High- vs. Low-Intensity Fatiguing Eccentric Exercise on Muscle Thickness, Strength, and Blood Flow

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Abstract

Hill, EC, Housh, TJ, Smith, CM, Keller, JL, Schmidt, RJ, and Johnson, GO. High- vs. low-intensity fatiguing eccentric exercise on muscle thickness, strength, and blood flow. *J Strength Cond Res* XX(X): 000–000, 2018—The purpose of this investigation was to examine the acute effects of equal volumes of fatiguing high- vs. low-intensity eccentric muscle actions on changes in muscle thickness, echo intensity, muscle blood flow, and adipose thickness. Eighteen men (mean $\pm$ $SD = 23.2 \pm 3.0$ years) performed eccentric peak torque (PT) and maximal voluntary isometric contraction (MVIC) trials before (pretest), immediately after (posttest), and 5 minutes after (recovery) performing randomly ordered fatiguing eccentric, isokinetic ($180^\circ \cdot s^{-1}$) muscle actions of the elbow flexors at 40% (72 repetitions) or 80% (36 repetitions) of eccentric PT. Muscle thickness, exercise-induced edema, muscle blood flow, and adipose thickness were also assessed via ultrasound at pretest, posttest, and recovery. There were no intensity-specific effects on the patterns of responses for eccentric PT, MVIC, muscle thickness, echo intensity, muscle blood flow, or adipose thickness. There were, however, effects across time that decreased from pretest to posttest and from pretest to recovery for eccentric PT (21.5 and 13.0%), MVIC (14.6 and 5.8%), and adipose thickness (10.0 and 6.0%), but increased for muscle thickness (7.6 and 5.9%), echo intensity (13.7 and 9.9%), and muscle blood flow (129.6 and 90.1%) (collapsed across 40 and 80%). These findings indicated that when matched for exercise volume, there were no intensity-related effects on the increases in muscle thickness, echo intensity, muscle blood flow, or the decreases in eccentric PT, MVIC, and adipose thickness after fatiguing eccentric muscle actions. Therefore, exercise volume, independent of exercise intensity and number of repetitions, may be a mediating factor of muscle fatigue and performance during eccentric muscle actions.

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Introduction

The importance of muscle swelling as a potential precursor to or indicator of muscle hypertrophy has been highlighted in recent investigations (3,10,25–27). It has been suggested that acute exercise-induced muscle swelling as assessed by the measurement of muscle thickness is associated with interstitial fluid shifts, which simulates the mTOR pathway via an intrinsic volume sensor (3,18,25,26). Muscle thickness measurements have also been used to quantify the hypertrophic effects of resistance training programs (3,18,25,26). Therefore, changes in muscle thickness may reflect the onset of hypertrophic processes after acute exercise bouts and the increases in muscle size that follow chronic resistance training (13,15).

Early changes (1 week) in muscle thickness as a result of resistance training are not always indicative of muscle hypertrophy and may reflect exercise-induced edema from muscle damage (3,15). Thus, describing the time course of early-onset muscle hypertrophy as a result of changes in muscle thickness is difficult (14,15), but changes in muscle thickness because of exercise-induced edema are quantifiable (3). For example, after an initial bout of resistance training in naive subjects, muscle thickness increased from baseline and remained elevated in 7 subsequent training visits performed over an 8-day period, but was not further increased by the additional training sessions (3). Thus, it has been hypothesized that further increases in muscle thickness after initial changes from baseline likely reflected training-induced increases in muscle hypertrophy (3,15).

To quantify changes in muscle thickness from muscle hypertrophy and not exercise-induced edema, Damas et al. (13) suggested simultaneous measurements of muscle thickness and exercise-induced edema via echo intensity from ultrasound. Specifically, increases in intramuscular water content from exercise-induced edema are proportional to the increases in echo intensity (13,14). Therefore, previous investigations (13,14) have attributed acute increases in muscle thickness and echo intensity to exercise-induced edema. It is plausible, however, that similar to the effects of intramuscular water content, changes in echo intensity may also be a function of exercise-induced increases in muscle blood flow, although no previous investigation has examined this relationship. Specifically, muscle blood flow increases after exercise and is proportionally related to exercise intensity and duration (4). Echo intensity, however, is not able to delineate between muscle blood flow and exercise-induced edema, therefore, these measurements should be taken separately when describing the influence of exercise-induced edema (as assessed by echo intensity) on changes in muscle thickness. Thus, it is possible that acute changes in muscle thickness and echo intensity may be due to both exercise-induced edema and muscle blood flow.

This investigation sought to examine changes in muscle thickness, echo intensity, and muscle blood flow as a result of acute eccentric exercise. It has been demonstrated (19,21,23,35) that eccentric muscle actions are important stimuli for muscle hypertrophy, but it has not been determined whether the magnitudes of muscle swelling associated with eccentric muscle actions would be dependent on the exercise intensity. Specifically, when matched for volume, would high- or low-intensity fatiguing eccentric exercise elicit greater increases in muscle swelling as indicated by changes in muscle thickness, echo intensity, and muscle blood flow? These findings would have implications to demarcate the intensity of eccentric exercise that may elicit the greatest changes in muscle hypertrophy as indicated by the early changes in muscle swelling.

This investigation also sought to determine if there would there be intensity-dependent decreases in performance as indicated by changes in maximal voluntary isometric contraction (MVIC) and eccentric peak torque (PT) and if the changes in muscle thickness and echo intensity could be explained by changes in muscle blood flow. It is also possible, however, that increases in exercise-induced edema or muscle blood flow may increase intramuscular fluid content and cause a compression of the adipose tissue layer. The resultant increases in muscle thickness, therefore, may reflect increases in exercise-induced edema and muscle blood flow that cause a reduction in the adipose tissue layer. Therefore, the purpose of this investigation was to examine the acute effects of equal volumes of fatiguing high- vs. low-intensity eccentric muscle actions on changes in muscle thickness, echo intensity, muscle blood flow, and adipose thickness. Based on previous investigations (4,13,14,16,37) that have examined acute changes in muscle thickness and muscle blood flow, we hypothesized that muscle thickness and muscle blood flow would increase to a greater extent as a result of the 40 vs. 80% intensity eccentric exercise. In addition, we hypothesized (13,14) that the increases in muscle thickness would be related to the changes in echo intensity and muscle blood flow and echo intensity would be related to muscle blood flow.

Methods

Experimental Approach to the Problem

The present study examined the effects of high- vs. low-intensity fatiguing eccentric exercise on eccentric PT, MVIC, muscle thickness, exercise-induced edema, muscle blood flow, and adipose thickness. In addition, the present study examined the contributions of exercise-induced edema and muscle blood flow as they relate to changes in muscle and adipose thickness. After a familiarization visit, the subjects performed eccentric PT and MVIC trials before (pretest), immediately after (posttest), and 5 minutes after (recovery,) performing randomly ordered fatiguing eccentric, isokinetic ($180^\circ \cdot s^{-1}$) muscle actions of the elbow flexors at 40 or 80% of eccentric PT (equated for total work). Muscle thickness, exercise-induced edema, muscle blood flow, and adipose thickness were also assessed at pretest, posttest, and recovery. In addition, a Pearson correlation matrix was used to examine the pretest to posttest and pretest to recovery changes in eccentric PT, MVIC, muscle thickness, exercise-induced edema, muscle blood flow, and adipose thickness.

Subjects

Twenty men volunteered to participate in this investigation, but 2 of the men withdrew from the study because of time considerations. Thus, the data from 18 men ($n = 18$; mean age $\pm$ $SD = 23.2 \pm 3.0$ years [age range: 19–28 years old]; body mass $= 85.4 \pm 12.1$ kg; height $= 179.6 \pm 8.2$ cm; resistance training $= 6.9 \pm 2.8$ $hr \cdot wk^{-1}$) were used for subsequent analyses. The subjects had no known cardiovascular, pulmonary, metabolic, muscular, or coronary heart disease, or regularly used prescription medication. In addition, at the time of testing, all subjects had been actively participating in resistance training for at least the past 6 months. The subjects visited the laboratory on 3 occasions separated by at least 72 hours within a 1-month period and performed the testing procedures at the same time of the day. Subjects were instructed to avoid performing upper body exercise 48 hours before the testing visit, and subjects were rescheduled if they were currently experiencing any muscle soreness (score of 2 or greater on a 10-point scale) as determined by a visual analog scale (28). The study was approved by the University of Nebraska Lincoln's Institutional Review Board for Human Subjects, and all subjects completed a health history questionnaire and signed a written informed consent form before testing.

Procedures

Familiarization. The first laboratory visit consisted of an orientation session to familiarize the subjects with the testing protocols. During the orientation, the subjects performed submaximal and maximal isometric muscle actions, as well as submaximal and maximal eccentric isokinetic muscle actions of the elbow flexors at a velocity of $180°\cdot s^{-1}$. To familiarize the subjects with the fatiguing protocols, the subjects practiced performing submaximal eccentric isokinetic muscle actions at a velocity of $180°\cdot s^{-1}$ at intensities that corresponded to 40 and 80% of their eccentric PT, which was visually tracked using real-time torque displayed on a computer monitor programmed using LabVIEW 13.0 software (National Instruments, Austin, TX, USA).

Determination of Eccentric Peak Torque and MVIC. During testing visits 1 and 2, the subjects performed a warm-up consisting of 3 sets of 10 repetitions of eccentric-concentric muscle actions of the dominant (based on throwing preference) elbow flexors with a 1-minute rest between sets. Each repetition was performed at a velocity of $180°\cdot s^{-1}$ on the calibrated isokinetic dynamometer at approximately 50% effort. After the warm-up, the subjects rested for 5 minutes and then randomly performed 2 pretest eccentric PT and 2 MVIC trials. The eccentric muscle actions were performed through a 90° range of motion (90-0° of elbow flexion, where 0° corresponds to full extension at the elbow), and the MVIC muscle actions were performed for 3 seconds at a joint angle of 45°. Using the same procedures as the pretest trials, eccentric PT and MVIC trials were also performed immediately after (posttest) and 5 minutes after (recovery) completing the fatiguing protocol.

Fatiguing Protocols at 40 and 80% of Eccentric Peak Torque. After the determination of the pretest eccentric PT and MVIC, the subjects randomly (on separate visits) performed a fatiguing eccentric protocol at either 40 or 80% of their pretest eccentric PT at a velocity of $180°\cdot s^{-1}$. Real-time torque was displayed on a computer monitor, and each eccentric contraction was followed by a passive concentric muscle action that was assisted by the investigator. To control for exercise volume, the subjects performed 72 consecutive repetitions during the 40% fatiguing protocol and 36 consecutive repetitions during the 80% protocol.

Ultrasound Measurements. Muscle blood flow, echo intensity, muscle thickness, and adipose thickness were assessed via ultrasound before (pretest), immediately after (posttest; 57 ± 8 seconds), and 5 minutes after completing the fatiguing protocol (recovery; 298 ± 3 seconds). Ultrasound images of the dominant elbow flexors were obtained using the brightness mode (B-mode), and blood flow was assessed from the brachial artery proximal to the antecubital fossa (9) obtained using an ultrasound imaging device (GE Logiq e, USA) and a multi-frequency linear-array probe (12L-Rs; 5–13 MHz; 38.4 mm field-of-view). All ultrasound measurements were performed at an imaging or repetition frequency of 10 MHz and a gain of 58 dB. Muscle thickness was determined as the distance from the adipose tissue-muscle interface to the muscle-bone interface (24). Adipose thickness was determined as the distance from the surface of the skin to the adipose tissue–muscle interface (2). Muscle thickness, echo intensity, and adipose thickness were all assessed at 66% of the distance from the medial acromion of the scapula to the fossa cubit (1). Echo intensity, as assessed by grayscale analysis (0 arbitrary units [AU] corresponds to black image and 255 AU corresponds to white image), was performed using the histogram function and was determined from the same region of interest as muscle thickness. Ultrasound images were analyzed using ImageJ software (Version 1.47v.; National Institutes of Health, Bethesda, MD, USA), and before all analyses, images were scaled from pixels to centimeters using the straight-line function in ImageJ. All blood flow measurements were assessed at an insonation angle of 60° to the brachial artery collected over a period of 3 cardiac cycles (32,33) using Pulsed Wave Doppler and derived from arterial cross-sectional area and time averaged flow velocity based on previous recommendations (16). All measurements were taken while the subjects were lying in the supine position on the isokinetic dynamometer, with both their arms and legs supported. Care was taken to ensure that consistent, minimal pressure was applied with the probe to limit compression of the artery. To enhance acoustic coupling and reduce near-field artifacts, a generous amount of water-soluble transmission gel was applied to the skin before each measurement.

Data Analysis and Reliability. Test-retest reliability for pretest eccentric PT, MVIC, muscle thickness, echo intensity, muscle blood flow, and adipose thickness was assessed from testing visit 1 and testing visit 2. Repeated-measures analysis of variances (ANOVAs) were used to assess systematic error, and model 2,k (36) was used to calculate intraclass correlation coefficients (ICCs) and *SEM*s (38). The 95% confidence intervals for the mean values of the dependent variables were calculated with the studentized *t*-distribution.

Statistical Analyses

Separate 2 (Intensity [40, 80%]) × 3 (Time [pretest, posttest, recovery]) repeated-measures ANOVAs were used to analyze the eccentric PT, MVIC, muscle blood flow, echo intensity, muscle thickness, and adipose thickness values as a result of 40 and 80% fatiguing protocols. Significant interactions were decomposed with follow-up repeated-measures ANOVAs and Bonferonni-corrected dependent samples *t*-tests. Greenhouse-Geisser corrections were applied when sphericity was not met according to Mauchly's Test of Sphericity and partial eta squared effect sizes (η_p^2) were calculated for each ANOVA. In addition, a Pearson correlation matrix was determined from the change scores (pretest to posttest and pretest to recovery) for eccentric PT, MVIC, muscle blood flow, echo intensity, muscle thickness, and adipose thickness for the 40% protocol, 80% protocol, and combined 40 and 80% protocol. All statistical analyses were performed using IBM SPSS v. 21 (Armonk, NY, USA), and an alpha level of $p \leq 0.05$ considered statistically significant for all comparisons.

Table 1. Intraclass correlation coefficients (ICCs), *SEM*, mean values of visits 1 and 2, and analysis of variance *p* value of systematic error for all measured variables.*†

Variables	ICC	*SEM* (%)	Mean visit 1	Mean visit 2	*p*
MVIC (Nm)	0.982	5.0	61.0	59.8	0.310
Eccentric peak torque (Nm)	0.969	3.7	73.3	72.1	0.249
Muscle thickness (cm)	0.934	5.5	3.82	3.87	0.571
Echo intensity (AU)	0.823	5.7	112.7	111.8	0.978
Blood flow ($mL \cdot min^{-1}$)	0.866	13.3	185.4	173.5	0.180
Adipose thickness (cm)	0.935	8.0	0.251	0.248	0.681

*MVIC, maximal voluntary isometric contraction.
†There were no significant ($p > 0.05$) mean differences for visit 1 vs. visit 2 for any of the variables. All measurements were performed at baseline before the warm-up and fatigue protocol.

Results

Reliability

Table 1 includes the ICC, *SEM*, mean of visits 1 and 2, as well as the *p* value for systematic error. There were no mean differences for visit 1 vs. visit 2 ($p > 0.05$) for any of the variables. The ICC values ranged from 0.823 to 0.982, and the *SEM* ranged from 5.0 to 13.3% of the grand mean. There was no difference ($p = 0.655$) in exercise volume for the 40% (2,080.8 ± 544.3 Nm) vs. 80% (2,107.2 ± 643.9 Nm) protocols.

Performance Changes in MVIC and Eccentric PT

There was no significant ($p = 0.471$, $\eta_p^2 = 0.057$) Intensity × Time interaction, but there was a significant main effect for time ($p < 0.001$, $\eta_p^2 = 0.670$). Specifically, MVIC decreased from pretest to posttest and partially returned to pretest levels at recovery (Figure 1 and Table 2). Thus, the 40 and 80% protocols induced similar decreases in MVIC that were still partially reduced at recovery (pretest > recovery > posttest).

There was a significant ($p < 0.001$, $\eta_p^2 = 0.645$) Intensity × Time interaction for eccentric PT. Follow-up analyses indicated that there were significant decreases in eccentric PT from pretest to posttest that partially returned to pretest levels at recovery as a result of both the 40% ($p < 0.001$, $\eta_p^2 = 0.669$) and 80% ($p < 0.001$, $\eta_p^2 = 0.639$) protocols. In addition, there were no significant ($p > 0.05$) differences in

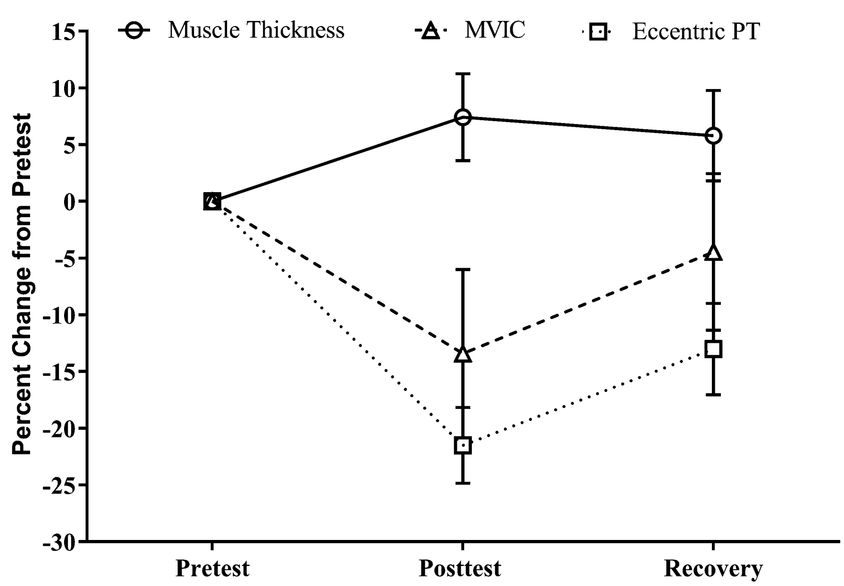

Figure 1. Pretest, posttest, and recovery responses for muscle thickness, maximal voluntary isometric contraction (MVIC), and eccentric peak torque (PT) collapsed across the 40 and 80% fatiguing eccentric protocols. There were significant ($p < 0.05$) increases in muscle thickness (collapsed across the 40 and 80% protocols) that were still partially elevated at recovery. In addition, there were significant ($p < 0.05$) decreases in MVIC and eccentric PT (collapsed across the 40 and 80% protocols) that were still partially reduced at recovery. See Results section for a description of overall and follow-up analyses.

Table 2. Means values (*SD*) for maximal voluntary isometric contraction (MVIC), eccentric peak torque (PT), muscle thickness, echo intensity, blood flow, and adipose thickness for the 40 and 80% protocols.*

	40% protocol			80% protocol		
Variables	Pretest	Posttest	Recovery	Pretest	Posttest	Recovery
MVIC (Nm)	61.3 ± 16.5	52.9 ± 17.0	58.0 ± 15.8	59.5 ± 16.2	50.3 ± 15.7	55.8 ± 16.8
Eccentric PT (Nm)	73.5 ± 10.4	56.2 ± 11.5	65.1 ± 12.4	71.9 ± 11.2	57.9 ± 8.0	61.4 ± 11.1
Muscle thickness (cm)	3.82 ± 0.63	4.17 ± 0.60	4.08 ± 0.66	3.86 ± 0.61	4.09 ± 0.62	4.05 ± 0.59
Echo intensity (AU)	112.7 ± 13.3	126.6 ± 11.3	125.3 ± 13.0	112.8 ± 11.1	129.9 ± 11.5	122.5 ± 12.1
Blood flow ($ml\cdot min^{-1}$)	188.6 ± 56.3	416.1 ± 185.3	361.1 ± 158.6	177.2 ± 46.3	423.9 ± 237.1	334.2 ± 126.3
Adipose thickness (cm)	0.25 ± 0.06	0.23 ± 0.06	0.24 ± 0.05	0.25 ± 0.06	0.22 ± 0.06	0.23 ± 0.06

*There were significant ($p < 0.05$) increases (collapsed across the 40 and 80% protocols) for muscle thickness, echo intensity and blood flow, but decreases for MVIC, eccentric PT, and adipose thickness. At recovery, muscle thickness, echo intensity, MVIC, and eccentric PT had partially returned to pretest levels, whereas blood flow and adipose thickness remained elevated and reduced, respectively. See Results section for a description of overall and follow-up analyses.

eccentric PT at pretest, posttest, or recovery between the 40 and 80% protocols. Thus, the 40 and 80% protocols induced similar decreases in eccentric PT that were still partially reduced at recovery (pretest > recovery > posttest).

Muscle Thickness

There was no significant ($p = 0.152$, $\eta_p^2 = 0.118$) Intensity × Time interaction, but there was a significant main effect for time ($p < 0.001$, $\eta_p^2 = 0.531$). Specifically, muscle thickness increased from pretest to posttest and partially returned to pretest levels at recovery (Figure 1 and Table 2). Thus, the 40 and 80% protocols induced similar increases in muscle thickness that were still partially elevated at recovery (posttest > recovery > pretest).

Adipose Thickness

There was no significant ($p = 0.698$, $\eta_p^2 = 0.024$) Intensity × Time interaction, but there was a significant main effect for time ($p = 0.002$, $\eta_p^2 = 0.345$). Specifically, adipose thickness decreased from pretest to posttest and remained reduced at recovery (Table 2). Thus, the 40 and 80% protocols induced similar decreases in adipose thickness that were still evident at recovery (pretest > posttest and recovery).

Echo Intensity

There was no significant ($p = 0.303$, $\eta_p^2 = 0.076$) Intensity × Time interaction, but there was a significant main effect for time ($p < 0.001$, $\eta_p^2 = 0.783$). Specifically, echo intensity increased from pretest to posttest and partially returned to pretest levels at recovery (Table 2). Thus, the 40 and 80% protocols induced similar increases in echo intensity that were still partially elevated at recovery (pretest < posttest and recovery).

Muscle Blood Flow

There was no significant ($p = 0.416$, $\eta_p^2 = 0.057$) Intensity × Time interaction, but there was a significant main effect for time ($p < 0.001$, $\eta_p^2 = 0.606$). Specifically, muscle blood flow increased from pretest to posttest and remained elevated at recovery (Table 2). Thus, the 40 and 80% protocols induced similar increases in muscle blood flow that were still evident at recovery (pretest < posttest and recovery).

Pearson Correlation Matrix

There were no significant correlations ($p = 0.082–0.926$, $r = -0.428$ to 0.447) between the change scores from pretest to posttest among any of the variables ($p > 0.05$). From pretest to recovery, however, echo intensity was inversely related to adipose thickness for the 40% ($p = 0.010$, $r = -0.622$), 80% ($p = 0.013$, $r = -0.604$), and combined 40 and 80% ($p < 0.001$, $r = -0.553$) protocols. That is, as adipose thickness decreased, echo intensity increased.

Discussion

There were no intensity-specific effects on the patterns of responses for muscle thickness, echo intensity, or muscle blood flow as a result of the fatiguing 40 or 80% protocols.

The pretest to posttest and pretest to recovery increases in muscle thickness (Figure 1) were consistent with the patterns of responses for echo intensity and muscle blood flow (Table 2), which also increased across these times points. In addition, the magnitudes of increases in muscle thickness and echo intensity were consistent with previous investigations (3,6–8,31). For example, Buckner et al. (3) reported increases in muscle thickness of approximately 0.3 cm at both posttest and at 5 minutes of recovery after a bout of dumbbell curls performed at 70% of 1 repetition maximum. Furthermore, previous investigations (6–8,31) have reported 7–25% increases in echo intensity immediately or 48 hr after performing 24–30 maximal eccentric muscle actions of the elbow flexors.

The similar increases in muscle blood flow as a result of both the 40 and 80% protocols in the present study (Table 2 and Figure 1), however, were not consistent with previous investigations (4,11,34,37). Postexercise increases in muscle blood flow have been attributed to partial or total vascular occlusion during the exercise bout that increases as a function of exercise intensity and plateaus at approximately 50% of MVIC during concentric and isometric muscle actions. In the present study, muscle blood flow increased similarly as a result of both the high- (80%) and low-intensity (40%) fatiguing eccentric protocols, which may reflect complete vascular occlusion at both intensities. For example, during isometric forearm flexion muscle actions, muscle blood flow is totally occluded at 50% of MVIC (22), and maximal eccentric force production is typically greater than that of isometric and concentric muscle actions (19). In the present study, eccentric PT was 21% greater ($p < 0.001$) than MVIC (Table 2), and there was no significant difference ($p > 0.05$) between 50% of MVIC (30.2 Nm) and 40% of eccentric PT (29.1 Nm). Therefore, it is possible that total blood flow occlusion occurred during both the 40 and 80% fatiguing protocols, which resulted in similar posttest and recovery muscle blood flow responses. Unlike isometric muscle actions, however, dynamic muscle actions exhibit varying forces across a range of motion (despite reaching target force during each repetition). Furthermore, postexercise increases in muscle blood flow are proportional to the time duration of vascular occlusion (4,11). Thus, it is likely that the 80% protocol resulted in a greater time duration of vascular occlusion across the range of motion compared with the 40% protocol where forces are lower throughout the range of motion. The present findings for the postexercise muscle blood flow responses, however, were not consistent with this hypothesis and may reflect mode-specific, time-dependent muscle blood flow responses during static vs. dynamic muscle actions.

Despite similar fatigue-related patterns of increases for muscle thickness, echo intensity, and muscle blood flow, there were no significant correlations among the change scores from pretest to posttest or pretest to recovery for these variables. In addition, the increases in muscle thickness were unrelated to adipose thickness, which decreased similarly from pretest to posttest and remained reduced at recovery as a result of both the 40 and 80% protocols (Table 2). The decreases in adipose thickness may have reflected a compression of the adipose tissue layer between the skin and muscle surfaces as a result of the increases in exercise-induced edema. For example, it is possible that the increases in exercise-induced edema increased the fluid content of the muscle (i.e., muscle swelling) and caused a compression of the adipose tissue layer. In support of this, there was a significant correlation between the decreases in adipose thickness and increases in echo intensity (exercise-induced edema) when measured at recovery, but not at posttest.

There were no differences between the high- and low-intensity protocols for the fatigue-induced decreases in MVIC torque or eccentric PT (Table 2 and Figure 1). Furthermore, at recovery, MVIC torque and eccentric PT had partially returned to pretest levels as a result of the 40 and 80% fatiguing protocols (Table 2 and Figure 1). These findings indicated that performing fatiguing eccentric exercise did not result in an intensity-related effect on torque, despite the differences in the total number of repetitions performed and, presumably, the time under tension, when exercise volume was similar. In addition, it is possible that similar fatigue-induced decreases in torque regardless of the mode or intensity were related to the effects of blood flow that may have been occluded similarly as a result of the 40 and 80% fatiguing protocols. The findings of the present study were consistent with the effects of fatiguing eccentric exercise on MVIC from previous studies (20,29,30). For example, for the forearm flexors, MVIC torque decreased by 20.8–50.1% after 24–150 eccentric muscle actions at 30–60$^\circ \cdot s^{-1}$ (29,30). For the leg extensors, Hill et al. (20) reported 8.9–17.9% decreases in MVIC torque as a result of fatiguing eccentric muscle actions performed at velocities of 60–180$^\circ \cdot s^{-1}$. The decreases in eccentric PT in the present study were also consistent with previous investigations (5,12,17) that reported 9.8–23.0% decreases in eccentric PT after 30–320 eccentric muscle actions at 30–60$^\circ \cdot s^{-1}$. Thus, in conjunction with previous findings (5,12,17,20,29,30), there were decreases in MVIC and eccentric PT as a result of fatiguing eccentric muscle actions performed at different velocities, intensities, and for various muscle groups.

The primary findings of the present study indicated that, when matched for exercise volume, there were no intensity-related effects on the increases in muscle thickness, echo intensity, muscle blood flow, or the decreases in MVIC, eccentric PT, and adipose thickness after fatiguing eccentric exercise. In addition, contrary to our hypothesis, there were no significant correlations between the pretest to posttest or pretest to recovery changes for muscle thickness, echo intensity, or muscle blood flow. The similar increases in muscle blood flow as a result of both the 40 and 80% protocols suggested that both exercise intensities may have been sufficient to elicit total vascular occlusion. In addition, both the 40 and 80% fatiguing protocols resulted in decreases in MVIC torque and eccentric PT that were still evident at 5-minute recovery.

Practical Applications

The findings of the present study indicated that both high- and low-intensity fatiguing eccentric exercise induced similar effects on muscle thickness, echo intensity, muscle blood flow, MVIC, eccentric PT, and adipose thickness when matched for exercise volume, but the time to recovery was different among these variables. Thus, when prescribing exercise for athletes or patients, coaches and practitioners should consider exercise volume separate from exercise intensity and the number of repetitions as a mediating factor of muscle fatigue and performance during eccentric muscle actions. Furthermore, coaches and practitioners should consider the length of rest when prescribing eccentric exercise as 5 minutes of recovery may not be sufficient to allow for performance or physiological measures to return to pretest levels.

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