ISB 2013 BRAZIL
XXIV CONGRESS OF THE INTERNATIONAL SOCIETY OF BIOMECHANICS
XV BRAZILIAN CONGRESS OF BIOMECHANICS

PRECEDING FORCE TIME-HISTORY AFFECTS FATIGUE ACCUMULATION DURING REPETITIVE HAND GRIP TASKS

[1] Michael W. Sonne, [1]Joanne N. Hodder and [1]James R. Potvin
[1]McMaster University, Hamilton, On, Canada, McMaster Occupational Biomechanics Lab

SUMMARY

Neuromuscular fatigue had been linked to the development of occupational musculoskeletal injury. The accumulation and recovery from fatigue has been documented to be contingent on the nature of the task. This study confirms that fatigue accumulation is depends on the relative force demands immediately preceding a task.

INTRODUCTION

Fatigue is marked by a reduction in the force generating capacity of the neuromuscular system, and its process is complex; involving both centrally and peripherally mediated factors [4]. The possible impact of fatigue on the development of musculoskeletal injury has led to the development of fatigue models to aid in the prediction of fatigue progression and the determination of adequate rest periods [1,7]. However, current models may lack industrial relevance for ergonomic purposes. Previous studies, on which fatigue models have been based, have either used sustained contractions to exhaustion or intermittent, isotonic contractions with consistent effort and complete rest durations each cycle [1,7]. Neither of these conditions is particularly relevant to industrial applications. More recently, Yung and colleagues [9] assessed fatigue accumulation during more complex tasks, including not only intermittent tasks, with complete rest periods (0% MVC), but also intermittent tasks without complete rest. Both sets of conditions had the same overall average effort, but the conditions without complete rest periods accumulated fatigue more quickly. Thus, the quality of the rest period does impact fatigue accumulation. The purpose of the current study was to further examine fatigue accumulation throughout the course of a task that features a more industrially relevant complex force production pattern.

METHODS

Ten right hand dominant female participants (23.3 ± 3.7 years, 1.65 ± 1.0 m, and 63.4 ± 7.3 kg), with no shoulder, elbow, or wrist pathology, were recruited for this study. Grip force and surface electromyography of the brachioradialis (BRD) and flexor carpi ulnaris (FCU) were measured while participants performed intermittent visually targeted gripping efforts to fatigue. Grip force was measured with an instrumented hand-grip dynamometer in their dominant hand with their arm straight and at their side. Both force and EMG data were sampled at 2000 Hz; AD converted and stored offline for processing. The pattern of grip force consisted of six isotonic plateaus at 0% of maximum voluntary contraction (MVC), then 15%, 30%, 45%, 30%, and then 15% MVC. After each plateau there was a 3 second post-plateau MVC followed by a 3 second rest period. This pattern was repeated until the participant was no longer able to sustain the force level of two consecutive plateaus or had post-plateau MVC's of <65%. Participants practiced the visually targeted gripping using their left hand prior to performing the protocol with their right hand.

Analysis was completed on each participant's first and last cycle. The post-plateau grip force MVCs were obtained by a 0.5 s moving average. Mean power frequency (MnPF) was calculated at one-second intervals during the middle 13 seconds of each force plateau, and values were fit to a second order polynomial regression equation. The intercept and full term values were used as the initial and final MnPF. Repeated-measures ANOVAs compared: 1) the post-plateau grip forces between submaximal plateaus and between the first and last cycle and, 2) the change in MnPF of the BRD and FCU both during and between each submaximal plateau and between plateaus. A Tukey's honest significant difference ($p<0.05$) post-hoc t-test was used to examine the effects.

RESULTS AND DISCUSSION

Five participants completed 2 cycles of the task before no longer meeting the continuation criteria, and five participants completed 3 cycles.

Force

There was a significant main effect of cycle ($p<0.0001$) and plateau ($p<0.0001$) on post-plateau grip peak force. The average peak grip forces, pooled across all post-plateau MVCs within the first and last cycle, were 89.0±8.4% MVC and 68.5±7.9% MVC, respectively. Independent of cycle, post-hoc testing revealed significant changes between the initial fully rested MVC and all post-plateau MVCs. Of particular interest were the significant differences in fatigue accumulation between that which occurred during on ascending portion of the pyramid (15% after 0% and 30% after 15%MVC), and that during the descending portion (30% after 45% and 15% after 30%%MVC). Significant decreases in MVC ($p<0.05$) occurred during the ascending portion (5.4% and 5.6% MVC decreases, respectively), however, there are no significant changes in strength during these two plateaus during the descending portion (Figure 1).

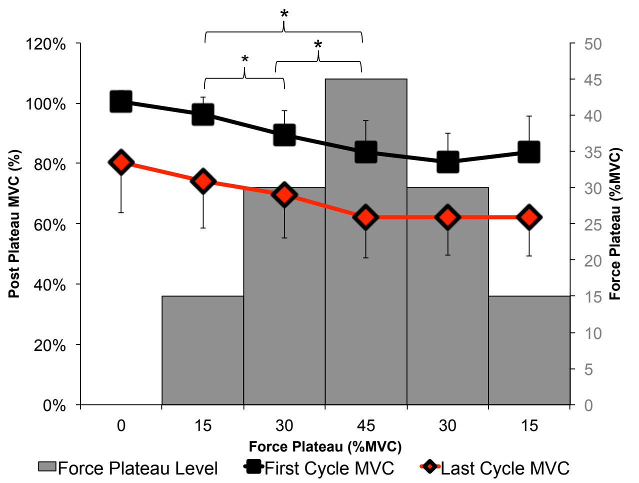

Fig. 1. Average peak grip force for the post-plateau MVC (SD) for the first and last cycle (n=10). * indicated significant differences, p <0.05.

EMG

There was a significant interaction between time point (start vs end of plateau) and cycle, as well as time point and plateau for FCU MnPF. The average MnPF values were significantly less at the end of the last cycle than at the end of the first cycle (Figure 2). There was a significant interaction between plateau and time point (start vs end of plateau) for the MnPF of the BRD (p<0.0001). A significant decrease in MnPF occurred from the start to the end of the 45% MVC plateau (Figure 2). The MnPF was significantly higher at the end of the 30% plateau than at the end of the 45% plateau (Figure 2). Cycle was found to have an effect on BRD MnPF with values being higher in the first cycle than in the last cycle (Figure 2).

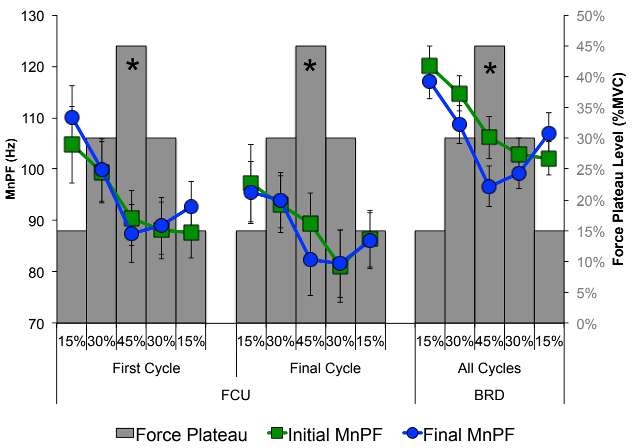

Fig. 2. Initial and final MnPF values (SE) for the FCU and the BRD. * indicates a significant decrease in MnPF from the start to the end of the 45% plateau for both muscles when pooled across cycles.

DISCUSSION

This study aimed to identify the effect of a complex force-time history on the accumulation of fatigue during a hand grip task. A lack of significant fatigue accumulation during the descending portion of a force pyramid illustrated that it may be important to account for the demands preceding a task, when determining the amount of fatigue that will accumulate during that task. As expected, the significant decrease in MVC force from the first to the last cycle confirmed that the participants were fatigued over the course of the trial. However, the lack of significant maximum force changes following the plateaus on the descending aspect of the force pyramid indicates that the magnitude of an immediately preceding demand on a muscle group can interact with the fatiguing effects of a subsequent demand. These changes in force generating capacity were confirmed by related changes in the myoelectric signal spectrum.

Yung et al., [9] conducted an experiment where participants completed various force patterns with average force levels of 15% MVC. In patterns where force levels intermittently were higher and lower than the average force but did not return to 0% MVC, the fatigue accumulation was less than that seen during a sustained isometric contraction. In trials where participants did not return to 0% MVC, fatigue accumulation was still less than in a sustained contraction. When moving between a force of greater magnitude to a force of lesser magnitude, it is possible that the drop in tension may result in the redistribution of muscle activity to decrease fiber overload and promote uniform changes in the extra-cellular environment within the muscle [4]. Yung et al. [9] also found differences in blood flow velocity between a sustained isotonic contraction of 15% MVC, and an isometric contraction alternating between 7.5% and 25.5% MVC. Following conditions where blood flow is reduced, lesser forces may lead to re-perfusion of the muscle and increases in MVC [9]. Thus, descending the pyramid from a plateau of 45% to 30%, and then to 15% MVC, may allow for a re-perfusion of the muscle and consequent maintenance of maximum force generating capacity.
The force results were supported by a significant decrease in the MnPF of the EMG signal in both muscles for the 45% MVC plateau and in BRD over the course of the first and last cycles. The drop in MnPF is a result of a conduction velocity decrease in the active muscle fiber [3,8], and an increase in motor unit firing synchronicity [6].

CONCLUSIONS

Future research will aim to model the fatigue response during a complex force-time history, as well as determine the central and peripheral contributions to fatigue during this type of task. The continued examination of complex force histories and pursuit of accurate models to predict fatigue accumulation will lead to important gains in the field of occupational biomechanics, allowing ergonomists to predict which jobs will cause fatigue and possibly prevent injuries to workers.

REFERENCES

1. Bystrom & Fransson-Hall, *Hum Factors,* **36**(1), 1994.
2. Ebersole et al., *J. Electromyog Kinesiol*, **16,** 2006.
3. Enoka & Duchateau, *J.Physiol*, **586** (1), 2008.
4. Falla & Farina, *Exp. Brain. Res.,* **182,** 2007.
5. Gandevia, Psychol Rev, **81,** 2001.
6. Krog-Lund & Jorgensen, Eur J Appl Physiol, **64**, 1992.
7. Rhomert, *Applied Ergonomics*, **4**, 1973.
8. Vollestad, *J Neurosci Methods*, **74**, 1997.
9. Yung et al.,*Eur J Appl Physol*, **112**, 2012.
10. Zhang et al., *Acta Physio Scand,* **180**, 2004.