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Relationship of EMG and Subjective Discomfort Ratings for Repetitive Handling of Lightweight Loads

Inseok Lee, Sungpill Jo

Department of Civil, Safety and Environmental Engineering, Hankyong National University, Anseong, 456-759

Corresponding Author
Inseok Lee
Department of Civil, Safety and Environmental Engineering, Hankyong National University, Anseong, 456-759
Phone : +82-31-670-5286
Email : lis@hknu.ac.kr

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Objective: The aim of this study is to evaluate the effect of weight of load and time on the physical workload of repetitive upper-limb tasks with handling light weight loads using EMG and perceived discomfort, and to investigate the relationship between EMG and perceived discomfort for those repetitive tasks of moving light weight loads.

Background: Repetitive upper-limb motion is known as one of the main risk factors of musculoskeletal disorders, and a lot of repetitive tasks are carried out while handling light weight loads in the industry. In evaluating the workload of repetitive tasks handling light weight loads, EMG and perceived discomfort can be used, though their relationship in those work conditions are not much investigated.

Method: A laboratory experiment with 18 healthy males were conducted to record EMG signals from 5 muscle sites of the right arm and shoulder and rate perceived discomforts for the body parts and the whole body while carrying out repetitive materials-handling tasks for 52min. The subjects were divided into 3 groups which handled the loads of 1kg, 2kg and 3kg, respectively. ANOVAs were conducted to analyze the effects of the weight and time on RMS of EMG amplitude (normalized RMS: NRMS), median frequency of power spectrum of EMG (normalized MDF: NMDF) and perceived discomfort. The correlations between NRMS and NMDF and perceived discomfort were also analyzed.

Results: Statistically significant muscular fatigue effects were not found from NRMS and NMDF in most muscles, while there were significant increases of discomfort as the task time elapsed. It was shown that there were an increasing trend of the muscular activity as the weight of load increased and a decreasing trend of median frequency of EMG of upper and lower arms as time elapsed. It was found that there were significant negative correlations between NMDFs from the lower arm and discomfort ratings, though the relationships were weak.

Conclusion: It can be concluded that the working conditions adopted in this study were not enough to induce muscular fatigue, while there was significant increase in perceived discomfort. A further study is necessary to integrate the objective and subjective measures for more reliable and sensitive evaluation of workload of repetitive tasks of handling light weight loads.

Application: This study can be used as a basic study for the evaluation of workload of repetitive tasks handling light weight loads.

Keywords: Repetitive upper-limb motion, Muscular fatigue, EMG, Perceived discomfort, Borg's CR-10

1. Introduction

In many cases, workers of manufacturing assembly lines are engaged in repetitive bolting work using hand tools. One characteristic of such a work is to manually handle relatively light tools or materials repetitively. Although there is no standard definition of a light tool, handling of a tool with less than 3kg in weight is observed a lot empirically. Repetitive upper limb motion in those tasks is known to be one of the main risk factors of musculoskeletal disorders in the arm and shoulder (Larsson et al., 2007; Nordander et al., 2009; Van Rijn et al., 2010). Repetitive tasks with upper-limb motions are known to cause muscular fatigues on hand, wrist, arm, shoulder and neck, which are highly related to the development of musculoskeletal disorders, even though the task is to handle lightweight load with less than 20% of maximum muscular strength (Bosch et al., 2009; De Looze et al., 2009).

Many studies have been carried out on the evaluation of upper-limb repetitive tasks (Kilbom, 1994), and many of them were based on psychophysical approaches (Mukhopadhyay et al., 2007; Finneran and O'Sullivan, 2010; Lin et al., 2010). The psychophysical study on the basis of perceived discomfort has the economic merit as compared to the physiological or biomechanical methods that require relatively high-priced equipment and it has been acknowledged as a systematic workload evaluation methodology based on psychophysics. However, the lack of verification on the reliability is still reported as a weak point of the subjective evaluation methods (Kee and Karwowski, 2003). Due to such a lack of verification, many studies to evaluate workload are adopting objective measures in order to verify the subjective ratings of perceived discomfort indirectly.

EMG (Electromyogram) is used a lot to evaluate workload of a task handling external load. EMG indicating muscular contraction activity is known to be used to show the degree of muscular activity and muscular fatigue. According to existing studies, the muscular fatigue is known to be highly related with the increase of EMG amplitude and the decrease of EMG power spectrum frequency (Winter, 1990; Kumar and Mital, 1996). EMG is also used for the evaluation of workload of a task repeatedly handling light weight loads (Fedorowich et al., 2013; Qin et al., 2014). Qin et al. (2014) conducted a study that comparatively evaluated differences of muscular fatigue according to age using the RMS of EMG amplitude and the median power frequency of EMG in a task moving light pins. Fedorowich et al. (2013) compared the differences of shoulder and neck muscular fatigue by gender using the RMS of EMG amplitude in an upper limb motion experiment. In these two studies, the subjects carried out repetitive upper-limb motions by lifting light pins, without consideration of the weight of the load, or with no load to work on in the experiments.

As stated above, workers in the manufacturing industry handle tools or loads with various weights, although they are relatively light weight. This study aimed to show how the weight of load affects the workload of repetitive upper-limb tasks and verify if it is valid using EMG, an objective measurement, and discomfort, a subjective rating, as the methods to evaluate workload of repetitive upper-limb tasks. This study evaluated workload using EMG and discomfort ratings concerning the effects of load's weight and task time in a task repetitively handling light weight loads with 3Kg and less in weight. This study actually analyzed correlations between objective and subjective measurements in the workload evaluation under such a working condition. The purpose of this study is to lay the foundation for systematic evaluation of workload of repetitive upper limb task handling light weight loads as a basic study.

2. Method

2.1 Subjects

In the experiment of this study, 18 male college students participated. The subjects' mean($\pm$SD) age, height, weight, elbow height and arm length were 24.2$\pm$1.0 years, 174.4$\pm$4.0cm, 68.8$\pm$7.7kg, 109.5$\pm$3.2cm and 62.3$\pm$2.5cm, respectively, and they were all right-handed. The subjects had no experience of musculoskeletal disorders on shoulder, arm and wrist for the past one year, and they maintained healthy state on the day of the experiment.

2.2 Repetitive materials-handling task

The subjects repetitively moved two dumbbells placed on area A on the table to area B, and then moved back them to the area A again, respectively (Figure 1). The area A was away from a subject's body by forearm length (32~35cm) to the front, and the area B was set to be away from a subject's body by arm length (60~63cm) to the front. A unit task was defined as 12 movements of the dumbbell in total, in which the two dumbbells were moved back and forth 3 times, respectively. Each subject took a break after carrying out one cycle of task by consecutively performing the unit task seven times in total. During the one cycle of task composed of seven unit tasks, each subject moved the dumbbells 84 times in total (12 times of movement per unit task x 7 unit tasks per a cycle of task). A cycle of task took about 147 seconds on average. After carrying out one cycle of task, each subject sat and took about 28 seconds of rest (about 19% of the task time). Consequently, each subject repeated one cycle of task in every 175 seconds including the break. However, each subject conducted the task at his desired speed, and therefore, actual task performing time and break time were slightly different, according to subject. Each subject performed the 18 cycles of task in total consecutively, and carried out 1,512 times of the dumbbell moving motions in total, and about 52 minutes were required to finish the whole task.

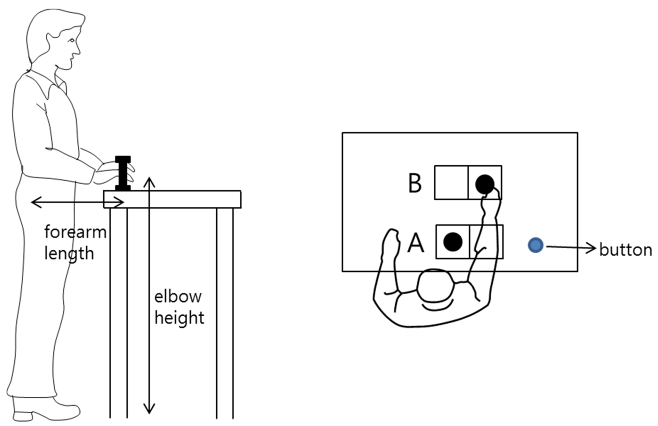

Figure 1. Materials-handling task in the experiment

2.3 Weights of load

For the repetitive motion experiment, three weights of dumbbells - 1kg, 2kg and 3kg - were used. The subjects were divided into three groups with six people per group, and each group conducted the experiment moving different weights of dumbbells by group. That is, each subject performed the repetitive task with only one weight of dumbbell.

2.4 Dependent measures

To evaluate workload in the repetitive upper-limb task, this study used EMG as an objective measurement, and perceived discomfort rating as a subjective measurement. Surface EMG was measured on the upper trapezius (UT) (upper shoulder), anterior deltoid (AD) (front shoulder), biceps brachii (BB) (upper arm), and flexor digitorum superficialis (FD) and extensor digitorum communis (ED) (forearm), when each subject carried out the repetitive task. The EMG electrodes were placed on the following muscle sites by referring to existing studies: for upper trapezius, the middle position between the acromion and C7 cervical vertebrae where the muscle contracts when the right shoulder is lifted; for anterior deltoid, the site about 2.5cm away from the acromion in the forward direction where the muscle contracts when the upper arm is flexed to 90˚; for biceps brachii, the position away from the inside of the elbow about 30% of the distance between the inside of the elbow and the acromion in the upper arm where the muscle contracts when the upper arm is naturally down and the elbow is flexed 90˚; for flexor digitorum superficialis, the position away from the inside of the elbow about 40% of the distance between the inside of the elbow to the wrist in the lower arm where the muscle in the ulnar direction contracts when fingers were flexed; and for extensor digitorum communis, the position away from the outside of the elbow about 40% of the distance between the outside of the elbow to the wrist in the lower arm where the muscle in the radial direction contracts when fingers were extended (Hermens et al., 1999; Perotto et al., 2005; Criswell, 2010). EMG signals were measured while the subjects carried out the experimental task with the right hand. Among the measured signals, those measured in the last unit task in every 6^{th} cycle of task were extracted and used in the analysis.

For perceived discomfort ratings, Borg's CR10 scale was used (Borg, 1998). Concerning body parts, the discomforts were rated on the neck (NC), shoulder (SH), upper arm (UA) and lower arm (LA). In addition, the subjects were instructed to rate their perceived discomfort on the whole body (WB). Each subject rated their perceived discomforts 3 times in total, whenever every 6^{th} cycle of task was finished.

2.5 Equipment and materials

A wireless EMG measurement system (Telemyo DTS system, Noraxon, USA), a work table for the repetitive upper-limb task and dumbbells were used in the experiment. For EMG, surface EMG measurement was carried out, and the digital sampling was performed with 1,500Hz. The distance between two surface electrodes was 20mm, and SENIAM was referenced for the electrodes' locations (Hermens et al., 1999).

Task areas A and B were set on the work table. The task area A is the location within normal task area, where is reachable when a subject flexes elbow by 90˚. The task area B is the location within the maximum task area where is reachable when a subject extends arm maximum. The task areas A and B were adjusted according to each subject's arm length. The height of the work table was adjusted by each subject in a manner that a subject could grab dumbbells at the height when he naturally flexes elbow by 90˚ in the standing position. The location of a subject was marked before starting the experiment so that the subject could carry out the task from a certain distance from the work table. Therefore, the subject conducted the task standing at the marked location. The chair for rest was placed at the back of a subject so that the subject could sit and take a rest, after conducting the task.

Dumbbells used in the experiment have the uniform thickness of handles.

2.6 Experimental procedure

The subjects voluntarily agreed to participate in the experiment, after being informed of the purpose and details of the experiment before they took part in the experiment. Prior to conducting the experiment, each subject's height, weight, elbow height and arm length were measured, and the method of rating perceived discomfort using Borg's CR10 scale was explained.

After placing EMG electrodes for each muscle, the subjects were instructed to exert maximum voluntary contraction (MVC) per muscle, and the EMG at that time was measured. MVC measurements were carried out two times per muscle, and each subject was instructed to take a sufficient rest between consecutive measurements.

Each subject conducted the task standing at the location marked in front of the work table, and the work table's height and areas A and B were set to be suitable for each subject, before starting the task. Each subject started the task in line with auditory signal with comfortable standing posture. Whenever each unit task (12 times of moving dumbbells) was finished, each subject contacted the round-shaped marker once on the work table, took a standing posture with comfortably taking down two arms, and then continued the task again. This was to mark the beginning and end of each unit task, since confusion on the number of task could be caused due to the repetitive tasks. When one cycle of task was finished, each subject took a rest sitting on a chair at the back of the task point, and the subject began the task again in line with the auditory signal, after a certain time.

2.7 Data processing and analysis

EMG signals were extracted in 8 sections, where muscles were activated with carrying motions in the last unit task of the 6^{th}, 12^{th} and 18^{th} cycles of task. The median frequency (MDF) and mean RMS of amplitude in each section were calculated to be used for the analysis. The mean RMS of EMG signal amplitude in each section was calculated after processed by 10~500Hz bandpass filtering and rectification, and RMS smoothing with 200ms of window. MDF was calculated by obtaining power spectrum through FFT, after 10~500Hz bandpass filtering on the extracted EMG signals.

The RMS and MDF of EMG amplitude were normalized for each subject, and were used for the analysis. For the normalization of RMS of amplitude, the mean RMS calculated from the EMG signals extracted in each muscle's MVC was used. Namely, NRMS (Normalized RMS) was defined as the ratio of RMS of each muscle's EMG amplitude to RMS_{max} that was calculated through MVC measurement (Equation 1). MDF normalization was conducted based on the MDF measured after the 6^{th} cycle of task. That is, normalized MDF (NMDF) was defined as the ratio of MDFs to the MDF measured after the 6^{th} cycle of task (Equation 2).

$NRMS_i = RMSi / RMS_{max}$ (Equation 1)
$NMDF_i = MDF_i / MDF_1$ (Equation 2)

Where i = 1, 2, 3 (Measurement 1 was at the end of the 6^{th} cycle of task, 2 was at the end of the 12^{th} cycle of task and 3 was at the end the 18^{th} cycle of task)

RMS_{max}: RMS of MVC's EMG amplitude

Two-way ANOVAs were carried out to statistically analyze the effects of the weights of load (Weight, 1kg, 2kg and 3kg) and task time (Time, 1^{st}, 2^{nd} and 3^{rd}) on the NRMS, NMDF and perceived discomfort ratings. Also, Pearson correlation analysis was carried out to analyze the correlation between the objective measurement, EMG signal, and the subjective measurement, perceived discomfort ratings. Statistical significance was judged at significance level of 0.05, and SAS (version 9.2) was used for statistical analysis.

3. Results

3.1 ANOVA for NMDF and NRMS

In the results of ANOVAs for NMDF and NRMS of each muscle, the main effects of Weight and Time and their interaction effect were shown to be significant for NMDF of FD in the for arm, and the main effect of Time on NRMS of UT of upper shoulder was significant ($p < 0.05$) (Table 1). In the other muscles, no significant main effect and interaction were found on NMDF and NRMS.

NMDF did not show a uniform trend according to the weight of load. The NMDF of forearm's FD, the muscle that showed a statistically significant effect, showed an increasing trend as weight increased. The ED of forearm showed an increasing trend of NMDF according to load's weight increase, despite no statistical significance (Figure 2). In the case of forearm's FD that showed statistically significant change according to Time, NMDF decreased and then increased, as Time elapsed. Forearm's ED showed a gradually decreasing trend of NMDF according to Time elapse, despite no statistical significance. At AD of shoulder and BB of upper arm, NMDF slightly increased and showed a decreasing trend in the third measurement, as Time increased.

Table 1. ANOVA results for NMDFs, NRMSs, and Discomfort ratings (*p*-values)

Measures		Source of variation		
		Weight	Time	Weight × Time
NMDF	UT**	0.357	0.462	0.206
	AD	0.172	0.305	0.529
	BB	0.217	0.746	0.301
	FD	**0.036***	**0.019***	**0.006***
	ED	0.745	0.267	0.932
NRMS	UT	0.179	**0.029***	0.487
	AD	0.099	0.872	0.077
	BB	0.125	0.716	0.695
	FD	0.806	0.360	0.929
	ED	0.698	0.677	0.298
Discomfort	NC	0.283	**<.0001***	0.470
	SH	0.395	**0.001***	0.916
	UA	0.384	**<.0001***	0.170
	LA	0.724	**<.0001***	0.628
	WB	0.332	**<.0001***	0.428

*Statistically significant at α=0.05.
**UT: Upper Trapezius, AD: Anterior Deltoid, BB: Biceps Brachii, FD: Flexor Digitorum, ED: Extensor Digitorum; NC: Neck, SH: Shoulder, UA: Upper Arm, LA: Lower Arm, WB: Whole Body.

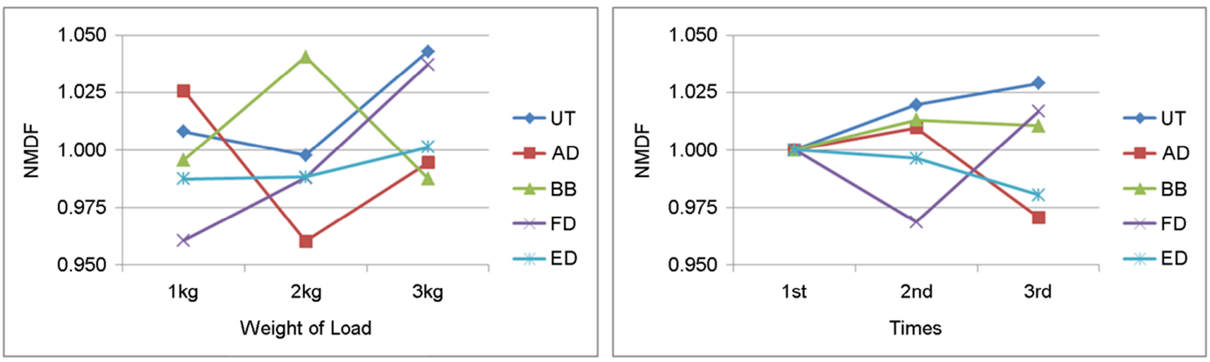

Figure 2. Mean NMDFs according to weight of load and time

NRMS showed an increasing trend according to load's weight increase. Although, statistically not significant, UT demonstrated a trend of NRMS increase according to the load's weight increase. The remaining muscles showed similar values of NRMS at 1kg and 2kg, but showed an increasing trend of NRMS at 3kg. According to Time, NRMS did not show big change. At UT of upper shoulder, NRMS was statistically significant by showing higher value at the third measurement than the first and second measurements.

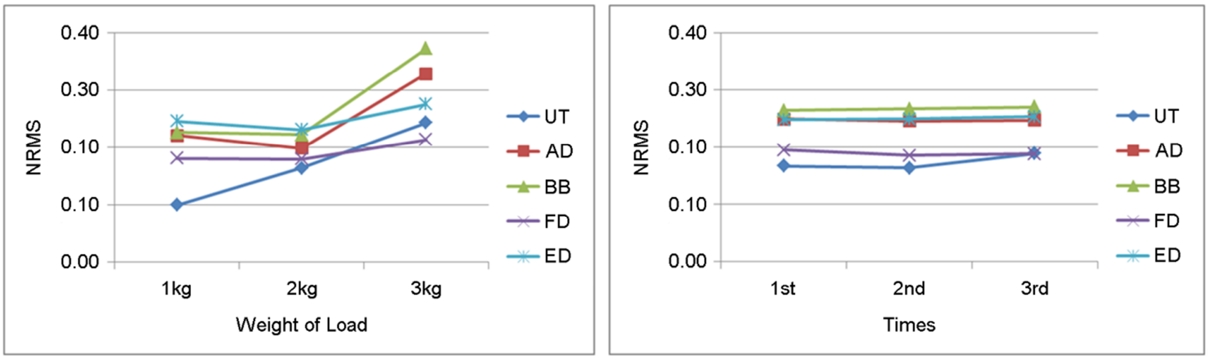

Figure 3. Mean NRMS's according to weight of load and time

3.2 ANOVA for perceived discomfort ratings

As a result of ANOVA for perceived discomfort ratings, the main effect of Time was significant on perceived discomfort ratings for each body part and whole body ($p<0.05$), and the main effect of Weight and the interaction between Weight and Time were not significant ($p>0.05$) (Table 1). Perceived discomfort ratings increased according to Time elapsed (Figure 4). As a result of Tukey test, the perceived discomfort ratings showed statistically significant differences on WB and LA per rating time. The perceived discomfort ratings of UA, SH and NC at the third measurement showed statistically significant different from those reported at the first and second ratings, while the perceived discomforts reported at the first and second ratings did not show significant differences (α=0.05). According to the weight of load, statistically significant differences were not shown; however, the perceived discomfort ratings at 3kg were higher than at 1kg and 2kg (Figures 4 and 5). Regarding perceived discomfort ratings on WB, discomfort showed an increasing trend according to weight, as Time elapsed. Although there was no statistical

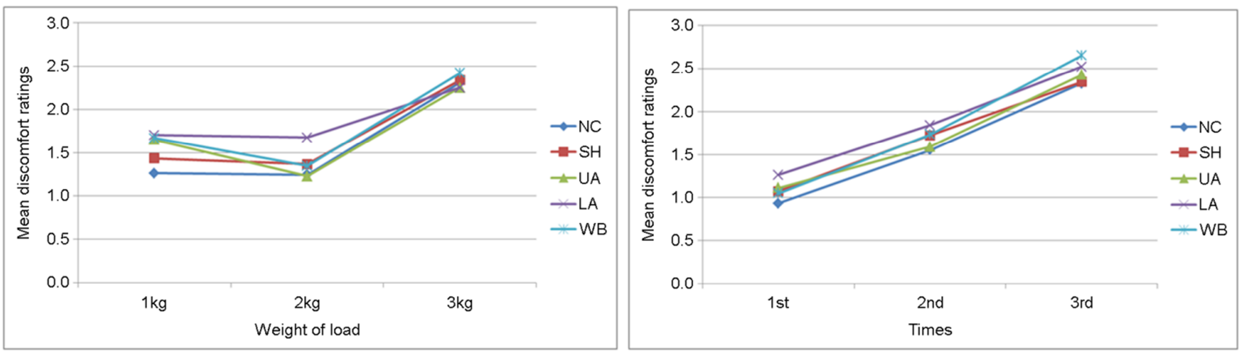

Figure 4. Mean discomfort ratings according to weight of load and time

significance, the perceived discomfort ratings did not show large differences according to the weight of load after the 6th cycle of task, but higher perceived discomfort ratings were shown at 3kg than 1kg and 2kg after the 18th cycle of task (Figure 4).

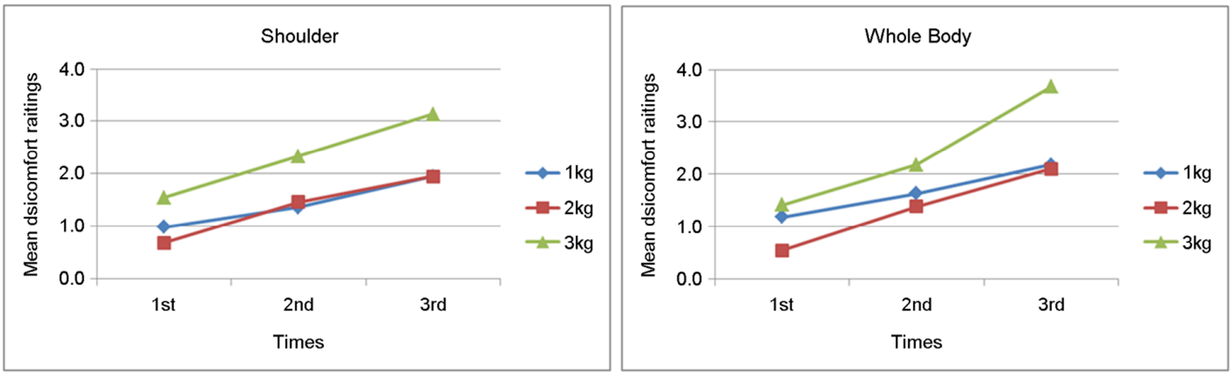

Figure 5. Mean discomfort ratings for shoulder and whole body

3.3 Correlation analysis between EMG and perceived discomfort ratings

Correlation analyses were carried out between perceived discomfort ratings and NRMS & NMDF calculated from EMG signals by calculating Pearson correlation coefficients (Table 2). As a result of the analysis, NC and forearm's FD showed statistically significant and positive correlation between NRMS and perceived discomfort ratings. In NMDF and perceived discomfort ratings, forearm's FD and ED showed statistically significant and negative correlation with perceived discomfort ratings of each body part and WB (α=0.05).

Table 2. Correlation coefficients (r) between discomfort ratings and NRMS and NMDFs

Variables		NRMS					NMDF				
		UT	AD	BB	FD	ED	UT	AD	BB	FD	ED
Discomfort	NC	-0.14	-0.09	-0.25	**0.29***	-0.21	0.00	0.27	0.23	**-0.26***	**-0.29***
	SH	-0.12	-0.11	-0.28	0.20	-0.21	0.03	0.25	0.23	**-0.27***	**-0.23***
	UA	-0.01	-0.04	-0.27	0.21	-0.12	0.05	0.17	0.07	**-0.31***	**-0.30***
	LA	0.03	-0.01	-0.35	0.08	0.01	-0.02	0.08	0.24	**-0.40***	**-0.32***
	WB	0.00	-0.07	-0.27	0.14	-0.11	0.02	0.12	0.06	**-0.31***	**-0.33***

*Statistically significant at α=0.05.

4. Discussion

When muscles are fatigued, it is known that the amplitude of EMG increases and the median frequency decreases. In this study, we tried to verify whether muscular fatigue occurred through an experiment when light loads were repetitively handled. As a result of the experiment, the five muscles, namely, UT of the upper shoulder, AD of shoulder, BB of upper arm, and FD and ED of forearm, where EMGs were measured from, did not show a clear fatigue phenomenon. As task time elapsed, the NMDFs of AD, BB and ED decreased, and the NRMS of UT increased; however, only the NRMS of UT showed a statistically significant difference. The NMDF of forearm's FD, which showed a statistical significant effect, decreased and then increased again, as Time went on, which implies the phenomena of muscular fatigue was not clearly verified. From this result, it is difficult to regard the working conditions set in this study, which includes 1~3kg of loads, 34 times of repetition per minute and about 30cm of carrying distance, as causing muscular fatigue to the subjects measurable by the measurement of EMG.

EMG amplitudes showed an increasing trend according to the weight of load. Although statistical significances were not acquired, there were no big differences of amplitude in 1kg and 2kg of load's weights as shown in Figure 3, but the amplitudes increased at 3kg, as compared to 1kg and 2kg. From the result showing difference in muscular activity according to the weight of load, it was confirmed that the EMG measurement was conducted validly. However, the reason why statistically significant differences were not demonstrated was that the loads were relatively light, and six subjects per weight of load participated in the experiment, which seemed to be insufficient level to offset the variance among the subjects. In the NMDF result, muscular fatigue was not shown, given that change aspect was not uniform according to the weight of load.

In the workload evaluation by perceived discomfort ratings, the discomfort clearly increased as time elapsed, and statistically significant result was also demonstrated. This means that muscular fatigue was not shown physiologically, but the workload level perceived subjectively by the subjects increased. Although the difference of perceived discomfort ratings according to load's weight was not statistically significant, the discomfort was higher at 3kg than 1kg and 2kg. Such a result was similar to the result from the amplitude of EMG, which implies that the discomfort ratings perceived by the subjects were similar to the muscular activation level. The discomfort on shoulder at 3kg was higher than 2kg over the entire task time, and the difference of the perceived discomfort ratings on whole body at 3kg and 2kg increased as time elapsed.

The EMG amplitude and median frequency were analyzed not to have high correlations with perceived discomfort ratings. The muscles showing statistically significant correlations with perceived discomfort ratings were the NMDF of forearm's ED and FD, which demonstrated a weak level of negative correlations (FD: -0.26 ~ -0.40, ED: -0.23 ~ -0.33). ED showed a decreasing trend of NMDF as time elapsed, and demonstrated a negative correlation with perceived discomfort ratings showing an increasing trend as time elapsed. In the case of FD, the mean NMDF measured lastly increased, compared to the initial stage; however, a negative correlation with the perceived discomfort ratings that increased with time elapse was shown, which seems to be derived from big variance among the subjects. That is, although NMDF on average increased, due to the difference among the subjects, the correlation between NMDF and the perceived discomfort ratings of each subject showed a negative correlation on average. Such a result appears to have a relation with the limitation in compensating the variation among the subjects, in view of the six the subjects per weight of load.

Although EMG signals did not show clear muscular fatigue, there was change of EMG related with workload, despite no high sensitivity in that the median frequency of EMG showed a negative correlation with the increase of perceived discomfort ratings according to body part. Therefore, if perceived discomfort ratings in addition to EMG signals are used together for workload evaluation, they seem to be of help to the improvement of evaluation's validity and reliability. A further study evaluating workload by drawing a unified index based on the use of subjective evaluation method, perceived discomfort ratings, and an objective evaluation method, EMG signals, together is considered to be needed.

5. Conclusion

In this study we conducted an experiment evaluating workload by using EMG and perceived discomfort ratings, while subjects repeatedly moved relatively light weights of loads from 1kg to 3kg. Each subject repeatedly handled 1,512 times of loads for about 53 minutes. The experiment imitated repetitive task of a manufacturing line using light hand tool of 3kg and less. In the experiment, each subject repeated about 34 times of upper limb task per minute. Such a working condition was similar to the assembly work with short work cycle.

From the result of the experiment, it was shown that perceived discomfort ratings increased according to time elapse, in the case of repetitively moving even relative light load. The increase of perceived discomfort ratings was more clear in handling 3kg of load than handling lighter ones, which implies the weight of load is an important task variable. Overall, the perceived discomfort ratings at 3kg were higher than the lighter loads.

In evaluating workload of handling repetitive task of moving light loads with 3kg and less, it was more valid to use perceived discomfort ratings than evaluating objective muscular fatigue using EMG. In the EMG signals, the muscular fatigue was not clearly shown, however, perceived discomfort ratings showed clear differences, as time elapsed. However, perceived discomfort ratings were an evaluation tool just depending on worker's subjective evaluation, and sensitivity was high. Meanwhile, debate on their reliability is high, due to the lack of objective grounds and variation among the subjects. In this regard, a study on the method evaluating workload by combining perceived discomfort ratings and EMG signals appears to be a means to enhance the validity and reliability of workload evaluation on the task handling light loads.

The subjects carried out a repetitive task accompanied by more than 30 times of upper limb motions per minute for about 52 minutes as a laboratory experiment. As time elapsed, the reason why perceived discomfort ratings increased continuously is that the repetitive upper limb task makes a worker exposed to cumulative workload. Despite light load, such a task has a risk to cause the musculoskeletal disorders on upper limbs.

Six subjects per load's weight participated in this study, due to operational difficulty in reality including more than one hour of experiment time, which is evaluated to be insufficient to ensure reliability as a workload evaluation experiment. The improvement of experiment's reliability is considered to be necessary by securing the subjects additionally in the further study.

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Author listings

Inseok Lee: lis@hknu.ac.kr
Highest degree: Ph.D, Department of Industrial Engineering, POSTECH
Position title: Professor, Department of Civil, Safety and Environmental Engineering, Hankyong National University
Areas of interest: Physical Ergonomics, Workload Evaluation, Agricultural Ergonomics, Accessible Design, Industrial Safety

Sungpill Jo: feelfree89@naver.com
Highest degree: BS, Department of Safety Engineering, Hankyong National University
Position title: Researcher, Department of Civil, Safety and Environmental Engineering, Hankyong National University
Areas of interest: Occupational Ergonomics, Safety and Health, Workload Evaluation