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Abstract

The purpose of this investigation was to determine the influence of contraction velocity on the eccentric (ECC) and concentric (CON) torque production of the biceps brachii. After performing warm-up procedures, each male subject ($n = 11$) completed 3 sets of 5 maximal bilateral CON and ECC isokinetic contractions of the biceps at three different speeds on a Biodex System 3 dynamometer. The men received a 3-minute rest between sets and the order of exercises was randomized. Peak torque (Nm) values were obtained for CON and ECC contractions at each speed. Peak torque scores (ECC vs. CON) were compared using a t-test at each speed. A repeated measures analysis of variance was used to determine differences between speeds. ECC peak torque scores were greater than CON peak torque scores at each given speed. No differences were found between the ECC peak torque scores ($p = 0.62$) at any of the speeds. Differences were found among the CON scores ($p = 0.004$). Post hoc analysis revealed differences. The data suggests that ECC contractions of the biceps brachii were somewhat resistant to a force decrement as the result of an increase in velocity, whereas CON muscular actions of the biceps brachii were unable to maintain force as velocity increased.

Keywords

peak torque, force-velocity curve, weight lifting

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The Effects of Isokinetic Contraction Velocity on Concentric and Eccentric Strength of the Biceps Brachii

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Abstract. Drury, D.G., K.J. Stuempfle, C.W. Mason, and J.C. Girman. The effects of isokinetic contraction velocity on concentric and eccentric strength of the biceps brachii. *J. Strength Cond. Res.* *20(2):390–395. 2006.*—The purpose of this investigation was to determine the influence of contraction velocity on the eccentric (ECC) and concentric (CON) torque production of the biceps brachii. After performing warm-up procedures, each male subject (n = 11) completed 3 sets of 5 maximal bilateral CON and ECC isokinetic contractions of the biceps at speeds of 90, 180, and 300°·s^{-1} on a Biodex System 3 dynamometer. The men received a 3-minute rest between sets and the order of exercises was randomized. Peak torque (Nm) values were obtained for CON and ECC contractions at each speed. Peak torque scores (ECC vs. CON) were compared using a t-test at each speed. A repeated measures analysis of variance was used to determine differences between speeds. ECC peak torque scores were greater than CON peak torque scores at each given speed: 90°·s^{-1}, p = 0.0001; 180°·s^{-1}, p = 0.0001; and 300°·s^{-1}, p = 0.0001. No differences were found between the ECC peak torque scores (p = 0.62) at any of the speeds. Differences were found among the CON scores (p = 0.004). Post hoc analysis revealed differences between 90°·s^{-1} (114.61 ± 23) and 300°·s^{-1} (94.17 ± 18). These data suggest that ECC contractions of the biceps brachii were somewhat resistant to a force decrement as the result of an increase in velocity, whereas CON muscular actions of the biceps brachii were unable to maintain force as velocity increased.

Key Words. peak torque, force-velocity curve, weight lifting

Introduction

The production of dynamic force by a muscle is dependent upon a complex interaction of variables, which may include the type of contraction and the contraction velocity. The interplay between these 2 specific variables has been an area of intense study for more than 65 years (20). In 1935, Fenn and Marsh discovered a consistent relationship between the velocity of muscle shortening and the active force produced (7). Further explanation of this relationship was presented by A.V. Hill in 1938 (11) and Bernard Katz in 1939 (14). Based upon these groundbreaking studies, Hill was able to create an equation for this relationship that is still in use today (20). This phenomenon, commonly referred to as the "force-velocity curve," remains one of the cornerstones of our understanding of dynamic muscle physiology (6, 19). In brief, the force-velocity curve is characterized by a muscle's decreasing ability to produce force concentrically (CON) as the velocity of the muscular contraction increases. Conversely, the maximal force a muscle can produce will increase as the CON contraction velocity decreases (20). Although this phenomenon is not completely understood (9), several researchers have proposed that the decrement in force during fiber shortening is, in part, due to innate structural limitations in the muscle fibers and their ability to break and reconnect cross-bridge connections within the sarcomere (9, 18).

Although the force-velocity curve of CON contractions has been investigated thoroughly (16, 18), the force-velocity relationship of eccentric (ECC) contractions has not been well defined (18, 19). Numerous researchers have found ECC force to be somewhat independent of velocity (10, 20). Others have reported that ECC force actually improves with increases in velocity (25, 30), whereas still others have reported increases in the variability of ECC force with alterations in velocity (3). To complicate these issues even further, many of these studies have been conducted on isolated animal tissues (5).

The ECC to CON strength differences of a given muscle can be of concern to athletes and coaches who are involved with sports that specifically tax one type of contraction vs. the other (27). However, most sports require a dynamic combination of CON and ECC contractions that ultimately translate into sports performance. It is the responsibility of the strength coach and-or trainer to provide a detailed analysis of the physiological requirements necessary for athletic success (9). This assessment must include information regarding the type of contractions (ECC vs. CON) most often used by the athlete and a training program to match these needs (9). Too often, athletes are assessed based upon strength parameters that are exclusively testing the limits of their CON muscular function. Because both type of muscular contraction (ECC and CON) are important to performance, research that can describe their relationship to one another is important and necessary.

A vivid example of the dynamic interplay between CON and ECC contractions can be found in the practical explanation of plyometric training. Depth jumps and bounding require a rapid transition from the ECC deceleration phase of receiving the body's weight to the CON acceleration phase of the next jump. It has been well documented that this form of training is effective for increasing strength and performance despite the muscle damage often associated with the excessive ECC forces. In essence, plyometric training is a method of providing a contraction-specific overload to maximize the training stimulus needed to tax two different contraction types that vary in strength. Understanding how different muscles of the body may respond to velocity and contraction-specific training may allow athletes to train at greater intensities without injury.

Because intact muscles are subject to neural and metabolic influences that can alter force production, it is important to consider the force-velocity characteristics of intact human muscle separately from the in vivo findings of animal models (21, 24). Through consistent exposure to specific types of training, the neuromuscular system can alter and can improve its contraction economy using less muscle to do the same work (17). Therefore, to fully appreciate the dynamics of the force-velocity curve, one must attempt to study muscles under conditions that are similar to how the muscles are trained. The unique stimuli presented repeatedly as part of a structured training program may affect the way in which the force-velocity curve is altered (17). Furthermore, several researchers have determined that the force-velocity curve described earlier may be muscle specific (6, 24), especially with regards to ECC movements. Therefore, the purpose of this investigation was to quantify the strength differences between ECC and CON bilateral isokinetic contractions of the biceps brachii and to determine how these muscles are affected by changes in contraction velocity.

METHODS

Experimental Approach to the Problem

Maximal peak torque values were obtained for the biceps brachii during isokinetic biceps flexion and extension at 3 different contraction speeds to compare the strength changes that result from changes in velocity.

Subjects

Eleven healthy men (age = 19.81 ± 1.25 years) were recruited from the college community. Subjects gave their written informed consent to participate and were verbally informed of the risks and procedures involved with this study. Our Institutional Review Board approved all methods and procedures prior to data collection. Subjects completed a health history questionnaire, which also included questions regarding their weight-training history. All subjects reported that they were trained currently, with a minimum of 6 months of prior weight-training experience. Although we did not attempt to control the training intensity or volume of these men, each reported having trained with weights at least 3 times per week for a period of at least 6 months. The average height of our subjects was 179.68 (±3.79) cm, the average weight was 84.23 (±14.67) kg, and the average percentage fat was 13.09% (±6.06).

Instrumentation

A wall-mounted stadiometer and a SECA scale (Volgle and Halke, Hamburg, Germany) were used to measure height and weight, respectively. Body composition was obtained using Lange skinfold calipers (Beta Technology Corp., Santa Cruz, CA) and a 3-site formula previously described by Jackson and Pollock (13). Peak torque measurements of the biceps brachii were obtained using a Biodex System 3 isokinetic dynamometer (Biodex Medical, Shirley, NY) in conjunction with the corresponding analysis software (System 3 Advantage Software 3.2) provided with the Biodex system. Because the Biodex System 3 machine is not sold with the capability to obtain bilateral measurements, an adjustable extension bar was added to the force arm of the dynamometer. We chose to assess these men bilaterally, because most of them used bilateral exercises when training the biceps brachii. To accommodate a bilateral assessment of the biceps brachii,

FIGURE 1. Patient set-up for the bilateral measurement of the biceps brachii.

the dynamometer head was rotated away from the chair and a free-standing preacher curl bench was used to stabilize the subject. The dynamometer was aligned then with the rotation point of the elbow, and the length of the force arm was adjusted so that the customized bar fit comfortably in the palm of both hands (Figure 1). Submaximal warm-up activity was performed on a Monark Upper Body Ergometer (Monark, Varberg, Sweden).

Testing Procedures

Procedures began with the acquisition of height, weight, and body composition. Prior to strength testing, the men completed a thorough warm-up, which included 5 minutes of upper body cycling (2 kp @ 50 rpm) and 3 sets of static stretches of the biceps (held for 15 seconds). Although stretching can indeed augment the production of maximal force, we found it necessary to include stretching in the warm-up procedures to help avoid the possible muscular strain often associated with maximal effort. These procedures were consistent among the men and therefore any variation that may have resulted from the stretching procedures would at least be consistent among the participants. Recent investigations of the force velocity relationship using intact human muscle have used warm-up procedures similar to the protocol described here (3, 22). The subject then was asked to sit down on the preacher curl bench that was adjusted so that his humoris was parallel to the padded surface. The Biodex System 3 dynamometer then was adjusted so that the rotation point of the dynamometer was aligned with the rotation point of the subject's elbow joint.

Isokinetic testing of the biceps brachii was conducted both concentrically and eccentrically at 3 different speeds: 90, 180, and $300°\cdot s^{-1}$. These particular speeds were chosen to represent and to approximate numerous points on the velocity continuum that have been used previously to investigate this phenomenon (21, 26, 27). The men were asked to complete 5 maximal CON and ECC repetitions at each speed with a rest period of 3 minutes between sets. Range of motion was limited by predetermined stopping points that were programmed into the Biodex dynamometer specifically for this protocol. Extension was limited to 170°, whereas flexion was limited to 45°. A brief

Table 1. Bilateral peak torque scores (Nm) for eccentric (ECC) and concentric (CON) contractions of the biceps brachii at 3 speeds.

	Eccentric mean (*SD*)	Concentric mean (*SD*)	*p* Values ECC vs. CON
90°·second^{-1}	170.06 ± 36.84	114.62 ± 23.07	$p = 0.0001$*
180°·second^{-1}	162.21 ± 27.47	94.17 ± 18.73	$p = 0.0001$*
300°·second^{-1}	172.14 ± 30.94	87.13 ± 21.31	$p = 0.0001$*
p value ANOVA	$p = 0.62$	$p = 0.004$*	

* $p < 0.05$.

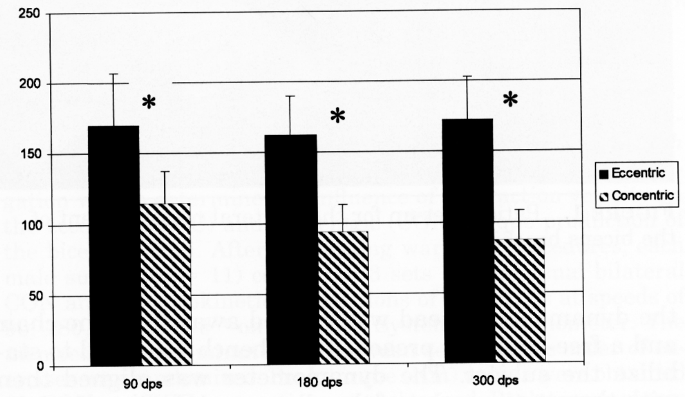

Figure 2. Eccentric to concentric peak torque (Nm) comparison at 3 speeds (90°·s^{-1}, 180°·s^{-1}, and 300°·s^{-1}).

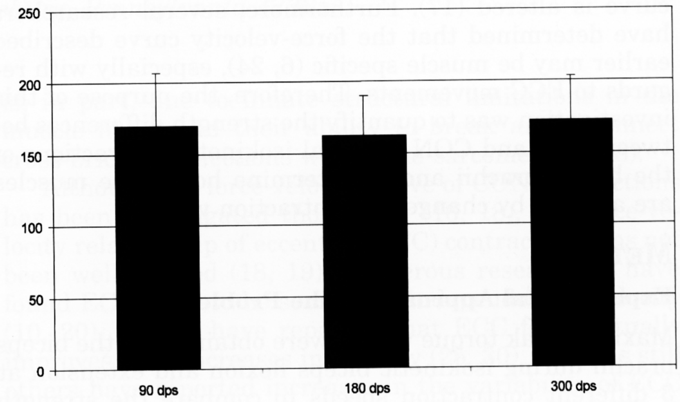

Figure 3. Peak Torque for eccentric bilateral contractions of the biceps brachii at 3 different speeds (90°·s^{-1}, 180°·s^{-1}, and 300°·s^{-1}).

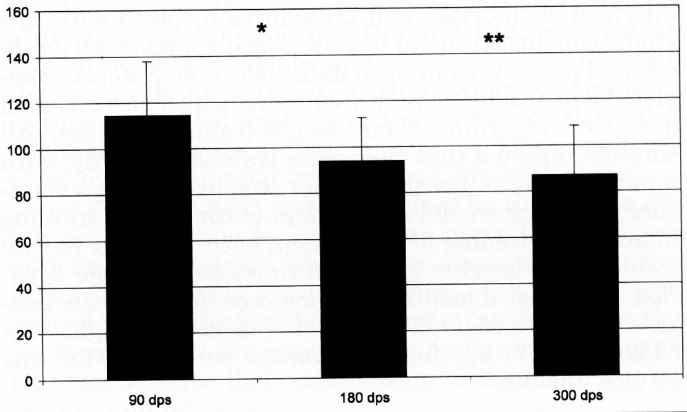

Figure 4. Peak torque for concentric bilateral contractions of the biceps brachii at 3 different speeds (90°·s^{-1}, 180°·s^{-1}, and 300°·s^{-1}). $P = 0.0043$. *90 vs. 180°, $p = 0.0388$; **90 vs. 300°, $p = 0.0.0007$; 180 vs. 300°, $p = 0.12$.

pause was used between each contraction to limit the potential for prestretch alterations of force. After each pause, a brief period of isometric force production was needed to initiate the assessment of the next repetition. The order of the conditions (dynamometer speed) was randomized and the repetition within each set with the greatest torque (Nm) was used for analysis.

Statistical Analyses

Peak torque values from each type of contraction (CON and ECC) at each speed (90, 180, and 300°·s^{-1}) were used for analysis. A dependent *t*-test was used to compare the ECC and CON peak torques scores at each given speed. A repeated measures analysis of variance (ANOVA) was used to determine differences among the peak torque values for the 3 speeds for each contraction type. Finally, post hoc analysis of the ANOVAs was achieved through the use of Fisher protected least significant difference test. The a priori level of significance was set at 5% ($p \leq 0.05$).

Results

Concentric to Eccentric Comparison

All 11 subjects who participated in the testing completed all the prescribed sets and repetitions. Means and standard deviations are reported in Table 1. Eccentric peak torque was significantly higher than CON peak torque at all 3 speeds (90°·s^{-1}, $p = 0.0001$; 180°·s^{-1}, $p = 0.0001$; and 300°·s^{-1}, $p = 0.0001$). Figure 2 shows the differences between contraction types at each speed.

Eccentric Speed Comparison

There were no significant differences between ECC peak torque scores among any of the 3 speeds ($p= 0.5478$). Table 1 shows the means and standard deviations, whereas Figure 3 shows the ECC speed comparisons.

Concentric Speed Comparison

There were significant differences in CON peak torque scores among the 3 speeds ($p = 0.0043$). Post hoc analysis revealed differences only between 90°·s^{-1} (114.61 ± 23 Nm) and 180°·s^{-1} (94.17 ± 18 Nm), $p = 0.03$. Figure 4 shows data for the CON speed comparisons.

Discussion

The primary finding of this investigation was that peak ECC torque did not change with increases in velocity, whereas peak CON torque decreased as velocity increased. These findings are in general agreement with other investigations of the CON and ECC force-velocity relationship in intact human muscle (12, 17, 27). Although our CON data were consistent with what is currently understood about the CON force-velocity curve (6, 11, 20), our ECC data are subject to interpretation in the context of numerous investigations that both agree with (24, 27) and oppose (15, 23) our findings.

In an investigation of the ECC and CON force-velocity relationships of the quadriceps, Westing et al. (27) found that ECC force-velocity changes were far more resistant to augmentation with increases in velocity. In fact, in all but one of their subjects, these researchers found no significant change in peak torque during the ECC contractions at any of the isokinetic speeds studied (30, 120, and $270°\cdot s^{-1}$). When considering the CON data of our investigation, a predictable force decrement that typically accompanies increases in contraction velocity was evident at the highest speed (27). These data are in agreement with those of Westing et al. (27), despite differences in the muscles studied and the differences in contraction velocities. In both investigations, CON decreases in force were observed with increases in velocity. Furthermore, no differences in ECC force production were found among any of the speeds studied in either the study by Westing and colleagues (27) or among the data reported here.

In other investigations comparing ECC and CON contractions of the biceps, Komi and Buskirk (17, 18) found a similar increase in the difference between the CON and ECC scores when the velocity of the contraction increased. In their discussion these researchers stated, "According to the force-velocity characteristics, the muscle tension at the same velocity is always higher in eccentric work and this difference becomes greater as a function of increase in the contraction velocity" (18, p. 123). Our findings support those of Komi and Buskirk, despite the fact we used a bilateral movement and they used unilateral assessments of the biceps brachii.

Other investigators have shown an inverse relationship of the traditional force-velocity curve when studying the elbow flexors under ECC conditions (15, 23). More specifically, ECC force actually increased with subsequent increases in contraction velocity. These findings for the biceps brachii are inconsistent with most of the investigations of the quadriceps femoris (27). Consequently, Westing et al. (27) have speculated that ECC force-velocity characteristics may be subject to muscle specificity. Because we also used the biceps brachii, our findings contradict the findings of those investigations previously mentioned (15, 23). We found no differences in ECC peak torque with changes in velocity. This could be the result of an inherently less-pronounced force velocity relationship for ECC movements (12), or it may be the result of a greater variability in the ECC data that is commonly found with this type of contraction (26, 28). Several researchers have observed an increase in the variability of motor unit recruitment during ECC movements, which may make finding statistical differences for ECC movements harder to establish than those for CON movements. When considering the variability of the data reported here, the ECC standard deviation scores are larger than the CON scores in both absolute and relative terms at each speed. Although this was not statistically analyzed as part of this study, the differences in variability between ECC and CON peak torque scores are of relevance for further study.

Of the investigators who have found no differences in ECC torque with regard to contraction velocity, many cite the possibility of a neural inhibitory mechanism that may protect muscles from excessive forces during high-speed ECC loading (3, 6, 12, 24, 27). Evidence supporting this theory has been provided by numerous studies of electrically stimulated muscle (24, 29). During the concurrent electrical stimulation of muscle undergoing a maximal isometric or CON contraction, the resultant forces produced seem to remain fairly constant with those produced without electrical stimulation. In contrast, electrically stimulated muscle undergoing a maximal ECC contraction has produced substantial increases in force and motor unit recruitment (2, 24). Theoretically, the motor units left unrecruited during a maximal voluntary ECC contraction may have been neurologically inhibited (12, 24, 27). If this mechanism is indeed sensitive to ECC contractions above a certain velocity threshold, this may explain the leveling off phenomenon that has been reported here and in numerous investigations in humans (12, 21).

Other investigators have demonstrated a 'dis'-inhibition of the theoretical ECC protective mechanism with training (12, 27, 28). Because all our subjects were trained, it may be possible that they had altered some of their ECC inhibition to speed, possibly decreasing some of the neural inhibitory influence that regulates maximal ECC force. This may have occurred in those who use heavy negatives and other forms of ECC overload. Although our subjects reported activity levels that would generically classify them as being 'trained,' no attempt was made to regulate the specific type of training of this sample. Because neural inhibition does not seem to be as active during CON contractions (12, 24), it is not surprising that our CON torque data produced the typical inverse relationship to increases in velocity.

In reviewing the literature regarding CON and ECC force-velocity curves, it is important to distinguish between the animal studies and those that have been conducted on humans (27). Many of the classic studies in this area were conducted on the isolated muscle fibers of animals and have served as the basis for our current understanding of these relationships (27). Conversely, the CON and ECC force-velocity relationships of intact human muscle have received limited attention (3, 27). Although most mammalian muscle tissues share an abundance of contractile properties and are indeed comparable in many situations, the method of investigation is of relevance here. When considering the ECC and CON force-velocity curves, one must bear in mind that the contractile properties of muscle are subject to augmentation by efferent stimuli, afferent stimuli, and neural inhibition that are obviously interrupted during dissection. Therefore, for the purposes of interpreting our findings, we will limit our discussion to those studies that have used humans in their research.

The fact that our ECC scores produced more torque than their CON counterparts for any given speed is consistent with most studies in this area and is a relationship well established in the literature (9). However, the specific relationship of force produced by these 2 types of contractions is subject to change based upon training specificity, pennation of the muscle (27), neural influence (4), fiber composition (1, 8), and other factors. Furthermore, when considering gross motor movements in humans, the force produced for analysis is actually the result of numerous muscles that are influenced by both central and peripheral factors (24, 27). Accordingly, this relationship is very complex and, to date, has received little attention in the literature (3, 27).

The execution of an ECC contraction is a much more complicated motor act than a CON contraction (4). Eccentric contractions require less motor input (3, 4), yet produce more force (12, 21). Theoretically, ECC contractions may conserve energy by using a passive contribution of force through the series elastic component and the parallel elastic component (12). In so doing, the contractile component (actin and myosin) may accomplish a greater force with less fiber recruitment (12). Also, the detachment of cross-bridge connections during a CON contraction is dictated by the cycling rate of the actin and myosin. This cycling rate is partially controlled by ATP availability, and the enzyme ATPase. The ATPase isozyme found in type II anaerobic fibers is faster than the alternative form of this enzyme found in type I fibers (8). During an isokinetic ECC contraction, the acto-myosin rigor complex may be interrupted mechanically or 'popped' by the excessive force produced by the dynamometer creating a mechanical detachment vs. a chemical detachment of the myosin head (6). This departure from the enzymatically determined cross-bridge cycling of the CON contraction may contribute to increases in force observed in this investigation and others (6).

The relative distribution of fiber types within a muscle also may affect the CON to ECC values for that given muscle (8). When considering muscle groups that are composed of a large percentage of type II (anaerobic) fibers, one might assume the CON and ECC torque scores would be closer. Hypothetically, if fast twitch fibers are recruited in larger motor pools and also are stimulated by contraction velocity, these fibers would help maintain force at higher CON speeds (8). Conversely, muscles composed of primarily type I (aerobic fibers) would be highly susceptible to the CON force decrements that accompany increases in velocity (1). Because ECC torque does not seem to be limited by the same factors as the CON force-velocity curve, it is logical to assume that fiber typing specific to a given muscle may play a role in the determination of this muscle-specific phenomenon. Although the CON and ECC strength of a given muscle is probably determined by a host of physiological and neurological factors, fiber type has been identified by several researchers as a likely area of influence that results in muscle-group specificity (8, 24).

Practical Applications

The force-velocity characteristics of CON muscular actions have been effectively characterized in both animal and human models. The research regarding the force-velocity characteristics of ECC actions has revealed a much more complex interaction of physiological factors. In this investigation, our findings suggest that isokinetic CON actions of the biceps brachii decrease in force as velocity increases. However, in this investigation, the ECC contractions of the biceps brachii seem to be resistant to the velocity-specific decreases found concentrically. This physiological phenomenon may help support joints where an imbalance in muscle mass of opposing muscle groups can be overcome by a concurrent recruitment of CON and ECC contractions. For example, during a sprinting race, the CON contraction of the quadriceps is accompanied by a forceful ECC contraction of the hamstrings. Although the quadriceps collectively have more muscle mass, the hamstrings are able to counter the quadriceps and to stabilize the joint because during a CON contraction of the quadriceps, the hamstrings must contract eccentrically. This relationship also may apply to maximal throwing activities where the biceps are responsible for a high velocity ECC deceleration of the lower arm. In our investigation, we demonstrated that the biceps were relatively resistant to velocity-specific decreases in force. The differences between ECC and CON contractions found in this investigation may be due to the training habits of our subjects or other muscle-specific characteristics (i.e., fiber type). Because of these apparent differences in CON and ECC contractions, therapists, trainers, and exercise physiologists may want to consider altering the contraction velocity of specific exercises to meet the needs of each contraction type (ECC vs. CON) when maximal torque generation is the desired goal. In so doing, one may stimulate ECC adaptations that may have been previously unrealized. Furthermore, the velocity-specific ECC adaptations may help the athlete develop a tolerance for the higher intensities associated with ECC training, which may lead to further neuromuscular adaptations that may improve performance and protect against injury.

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