EMG of Forearm Muscles in Torqueing Task with Respect to Grip Force, Stroke Rotation and Frequency

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ABSTRACT

The objective of present study was to investigate the effect of grip force, stroke rotation and frequency on EMG activities of forearm muscles. Twenty seven participants volunteered in this study. Participants performed repetitive upper limb exertions at three levels of grip force (50N, 70N & 90N), three levels of stroke rotation (30°, 45° and 60°) and three levels of frequency (10 exertions/min, 15 exertions/min & 20 exertions/min). The study was divided into three groups based on grip force therefore a 3x3 factorial design was used. Task duration was 5 minutes for each combination. Multivariate analysis of variance (MANOVA) was used and found normalised EMG of muscles FCR, FCU and ECR was significantly affected by grip force; and frequency was significant on normalised EMG of muscles FCR, ECR and ECU. Also, slope of median frequency (relative indication of muscle fatigue) was significantly affected by grip force on muscles FCR, ECU and stroke rotation on muscle FCU. Both two-way interaction (grip force & frequency) and (grip force & stroke rotation) were found significant on muscle ECU. Three-way interaction effect was found significant only on muscle FCU. Results found that extensor muscles were more fatigued in torqueing and gripping task. Although findings of present study revealed that if occupational task designers taken care of factors considered in this study, working environment could be more comfortable and productive.

Key words: Stroke rotation, torqueing, gripping, EMG

INTRODUCTION

Surface Electromyography is one of the most important tool for evaluation of MSDs [1]. Many researchers used EMG for evaluation of muscle activation and muscle fatigue during different kinds of tasks in terms of normalised EMG [2,3,4,5]; average EMG [6,7,8,9] and median frequency [4,10].

Many researchers found that forearm rotation angle significantly affected discomfort in flexion task [11,12], torqueing task [13,14,15,16,17] and gripping task [6,18,19,20]. Also literature reported that stroke rotation significantly affected discomfort in screwing task [21] and combined effect of torqueing with gripping task [22]. Also, Literature survey showed that torque has strong association with musculoskeletal disorders and injuries in industrial task. Therefore researchers investigated effect of torque on discomfort and found that torque was significantly affected forearm discomfort [13, 14, 16, 17, 23]. Grip force also plays an important role in risks of WMSDs and found from literature grip force was significant on discomfort [21, 24]. Also frequency of exertion found significant in flexion task [25, 26], assembly task [27,28], cyclic push task [8]. However, Bano et al. [22] found frequency of exertion very close to significant during combined effect of torqueing with gripping task.

Bano et al. [21] investigated effect of grip type, stroke rotation and handle size on discomfort in screwing task. They evaluated combined effect of torque and grip on discomfort and found grip force and stroke rotation both were significant. In another study of Bano et al. [22] investigated effect of stroke rotation and frequency of exertion on discomfort in combined torqueing with gripping task. They found that stroke rotation was significant on discomfort and frequency of exertion was very close to significant. Also Mukhopadhyay et al. [15] investigated combined effect of intermittent isometric torque and grip force on forearm discomfort. They found that combined effect of torque and gripping exertions were highly significant on discomfort. However, literature survey showed that there was lack of studies which investigated combined effect of torque with grip on discomfort. Also none of studies found, which evaluated combined effect of grip force and torque on discomfort in terms of muscle activation and muscle fatigue. Therefore present study was designed to investigate the effect of grip force, stroke rotation and frequency of exertion on EMG activity of forearm muscles.

Null hypothesis for the study was as follows :

"There were no main and/or interaction effects of grip force, stroke rotation and frequency of exertion on EMG activity of forearm muscles".

METHOD

Experimental Design: Twenty seven right handed participant volunteered in this study. Participants performed repetitive upper limp exertions for 5minutes duration. Three levels of stroke rotation (30°, 45° and 60°), three levels of grip force (50N, 70N & 90N) and three levels of frequency of exertion (10 exertions/min, 15 exertions/min & 20 exertions/min) were considered as independent variables. Experiment was divided into three groups on basis of grip force; 50N, 70N and 90N due to availability of participants for longer duration of a set of experimental conditions. Therefore, a 3x3 factorial design was used and 9 conditions were assigned for each participant of each group. Effect of independent variables was investigated on EMG activities of five forearm muscles (Flexor Carpi Radialis (FCR), Flexor Carpi Ulnaris (FCU), Flexor Digitorum Superficialis (FDS), Extensor Carpi Radialis (ECR), and Extensor Carpi Ulnaris (ECU)).

To perform an experiment, a rig was designed and fabricated as shown in Fig. 1. The interfacing of equipments with laptop was also shown in Fig 1.

Procedure: Participant was briefed about experiment and was asked to give prior consent. After preliminary attachment of EMG sensors (Model: SX230 EMG sensor; Make: Biometrics Ltd. UK) and apparatus, participant sat on an adjustable chair at fixed position on floor with regard to experimental rig. Elbow flexed at 90° without upper arm adduction and with neutral forearm angle. Participant at rest called minimum EMG while exerted maximum voluntary contraction called maximum EMG these were recorded for each muscle prior to experiment. Participant performed repetitive gripping and torqueing exertions such that they applied force of 50N on grip meter (Model: Precision Dynamometer G200; Make: Biometrics Ltd. UK), rotated their right hand in supination direction at particular angle for one second, released and rested for some seconds (as per frequency of exertions in respective condition) and repeated same task for 5minutes of duration. Time was controlled by an analogue clock on computer screen and started green light at the end of each condition. EMG activities of each muscle were saved for respective participant at end of each condition. A rest of at least 5 minutes was provided between each condition. Further 80 minutes were required for remaining 8 treatments for a participant of first group of the study. Same procedure was repeated for group 2 (Grip force=70N) and group 3 (Grip Force= 90N).

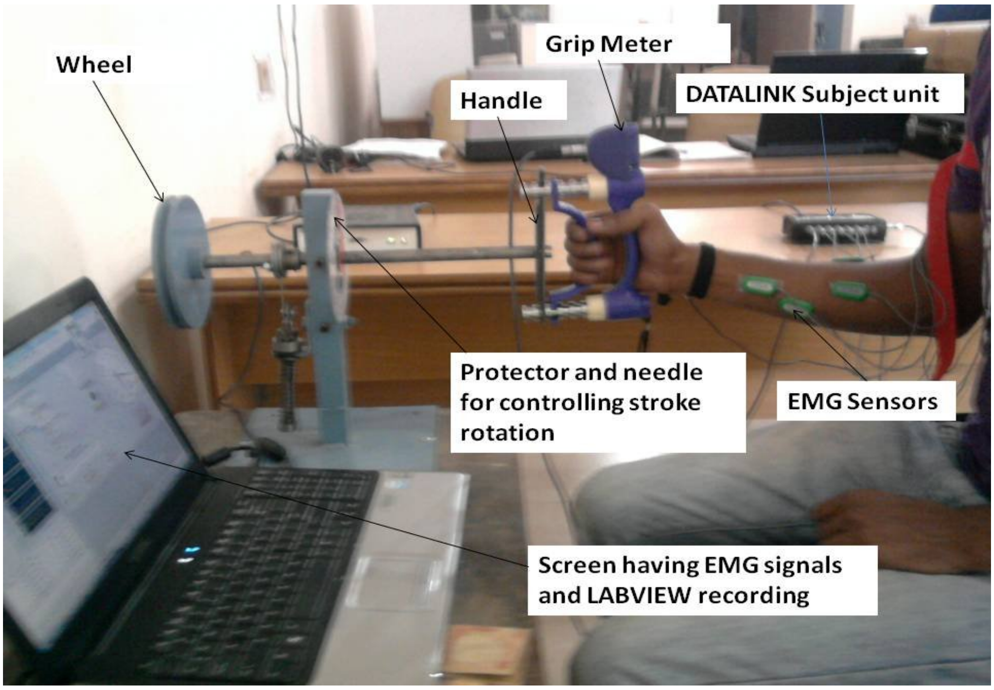


Fig 1: Experimental setup

RESULTS

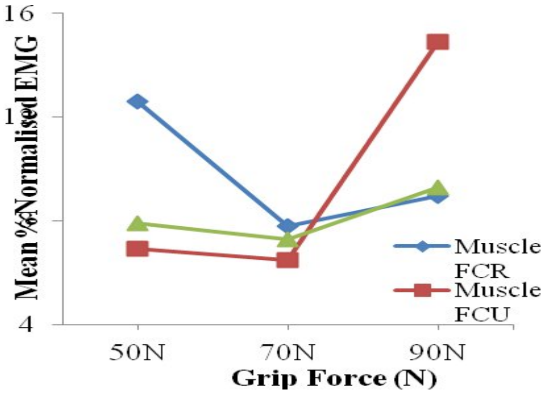
RMS values of all muscles with respect to all conditions and participants were normalised using formula [29] as given below.

$$\%\text{Normalised EMG} = \frac{(rmsEMG_i - rmsEMG_{min})}{(rmsEMG_{max} - rmsEMG_{min})} \times 100\%$$

Results of MANOVA performed on normalised EMG values, showed that main effect of grip force and frequency of exertion were significant on %normalised EMG of muscles FCR ($p=0.001$), FCU ($p<0.001$), ECR ($p=0.008$) and FCR ($p=0.027$), ECR ($p<0.001$), ECU ($p=0.034$) respectively. Other main and interaction effects were not significant on %normalised EMG of any muscle. It was also noticed that flexor muscles were significantly affected by grip force and extensor muscles were significantly affected by frequency of exertions in repetitive gripping with torqueing task.

Significantly affected muscles with respect to grip force were illustrated in Fig 2. It was observed that muscle FCU was highly activated while activation level for muscles FCR and ECR was seen to be approximately same at 90N grip force. Therefore, t-test was applied on percentage normalized EMG data and found significant difference in activation of muscles FCR and FCU ($t=-2.743$, $p=0.008$) and also significant difference in activation of muscles FCU and ECR ($t=-2.552$, $p=0.013$).

Similarly, t-test was applied at grip force 50N and found that muscles FCR & FCU was also significantly different ($t=5.943$, $p<0.001$) and muscles FCR & ECR as well ($t=3.226$, $p=0.002$). It was very interesting that all muscles had same activation level for grip force 70N therefore, one-way repeated measure ANOVA was applied and found no significant difference of all muscles (FCR, FCU and ECR) on percentage normalised EMG ($p=0.142$).



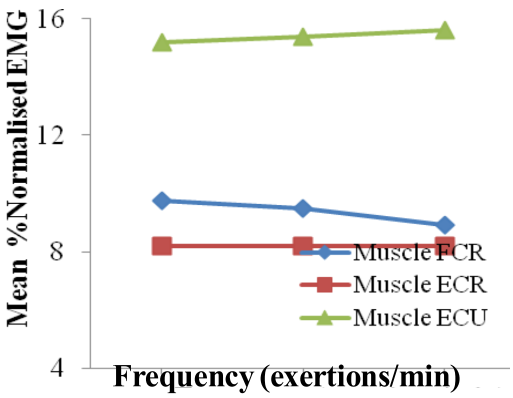


Fig 2: Mean % Normalised EMG for grip for frequency by forearm muscles

Fig 3: Mean % Normalised EMG force by forearm muscles

Similarly, significant muscles (affected by frequency) were plotted in Fig 3 and it was observed that muscle ECU had highest activation for all levels of frequency than other two muscles. However there was not very much difference in activation of muscles FCR and ECR for all levels of frequency. Interestingly, it was noticed that a trend for activation of muscles FCR, ECR and ECU for all levels of frequency seem to be parallel. Therefore, a parallelism test was applied on the data obtained for above said muscles at three levels of frequency. The difference of normalised EMG of each muscle at all levels of frequency was calculated and one-way repeated measure ANOVA was performed. There was no significant difference found between difference of two muscles (ECU and FCR) (p=0.873) and other two muscles (FCR and ECR) (p=0.129). Hence, parallelism test verified.

Further MANOVA performed on slope of median frequency showed that grip force was significant effect on the muscles FCR (p=0.023) and ECU (p=0.009); stroke rotation was found to be significant on muscle FCU (0.015). No other main effect was found significant. Interaction effect of grip force and frequency was found significant on slope of median frequency of muscle ECU (0.028) and grip force and stroke rotation was significantly affected on slope of median frequency of muscle ECU (0.012). A three-way interaction was significantly affected on slope of median frequency of FCU (p= 0.019). Graphical interpretation of response in terms of slope of median frequency (based on linear regression) of signal was presented in Fig 4 & 5.

Fig 4 illustrated fatigue of a significant muscle ECU with respect to interaction of grip force and frequency of exertion. Increasing trend of fatigue was found for almost all frequency levels. Also, noticed that lowest fatigue was found at grip force 50N further it was seen that level of fatigue increased as grip force increases and had maximum fatigue (mean slope -0.031 units) at 90N grip force. Similarly, same trend of fatigue was observed for all frequencies. Although, at 50N grip force highest fatigue was found for frequency of 15 exertions/minute while highest fatigue at 90N grip force was found for frequency of 10 exertions/minute. Moreover the difference of fatigue at 70N grip force was more as compared to fatigue difference at 50N. Therefore, t-test was applied on the data at grip force 70N for all levels of frequency, no significant difference was found between two levels of frequency (10 exertions/minute & 15 exertions/minute) (p=0.611) and other two levels (10 exertions/minute & 20 exertions/minute) (p=0.112). Similarly, t-test was also applied on the data at 90N grip force for all frequencies, no significant difference was found between two levels of frequency (10 exertions/minute & 15 exertions/minute) (p=0.051) and other two levels (10 exertions/minute & 20 exertions/minute) (p=0.153).

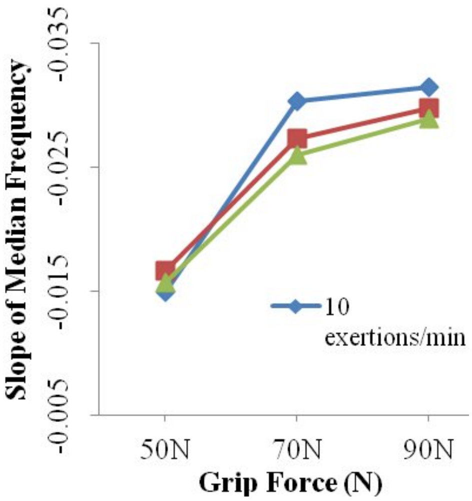


Fig 4: Slope of median frequency versus grip force for muscle ECU at different frequencies

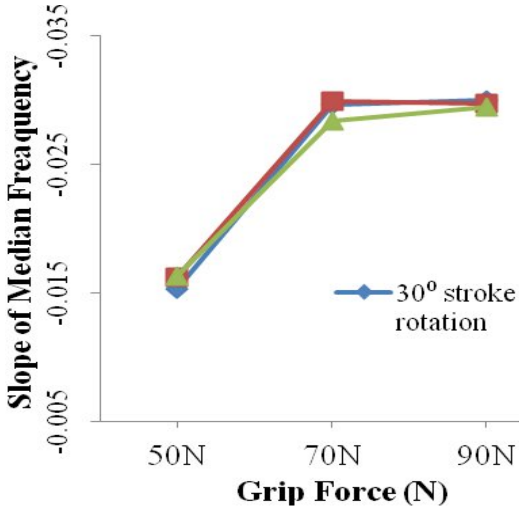


Fig 5: Slope of median frequency for grip force of muscle ECU by different stroke rotations

Fig 5 illustrated fatigue of a significant muscle ECU for interaction of grip force and stroke rotation. It was observed that fatigue was increased as grip force increases from 50N to 70N whereas no change in fatigue was found when grip force was further increased till 90N. Similar trend of fatigue was found for all levels of stroke rotation. It was also noticed that minimum fatigue (mean slope -0.016 units) in muscle ECU was found at grip force 50N.

DISCUSSION

EMG is widely used as prediction methods to correlate feeling of discomfort with WMSDs, may be developed due to postural, force and frequency related factors [5,16,17]. An analysis showed that extension muscles were more fatigued compared to flexion muscles. Although in this study only five superficial muscles of forearm were recruited for EMG recording. These muscles by enlarge gives general idea about fatigue of forearm as many researchers have used for evaluation of repetitive tasks in simulated [13,16,11,12] or occupational environment [30,31]. In line with results of present study O'Sullivan and Gallwey [13] has reported highly significant effect of pronation and supination torque on ECRB muscle. Hoozemans and Dieën [5] also reported that extensor muscle activity is highly associated with power grip activity. Task of present study was combination of power grip and supination torque. Therefore it is found supportive that extensor muscles are more affected for combined gripping with torque for repetitive exertions.

Slope of median frequency indicated rate of development of muscle fatigue. As in gripping task, previous studies [32,33] reported that development of fatigue in extensor was more quickly than flexor muscles. Present results showed significantly faster rate of fatigue development at 70N and 90N grip force than 50N. Therefore, it can be concluded that task below 70N grip force level could be prolonged for longer duration at frequency range 10-20exertions/minute. So these outcomes were in line with previous studies [10,18], reported higher muscle activity for tasks involving grip. It is known that muscle force and muscle length play an important role in defining relationship between EMG amplitude and grip force. Muscle length changes with rotation of forearm [34], changes in muscle arm occur due to change in muscle length [35] and change in moment arm with change in forearm rotation [36, 37].

CONCLUSIONS

Extensor muscles (especially ECU) were found highly active and more fatigued compared to flexor muscle for combined gripping with torqueing task. It was also found that %normalised EMG was more for 15 & 20 exertions/minute compared to 10 exertions/minute.

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