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Electromyographical Study on Muscle Fatigue in Repetitive Forearm Tasks

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Summary: The purpose of this study was to examine whether repetitive muscle tasks in low weight load might influence the fatigue of forearm muscles, and to identify ergonomic risk factors of forearm muscle fatigue in these tasks. Sixteen healthy male volunteers performed eight wrist extensions in different frequency, weight and angle loads while being instructed to keep a dominant upper limb posture as constant as possible. Surface electromyograph (sEMG) was recorded from right *extensors digitorium* (ED), *flexor carpi radialis* (FCR), *flexor carpi ulnaris* (FCU) and *extensor carpi ulnaris* (ECU) during the task performance. Our results showed that mean power frequency (MPF) and median frequency (MF) values of ED, FCR and FCU were significantly lower ($P<0.05$) at high frequency load level than at low load level. However, MPF and MF values of ED were significantly lower ($P<0.01$) in higher load groups of frequency, angle and weight than in lower load groups. These results indicated that the fatigue of muscles varied in the same task, and the number-one risk factor of ECU, ED and FCR was angle load.
Key words：electromyography; repetitive tasks; risk factors; muscle fatigue

Work-related musculoskeletal disorders (wMSD) are the most common self-reported work-related illness in the United Kingdom, USA and South Korea[1, 2]. A similar pattern may occur in our country in the next decade along with an increasing public awareness of work-related illness[2, 4]. Among wMSD, upper limb disorders which are also named cumulative trauma disorders (CTD) rank very high, second only to back complaints and were identified as a risk to profitability and productivity[4].

Extensive manual work involving forearm muscle exertion and extreme wrist postures is associated with CTD[4]. However, reports about the relationship between muscle load and stress were skimpy in China. Because of the ethnic difference between Chinese and European, analyzing the relationship between muscle load and stress in Chinese should be interesting, important and useful. In the present study, 16 male volunteers were recruited and were asked to perform wrist extensions in laboratory to analyze the relationship between fatigue of 4 forearm muscles, e.g., *flexor carpi ulnaris* (FCU), *flexor carpi radialis* (FCR), *extensor digitorium* (ED) and *extensor carpi ulnaris* (ECU), and their risk factors in repetitive tasks.

1 SUBJECTS AND METHODS

1.1 Subjects

Sixteen male volunteers (mean age=19.2 y, SD=2.0) participated in this study. They were all free of pain or discomfort related to upper limb and informed consents were obtained from them prior to the participation in the study.

1.2 Experimental Design

The experiment was a $2\times2\times2$ repeated measures full factorial design with frequency, weight and angle loads of wrist extension as the independent variables (table 1). The experimental task involved repetitively extending the pronated wrist from a neutral posture to a given angle against gravity of a weight held in hand. Wrist extension was between a neutral posture and 45° or 90° extension. Weight loads were controlled at 1.96 N and 4.90 N by changing the weight held in hand. The task was performed at 8.0 and 33.3 motions/min. All experimental conditions were presented in a random order and only one condition was presented to subject in a 24-h period. Every task was performed continuously for 20 min. A two-minute warm-up period was allowed before the beginning of each session (table 1, fig. 1).

Table 1 Loads in 8 different tasks

Tasks	Weight（N）	Frequency (/min)	Angle（°）
1	1.96	8.0	45
2	1.96	8.0	90
3	1.96	33.3	45
4	1.96	33.3	90
5	4.90	8.0	45
6	4.90	8.0	90
7	4.90	33.3	45
8	4.90	33.3	90

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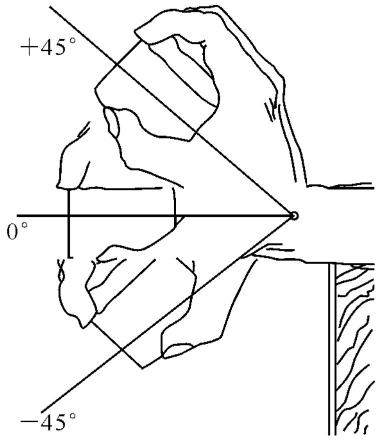

Fig. 1 The schematic diagram of the experimental movement

Surface electromyographic signals (sEMG) (machine used: BIOTEL44, Glonner Co., Germany) was detected with a pair of surface AgCl electrodes (Tyco Healthcare Co., USA) over the bellies of *extensor carpi ulnaris*, (ECU), *extensor digitorium* (ED), *flexor carpi radialis* (FCR) and *flexor carpi ulnaris* (FCU) of the right forearm. Electrode distances were 20 mm with input impedance being 50 MΩ and a gain 1000. EMG data was recorded at a sampling frequency of 1024 Hz.

Before all of the tasks, each of the subjects performed a maximum voluntary contraction (MVC) for 2–3 s in a custom-built fixture (fig. 2)[5, 6] to measure the exertion torque of the muscles and to record their sEMG at the same time. These sEMG signals were designated as 100% MVE. After each of the tasks, 20% MVC was performed and 20% MVE was recorded immediately. (fig. 2)

1.3 Data Processing and Statistical Analysis

In the fast fourier transform (FFT) processing of each of the tasks, the MF and MPF of the 20% MVE data were calculated by using DIAdem 1.1 (National Digital Co., USA). Paired *t*-tests and multi-regressions were used for evaluation of the variance between load levels. The statistical analysis system (SAS Institute Inc., Cary, NC, USA) was used.

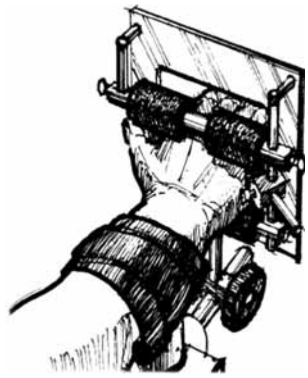

Fig. 2 The fixture used to test %MVE

2 RESULTS

The mean MPF and MF data are given in table 2, which shows that, with ED, all main influencing loads and their interactions significantly affected MPF and MF (for angle and weight load, $P<0.05$; for frequency load, $P<0.01$).

The lowest MPF (115.15 Hz) was recorded in ED when weight load was at 4.90 N, while the highest MPF (161.25 Hz) was recorded in FCU when frequency load was at 8.0 moves/min. The data also revealed that angle, frequency and weight loads had a greater effect on ED than on the other muscles. The MPF for each muscle decreased as angle, frequency and weight load were increased.

The maximal and minimal MF values (178.58 Hz and 111.58 Hz, respectively) were recorded at the angle load of 45° and at the frequency load of 33.3 moves/min. The MF and MPF values for the four muscles were very similar, both having a negative correlation with the load levels of all kinds of load. The frequency load had a greater effect on MF and MPF values than other kinds of load (for ED and FUR $P<0.05$, for FCU $P<0.01$) (table 2).

Multi-regression analysis revealed that the highest partial R2 values for ECU, ED and FCR were found in angle loads (table 3). In view of the positive correlation between load risk and partial R2 value, this result indicated that angle was the number-one risk factor in our experiment (table 3).

Table 2 MPF and MF in different kinds and various levels of loads (Hz, $\bar{x}\pm s$)

Indices	Muscles	Angle		Frequency		Weight	
		45°	90°	8.0 moves/min	33.3 moves/min	1.96 N	4.90 N
MPF	ECU	147.36±3.89	136.59±8.53	144.26±3.86	139.69±11.67	142.44±5.17	141.51±11.73
	ED	123.11±4.56	115.39±6.78**	121.68±5.17	116.82±8.00*	123.00±5.35	115.15±6.27**
	FCR	149.04±3.33	149.01±2.50	151.25±1.15	146.80±1.67*	158.95±3.34	158.18±3.84
	FCU	159.92±2.92	157.21±3.59	161.25±1.39	155.88±2.27**	114.52±2.85	113.48±3.42
MF	ECU	178.58±2.88	169.94±7.41	176.06±2.67	172.46±9.86	175.09±4.01	173.44±9.75
	ED	158.07±3.47	150.69±6.67**	156.86±3.72	151.90±7.92*	157.62±4.41	151.14±6.75**
	FCR	114.12±3.48	113.87±2.90	116.42±1.41	111.58±1.73*	126.90±3.96	126.55±4.43
	FCU	128.29±3.79	125.15±3.80*	129.92±1.87	123.53±2.17**	149.63±2.49	148.42±3.18

*$P<0.05$, **$P<0.01$, paired comparison *t*-test between 2 load levels

Table 3 Multi-regression analysis about the risk factors of the muscles

Muscles	Parameters	Parameter estimation	Standard error	*F* value	*P* value	Partial R^2
ECU	Intercept	190.1675	7.20917	695.83	<.0001	—
	Angle	−0.19202	0.09003	4.55	0.0861	0.4400
	Frequency	−0.14231	0.16014	0.79	0.4149	0.0764
ED	Intercept	177.0806	4.55868	1508.91	<.0001	—
	Angle	−0.16415	0.04761	11.89	0.0261	0.3908
	Weight	−21.6132	7.14164	9.16	0.0389	0.3011
	Frequency	−0.19622	0.08468	5.37	0.0814	0.1765
FCR	Intercept	171.5539	4.35864	1549.17	<.0001	—
	Angle	−0.12096	0.06126	3.9	0.0957	0.3939
FCU	Intercept	163.7731	5.73708	814.9	<.0001	—
	Weight	−21.0671	9.73225	4.69	0.0827	0.3965
	Angle	−0.09472	0.06488	2.13	0.2041	0.1804

* In the same regression/the same muscle, the effect of the factor takes positive correlation with partial R^2 value

3 DISCUSSION

Prevention of various kinds of wMSD is a cornerstone of ergonomics. Estimation of the physical exposure and its physiological consequences are essential activities in ergonomic work. Therefore, to determine the dose-relationship between muscle loads and stress is necessary. Two approaches are usually used to study this dose-relationship: external load approach and internal load approach. The internal load is related to muscle fatigue and may lead to various detrimental consequences, such as wMSD, in different tissues[4]. Muscle fatigue, defined as a decreased force-generating capacity or an inability to maintain movement performance, is an inevitable phenomenon associated with muscular work[7]. sEMG is the unique technique employed to study internal load and its effects because only this technique can get 'on-line' information of muscle internal load and muscle stress or fatigue[4]. sEMG reflects the internal load and is thus dependent on both the external load, effected by the task, and individual factors[8]. In order to avoid the individual variations among subjects, some sEMG approachs are usually used to analyze muscular fatigue. Luttmann *et al*[8] proposed three of such techniques (1) the execution of test contractions of known force in a defined posture, (2) the comparison of sEMG for reference activities of comparable workload, and (3) taking amplitude and spectral shifts into account at the same time in order to discriminate between force-related and fatigue-induced sEMG changes. In order to control the performance of the tasks with ease, the first method was used in our experiment.

Extensive manual work involving forearm muscle exertion and extreme wrist postures is associated with CTD. Repetitive force exertion, measured as forearm EMG activity, has been identified as a risk factor while wrist flexion, and extreme wrist postures or wrist angular velocity and acceleration have been identified as risk factors by others [4, 10]. Most of the work concerning the relative importance of different risk factors related to CTD focused on the effects of force and repetition rate. In some studies on CTD, high repetition rate seemed to be the greatest risk factor, whereas other studies on CTD suggested that force appeared to be a greater risk[1]. The 1988 National Health Survey in the United States concluded that the risk factor most strongly associated with CTD was repetitive bending or twisting of the hand and wrists at work[11, 12]. The results of our experiment showed that the fatigue of forearm extensor and flexor were affected by weight, frequency and angle load, indicating these loads were risk factors in wrist movement, however, the risk levels of them were different. The angle was the number-one fatigue risk factor of forearm agonistic extensor and flexor, indicating better posture design could be effective for the prevention of CTD in tasks with low weight and frequency loads. These results were generally consistent with the previously reported findings[4, 10-12]. A main finding of our study is the existence of a significant difference in muscle fatigue between flexor and extensor in forearm, indicating that flexor and extensor had different activity patterns and performed different functions in these tasks. An antagonistic co-contraction of the antagonistic muscles was necessary to achieve wrist joint stability, whilst the agonistic muscle performed the most amount of the extension movement. As an agonistic muscle, ED mainly performs wrist extension and was the muscle at the highest fatigue level. On the contrary, as an antagonistic muscle, FCU and FCR contracted slightly to achieve the wrist joint stability and therefore were at low fatigue level. An interesting result of our experiment was that the muscle at the lowest fatigue level was ECU, indicating it was a subordinate agonistic muscle in these tasks.

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REFERENCES

1 Muggleton J M, Allen R, Chappell P H. Hand and arm injuries associated with repetitive manual work in industry: a review of disorders, risk factors and preventive measures. Ergonomics, 1999,42:714-739

2 Yun M H, Lee Y G, Eoh H J *et al*. Results of a survey on the awareness and severity assessment of upper-limb work-related musculoskeletal disorders among female bank tellers in Korea. International J Ind Ergon, 2001,27: 347-357

3 Viikari J E. The scientific basis for making guidelines and standards to prevent work-related musculoskeletal disorders. Ergonomics, 1997, 40:1097-1117

4 Haegg G M, Luttmann A, Jaeger M. Methods for evaluating electromyography field data in ergonomics. J Electromyogr Kinesiol, 2000(10):301-312

5 Simoneau G G, Marklin R W, Berman J E. Effect of computer keyboard slope on wrist position and forearm electromyography of typists without musculoskeletal disorders. Phys Ther, 2003,83:816-830

6 Lynn P A. Direct on-line estimation of muscle fiber conduction velocity by surface electromyography. IEEE Trans Biomed Eng, 1975,10:565 -571

7 Jaric S, Blesic S, Milanovic S *et al*. Changes in movement final position associated with agonist and antagonist muscle fatigue. Eur J Appl Physiol, 1999, 80:467-471

8 Luttmann A, Jaeger M, Laurig W. Electromyographical indication of muscular fatigue in occupational field studies. Int J Ind Ergon, 2000,25: 645-60

9 Hansson G A, Balogh I, Ohlsson K *et al*. Impact of physical exposure on neck and upper limb disorders in female workers. Appl Ergon, 2000,31:301-310

10 Haegg G M, Oester J, Bystrom S. Forearm muscular load and wrist angle among automotive assembly line workers in relation to symptoms. Appl Ergon, 1997, 28:41-47

11 Lemasters G K, Atterberg M R, Booth A D *et al*. Prevalence of works related musculoskeletal disorders in active union carpenters. Occup Environ Med, 1998, 55:421-427

12 Polanyi M F, Cole D C, Beaton D E *et al*. Upper limb work-related musculoskeletal disorders among newspaper employees: cross-sectional survey results. Am J Ind Med, 1997,32:620-628

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