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Concentric and Eccentric Muscle Fatigue of the Shoulder Rotators

Abstract

Previous research has demonstrated fatigue resistance for eccentric compared with concentric muscle contractions in the lower extremity. The purpose of this study was to determine if eccentric fatigue resistance was also evident in the internal and external rotators of the shoulder. Ten subjects performed three sets of 32 maximum isokinetic contractions in shoulder internal and external rotation at 120°/s. One arm performed eccentric contractions and the contralateral arm performed concentric contractions. Subjects were also tested for isometric strength prior to and immediately following the isokinetic contractions. Percent change in isokinetic torque (first five repetitions versus last five for each set) and isometric torque was compared between the arms performing eccentric and concentric contractions. Fatigue with isokinetic contractions was not different between eccentric and concentric internal rotation (25% vs. 26%, $p = 0.76$) and external rotation (24% vs. 32%, $p = 0.11$). Similarly, fatigue with isometric contractions was not different between eccentric and concentric internal rotation (11% vs. 5%. $p = 0.33$) and external rotation (15% vs. 7%, $p = 0.07$). These results indicate that unlike previously described fatigue resistance for eccentric muscle contractions in the quadriceps, dorsiflexors and plantarflexors, fatigue was not different between eccentric and concentric muscle contractions of the internal and external rotators of the shoulder.

Key words
Internal rotation · external rotation · isometric maximum voluntary contraction

Introduction

Strength loss can occur immediately following prolonged exercise involving eccentric, concentric or isometric contractions. This acute loss of force-generating capacity represents muscle fatigue [11,12]. Maximum eccentric contractions have been shown to be extremely fatigue-resistant despite high force production [12,25]. Hortobágyi et al. [12] demonstrated force decrements of 41% and 32% during 50 maximal isometric and concentric contractions of the plantar flexors, respectively, but found no change in force during 50 eccentric contractions. Similarly Tesch et al. [25] demonstrated 34 – 47% fatigue during 96 maximal concentric contractions of the knee extensors with no fatigue while performing the same number of maximal eccentric contractions. Pasquet et al. [21] investigated the fatigue effects on the dorsiflexors during concentric and eccentric contractions. While performing 5 sets of 30 maximum voluntary contractions at a constant speed, the concentric contractions had a loss of 31.6%, while the eccentric group only lost 23.8%.

The lack of fatigue during repeated eccentric contractions in the knee extensors [25] and plantar flexors [12] contrasts with other studies that followed subjects on subsequent days for evidence of muscle damage. Isometric strength loss has been demonstrated immediately following eccentric contractions of the elbow flexors [5 – 7,9,18 – 20,24] and knee extensors [2 – 4,14]. Eccentric and concentric isotonic strength loss has also been demonstrated immediately following eccentric contractions of the knee

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extensors [22]. Although these studies demonstrate that fatigue can be induced with eccentric contractions, there was no comparison to concentric fatigue.

In contrast to fatigue resistance in lower extremity muscle groups, Linnamo et al. [13] found that fatigue was not different between eccentric and concentric contractions of the elbow flexors. Force was decreased by 53% following 100 maximum eccentric contractions and by 50% following 100 maximum concentric contractions. It is not known if other upper extremity muscle groups also demonstrate similar fatigability between eccentric and concentric contractions.

Considering the emphasis on function of the internal and external rotators of the shoulder in training for sports, such as baseball, cricket, tennis, and volleyball [1,10,16,17,23,26], it is important to understand the functional capacity of these muscle groups. Differential fatigue with eccentric versus concentric contractions will affect the balance of muscle control during movements where one-muscle group functions as an accelerator (concentric contraction) while the antagonist functions as a decelerator (eccentric). Surprisingly, the difference in eccentric versus concentric fatigue has not been examined for the internal and external rotators of the shoulder. Therefore, the purpose of this study was to compare fatigue following eccentric versus concentric contractions of the internal and external rotators of the shoulder. Considering that several studies have demonstrated eccentric fatigue resistance in lower extremity muscle groups [12,21,25] and that only one study has shown no fatigue resistance in an upper extremity muscle group [13], it was hypothesized that the shoulder rotators would display eccentric fatigue resistance.

Materials and Methods

Subjects

Ten subjects (9 men, 1 woman) with no history of upper extremity injury within the past 2 years were recruited to participate in this study. The subjects mean age was 32.6 years old (range 25 – 44), all patients, except one, were right hand dominant. Institutional review board approved the procedures and subjects gave informed consent.

Procedures

Subjects reported to the research lab on two separate occasions, one week apart. One week prior to testing, each subject was familiarized with the isokinetic dynamometer (Biodex Multi-Joint System, Biodex Medical Systems Inc., Shirley, NY) set-up for internal and external rotation at 90° of abduction and 90° of elbow flexion (90/90 position) and performed a practice trial. The upper extremity (dominant or non-dominant) and order of the fatigue protocol (eccentric or concentric) were randomly selected for each subject. During the practice trial of 10 maximal repetitions at 120°/s, subjects performed the contraction type with the corresponding upper extremity (dominant and non-dominant) that they would be performing the fatiguing protocol during the test session.

One week after the familiarization session, subjects reported for testing. Subjects were given a 5 min warm-up on an upper body ergometer and were then seated at the isokinetic dynamometer in the upper extremity 90/90 position. Range of motion was set from 0° of internal rotation to 90° of external rotation. First, three maximal isometric external rotation contractions followed by three maximal isometric internal rotation contractions were performed at 45°. A 1-min rest separated all isometric contractions. Following the maximal isometric contractions, subjects began either the eccentric or concentric fatiguing protocol (order dependent on randomization). Both the eccentric and concentric protocols consisted of 3 sets of 32 repetitions [25] with a one-minute rest period between sets. Reciprocal contractions were performed in each contraction mode. A maximal internal rotation eccentric contraction was followed by a maximal external rotation eccentric contraction and vice versa. There was a one second delay at each end range of motion to allow the subject to prepare for the reciprocal movement. At completion of the fatiguing protocol, subjects repeated the three maximal isometric contractions for internal and external rotation at 45°. Subjects then repeated the testing protocol for the contralateral side utilizing the opposite contraction type.

The fatigue protocol replicated the protocol of Tesch et al. [25], (3 sets of 32 repetitions) but used a slower isokinetic speed (120° versus 180°/sec). Based on preliminary testing, it was determined that some subjects might be unable to reach peak torque during the isokinetic phase of the movement at 180°/sec.

Change in isokinetic torque was expressed as a percentage change in the torque for the first and last five repetitions of each set. The effect of contraction mode on fatigue was analyzed using a mode (eccentric versus concentric) by fatigue (contraction number – 1 – 5 vs. 26 – 32 vs. 33 – 37 vs. 60 – 64 vs. 65 – 69 vs. 92 – 96) repeated measures analysis of variance. Percent change in isometric torque (pre isokinetic contractions versus post isokinetic contractions) was analyzed using paired *t*-tests. Differences in pre-fatigue absolute strength between eccentric and concentric contraction modes were analyzed using paired *t*-tests.

Based on the within subject variability in eccentric and concentric fatigue reported by Linnamo et al. [13], and assuming similar variability for the within subject variability in the fatigue difference between eccentric and concentric contractions, it was estimated that with 10 subjects a 15% difference in percent fatigue between eccentric and concentric contractions could be detected at an alpha level of 0.05 and a beta level of 0.2 (80% power). Considering that the procedures of Tesch et al. [25] were replicated here, and that a fatigue difference between eccentric and concentric contractions of greater than 30% was demonstrated in that study, the current sample size was sufficient to demonstrate a meaningful difference in fatigue between contraction modes.

Results

Average isokinetic torques for the initial and final five contractions of each set of eccentric and concentric shoulder internal and external rotation are shown in Table **1**. Peak isometric torque prior to and following eccentric and concentric contractions are

Table 1 Average torque production for the first five and last five eccentric and concentric contractions for each set of 30 maximum internal and external rotation

	Internal rotation torque (Nm)		*External rotation torque (Nm)*	
	concentric	*eccentric*	*concentric*	*eccentric*
Set 1				
1–5	30.6 ± 7.0	34.9 ± 6.5	19.0 ± 4.8	26.8 ± 4.7
27–32	24.2 ± 5.8	27.5 ± 6.0	14.6 ± 3.6	21.1 ± 4.5
Set 2				
33–37	27.0 ± 6.5	30.6 ± 6.6	17.1 ± 4.8	24.2 ± 4.5
60–64	23.4 ± 6.5	26.6 ± 6.8	13.7 ± 3.4	20.1 ± 5.2
Set 3				
65–69	26.7 ± 8.0	29.2 ± 7.0	17.1 ± 4.9	23.3 ± 5.6
92–96	22.4 ± 5.9	25.9 ± 4.4	12.7 ± 2.9	20.2 ± 4.8

Internal Rotation: Mode (eccentric vs. concentric) by Fatigue (initial 5 vs. final 5), p = 0.85. External Rotation: Mode (eccentric vs. concentric) by Fatigue (initial 5 vs. final 5), p = 0.77

Table 2 Isometric torque production prior to and following 96 maximum eccentric and concentric isokinetic contractions for shoulder internal and external rotation

	Internal rotation		*External rotation*	
	concentric	*eccentric*	*concentric*	*eccentric*
Pre	40.1 ± 7.9	38.9 ± 7.9	27.5 ± 7.6	26.8 ± 5.2
Post	37.9 ± 7.9	34.8 ± 9.7	23.7 ± 7.9	25.0 ± 5.1

Internal Rotation: Mode (eccentric vs. concentric) by Fatigue (Pre vs. Post 5), p = 0.41. External Rotation: Mode (eccentric vs. concentric) by Fatigue (Pre vs. Post), p = 0.11

shown in Table **2**. Eccentric external rotation strength (average torque for first five repetitions of the first set) was significantly greater (41 %) than concentric strength ($p < 0.001$) but not different from isometric strength (3 % lower, $p = 0.9$). Eccentric internal rotation strength (average torque for first five repetitions of the first set) was not significantly greater than concentric strength (14% higher, $p = 0.19$) or isometric strength (11% lower, $p = 0.1$). For both eccentric and concentric contractions, internal rotation strength was greater than external rotation strength (eccentric 30%, $p < 0.0001$; concentric 60%, $p < 0.0001$).

There was progressive fatigue in both internal and external rotation strength for both eccentric and concentric isokinetic contractions (all, $p < 0.0001$, Table **1**). However, there was no significant difference in fatigue for eccentric versus concentric contractions in internal rotation (75% of baseline vs. 74%, mode × fatigue, $p = 0.99$; Fig. **1**) or external rotation (76% of baseline vs. 68%, mode × fatigue, $p = 0.22$; Fig. **2**).

Fatigue was also apparent with isometric testing (Table **2**) in external rotation following concentric contractions (7 ± 4%, $p < 0.01$) and eccentric contractions (15 ± 11 %, $p < 0.01$). Isometric fatigue tended to be higher following eccentric contractions ($p = 0.07$). There was no significant fatigue with isometric testing in internal rotation following concentric (5 ± 9%, $p = 0.1$) or eccentric (11 ± 16%, $p = 0.052$) contractions. Additionally, the difference in these non-significant fatigue effects (eccentric versus concentric) was not significant ($p = 0.33$).

Discussion

The main finding in this study was that there was no apparent fatigue resistance for eccentric contractions in internal or external shoulder rotation. These results are in agreement with the findings of Linnamo et al. [13] who reported no difference in fatigue between eccentric and concentric contractions of the elbow flexors. The results are in contrast to other studies showing eccentric

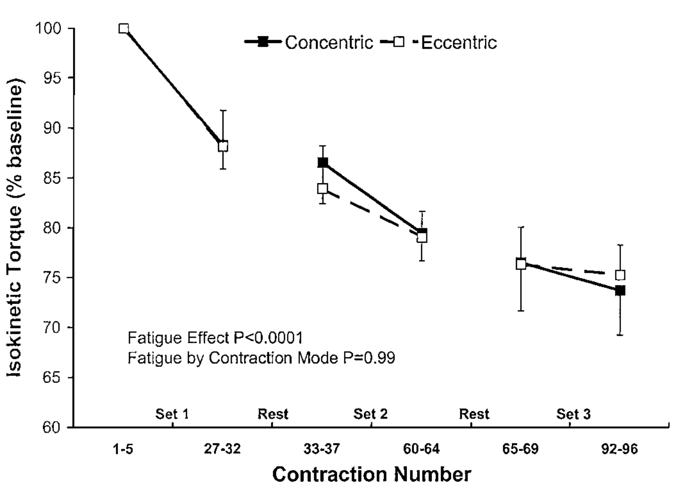

Fig. **1** Internal rotation fatigue for the first and last five contractions for each of the three sets of 32 eccentric and concentric contractions. Fatigue is expressed as percent change in torque from the average of the first five contractions of the first set. Main effect of Fatigue (contraction number), $p < 0.0001$; Fatigue × Mode (eccentric versus concentric), $p = 0.99$.

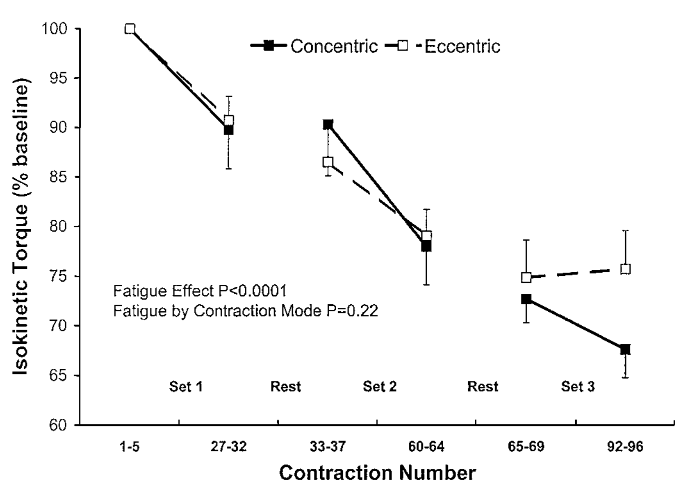

Fig. **2** External rotation fatigue for first and last five contractions for each of the three sets of 32 eccentric and concentric contractions. Fatigue is expressed as percent change in torque from the average of the first five contractions of the first set. Main effect of Fatigue (contraction number), $p < 0.0001$; Fatigue × Mode (eccentric versus concentric), $p = 0.22$.

fatigue resistance in lower extremity muscle groups [12,21,25]. Therefore, eccentric fatigue resistance might be specific to lower extremity muscle groups.

Based on the results, the sample size in the current study was sufficient to demonstrate a 14% difference in fatigue between eccentric and concentric contractions at an alpha level of 0.05 and a beta level of 0.2 (80% power). This is in agreement with the estimated effect size for this sample described in the methods. Considering that the observed difference in fatigue between eccentric and concentric contractions was 1% for internal rotation and 8% for external rotation, the possibility of a type II error is low.

There appears to be no consensus on the mechanism for eccentric fatigue resistance demonstrated in lower extremity muscle groups. Eccentric fatigue resistance in the quadriceps was attributed to sub-maximal motor unit activation during maximum voluntary eccentric contractions and greater potential for motor unit rotation during repeated eccentric contractions [25]. In support of this theory, Dudley et al. [8] demonstrated incomplete voluntary activation of the quadriceps during maximal voluntary eccentric contractions. By contrast, eccentric fatigue resistance in the plantarflexors and dorsiflexors was attributed to non-neural factors. In the plantarflexors, eccentric fatigue resistance was attributed to the greater mechanical efficiency for eccentric contractions [12]. In the dorsiflexors eccentric fatigue resistance was attributed to Ca^{2+} mediated excitation-contraction coupling processes [21]. If eccentric fatigue resistance were attributable to peripheral factors, such as mechanical efficiency or excitation-contraction coupling, such an effect would be expected in all muscle groups. The apparent lack of eccentric fatigue resistance in upper extremity muscle groups demonstrated here for the shoulder rotators, and previously for the elbow flexors [13], may be explained by differences in neural control of eccentric contractions in upper versus lower extremity muscle groups. However, discussion of neural control of eccentric and concentric contractions of upper and lower extremity muscle groups is not within the scope of this study.

Surprisingly, pre-fatigue eccentric strength was not greater than isometric strength for internal rotation (11% lower) or external rotation (3% lower). Eccentric internal and external strength has been shown to be markedly higher than isometric values when tested in 45° of abduction [12,15]. Malerba et al. [15] performed isometric tests at 20° and 60° of external rotation. In the present study, strength was assessed at 90° of abduction with isometric tests performed at 45° of external rotation and isokinetic tests performed from 0 – 90° of external rotation. Maximum eccentric force and the ability to maintain force output with repeated contractions may be compromised with the shoulder rotators working at 90° of abduction.

The current results with respect to isometric versus eccentric strength also contrasts with the results of Pasquet et al. [21] in the dorsiflexors, where eccentric strength was 20% higher than isometric. Similarly, plantarflexion eccentric strength was approximately 18% higher than isometric strength [12]. It has been estimated that eccentric force production should be 150% of isometric force production [27]. The fact that maximum voluntary eccentric force production does not reach 150% of maximum isometric force production has been attributed to neural inhibition during eccentric contractions [27]. Therefore, low eccentric force production in internal and external rotation (relative to isometric), in the present study, may be attributable to neural inhibition. However, it is important to note that neural inhibition during eccentric contractions is thought to contribute to fatigue resistance [25] and eccentric fatigue resistance was not observed in the present study.

In conclusion, fatigue in internal and external shoulder rotation was similar between eccentric and concentric contractions. These findings agree with previous findings in the elbow flexors [13] but are in contrast with eccentric fatigue resistance seen in lower extremity muscle groups [12,21,25]. Further research is required to examine the possibility that eccentric fatigue differs between upper and lower extremity muscle groups.

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