The Effects of Isokinetic Fatigue on Recovery of Maximal Isokinetic Concentric and Eccentric Strength in Women

Holly M. Bilcheck¹, William J. Kraemer², Carl M. Maresh³, and Michael A. Zito²

¹Human Performance Laboratory, Department of Sport, Leisure and Exercise Sciences, and ²School of Physical Therapy, University of Connecticut, Storrs, Connecticut 06269; ³Center for Sports Medicine, The Pennsylvania State University, University Park, Pennsylvania 16802.

Reference Data

ABSTRACT

This investigation examined the effects of different types of isokinetic eccentric and concentric exercise on subsequent isokinetic maximal concentric and eccentric muscle strength performances at 30°·s⁻¹ and 120°·s⁻¹ during the acute 10-min recovery period. Tests were administered at 2.5, 5, and 10 minutes into recovery. Sixteen physically active women were randomly assigned to either a control group (n=6) or an experimental group (n=10). Each subject in the control group was asked to attend two testing sessions consisting of randomly assigned concentric and eccentric modes of testing without any fatigue tasks. A LIDO™ Active Isokinetic System was used for the fatigue tasks and for measuring concentric and eccentric peak torque values at 30°·s⁻¹ and 120°·s⁻¹ velocities of movement during the preexercise and following the fatigue task. Fatigue tasks (Concentric fatigue, Eccentric fatigue, and Concentric/Eccentric fatigue) consisted of each subject performing three sets of 30 repetitions at 120°·s⁻¹ with maximal effort. During the recovery period following the last set of repetitions, each subject was tested for concentric and eccentric strength at 30°·s⁻¹ and 120°·s⁻¹. Only with the concentric/eccentric fatigue task was there a significant decrease in concentric strength (30°·s⁻¹) observed 5 min postexercise. No other differences were observed during recovery following any of the fatigue tasks. The major finding is that concentric and eccentric muscle activity recovers quickly from an isokinetic fatigue task. From a practical perspective, exercise protocols can utilize shorter rest periods between sets without fear of compromising the force production and concentric and eccentric isokinetic testing protocols, or can utilize a rest period of 2.5 minutes and be assured that recovery has been completed.

Key Words: isokinetic strength, concentric, eccentric, fatigue, recovery, women

Introduction

To date, no studies have examined the differences in recovery patterns of maximal isokinetic concentric and eccentric muscle strength following isokinetic fatigue tasks. Isokinetic exercise describes dynamic movement at a constant velocity which is controlled by a dynamometer. Although the controlled movement of the dynamometer may be set at a constant velocity, this should not imply that the muscles producing force during movement are acting at a constant velocity. Regardless of the muscular force generated, the speed of movement is controlled so that it may not exceed the preset speed during isokinetic exercise.

Muscular fatigue has been defined as the failure to maintain a required or expected force (1, 6). Fatigue has also been thought of as a failure of normal physiological functions that produces reductions in maximum force generating capacity. Muscular fatigue occurs at maximal power outputs if attached cross-bridge formations in the force generation sites are decreased. Causes of fatigue have been attributed to central and peripheral inhibition, neuromuscular junction failure, and/or impaired excitation of the sarclemma (6). Fatigue also appears to be related to high rates of ATP turnover and neural stimulation, especially in the fast-twitch motor units. Voluntary maximal concentric and eccentric muscle action depends upon excitatory impulses from higher motor centers and a chain of events within the central nervous system including changes in spinal motor neuron excitability, excitation/contraction coupling, and the muscle sarclemma t-tubule system.

Isokinetic fatigue can be determined by quantifying the force production of a muscle group. Studies that have identified isokinetic fatigue have
been limited. Several studies (2, 5, 15) have operationally defined muscular fatigue as a 50% decline in production capabilities for a given muscle action. There are no definite conclusions as to whether muscular fatigue is of central or peripheral origin. Stephens and Taylor (14) suggested that neuromuscular junction fatigue is most important during the first minute of maximal voluntary contraction, but thereafter, contractile element fatigue increases. Insufficient oxygen supply, impaired blood flow, and ATP usage may also play a critical role in the development of fatigue mechanisms and may influence muscular recovery. The primary purpose of this investigation was to examine the effects of different types of isokinetic eccentric and concentric exercise on subsequent isokinetic concentric and eccentric muscle strength performances.

Methods

Subjects

Sixteen healthy women, ages 18 to 31, volunteered to participate in this investigation (see Table 1). None had any history of knee injury. The subjects were physically active but none were competitive lifters. An informed-consent document was signed by all subjects prior to testing. Each subject was instructed not to perform any exercise and to refrain from caffeine and alcohol ingestion for 24 hours prior to testing.

Experimental Design

All subjects were tested for concentric and eccentric isokinetic strength of their quadriceps in the dominant leg. To determine leg dominance, each subject was asked which leg she preferred to kick a ball with and which hand she used to write with.

Prior to testing, each subject was familiarized with the testing protocol and was allowed to practice on the equipment. Subjects were randomly assigned to either a control group (n=6) or an experimental group (n=10). Each subject in the control group was asked to attend two testing sessions consisting of randomly assigned concentric and eccentric modes of testing without any fatigue tasks. Each subject in the experimental group performed four randomly assigned test sessions. The fatigue tasks consisted of the following exercise activity combinations: Concentric fatigue, Eccentric fatigue, and Concentric/Eccentric fatigue. Subjects performed the specific fatigue task for three sets of 30 maximal muscle actions.

Instrumentation

A LIDO™ Active Isokinetic System (Loredan Biomedical, Inc., Davis, CA) was used for the fatigue tasks and for measuring concentric and eccentric peak torque values at 30° · s⁻¹ and 120° · s⁻¹ velocities of movement during the preexercise and postexercise periods. Concentric and Eccentric peak torque values at 30° · s⁻¹ and 120° · s⁻¹ were measured in the continuous passive motion operational mode. In this mode, the limb is moved back and forth at the specified test velocity, allowing a force to be exerted in either direction (isolated concentric or eccentric muscle actions).

The LIDO™ is designed with an electronic control actuator. Movement at the knee axis relative to the machine axis during isokinetic exercise is compensated by a sliding ankle attachment cuff that measures any change in the effective lever arm of the system. The reliability and validity of the LIDO™ Active System has been documented elsewhere (8, 9). This machine was calibrated in accordance with the manufacturer’s recommendations prior to testing.

Testing Protocol

Each subject was stabilized on the LIDO™ with the back fully supported in the sitting position. Chest, trunk, and thigh stabilization was employed to prevent excessive movement. The mechanical axis of rotation was aligned to the knee axis of rotation. The range of movement was 0°–90° for the quadriceps testing, where zero is defined as full extension. The investigator gave verbal encouragement to promote maximal performance from each subject during the testing session.

The isokinetic test protocol (Figures 1a and 1b) consisted of each subject performing four submaximal warm-up repetitions for each muscle action and velocity (30° · s⁻¹ and 120° · s⁻¹) followed by a 30-s rest period. The subject then performed three maximal efforts at each test velocity (30° · s⁻¹ and 120° · s⁻¹). A 30-s rest period was given between each velocity of speed tested. Following the maximal effort and a 2-min rest period, the subject performed a maximal effort fatigue task consisting of three sets of 30 repetitions at 120° · s⁻¹. A 1-min rest period was allowed between each set during the fatigue task. In this study, isokinetic fatigue was produced as the peak torque output declined.

Table 1

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<tr>
<th>Subject Characteristics</th>
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<tr>
<td>Age (yrs)</td>
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<tr>
<td>Control group (n = 6)</td>
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<td>Experimental group (n = 10)</td>
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over the performance of 30 repetitions in each set. A fatigue index was determined by dividing the peak torque values of the first three repetitions by the last three repetitions in which a decrement of 50% or greater was observed (Figures 2 and 3).

During the recovery period following the last set of repetitions, each subject was tested for concentric and eccentric strength at 30° · s⁻¹ and at 120° · s⁻¹ at three time intervals following the fatigue task. Tests were administered at 2.5, 5, and 10 minutes into recovery. Order of testing for the two velocities and muscle activity modes were randomized among subjects, with at least 4 days rest between testing sessions. Peak torque values were determined for each test velocity and each mode of muscle action. Peak torque was defined as the highest torque value obtained over the three trials as determined by the computerized output of torque curve for each subject.

**Statistical Analysis**

Statistical evaluation of the data was measured using a two-way analysis of variance with repeated measures (two movement velocities over four measurement points: preexercise and three recovery time-points for one tested muscle action). Statistical significance for this study was chosen at the p<0.05. Subsequent Tukey post-hoc analyses were used to determine pairwise differences when appropriate. If a significant change was observed in recovery, a multivariate ANOVA and Tukey tests were used to determine whether there were significant intertest differences between cells with the corresponding time-point and muscle action comparison.
Results

Figures 4 through 9 demonstrate that peak torque values at $30^\circ \cdot s^{-1}$ were greater than $120^\circ \cdot s^{-1}$ during the pretest and at each recovery time-point in the control group and the experimental group. Eccentric peak torque values at $30^\circ \cdot s^{-1}$ and $120^\circ \cdot s^{-1}$ were consistently greater than concentric peak torque values during the pretest and at each recovery time-point regardless of the fatigue task.

Figure 4 demonstrates concentric peak torque values determined at the pretest and recovery time-points at $30^\circ \cdot s^{-1}$ for the control group. No significant differences were observed during the pretest as compared to recovery time. Concentric peak torque values at $120^\circ \cdot s^{-1}$ also demonstrated no significant differences. Figure 5 demonstrates eccentric peak torque values determined at the pretest and during recovery time-points at $30^\circ \cdot s^{-1}$ and $120^\circ \cdot s^{-1}$ in the control group. No significant differences were observed over time.

Figure 6 demonstrates the eccentric peak torque value during the preexercise in response to the Eccentric fatigue task (three sets of 30 maximal repetitions at $120^\circ \cdot s^{-1}$) and during the recovery period. There were no significant differences in eccentric peak torque values across recovery time-points as compared to preexercise values. Peak torque values in response to the eccentric fatigue task at $120^\circ \cdot s^{-1}$ (Figure 6) also showed no significant differences across the recovery time-points as compared to preexercise values. Figure 7 demonstrates concentric peak torque values preexercise and after the Concentric fatigue task. There were no significant differences in concentric peak torque values across time-points. Likewise, no significant differences in concentric peak torque values at $120^\circ \cdot s^{-1}$ were observed across time-points as compared to pretest values.

Figure 8 demonstrates eccentric peak torque values during preexercise and in response to a Concentric/Eccentric fatigue task. There were no significant differences across time-points as compared to preexercise values. Similarly, no
significant differences in eccentric peak torque values at $30^\circ \cdot \sec^{-1}$ and $120^\circ \cdot \sec^{-1}$ across time-points were found as compared to preexercise values. Figure 9 demonstrates concentric peak torque values during the preexercise and in response to a Concentric/Eccentric fatigue task. Concentric peak torque values at $30^\circ \cdot \sec^{-1}$ were significantly lower ($p<0.05$) at the 5-min recovery time-point (75.0 ± 2.47). No other significant differences were determined at 2.5-min (79.8 ± 16.84) and 10-min (82.5 ± 12.54) recovery time-points. Figure 9 also demonstrates concentric peak torque values during preexercise and in recovery following a Concentric/Eccentric fatigue task at $120^\circ \cdot \sec^{-1}$. No significant differences were observed over time.

**Discussion**

The most significant finding of this study is that recovery of isokinetic concentric and eccentric peak torque values of the quadriceps muscle following various isokinetic muscular fatigue tasks is quite rapid. To date, this is the only study to have examined the recovery responses of concentric and eccentric muscle activity to various isokinetic fatigue protocols. The data from this investigation suggest that the nature of isokinetic fatigue may be quite different from other maximal exercise fatigue tasks, as recovery is generally achieved in a short period of time. The residual fatigue observed in this study after the Concentric/Eccentric fatigue task appears to indicate a need for both muscle actions in the fatigue stimulus. If the phenomenon of recovery from muscular exercise is related to muscle tissue disruption, few acute changes in protein arrangement appear probable. Therefore the cellular nature of isokinetic fatigue needs to be examined more closely.

In the present study, there were no significant differences in isokinetic eccentric peak torque values from preexercise to postexercise time-points (2.5, 5, 10 minutes) following various isokinetic fatigue tasks. In examining concentric peak torque values during recovery, the only significant difference in the concentric peak torque values occurred following the Concentric/Eccentric fatigue task. At the 5-min recovery time-point a significant decrement was observed. Still, this could be a random effect.

In contrast to the present study, Newham et al. (12) observed that maximal voluntary force of the quadriceps did not recover to preexercise values until 24 hours following fatiguing concentric and eccentric exercise. Likewise, Clarkson and Trembley (4) observed evidence of exercise-induced muscle damage, muscle soreness, and slow
recovery of force production following maximal eccentric exercise of the elbow flexors. Both studies utilized dynamic types of fatigue, and such changes need to be determined in regard to isokinetic activity. Furthermore, female subjects unaccustomed to exercise participated in those studies whereas the female subjects in this study were classified as physically active, which may have contributed to differences.

One possible explanation for the findings of this study is that significant disruption of the contractile unit or connective tissue associated with repetitive, high-intensity concentric and eccentric exercise did not occur. Therefore, profound changes in the muscle’s ability to produce force was not observed. Interestingly, although perceived muscle soreness was not specifically measured in this study, only two subjects reported muscular pain 24 to 48 hours following maximal effort eccentric exercise.

Although recovery following isokinetic fatigue was not specifically investigated, previous studies using isokinetic fatigue protocols have shown reductions in isokinetic concentric and eccentric strength (5). Sinacore et al. (13) recorded peak torque values following a 1-min bout of repeated maximal knee extensions and determined the rate of recovery at 30-second intervals.

Test-retest reliability until 2.5 minutes was high. A high negative correlation was also found between rate of recovery at 30° · s⁻¹ and endurance capacity (VO₂max). However, the design of Sinacore’s study focused on only one movement velocity and did not differentiate between concentric and eccentric muscle activity.

There are many factors to consider when evaluating maximal force-generating capacity and the development of neuromuscular fatigue in skeletal muscles. Muscular fatigue during the exercise is related to the specific demands of the exercise, type of muscle action, velocity of movement, number of motor units activated, their frequency of activation, and motivational factors. Although isokinetic fatigue during exercise occurs, such mechanisms do not appear to remain operational into recovery.

Merton (10) observed that the force output of maximal voluntary muscle actions of the adductor pollicus muscle was reduced by more than 50% after 1 to 3 minutes of stimulation following an isometric fatigue task. The force loss was attributed to the failure of the muscular contractile system. Other studies (3) have confirmed the observation that loss of force was not due to failure of the neuromuscular transmission or to reduction in central motor drive. The results of the present
study indicate that neither peripheral nor central mechanisms mediate any delay in recovery processes after isokinetic fatigue.

One possible explanation for the lack of depressed force production over a longer period of time is that, following sustained maximal muscle activity during the fatigue task, the central nervous system may have maintained full muscle activation. The decline in force production during exercise due to failure or impairment of the muscular contractile system was not capable of producing long-lasting fatigue. This was demonstrated by the full recovery of maximal voluntary effort generally within 2.5 minutes after exercise.

Other studies investigating low frequency fatigue indicate longer recovery periods in response to maximal force development and supramaximal tetanic nerve stimulation (7). The causative factors in the development of low frequency fatigue suggest impaired excitation/contraction coupling, whereby less calcium is released for each action potential with fewer cross-bridges contributing to force development. Such cellular mechanisms do not appear operational consequent to isokinetic exercise as used in this investigation.

During maximal voluntary muscle actions, motor units are provided with firing rates that are compatible with their contractile properties. It appears that the central nervous system is able to control the maximum force production and decrease the risk of propagation failure. Results of this study suggest that changes in the velocities of movement (30° · s⁻¹ to 120° · s⁻¹) did not significantly activate or maintain neural fatigue mechanism(s) into recovery.

Miller et al. (11) used nuclear magnetic resonance spectroscopy (NMR) to study muscle fatigue directly caused by changes in phosphocreatine (PCr), ATP, inorganic phosphate (Pi), and intracellular pH. They concluded that there are three components to fatigue: altered M-wave reflecting impaired muscle membrane excitation, loss of maximal voluntary muscle action with decreased PCr and pH, and a decrease in neuromuscular efficiency. After 10 minutes of recovery, alterations in M-wave fully recovered and maximal voluntary isometric activity was 83% of control values. The major conclusion drawn from that study was that during fatigue, changes in force, pH, and high-energy phosphates are closely related. It appears that the contribution of muscle membrane alteration to isokinetic fatigue into recovery differs from isometric fatigue mechanisms. The data from the present study suggest the rapid normalization of membrane function, restoration of high-energy phosphates and pH, restoration of maximal force, and normalization of the excitation/contraction coupling process.

Although this study investigated both concentric and eccentric muscle activity without examining ultrastructural components, it appears there is little overall difference in the behavior of recovery under similar exercise intensities. Lack of a significant fatigue response with concentric or eccentric activity may be specific to the intensity of exercise, type of fatigue task, modality of exercise, amount of protein disruption, and relative metabolic cost of the activity. The nature of isokinetic fatigue mechanisms remains speculative. Further study is needed to better characterize the mechanism(s) that mediate such rapid recovery in force production capabilities. Research should focus on the physiological responses to isokinetic concentric and eccentric muscle activity and the relative effects of fatigue on connective tissue and contractile elements of the muscle. It remains to be determined exactly where the threshold is for total work in isokinetic exercise to produce fatigue that results in long-term recovery decrements in force production.

Practical Applications
This study examined the response of peak torque values of concentric and eccentric muscle activity following various isokinetic fatigue tasks. The significant finding is that concentric and eccentric muscle activity recovers quickly (typically within 2.5 minutes) from an isokinetic fatigue task at 30° · s⁻¹ and 120° · s⁻¹. Therefore, exercise protocols can utilize shorter rest periods between sets without fear of compromising the force production. Furthermore, concentric and eccentric isokinetic testing protocols for athletes can utilize rest periods of 2.5 minutes and be assured that recovery has been completed. In physically active individuals, isokinetic eccentric and concentric fatigue tasks have little effect on force production capabilities into recovery.

References
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Author Note
We would like to thank a dedicated group of subjects. The current address for Holly Bilcheck is Temple Physical Therapy, 230 George Street, New Haven, CT 06510.