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Force time-history affects fatigue accumulation during repetitive handgrip tasks

Michael W. Sonne *, Joanne N. Hodder, Ryan Wells, Jim R. Potvin

McMaster Occupational Biomechanics Lab, McMaster University, Hamilton, ON, Canada

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ABSTRACT

Muscle fatigue is associated with a higher risk of workplace injury, in particular during repetitive tasks. This study aimed to identify the effect of a complex force–time history (a task with multiple different submaximal effort levels) on fatigue accumulation and recovery during a handgrip task. We measured surface electromyography of the brachioradialis (BRD) and flexor carpi ulnaris (FCU) of ten right hand dominant females with no history of upper limb injury while they performed a complex submaximal visually targeted gripping task. The task consisted of 15%, 30%, 45%, 30%, and 15% maximum voluntary contraction (MVC) plateaus. Each plateau was held for 15 s, followed by a 3 s MVC and 3 s of rest. The "pyramid" was repeated until fatigue criteria were met. Grip force, average EMG and mean power frequency (MnPF) for first cycle and fatigued last cycle, were compared. Post-plateau peak grip force was on average 20.5% MVC lower during the last cycle ($p < 0.01$). Post-plateau grip forces decreased on average by 5.1% MVC after the first 15% MVC plateau (from baseline), by 5.3% MVC after the 30% MVC plateau and 6.8% MVC after the 45% MVC plateau. Further accumulation of fatigue after the second 30% MVC plateau however was minimal, only decreasing by 1.6% MVC. Recovery appeared to occur during the last 15% MVC plateau with an increase in post plateau grip force of 1.6% MVC. Interestingly, MnPF parameters confirmed significant fatigue accumulation during the back end of a force pyramid. We conclude that in a pattern of contractions with ascending, then descending force intensity, voluntary force recovery was present when the preceding force was of a lower intensity. These findings indicate preceding demands play a role in fatigue accumulation during complex tasks.

1. Introduction

Muscle fatigue is a complex and highly researched topic, with important implications for ergonomics. Fatigue is a process that decreases the contractile capacity of muscles. When this occurs in the workplace, the force producing capacity of the worker is diminished, and tasks require a higher relative effort. Maintaining the same pace and/or force level becomes more difficult, increasing the likelihood of sustaining an injury. In ergonomics, fatigue models are used to determine acceptable rest allowances for a given exertion level and duration. This approach, of determining the maximum holding or endurance time for an exertion and the required rest allowance, was first modeled by (Rohmert, 1973). That model, however, is criticized for predicting that efforts less than 15% maximum voluntary contraction (MVC) can be held indefinitely. Interestingly, in the same communication, data are presented, from Rohmert's work in 1962, showing that a static hold at slightly higher than 15% (ie. 20% MVC) reduced MVC production by 40% after only 6 min (although the type of contraction is not described).

Many authors have since shown that fatigue development occurs at intensities much lower than 15% MVC (Björkstén and Jonsson, 1977; Erik Mathiassen and Åhsberg, 1999; Sato et al., 1984). Shoulder flexor fatigue occurs in less than 20 min with an 8% MVC static contraction (Erik Mathiassen and Åhsberg, 1999), elbow flexor fatigue occurred within 60 min at 7.9% MVC (Björkstén and Jonsson, 1977). As a result, the guidelines proposed by Rohmert (1973) would possibly recommend acceptable work limits that could result in fatigue in an occupational setting. It is important that the fatiguing contributions of these low level contractions are accounted for in future models to be used in the workplace.

In 2009, a review of the literature found 24 fatigue models using the maximum endurance time approach, with some being joint specific while others were more general (El ahrache and Imbeau, 2009). Ma et al. (2011) used an equation, where the normalized

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* Corresponding author at: Department of Kinesiology, Faculty of Science, McMaster University, Hamilton, Ontario L8S 4K1, Canada. Tel.: +1 519 996 3746.

E-mail address: sonnemw@mcmaster.ca (M.W. Sonne).

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force level was set to an exponent to predict endurance times, to define fatigue. They also included different constants for each joint. Frey Law and Avin (2010) also developed a joint-specific fatigue model and examined differences in endurance time between joints. With regards to their utility in ergonomics, a limitation of all of these models is that they were developed using endurance tasks, or tasks that featured intermittent isotonic contractions of the same intensity. These types of exertions are not often found during modern industrial work.

Industrial tasks often require varying levels of effort, which affects fatigue accumulation. A study by Byström and Fransson-Hall (1994) determined the effects of various intermittent handgrip contractions on fatigue accumulation, as measured by lactate concentration. Continuous contractions accumulated lactate concentrations far more quickly than contractions at the same intensity with intermittent rest breaks. However, a limitation of that study was that complete rest occurred during the intermittent contraction condition, which often is not the case in industrial tasks and, therefore, the results may not be directly applicable to ergonomics.

Recently, Yung et al. (2012) assessed the fatiguing effects of intermittent contractions, with and without complete rest, as assessed by decreases in force generating capacity. They tested 5 elbow extension fatigue conditions, all of which had an average MVC-relative force demand of 15% MVC. One condition was a continuous 15% MVC contraction and four were intermittent in nature, with only one of those having a complete rest phase. Each intermittent task cycled through the same maximum and minimum demand level. They found that, in spite of the each condition having the same average demand, the 5 conditions induced differing levels of fatigue accumulation. The continuous, isotonic condition caused the greatest level of fatigue. The one intermittent condition, with a complete rest phase, resulted in the least amount of fatigue. Interestingly, the intermittent contractions without complete rest did still allow for substantial fatigue recovery, compared to the isotonic condition.

Based on the fact that most of the available research data is based on either isotonic endurance trials, or simple intermittent tasks, it is still unknown how fatigue accumulates during the course of complex tasks with widely varying force levels, interspersed with rest. On an assembly line, a worker may move from lifting a tool, to tightening a bolt, to installing a weather strip on a door. These tasks all consist of varying MVC-relative force levels, and muscle demands, and will all contribute to the interaction between fatigue and recovery. The purpose of the current study was to further examine fatigue accumulation throughout the course of a task that features a complex force demand time-history.

2. Methods

2.1. Participants

The study consisted of ten right hand dominant females (23.3 ± 3.7 years, 1.65 ± 0.1 m, with 63.4 ± 7.3 kg) with no history of upper limb injury for this study. Participants provided written informed consent prior to testing. The study received clearance from the University Research Ethics Board.

2.2. Apparatus

Force data were collected using a digital pinch/grip dynamometer with an integrated force multi analyzer (MIE Medical Research Limited, Leeds, UK). Surface EMG were differentially amplified (gain = 1000–5000, input impedance = 10 GΩ s, 10–1000 Hz, CMRR = 115 dB at 60 Hz, Bortec, Octopus AMT-8, Calgary, AB, Canada) and A/D converted using a 12-bit card (National Instruments, Austin, TX). We sampled grip force and EMG at 2000 Hz using custom LabVIEW software (National Instruments, Austin, TX.).

2.3. Protocol

Participants began the experiment with a familiarization protocol using their non-dominant (left) hand. This process familiarized the participants to the visually targeted gripping task, without eliciting fatigue in the dominant hand. Participants performed two grip MVCs with their left hand using a handgrip dynamometer (MIE Medical Research Limited, Leeds, UK) and the average was used later to normalize the force profile we presented as feedback on the computer screen during the practice trial (Fig. 1). Participants then stood in front of the computer screen with their arms relaxed by their side while holding the dynamometer in their left hand. We presented the normalized profile on the screen, and they were instructed to, as accurately as possible, trace the profile as real-time grip force feedback appeared on the screen. The practice protocol consisted of 15-s plateaus of 15% MVC, then 30% MVC and then 45% MVC, presented in a random order, followed by a three-second maximum effort and three seconds of rest.

During the training and test session, participants held the handgrip dynamometer directly at their side, with the wrist in a neutral posture. There was a mark on the dynamometer where participants were instructed to put the webbing between their thumb and the index finger while gripping (Fig. 1). This ensured that the moment arm in the dynamometer was the same throughout all trials. While there was no brace to maintain wrist posture,

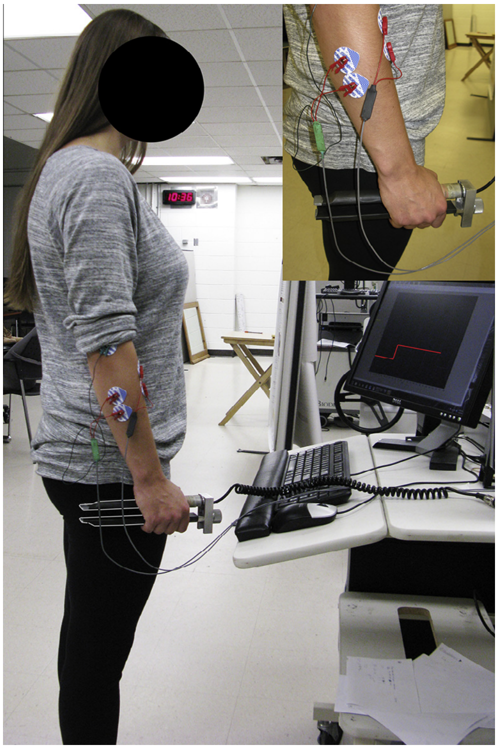

Fig. 1. Participants held the handgrip dynamometer at their side, with the wrist in a neutral posture. Participants were instructed to trace a template on a computer monitor by squeezing the dynamometer to match a red line with a grey template line. During the trial, the participants were instructed to keep the hand by the side, the arm close to the body, and the webbing of the thumb positioned on the dynamometer at the same place throughout the trial. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)