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Physical variation in low-load work – physiological effects during exposure & recovery

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Abstract. Trends in industry are leaning towards jobs that are more stereotyped at lower workloads. Physical variation is a potential ergonomic intervention. However, little is known of physiological response to different kinds of variation. To investigate this issue, three kinds of isometric contraction patterns with the same mean amplitude, cycle time, and duty cycle were compared. Fatigue responses were measured by multiple biomechanical and physiological approaches. In exercise, sustained and intermittent contractions with zero force had a greater number of statistically significant differences in fatigue responses. Intermittent contractions with amplitude ½ and 1½ of mean force had effects intermediate but close to the sustained contraction. In recovery, sustained contractions led to decreased twitch forces 24 hours post-exercise whereas both intermittent contractions recovered within 60 minutes. This suggests that time varying forces, even without complete muscular rest, may be a useful intervention to reduce local and perceived fatigue in workers performing low-load tasks.

Keywords: Physical variation, intermittent force, sedentary work, recovery, work physiology

1. Introduction

Current trends in industry are leaning towards specialized production systems, automation of work, and sedentary work tasks that are associated with low and less varying mechanical exposures. Previous research has focused on the reduction of high peak loads, which may not be feasible in low-load work [5,3].

A possible intervention to reduce local fatigue, and potentially musculoskeletal disorders, is physical variation [3]. Both field-based and controlled laboratory studies have provided insights into physical variation. Such studies are based on controlled repetition of periods of isometric contraction and rest. Although rest breaks alleviate fatigue, these protocols are not typical of exposure patterns and realistic interventions in occupational tasks [5]. It has been speculated that force variation, either an increase or decrease, may promote a motor control adaptation to reduce fatigue in low-threshold motor units during sustained contractions [7]. However, little is known of the physiological response to changing the kind of physical variation when compared to intermittent contractions with zero force periods [5,3].

Additionally, in order to better understand the effects of physical variation, there is a need to investigate its recovery and restorative processes following exposure [6]. This is particularly important, as these processes may have large implications in injury progression. The purpose of this study was to explore the biophysical effects of varying force, during exercise and recovery of up to 24 hours post-exercise.

2. Methods

2.1. Participants and Experimental Conditions

Fifteen male participants [age 24.0 +/- 4.0 (SD) yr] were recruited from a university student popula-

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tion. Five conditions were investigated, all of which had a mean force of 15% Maximum Voluntary Force (MVF), a duty cycle of 50%, and cycle time of 6 seconds. However, for this paper, responses will be described for three of the conditions. Conditions were a sustained isometric elbow extension at 15% MVF (15%Sus), an intermittent elbow extension alternating between 0% and 30% MVF (0%-30%Int), an intermittent contraction alternating between ½ and 1½ times the mean force, i.e. 7.5% to 22.5% MVF (7.5%-22.5%Int).

2.2. Data Collection Protocol

Each condition consisted of two sessions. The first session consisted of 10 minutes baseline activity, 60 minutes of exercise or until exhaustion, and 60 minutes of recovery. The second session was a 24-hour follow-up. Electromyography (EMG), mechanomyography (MMG), blood velocity recordings, ratings of perceived exertion (RPE) were collected continuously while test batteries (Low frequency fatigue tetani, supramaximal twitch forces, test contraction at 15% MVF, and a MVF) were collected during baseline, exercise, and recovery at 15-minute intervals. Data was collected at 2048 Hz using NIAD Collection software (version 1.0.0.10, University of Waterloo, 2001) and processed using Chart 4.0 (ADInstruments, Colorado Springs, CO, US) and Matlab 7.12 (MathWorks Inc., Natick, Mass., USA) software.

2.3. Fatigue Modeling and Statistical Analysis

Measured parameters, collected continuously during exercise, were plotted against time and normalized to baseline (heart rate and RPE) or to the first 2-minute exercise interval (EMG and MMG).

Responses were then fitted with either linear or non-linear regression curves. Blood flow velocity was measured every 2 minutes using 30-second windows, normalized to baseline (100%), and averaged.

Conditions were compared by one-way repeated measures ANOVA using their rate of response (slopes). Dunnett's post-hoc test was used to compare 7.5%-22.5%Int with 15%Sus and 0%-30%Int. Alpha level was set at 0.05.

Test battery measurements were collected at 15-minute intervals during exercise and recovery. When comparing stimulated and maximum voluntary force values at 24 hours post exercise and at baseline, both were normalized to the pre-experiment maximum voluntary force contraction. Cessation and recovery were compared to baseline using one-way repeated measures ANOVA and Dunnett's post-hoc test.

3. Results

Of the 27 total response parameters during exercise, 19 parameters were significantly different between 15%Sus and 0%-30%Int. 7.5%-22.5%Int led to 8 measured responses that were significantly different from 0%-30%Int and 7 parameters that were statistically different from the 15%Sus condition.

In recovery (Table 1), 15%Sus led to a reduction in twitch force up to 24 hours post-exercise ($p = 0.023$) and a reduction in LFF ratio ($p = 0.023$) up to 30 minutes after exercise. 0%-30%Int led to a depressed LFF ratio at 15 ($p = 0.005$) and 30 ($p = 0.002$) minutes recovery and reduced MVF up to 15 minutes post-exercise ($p = 0.013$). Lastly, 7.5%-22.5%Int did not result in significantly different values beyond cessation in MVF, twitch, and LFF.

4. Discussion

One primary finding from this study was that mechanical exposure variation reduced the rate of fatigue development when compared to the 15%Sus isometric condition. The 0%-30%Int contractions had a significantly slower rate of fatigue response than the 15%Sus contraction. The 7.5%-22.5%Int condition resulted in similar number of responses that were significantly different from 15%Sus (slower rate of fatigue development) and from 0%-30%Int. The greater number of large and statistically significant differences between the sustained (i.e. 15%Sus) and intermittent contractions with zero force (i.e. 0%-30%Int) suggests that these two contraction types belong at opposite ends of a spectrum of physiologic responses associated with time-varying isometric contractions. 7.5%-22.5%Int had effects closer to 15%Sus. The fact that 7.5%-22.5%Int led to reduced fatigue responses suggests that rest *per se* may not be critical to reduce the development of fatigue.

Since conditions were not continued until exhaustion – being terminated at 60 minutes – a direct comparison of recoveries between exercise protocols was not possible. Nevertheless, describing the recovery response for each condition may help characterize its long-term effects. For instance, based on electrically evoked twitch force response, in both 15%Sus and 0%-30%Int conditions, force potential decreased at the conclusion of exercise with a substantial rate of decrease in the sustained isometric condition. This is similar to previous findings who found a decrease in peak twitch force stimulation up to 150 minutes after a 10% MVC isometric wrist extension [2] and up to 60 minutes after an isometric elbow flexion at 15% MVC [4]. The 0%-30%Int condition, on the other hand, revealed a depressed peak twitch force after 15 minutes of recovery, but not significantly different from baseline. This may suggest that the 15%Sus leads to both a quick rate of decreased force production and sustained depression during recovery, mostly attributed to an impairment of the excitation-contraction coupling [2]. In keeping with this, studies have shown a decrease in twitch force to 16.9% of the initial twitch contraction, 15 minutes into recovery, after exposure to 20 minutes of intermittent maximal contractions [1]. Based on the lack of changes in electrically evoked twitch forces but a decline in MVF, 7.5%-22.5%Int may have resulted in fatigue that can be better explained by processes within the CNS. The development of both central and peripheral fatigue may be dependent on the quantity of variation of an intermittent contraction.

This research showed that common recommendations of increasing physical variation reduced fatigue rate and that the magnitude and shape of the intermittent force variations affected both exercise and recovery. Recovery measures reveal fatigue effects, up to 24 hours post exercise, after a sustained isometric contraction. Physical variation also led to significantly different measurement values after exercise but typically recovered to baseline within 60 minutes.

5. Conclusion

A question in the current literature on exposure and musculoskeletal disorders and fatigue in occupational settings is the effects of mechanical exposure variation. This study suggests that time varying forces, even without complete muscle rest, may be a useful ergonomic intervention to reduce local and perceived fatigue in workers performing low-load tasks.

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