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Muscle group specific changes in the electromechanical delay following short-term resistance training

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ABSTRACT

Objectives: The time delay between the onset of a muscle's electrical activity and force is believed to have important functional implications, and has been shown to decrease following resistance training in males. The purpose of this investigation was to examine changes in the voluntary electromechanical delay (EMD) for the leg extensors and flexors following a short-term resistance training intervention in females.

Design: Pretest/posttest control group experiment.

Methods: Twenty-two previously untrained females (mean ± SD age = 21 ± 2 years; mass = 65.4 ± 13.3 kg) were randomly assigned to training ($n = 10$) and control ($n = 12$) groups. The training group performed barbell back squats and deadlifts twice per week for four weeks. EMD for the vastus lateralis (extensors) and biceps femoris (flexors) was examined during maximal voluntary contractions at pre- and posttesting. Data were examined using analyses of covariance (ANCOVAs) with the pretest and posttest scores serving as the covariate and dependent variable, respectively, and by evaluating the number of participants that exceeded the minimal difference statistic.

Results: For the leg extensors, the adjusted EMD posttest mean for the training group was significantly lower than that for the control group (74.3 vs. 91.8 ms; $p = 0.015$; $\hat{\eta}^2 = 0.275$), and five training participants displayed decreases that exceeded the minimal difference. The ANCOVA for the leg flexors was not significant (adjusted means = 98.0 vs. 90.0 ms; $p = 0.487$; $\hat{\eta}^2 = .026$).

Conclusions: Four weeks of multi-joint resistance training resulted in decreased EMD for the leg extensors, but not the flexors.

1. Introduction

There is a time delay between the electrical activity of a muscle and the onset of force/torque.[1–3] This phenomenon is referred to as the electromechanical delay (EMD), and is present during both evoked and voluntary contractions.[1,3] EMD was first described by Nobel laureate Hill[2] and received considerable attention from physiologists in the 1970s.[4] Previous investigations have demonstrated that EMD is associated with two factors: (1) electrical and biochemical processes involved in excitation–contraction coupling and (2) length changes of the series elastic component.[4,5] The former was described by Cavanagh and Komi[4] as being nearly instantaneous, whereas the latter has often been used to explain findings related to musculotendinous stiffness.[5,6] Previous investigators have hypothesized that EMD may have important implications for functional performance, with longer delays potentially associated with increased anterior cruciate ligament injury rates in female athletes[7] and falls in older adults.[8]

Several previous investigations have used surface electromyographic (EMG) signal analyses to examine chronic resistance or plyometric training adaptations on EMD.[9–11] Hakkinen and Komi[9] reported no changes in EMD for the superficial quadriceps femoris muscles determined via reflex contractions following sixteen weeks of heavy, ballistic resistance training. Kubo et al.[5] demonstrated that twelve weeks of isometric training resulted in a significant increase in tendon stiffness and a 18.4% decrease in vastus lateralis EMD. Interestingly, Grosset et al.[6] reported opposite changes in plantarflexion EMD for plyometric versus endurance training, as evidenced by a correlation in the changes scores for EMD and musculotendinous stiffness. Most recently, Costa et al.[1]

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found that three days of resistance training had no influence on involuntary EMD, suggesting that a minimal training duration threshold may be required to influence this neuromuscular variable. Collectively, the ability to detect changes in EMD is related to various training program variables and the methodology used to calculate EMG and torque signal onsets.

There appear to be several noteworthy gaps in the literature pertaining to changes in EMD with training. First, in athletic and rehabilitative settings, large muscle mass, multi-joint resistance exercises are more common than single-joint training. Individuals involved in the development of training programs often prescribe these exercises over single-joint training because they more closely reflect human movement due to their use of dozens of muscles, each of which must function in a coordinated manner. However, with the exception of one study,[9] previous EMD investigations have assessed the effects of single-joint resistance training.[5,10,11] Furthermore, we are unaware of investigations that have examined short-term changes in EMD in response to training of the hamstring musculature. Since weak hamstrings increase injury risk,[12] understanding how short-term resistance training influences their neuromuscular control may help individuals develop safer, more effective exercise programs. This is particularly relevant in female athletes, who demonstrate considerably greater anterior cruciate ligament injury rates than their male counterparts. [12,13] Although it is known that females demonstrate significantly longer EMD than males,[14] the effects of resistance training for the leg extensors and flexors have only been examined in males. Therefore, the purpose of this investigation was to assess changes in EMD for the leg extensors and flexors following a short-term, multi-joint resistance training intervention in previously untrained females.

2. Methods

Twenty-two females (mean ± SD age = 21 ± 2 years; height = 162.2 ± 7.3 cm; mass = 65.4 ± 13.3 kg) completed this study. In order to participate, potential participants must have completely refrained from resistance training during the six months prior to enrollment. The participants were unfamiliar with the back squat and deadlift at the beginning of the study. Individuals were not able to participate if they were affected by neuromuscular or metabolic disease. This study's procedures were approved by the university's Human Research Protection Program. Participants were recruited via convenience sampling of university students with flyers and email announcements. All participants signed an informed consent form. Upon enrollment, participants were randomly assigned to training ($n = 10$) and control ($n = 12$) groups. Each participant refrained from resistance training outside of the investigation. Studies have demonstrated that contraceptive use and menstrual cycle phase do not influence EMD[15] and the mechanical properties of muscle.[16] Thus, contraceptive use was permitted as long as its usage had remained consistent over the previous three months.

Isometric strength testing was performed for the leg extensors and flexors before (pretest) and following (posttest) the intervention. A 72 h rest period was allotted between the final training session and the posttest. The participants were familiarized with the testing procedures during a separate visit to the laboratory 48 h prior to the pretest. For each participant, testing occurred at the same time of day (±1 h). Upon arrival to the laboratory, the participants were seated on an isokinetic dynamometer (Biodex System 3, Biodex Medical Systems, Shirley, NY) in accordance with the manufacturer's instructions. During each participant's initial visit to the laboratory, the dynamometer's settings were recorded to ensure consistency. Data collection began with a warm-up of isometric contractions corresponding to ~50% of each participant's perceived maximum. Isometric testing was performed at knee joint angles of 60 and 30 degrees for the extensors and flexors, respectively (0 = full extension).[17] Each maximal voluntary contraction (MVC) was 5 s in duration, and the participants were verbally encouraged to "push" or "pull" as hard and fast as possible. 2 min of rest were allotted between each MVC. The torque signals were digitized at a sampling rate of 1926 Hz (a preset commercial hardware device frequency).

Bipolar EMG signals were detected from the vastus lateralis and biceps femoris during each MVC. The signals were detected with two Trigno™ wireless surface EMG sensors (interelectrode distance = 10 mm [Delsys Inc., Natick, MA]) with a bandwidth of 20–450 Hz. The sensors were placed over the muscles in accordance with established guidelines.[18] A custom-built foam pad was secured to the posterior thigh to ensure that the biceps femoris sensor did not come into contact with the seat of the dynamometer.[3] Prior to testing, the skin was shaved and cleansed with rubbing alcohol. The participants refrained from placing lotion on their right thigh within 24 h prior to testing. The surface of the skin was marked periodically throughout the study to ensure that the sensors were placed in the same anatomical locations for each data collection session. During the warm-up, an investigator visually inspected the EMG signals to ensure low baseline noise and minimal line interference. The EMG signals were time synced with the torque signal, and were also digitized at a sampling rate of 1926 Hz.

All of the testing involved voluntary contractions. Signal processing was performed using custom programs with LabVIEW programming software (LabVIEW 2012, National Instruments, Austin, TX). The calculation of EMD was performed using high-resolution waveform graphs and methods similar to those described previously.[3,19] The onset of EMG was defined as the time at which the signal reached three SDs greater than its baseline mean.[3,19,20] The torque signal was filtered using a fourth-order, zero phase shift, low pass Butterworth filter with a 50 Hz cutoff. The baseline torque value was considered the limb weight and subtracted from the signal so that the baseline value was 0 N m. All analyses were performed on the scaled, filtered, and gravity-corrected torque signal. Torque onset was automated and based on the time at which the signal reached 7.5 and 4.0 N m for the leg extensors and flexors, respectively.[3,21] In addition to automatic processing, an investigator visually checked the location of the onsets to ensure accuracy. MVCs that included a countermovement prior to the increase in torque were discarded. For each testing session, when both MVCs were suitable for analysis, the contraction with the lowest EMG signal baseline noise was used. Example EMG and torque signals for one MVC have been shown in Fig. 1. Test–retest reliability statistics using the calculations described by Vincent and Weir[22] for our laboratory's voluntary EMD values are shown in Table 1.

The training group performed barbell back squat and deadlift exercises at the Texas Tech University Human Performance Laboratory twice per week for four weeks (i.e., eight training sessions). The participants were familiarized with the training techniques prior to training. All resistance training was closely supervised, the back squat exercise was spotted appropriately, and the participants received consistent verbal instructions. Both exercises were preceded by two warm-up sets. Excluding the warm-up sets, the participants performed five repetitions of two sets per exercise with 3 min of rest between each set. Each repetition was performed in a forceful manner with approximately 2 s concentric and eccentric phases. Back squats were always performed prior to deadlifts. Each participant squatted slightly below the parallel position, which was attained when the greater trochanter of the femur reached a position level to the patella. Deadlift technique was implemented as described in a previous investigation.[17] Due to the fact that the participants were unfamiliar with the exercises prior to the investigation, the external loads were based on