) ($r = 0.459$, $p < 0.01$), and between MD(%MVE) and MD(PLD) ($r = 0.821$, $p < 0.01$). Identifying certain correlations between the objective and subjective variables enabled the researchers to develop a foundation for objective correlates that might be later used as an objective tool for indirect fatigue predictions.

Limitations

There are several limitations of this study that should be illustrated. First of all, no force, except the dumbbell weight, was applied in the experiment, which is a limitation as it makes the study conditions and the actual working conditions dissimilar. Another limitation was the small sample size, which might impair the results generalization, and require the experiment to be repeated using a larger sample. Finally, the postures studied were dynamic in nature, and ever minor changes in the sub-

Table 9. Spearman's correlation coefficients for the variables in the study on shoulder girdle muscle activity and fatigue during automobile chassis repair in 2017

Variable	Spearman's correlation							
	UT(%MVE)		MD(%MVE)		UT(PLD)		MD(PLD)	
	ϱ	ς	ϱ	ς	ϱ	ς	ϱ	ς
UT(%MVE)	1.000		0.607**	0.000	0.459**	0.000	0.581**	0.000
MD(%MVE)			1		0.617**	0.000	0.821**	0.000
UT(PLD)					1		0.690**	0.000
MD(PLD)							1	

Abbreviations as in Table 8.
** The correlation is significant at a 0.01 level (2-tailed).

jects' postures or psychological factors might have influenced the testing results. So, the results may exhibit some errors.

CONCLUSIONS

1. The research simulated some of the postures assumed in the automobile chassis repair process. The dependent variables included SEMG signals from the MD and UT muscles, and PLD in the shoulder girdle muscle.
2. All the subjects completed all the tests, assuming 4 different postures and maintaining each of them for 60 s. The 4 postures varied in terms of dumbbell weight, signifying the hand-tools weight: W1 was 0.48 kg and W2 was 0.75 kg; the 4 shoulder postures were: shoulder flexions, of 150°, 120°, 90° and 60°, combined with an included elbow angle of 180°, 150°, 120° and 90°, respectively.
3. The analysis of the MPF results revealed that fatigue was not observed either in the trapezius or deltoid muscles in most of the postures, which could not work as a valid estimator of shoulder muscle fatigue at low load levels in this study.
4. The weight of the hand-tool had a significant influence on the subjective perception. A weight of 0.75 kg resulted in a significantly higher perceived level of discomfort.
5. The overhead tasks test (including combinations of hand-tool weights and shoulder postures) revealed that all the subjects could perform work for 60 s without any excessive perceived fatigue or pain in the shoulder girdle.
6. The results of this study suggested that these postures could affect the shoulder girdle muscle activity. As to posture T1, with the same hand-tool weight, the SEMG amplitude and PLD on MD were higher than those of UT. Therefore, in order to avoid altered joint mechanics, which can potentially lead to certain pathologies, careful consideration must be given to MD to avoid over-fatigue while assuming posture T1 in the work process.
7. There were some differences between posture T1 and the other 3 postures as regards muscle activation. Posture T1 had a higher shoulder forward flexion and a higher elevation in the scapular plane, as compared to the other 3 postures. Therefore, the different shoulder muscles had different fatigue contractions.
8. This study showed that during automobile chassis repair, it would be better to recommend more favorable postures (such as T4 = 60°/90° or T3 = 90°/120°) to keep the hands close to the body, in order to reduce torque on the shoulder joint. This objective could be achieved with the following measures: 1) designing more ergonomic hand tools; 2) adding assistive facilities (such as a workbench or a shoulder support) and shifting the unfavorable posture to favorable postures; 3) improving working methods and working routines.
9. This study revealed that postures and hand-tool weights could affect the shoulder girdle muscle activity. As for the automobile repair workers, they had to adopt many poor postures, and MSDs in the shoulder girdle were common, which could lead to pain and functional impairments of the shoulders, elbows and so on [3]. The results confirmed the risk of cumulative trauma disorders in automobile repair workers. Finally, as regards the statement in the references [43,44], it was recommended to be incorporated within periodical medical check-ups of this group of workers (or other workers with similar working conditions). They also contributed to the evaluation of the dynamics of pathological changes and were particularly helpful in early detection of occupational diseases.

ACKNOWLEDGMENTS

The authors would like to express their gratitude to the subjects involved in the tests for their time and effort.

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