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Original Article

Evaluation of a proposed chair with an arm support for wiring terminal blocks on a vertical plane

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Abstract: To reduce the muscular exertion of an operator wiring terminal blocks on a vertical plane, a chair with a unique back that can be used as a back support or arm support is proposed in this study. A digital version of the chair was first developed based on anthropometric data and tested with a digital anthropometric subject using the Jack software before the physical chair was developed. To evaluate the effects of the physical chair, an experiment of wiring terminal blocks was conducted with 12 subjects to test whether the use of the arm support can reduce muscular exertion. The results showed that (1) exertion on the anterior deltoid, upper trapezium, and erector spinae muscles decreased with decrease in terminal block height; (2) using the arm support reduced exertion on the anterior deltoid and upper trapezium muscles; and (3) the subjects reported less self-perceived fatigue in the wrist, elbow, and shoulder regions when the arm support was used. These results confirm that the proposed chair can reduce muscular workload in the shoulder muscle over a proper range of working heights. However, using the arm support may restrict certain working postures and lead to force generation in upper extremity muscles.

Key words: Musculoskeletal disorders, Jack software, Electromyography, Muscle workload

Introduction

Several occupational safety and health epidemiological studies show a causal relationship between physical exertion at work and work-related musculoskeletal disorders (WMSDs)[1)]. These disorders account for 29–35% of all workplace injuries in the United States from 1992 to 2010 that required time away from work for recovery[2)]. Several factors have been associated with WMSDs, including repetitive motion, excessive force, awkward and/or sustained postures, and prolonged sitting and standing[1, 3, 4)]. The reports of the National Institute for Occupational Safety and Health (2001) show that the majority of these injuries occur in the back (52.2%), followed by the upper extremity (26.0%), and then the trunk (10.8%)[5)]. The occurrence of WMSDs results in productivity loss[6)], job leaves[7)], worker injuries[4, 7)], medical costs[7)], diminished qualify of life[8)], and increased workplace stress[8)].

It has been widely accepted that awkward and constrained postures are the major factors in WMSD development[9, 10)]. In a typical industrial scenario, screw driving tasks (pronation or supination) are highly prevalent[11)]. In a common assembly line wiring task, most workers sit on chairs of fixed heights to accommodate a range of working heights. The circuit boards normally have vari-

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ous sizes and heights. Operators might need to work in awkward postures to adapt to the spatial configurations of the assembly line. Awkward postures have been found to be associated with decreased performance efficiency, while restricted postures serve as major causes of body discomfort[12]. The undesired effect that is brought about by awkward postures will continue to persist unless proactive steps are taken to evaluate and reduce the problem.

Providing proper aids and tools would be valuable in minimizing worker musculoskeletal discomfort and injuries and improving assembly line operation efficiency. Providing arm support can have a positive influence on the known risk factors for upper extremity disorders and for forearm and wrist movements and awkward postures[13, 14]. On the basis of electromyography (EMG) and pain/discomfort assessment results, some researchers have recommended arm suspension equipment or arm supports for works requiring awkward or restricted postures to reduce muscle load, discomfort, and pain in the neck and shoulder regions[15, 16]. To maintain such postures, the muscles have to perform extra work, especially when working with stretched arms or in a bent position. This means that muscles become tired quickly in awkward postures, even if the work does not require high muscle forces. In previous EMG studies, it was found that arm supports decreased muscle loads in the shoulder and neck regions in visual display unit (VDU) tasks involving typing or mouse usage[17–19] and in light assembly work[20, 21], but they had minor effects on the arm muscles[22].

Research objectives

The aim of this study is to evaluate the effect of providing arm support on a screw driving task. A self-built chair with an arm support was designed based on anthropometric data. The proposed chair was evaluated in an experiment that tested subjects' muscle activities and subjective ratings of fatigue while they performed a simulated wiring task of terminal blocks.

Subjects and Methods

Proposed chair

To test the benefits of an arm support, a chair was designed and developed. The chair was first prototyped using AutoCAD software. Anthropometric data of body height, shoulder width, and sitting height parameters which were used to design the chair were based on 18–44 yr old males in Taiwan[23]. The proposed chair has a height-adjustable seat and a back support (Fig. 1), which can be alternatively used as an arm support (Fig. 2a and 2b). The arm support was designed with a length of 50 cm, 24.4–36.4 cm above the sitting surface and 70.5–80.5 cm above the ground, to provide good support for the elbow and forearm of an operator in natural working postures. After the chair was developed in AutoCAD, it was evaluated using Jack. In Jack, the digital chair and a virtual humanoid were placed in a simulated wiring situation to confirm whether the operating ranges of the humanoid while using the chair meet the applicable design requirements. The virtual humanoid had the average body type of 10–90 percentile of the population. The tests of operating ranges include reaching abilities and levels of upper, medium, and lower working heights for different operating postures and body builds. Furthermore, it was evaluated whether the chair design would lead to extreme body postures or interferences with the work. After the evaluation, the digital chair model was physically built with few adequate modifications.

Fig. 1. The proposed chair with a height-adjustable seat and a back support, which can alternatively be used as an arm support.

Subjects

Twelve college students were recruited for this study. Their average age was 24.5 ± 1.4 yr, average height was 173.4 ± 6.0 cm, and average mass was 72.0 ± 5.7 kg. All subjects were right hand dominant, and none of them suffered from any neuromuscular or musculoskeletal disorder. Before the experiments, the experimental goals and protocols were disclosed to the subjects in verbal and in written form. They were familiarized with the actual operation movements of real assembly line workers, the measurement procedure, and experimental tasks. This study was approved by the local medical ethics and the human clinical trial committees (China Medical University Hospital), and all subjects signed informed consent forms before the experiments were conducted.

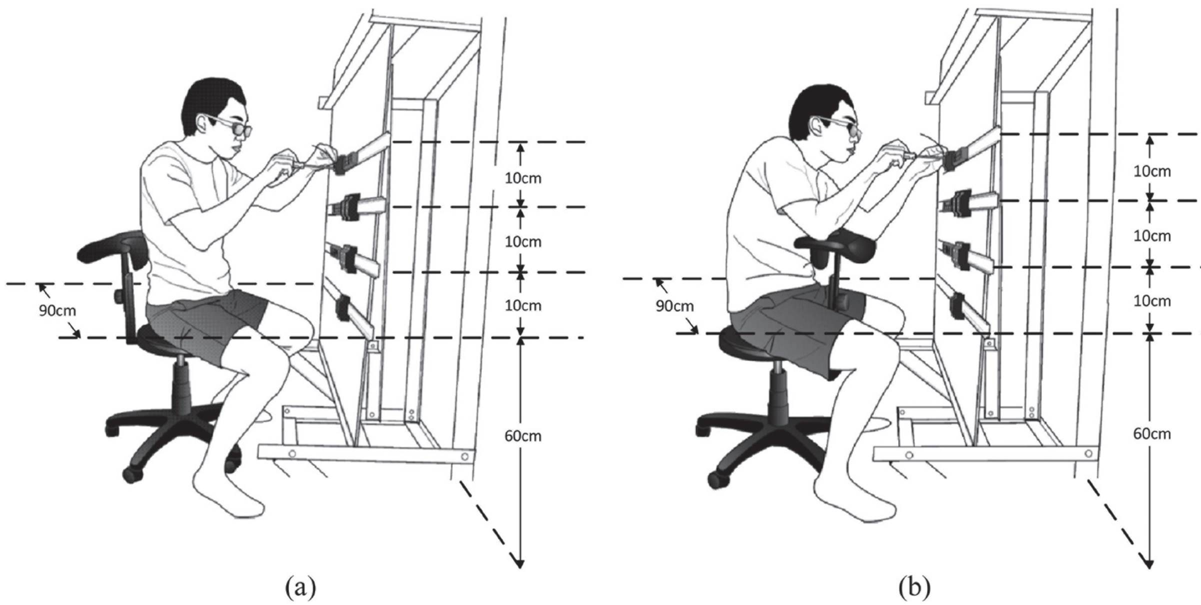


Fig. 2. Subject sitting on the proposed chair while using the support for back (a) and for arms (b) in wiring terminal blocks fixed on a vertical aluminum rack.

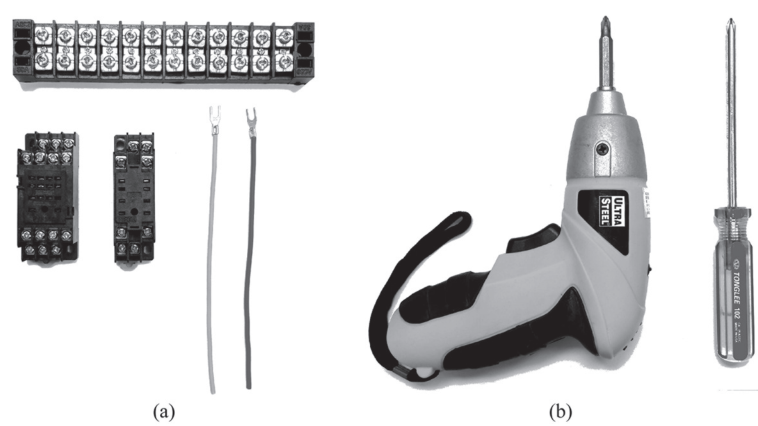


Fig. 3. Experimental tools: (a) three types of terminal blocks and (b) electric and manual screwdrivers.

Experimental settings and procedures

In the experiment, the subjects were asked to perform wiring tasks on three types of terminal blocks (Fig. 3a) fixed on a vertical aluminum rack in a laboratorial environment. As shown in Fig. 2, four aluminum bars, with 10 cm vertical intervals, were horizontally fixed on the rack. The lowest bar was 60 cm above the ground, and hence, the highest bar was 90 cm above the ground. Each bar was 90 cm wide and had 58 screw terminals. The wiring task required the subjects to insert a piece of wire into each screw terminal (Fig. 3a) with their left hand and drive the screw with the right hand using the designated tool. The screwing tasks were sequentially performed on 232 screw terminals from left to right on each bar and from top to bottom for the four bars.

Each subject was asked to perform the wiring tasks in four conditions, considering the arm support usage and screwdriver type. As shown in Table 1, in N1 and N2 conditions, the subjects performed the wiring task without the arm support (Fig. 2a), whereas in S1 and S2 conditions, the arm support was used (Fig. 2b). In addition, in N1, S1, and N2 conditions, the subjects used a manual screwdriver to perform the tasks, while in S2 condition, they used an electric screwdriver. Considering the above conditions, all subjects performed the wiring tasks in the following order: N1, S1, N2, and S2. The design allows for the analyses of the learning effect (N1 vs. N2) and differences between the effects of using manual and electric screwdrivers. The subject rested for 30 min before performing the wiring tasks for each experimental condition. After the four experimental tasks, each participant reported subjective perceived fatigue using a questionnaire.

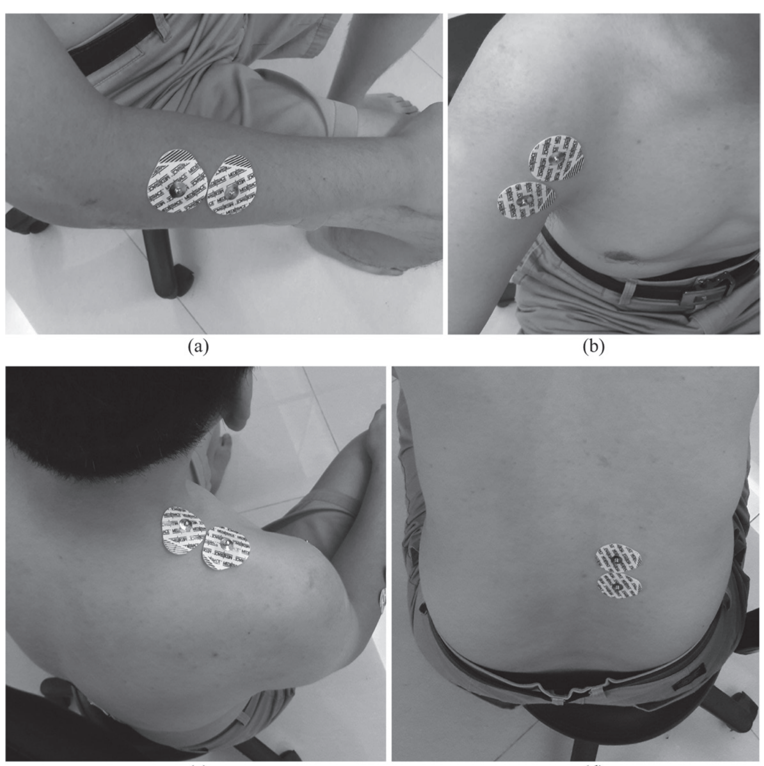
Experimental variables

The independent variables tested in the study include the arm support usage, terminal block height, and screwdriver type. As mentioned above, the same chair was used differently in the experiment to generate the with-arm-support condition (S1 and S2) and the without-arm-support condition (N1 and N2). The terminal block heights were 60 cm (L4), 70 cm (L3), 80 cm (L2), and 90 cm (L1) cm above the ground. In a preliminary study, the subjects performed the wiring tasks with negligible differences in EMG and body postures on the two medium levels. Hence, in the analyses, L1 and L4 heights were defined as low level and high level, respectively, whereas L2 and L3 heights were both defined as medium levels. A manual screwdriver and an electric screwdriver (Fig. 3b) were used as different conditions.

Table 1. Four experimental conditions

Experimental condition	Arm-support usage	Screwdriver type
N1	No	Manual
S1	Yes	Manual
N2	No	Manual
S2	Yes	Electric

The dependent variables measured in the study were performance time, usage rate of arm support, EMG, and the subjective ratings of fatigue. To assess muscular exertion of the subjects, surface EMG analyses were carried out while they performed the wiring tasks. As shown in Fig. 4, four muscles, comprising upper trapezius, anterior deltoid, extensor carpi radials, and erector spinae, on the dominant side of the subjects were measured. Each bipolar surface electrode was placed along the muscle, with the electrode center positioned at the point of recommended insertion for a needle electrode[24]. Raw EMG signals were amplified with a gain of 5,000, low-pass filtered at 500 Hz, and digitized and recorded at a rate of 1,000 Hz. Before the electrodes were placed, the skins of the subjects were



(a) (b) (c) (d)

Fig. 4. Placements of surface electrodes on the four measured muscles: (a) extensor carpi radials muscle, (b) anterior deltoid muscle, (c) upper trapezium muscle, and (d) erector spinae muscle.

Table 2. Comparisons of performance times required and usage rates of the arm support while wiring was performed at different terminal block heights under the four experimental conditions

Completion time (min)	Experimental condition			
Level of height	N1	S1	N2	S2
High (L1)	9.8 ± 2.0	9.7 ± 1.8	8.4 ± 1. 5	8.3 ± 1.1
Medium (L2+L3)	21.0 ± 3.8	21.2 ± 4.0	19.7 ± 3.1	18.8 ± 4.1
Low (L4)	9.4 ± 1.5	9.5 ± 1.6	10.7 ± 6.8	10.7 ± 8.6
Total time	40.2 ± 6.0	40.4 ± 6.2	36.2 ± 5.4	34.8 ± 5.0
Usage rate of arm support (%)	**Experimental condition**			
Level of height	N1	S1	N2	S2
High (L1)	NA	100 ± 0.0	NA	100 ± 0.0
Medium (L2+L3)	NA	88 ± 19	NA	87 ± 17
Low (L4)	NA	18 ± 32	NA	20 ± 33

N1 and N2: using manual screwdriver without arm support; S1: using manual screwdriver with arm support; S2: using electric screwdriver with arm support; NA: not applicable.

cleaned with acetone. A 5-s maximal manual muscle test was performed to obtain the maximum voluntary contractions (MVC) under isometric conditions for each muscle[25]. Subjective ratings of fatigue, as mentioned above, were collected using a questionnaire. The subjects reported self-perceived fatigue of seven body parts of interest: right shoulder, right upper arm, right elbow, right forearm, right wrist, upper back, and lower back, using eight-point Likert scales.

Data analysis

EMG processing

Original EMG signals were acquired at a sampling rate of 1,000 Hz. The original EMG signals were then divided into 1 s intervals using Viewlog software. The root mean square (RMS) value was calculated for each interval. This was equivalent to the averaged EMG amplitude at a sampling rate of 1 Hz in time series. The measured time series data were then transformed to percentage maximal voluntary contraction (%MVC) by normalizing the data using the formula,

$$\%\text{MVC} = \frac{EMG\ RMS\ of\ Work - EMG\ RMS\ of\ Rest}{EMG\ RMS\ of\ MVC - EMG\ RMS\ of\ Rest} \times 100\%$$

where *EMG RMS of Work* was measured when the wiring tasks were being performed, *EMG RMS of Rest* was measured at rest, and *EMG RMS of MVC* was measured at the maximum muscle exertion. The %MVC data were obtained using individual *EMG RMS of Rest* and *EMG RMS of MVC* for the individual muscles of the subjects.

The transformed %MVC data were analyzed with the amplitude probability distribution function (APDF)[26]. The 10th, 50th, and 90th percentiles of the APDF for %MVC data were used to describe low (static load, 10%ile), median (median load, 50%ile), and high (peak load, 90%ile) degrees of muscular exertions.

Video recordings were used to categorize and analyze data from different tasks and working heights. The degrees of muscular exertion were determined for each task and for different working height levels.

Statistics analysis

The SPSS for Windows version 12.0 was used for statistical analyses. A two-way analysis of variance with repeated measures was used for muscular exertion comparisons for different muscles under the influence of the task types (N1–N2, S2–N2, S1–S2) and working heights (high, medium, low). Bonferroni correction was used for post hoc multiple pairwise comparisons. Paired *t*-test was used to compare the subjective ratings of muscle fatigue with and without arm support. The statistical significance level was set at $p<0.05$.

Results

Performance time and usage rate of the arm support

Table 2 shows comparisons of the performance times required and usage rates of the arm support under the four experimental conditions when the subjects performed wiring tasks at different heights. As shown in Table 2, there was no significant difference in the performance times resulting from the different terminal block heights and experimental conditions. However, the usage rate of arm

Table 3. Comparison of muscular exertion (%MVC) at three levels of terminal block levels under the four experimental conditions

	%MVC	Height	Experimental condition				Tested Effects								
			N1	S1	N2	S2	N1 vs. N2			S1 vs. N2			S1 vs. S2		
							L	H	L×H	S	H	S×H	T	H	T×H
Extensor carpi radials	10%	High	4.4 ± 2.1	4.4 ± 2.3	4.2 ± 1.9	5.4 ± 1.9									
		Medium	4.0 ± 2.3	5.2 ± 3.4	3.4 ± 1.7	6.6 ± 2.6							*		
		Low	3.5 ± 2.6	4.4 ± 3.3	3.5 ± 2.0	6.2 ± 2.4									
	50%	High	11.8 ± 5.6	10.8 ± 5.6	10.4 ± 3.6	9.2 ± 3.1									
		Medium	11.4 ± 5.5	12.2 ± 7.2	9.9 ± 3.8	10.8 ± 3.7									
		Low	10.0 ± 4.8	11.7 ± 7.0	9.7 ± 4.3	10.5 ± 3.4									
	90%	High	25.1 ± 11.3	25.9 ± 11.8	23.5 ± 8.5	16.3 ± 5.3									
		Medium	29.0 ± 12.0	26.8 ± 11.2	24.0 ± 8.6	18.8 ± 9.4							*		
		Low	25.6 ± 9.9	25.6 ± 10.5	22.9 ± 7.8	17.3 ± 5.9									
Anterior deltoid	10%	High	4.5 ± 2.8	1.2 ± 0.4	5.1 ± 3.1	1.5 ± 1.2									
		Medium	3.3 ± 1.8	1.5 ± 0.7	2.7 ± 1.9	1.6 ± 1.0		***		***	**	***			
		Low	2.0 ± 0.8	1.6 ± 0.8	1.8 ± 0.8	1.7 ± 1.2									
	50%	High	14.6 ± 5.4	2.7 ± 2.0	18.7 ± 9.2	3.4 ± 3.1									
		Medium	12.1 ± 4.4	4.6 ± 3.1	12.8 ± 8.7	4.0 ± 2.8		***		***		**			
		Low	7.3 ± 4.3	5.0 ± 3.4	8.1 ± 4.0	4.6 ± 3.3									
	90%	High	20.3 ± 7.2	10.8 ± 11.6	26.6 ± 15.5	11.7 ± 7.6									
		Medium	19.1 ± 6.8	12.8 ± 7.0	23.4 ± 14.8	12.1 ± 8.0				***					
		Low	16.7 ± 7.7	14.2 ± 9.2	19.5 ± 11.4	14.1 ± 8.6									
Upper trapezium	10%	High	9.3 ± 5.9	2.4 ± 1.3	9.6 ± 6.4	3.7 ± 4.2									
		Medium	6.8 ± 5.9	3.7 ± 2.4	5.9 ± 6.3	3.4 ± 3.3		**		***		*			
		Low	4.6 ± 3.5	3.0 ± 2.6	4.4 ± 3.1	2.4 ± 1.2									
	50%	High	15.5 ± 9.9	5.3 ± 3.9	16.2 ± 8.9	6.3 ± 6.0									
		Medium	12.9 ± 9.0	7.5 ± 4.7	12.6 ± 8.5	7.4 ± 6.7		**		***					
		Low	8.4 ± 5.3	5.9 ± 5.0	8.1 ± 5.4	4.6 ± 2.4									
	90%	High	20.8 ± 15.2	10.2 ± 4.5	21.9 ± 12.1	12.0 ± 7.2									
		Medium	19.6 ± 14.5	14.3 ± 6.6	20.2 ± 10.7	14.2 ± 11.0				**					
		Low	15.2 ± 9.3	12.6 ± 8.4	14.4 ± 8.1	111.0 ± 6.0									
Erector spinae	10%	High	6.30 ± 2.54	4.55 ± 4.27	6.05 ± 2.87	4.50 ± 3.15									
		Medium	3.43 ± 1.29	3.58 ± 3.05	3.18 ± 1.41	2.95 ± 2.00		***			*				
		Low	2.94 ± 0.90	3.48 ± 2.91	2.80 ± 1.27	2.87 ± 1.89									
	50%	High	9.47 ± 3.31	7.09 ± 4.34	9.69 ± 3.84	7.85 ± 3.17									
		Medium	6.22 ± 2.90	5.54 ± 3.60	5.48 ± 3.24	4.85 ± 2.92		***			***			**	
		Low	4.00 ± 1.79	4.56 ± 3.17	3.90 ± 1.79	3.53 ± 2.22									
	90%	High	12.83 ± 3.80	11.26 ± 4.34	12.57 ± 4.00	12.91 ± 2.60									
		Medium	9.83 ± 3.80	9.50 ± 4.04	9.18 ± 3.50	10.11 ± 3.21		***			***			***	
		Low	6.18 ± 2.79	6.89 ± 3.67	6.36 ± 2.75	5.38 ± 2.48									

*$p<0.05$; **$p<0.01$; ***$p<0.001$.

L: the main effect of learning; H: the main effect of terminal block height; S: the main effect of arm support; T: the main effect of tool.

support decreased significantly with decreased terminal block height ($p<0.001$). Under self-selected posture adjustment, the usage rates of arm support under S1 condition were 100%, 88%, and 18% for high (L1), medium (L2 and L3), and low (L4) working heights, respectively.

Muscular exertion

Table 3 shows the comparisons of EMG RMS values at low (10%), median (50%), and high (90%) degrees of muscular exertions when the wiring task was performed at different heights between experimental conditions. To test the effects of learning, arm support, and tool, three sets of comparisons were performed as N1 vs. N2, S1 vs. N2, and S1 vs. S2. The effect of terminal block height was also analyzed in each comparison.

In the N1 vs. N2 comparison, mainly significant main

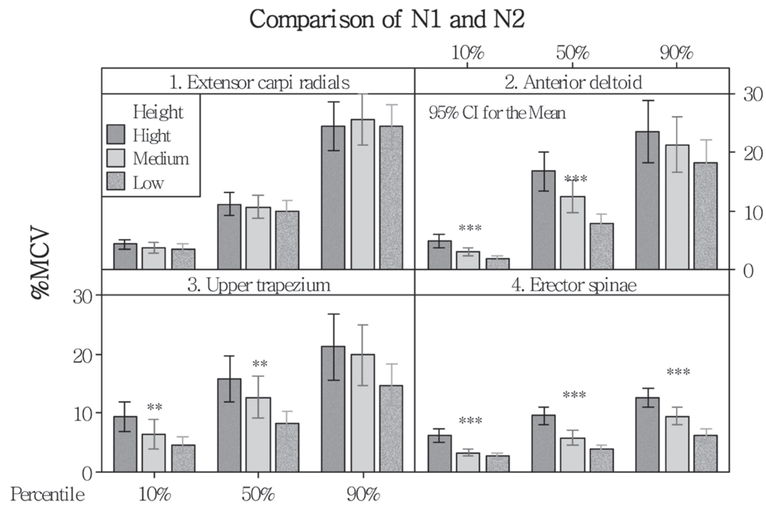


Fig. 5. Effects of terminal block height while comparing N1 and N2.
*p<0.05; **p<0.01; ***p<0.001.

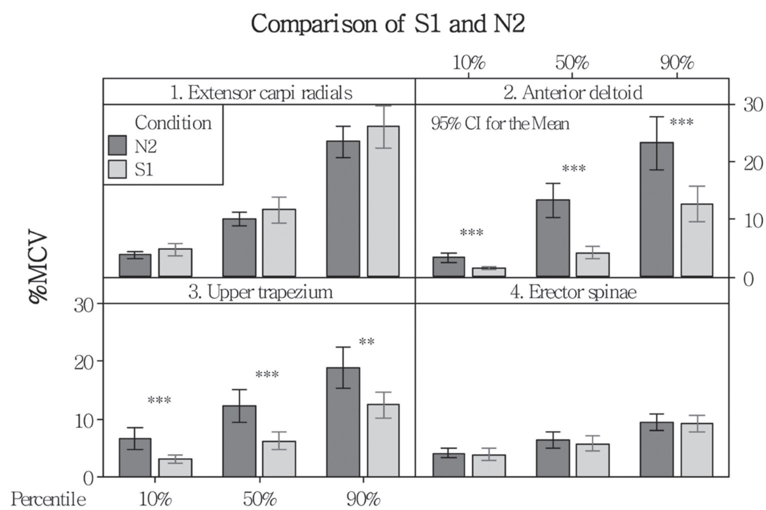


Fig. 6. Effects of arm support while comparing S1 and N2.
*p<0.05; **p<0.01; ***p<0.001.

effect of height was found on the anterior deltoid, upper trapezium, and erector spinae muscles. As shown on Fig. 5, the EMG RMS value decreased with decrease in terminal block height. The effect of learning and the interaction effect of learning and height were not significant.

In the S1 vs. N2 comparison, interesting effects were found. First, the significant main effect of arm support usage was found on the anterior deltoid and upper trapezium muscles. As shown on Fig. 6, the use of the arm support decreased the EMG RMS value. When the arm support was used, the MVC decreased approximately by 7–8% at medium or high workloads. Second, the main effect of terminal block height was found on the anterior deltoid and erector spinae muscles. Similar to the trend shown in Fig. 5, the EMG RMS value decreased with decrease in terminal block height. Finally, the interaction effect of arm support and terminal block height was found on anterior deltoid and upper trapezium. As shown in Fig. 7, without the arm support, the EMG RMS value decreased with decreasing terminal block height. However, with the arm support, following the change of terminal block height, the EMG RMS values were relatively small and without significant differences.

In the of S1 vs. S2 comparison, the main effects of tool and terminal block height were found on the extensor carpi radials and erector spinae muscles, respectively. As shown in Fig. 8, the use of electric screwdriver resulted in a higher

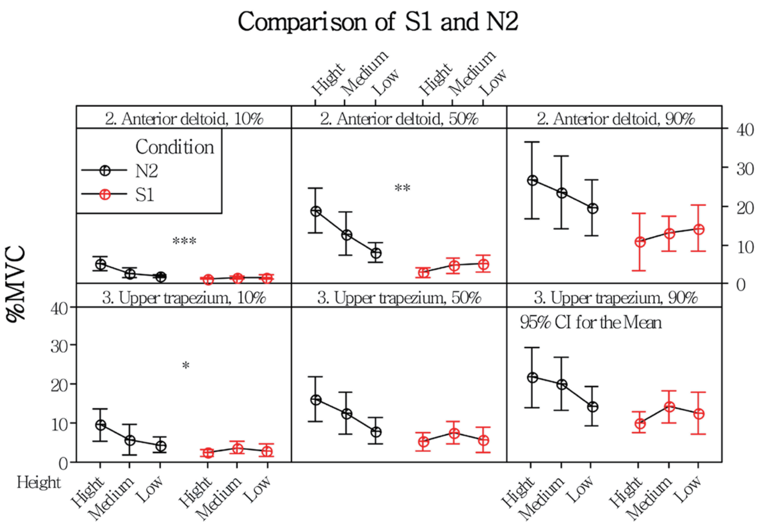


Fig. 7. Interaction effects of arm support and terminal block height while comparing S1 and N2.
*$p<0.05$; **$p<0.01$; ***$p<0.001$.

EMG RMS value at low working loads and lower EMG RMS value (8% MVC) at high working loads. Furthermore, similar to the trend shown in Fig. 5, the EMG RMS value decreased with decreasing terminal block height.

Subjective measurement

Regarding self-perceived exertion, Fig. 9 shows the effect of using arm support. As shown in the figure, the subjects perceived significantly less fatigue on the right shoulder, right elbow, and right wrist while using the arm support, with reduced discomfort values of 1.16, 0.66, and 0.67, respectively.

Discussion

The use of the arm support significantly reduced muscular exertion of the anterior deltoid and upper trapezius muscles. As shown in Table 3 and Fig. 6, the %MVC values of the anterior deltoid and upper trapezius muscles decreased when the arm support was used, irrespective of the levels of working loads (i.e., 10%, 50%, and 90%). In previous studies, it was found that for light assembly and soldering workers, using arm support can significantly decrease the anterior deltoid, shoulder and neck muscular exertion (e.g., supraspinatus)[16, 27, 28]. Using three different arm supports, comprising fixed, horizontally moveable, and spring-hanged types, Feng *et al.* showed with APDF analysis that the anterior deltoid and upper trapezius muscles experienced less fatigue during a computer task and an automatic pipette operation[29]. Westgaard and Winkel recommended that a dynamic/occasional contraction of over 30–50% MVC should be avoided or minimized to prevent working fatigue[30]. Kilbom and Malchaire *et al.* suggested that 15% MVC was an acceptable long term muscle working load[31, 32]. In this study, the working loads for the anterior deltoid and upper trapezius muscles under prolonged working situations were manageable using the arm support.

The forearm and lower back muscles did not benefit from the arm support usage. As shown in Table 3 and Fig. 6, there is no significant difference in the%MVC values of the extensor cap radials and erector spinae muscles with and without using the arm support. These results are consistent with those of previous studies[29, 33]. Sillanpää *et al.* showed that the forearm muscle activities during VDU work did not decrease, but increased when an arm support was used[33]. The present study's results also show that the extensor carpi radialis muscle activity was high for screw driving tasks. It is possible that the weight of the screwdriver increased the muscle static load (with and without forearm support) in the extensor carpi radialis by increasing the wrist moment. A high subjective grading of perceived exertion for the forearm muscles after performing the task was also obtained reflecting similar results. Thus, to reduce the forearm muscle load, it was suggested in a previous study that support should be better offered at the tool itself, rather than at the arm[34].

When working without the arm support, the subjects tended to compensate by exerting the elbow and shoulder muscles to perform the screw driving task. Forces from

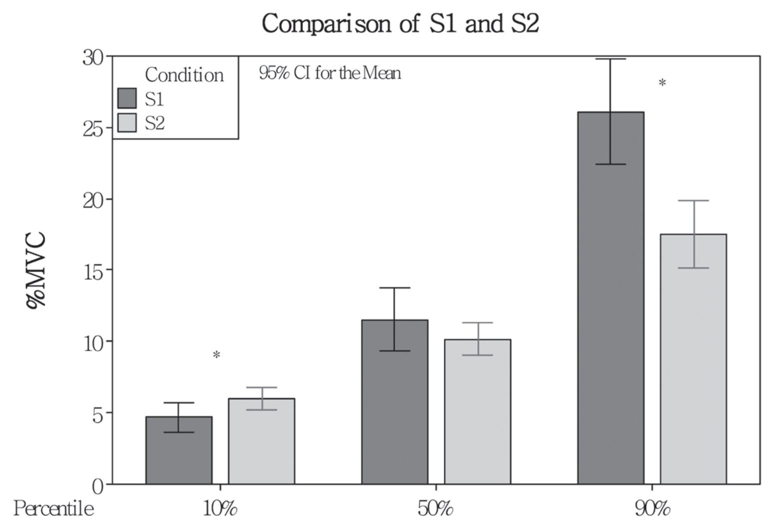


Fig. 8. Effects of tool while comparing S1 and S2.
*p<0.05; **p<0.01; ***p<0.001.

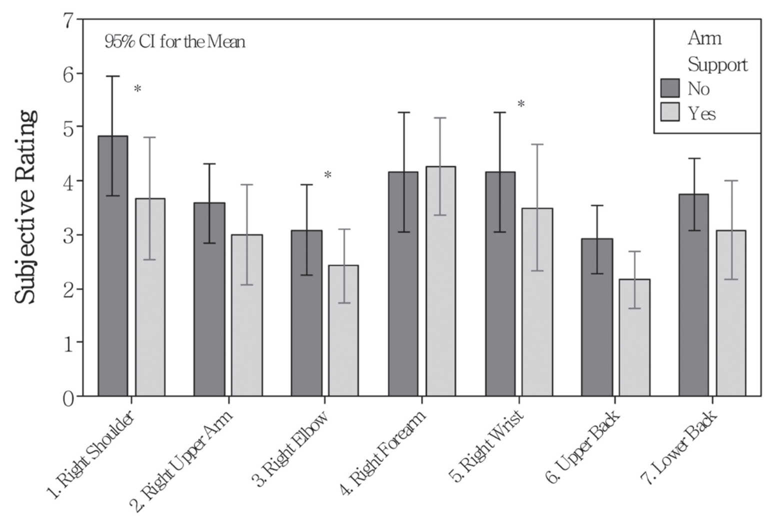


Fig. 9. Effects of using the arm support on subjective ratings of fatigue on seven body parts.
*p<0.05; **p<0.01; ***p<0.001.

the upper arms and shoulders could contribute in minimizing the strain load and muscle activities on the forearms. Because maintaining a screwdriver in a screw slot is an unstable task[35], the subject must increase the stiffness at the joints to maintain limb stability in the presence of applied external forces at the hand. The muscle stiffness therefore increases with muscle force[35, 36]. The use of arm support reduced muscular exertion in the upper extremity for the screw driving task, and this result was consistent with those of previous studies[34, 37]. Although the muscle loads on the neck and shoulder regions were reduced, the movement ranges for the elbow and shoulder joints were limited. The task was totally completed by the work of the forearm muscles; therefore, the workload in the extensor carpi radialis was increased. The use of electronic tools can help reduce the extensor carpi radialis workload without affecting the other muscle groups. Electronic tools are helpful, especially for repetitive tasks. In general, this study strongly recommends using electronic tools in combination with an arm support to reduce muscle fatigue and increase work efficiency.

Note that the EMG%MVC values of the erector spine muscle was independent of the arm support and was reduced with the decrease in working height. At the medium working height, the subject's spine tended to curve backward, decreasing the EMG%MVC values (Table 3 and Fig. 5). This could be because the arms were not required to be raised highly upward, decreasing the torque on the lower back. In a study on an assistant chair for video display terminal workstation, Park *et al.* demonstrated that the back muscle loads in three working postures were in the following order, forward-bending position >upright posture >back-slumped posture[19]. According to the results from Nachemson[38], sitting with the spine curved backward would apply greater stress to L3, but effectively decrease the muscle load on the erector spine because of the spinal column support effects.

The proposed chair in the present study was designed to allow users to self-select the arm support according to different working situations as indicated in the S1 and S2 conditions. The investigators were able to observe how and when the chair was chosen and used. This also eliminated the variations in comparing the arm support effect when the chair is used with or without the support. If the arm support height is adjustable, the chair would be more effective in minimizing the muscle load when applied in actual working situations. Height adjustment would work even better than the results found in tasks S2 vs. N2, where in S2, arm support was fixed at 24.4–36.4 cm above the sitting surface.

The limitations of the present study include the generalization of experimental environment and the test subjects. The effect of the proposed chair was studied on wiring tasks for three types of terminal blocks, which may not be the same as that in the actual workplace, for example, in job quantity or work sequence order. The muscle groups and types of tools used in the present study were also limited. Thus, these results might be difficult to apply to other tools or muscle groups. The working condition in the experiment was set-up with working heights at 60–105 cm above the ground and with users seated on a chair while performing a screw driving task. These results therefore should not be applied to dissimilar working conditions. Furthermore, the subjects recruited in this study were twelve healthy students who might not fully represent the features of actual workers. Further research should be conducted on assembly line worker to test the difference.

Conclusion

The proposed assistant chair with arm support effectively decreased muscle loads in the shoulder under the simulated work conditions. Because of the limitations on elbow and shoulder mobility, which may increase the workload on the forearm muscle groups while working with the arm support, appropriate tools should be used. This study demonstrated that using power tools in combination with the arm support produced the best results. However, the appropriate tools to be best combined with the arm support in a real working environment remains to be investigated. Under subjective work posture selection and arm support, the workload on the lower back muscle was the smallest at the lowest working height. However, further investigation should be conducted to determine whether this most commonly selected posture is indeed beneficial for the lumbar spine needs.

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References

1) Bernard BP, Putz-Anderson V (1997) Musculoskeletal disorders and workplace factors; a critical review of epidemiologic evidence for work-related musculoskeletal disorders of the neck, upper extremity, and low back.
2) Bhattacharya A (2014) Costs of occupational musculoskeletal disorders (MSDs) in the United States. Int J Ind Ergon **44**, 448–54.
3) Kumar S (2001) Theories of musculoskeletal injury causation. Ergonomics **44**, 17–47.
4) Gómez-Galán M, Pérez-Alonso J, Callejón-Ferre AJ, López-Martínez J (2017) Musculoskeletal disorders: OWAS review. Ind Health **55**, 314–37.
5) Burnett C, Lalich N, MacDonald L, Alterman T (2001) A NIOSH Look at Data from the Bureau of Labor Statistics–Worker health by industry and occupation. DHHS/CDC/NIOSH.
6) Ng YG, Tamrin SBM, Yik WM, Yusoff ISM, Mori I (2014) The prevalence of musculoskeletal disorder and association with productivity loss: a preliminary study among labour intensive manual harvesting activities in oil palm plantation. Ind Health **52**, 78–85.
7) Bhattacharya A, Leigh JP (2011) Musculoskeletal disorder costs and medical claim filing in the US retail trade sector. Ind Health **49**, 517–22.
8) Bae YH, Min KS (2016) Associations between work-related musculoskeletal disorders, quality of life, and workplace stress in physical therapists. Ind Health **54**, 347–53.
9) Li G, Haslegrave CM, Corlett EN (1995) Factors affecting posture for machine sewing tasks: the need for changes in

sewing machine design. Appl Ergon **26**, 35–46.
10) Li G, Buckle P (1999) Current techniques for assessing physical exposure to work-related musculoskeletal risks, with emphasis on posture-based methods. Ergonomics **42**, 674–95.
11) Ciriello VM, Webster BS, Dempsey PG (2002) Maximal acceptable torques of highly repetitive screw driving, ulnar deviation, and handgrip tasks for 7-hour workdays. AIHA J (Fairfax, Va) **63**, 594–604.
12) Haslegrave CM (1994) What do we mean by a 'working posture'? Ergonomics **37**, 781–99.
13) Duncan J, Ferguson D (1974) Keyboard operating posture and symptoms in operating. Ergonomics **17**, 651–62.
14) Serina ER, Tal R, Rempel D (1999) Wrist and forearm postures and motions during typing. Ergonomics **42**, 938–51.
15) Harms-Ringdahl K, Arborelius U, (Eds.) (1987) One-year follow-up after introduction of arm suspension at an electronics plant. Proceedings of Tenth International Congress, World Confederation for Physical Therapy.
16) Järvholm U, Palmerud G, Kadefors R, Herberts P (1991) The effect of arm support on supraspinatus muscle load during simulated assembly work and welding. Ergonomics **34**, 57–66.
17) Erdelyi A, Sihvonen T, Helin P, Hänninen O (1988) Shoulder strain in keyboard workers and its alleviation by arm supports. Int Arch Occup Environ Health **60**, 119–24.
18) Sihvonen T, Baskin K, Hänninen O (1989) Neck-shoulder loading in wordprocessor use. Effect of learning, gymnastics and armsupports. Int Arch Occup Environ Health **61**, 229–33.
19) Park MY, Kim JY, Shin JH (2000) Ergonomic design and evaluation of a new VDT workstation chair with keyboard–mouse support. Int J Ind Ergon **26**, 537–48.
20) Poonawala MF, Fernandez JE (1998) Effect of using arm supports as an aid to light assembly work. Advances in occupational ergonomics and safety, 479–82.
21) Fernandez JE, Agarwal R, Landwehr HR, Poonawala MF, Garcia DT (1999) The effects of arm supports during light assembly and computer work tasks. Int J Ind Ergon **24**, 493–502.
22) Milerad E, Ericson MO (1994) Effects of precision and force demands, grip diameter, and arm support during manual work: an electromyographic study. Ergonomics **37**, 255–64.
23) Wang M, Wang E, Lin YC (2002) Anthropometric data book of the Chinese people in Taiwan, 64, Ergonomics Society of Taiwan, Hsinchu.
24) Perotto AO (2011) Anatomical guide for the electromyographer: the limbs and trunk. Charles C Thomas Publisher, Springfield.
25) Caldwell LS, Chaffin DB, Dukes-Dobos FN, Kroemer KH, Laubach LL, Snook SH, Wasserman DE (1974) A proposed standard procedure for static muscle strength testing. Am Ind Hyg Assoc J **35**, 201–6.
26) Jonsson B (1982) Measurement and evaluation of local muscular strain in the shoulder during constrained work. J Hum Ergol (Tokyo) **11**, 73–88.
27) Feng Y, Grooten W, Wretenberg P, Arborelius UP (1999) Effects of arm suspension in simulated assembly line work: muscular activity and posture angles. Appl Ergon **30**, 247–53.
28) Visser B, de Korte E, van der Kraan I, Kuijer P (2000) The effect of arm and wrist supports on the load of the upper extremity during VDU work. Clin Biomech (Bristol, Avon) **15** Suppl 1, S34–8.
29) Feng Y, Grooten W, Wretenberg P, Arborelius UP (1997) Effects of arm support on shoulder and arm muscle activity during sedentary work. Ergonomics **40**, 834–48.
30) Westgaard RH, Winkel J (1996) Guidelines for occupational musculoskeletal load as a basis for intervention: a critical review. Appl Ergon **27**, 79–88.
31) Kilbom Å (1994) Repetitive work of the upper extremity: part II—the scientific basis (knowledge base) for the guide. Int J Ind Ergon **14**, 59–86.
32) Malchaire J, Cock N, Piette A, Leao RD, Lara M, Amaral F (1997) Relationship between work constraints and the development of musculoskeletal disorders of the wrist: a prospective study. Int J Ind Ergon **19**, 471–82.
33) Sillanpää J, Nyberg M, Uitti J, Takala EP, Kivi P, Kilpikari I, Laippala P (2003) Muscular activity in relation to support of the upper extremity in work with a computer mouse. Int J Hum Comput Interact **15**, 391–406.
34) Odell D, Barr A, Goldberg R, Chung J, Rempel D (2007) Evaluation of a dynamic arm support for seated and standing tasks: a laboratory study of electromyography and subjective feedback. Ergonomics **50**, 520–35.
35) Burdet E, Osu R, Franklin DW, Milner TE, Kawato M (2001) The central nervous system stabilizes unstable dynamics by learning optimal impedance. Nature **414**, 446–9.
36) McIntyre DC, Kelly ME, Staines WA (1996) Efferent projections of the anterior perirhinal cortex in the rat. J Comp Neurol **369**, 302–18.
37) Schüldt K, Ekholm J, Harms-Ringdahl K, Arborelius UP, Németh G (1987) Influence of sitting postures on neck and shoulder e.m.g. during arm-hand work movements. Clin Biomech (Bristol, Avon) **2**, 126–39.
38) Nachemson A (1975) Towards a better understanding of low-back pain: a review of the mechanics of the lumbar disc. Rheumatol Rehabil **14**, 129–43.