PLANTARFLEXOR ELECTROMECHANICAL DELAY: INFLUENCE OF CONTRACTION TYPE AND MUSCLE-TENDON UNIT LENGTH

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Electromechanical delay (EMD) is an important determinant of explosive neuromuscular performance. Factors such as muscle contraction type and initial muscle-tendon unit (MTU) length influence this delay period. The aim of this study is to compare differences in EMD from plantar flexors across different contraction modes and MTU lengths. EMD of physically-active individuals (n = 14) was assessed during a series of twitch and explosive isometric plantarflexions across different MTU lengths. For involuntary and voluntary explosive conditions, EMD tended to decrease while the MTU length increased from plantarflexion to neutral/dorsiflexion. No significant differences in EMD were observed between neutral and dorsiflexion MTU lengths. These results have implications for sporting performance where the ability to rapidly produce muscular force is crucial.

KEYWORDS: Explosive, force transmission, ankle joint, electrical stimulation

INTRODUCTION: Explosive muscular contraction is important in the performance of sporting movements i.e. sprinting, jumping, and throwing. These fast movements require high-velocity muscular contractions. For example, the rapid generation of muscular force is important to maximise block velocity in the sprint start. A delay in rapidly producing muscular force may negatively affect response times (Grosset, Piscione, Lambertz, & Perot, 2009) and complex movement performance (McLellan, Lovell, & Gass, 2011). Understanding the neural and mechanical mechanisms that influence explosive torque production is vital for sports performance. Electromechanical delay (EMD) is a measure of neuromuscular performance during explosive contractions. EMD is the delay period between the onset of muscle electrical activation and force production and reflects both the electrochemical processes (i.e. synaptic transmission, action potential propagation, excitation-contraction coupling) and mechanical processes (i.e. force transmission along active and passive parts of the series-elastic components) of the muscle-tendon unit (MTU) (Cavanagh & Komi, 1979). EMD is primarily determined by the time required to stretch the series elastic component of a muscle to the point where muscle force can be detected (Norman & Komi, 1979). Initial MTU length and type of contraction influence this phase lag. The influence of MTU length on involuntary EMD has been previously reported. EMD decreased as MTC length increased up to the point where tendon slack was taken up (Muraoka, Muramatsu, Fukunaga, & Kanehisa, 2004). Whether initial MTU length influences EMD of an explosive contraction in the plantarflexor muscles remains unclear. The primary aim of this study is to compare differences in EMD from voluntary explosive and involuntary isometric contractions of the plantarflexors across different contraction modes and MTU lengths. Understanding the determinants of plantarflexor EMD may enhance knowledge of the key components of explosive muscular performance.

METHODS: Following approval by the local University Research Ethics committee, fourteen participants (7 ♂, 7 ♀, 26 ± 3 years, 169.4 ± 6.6 cm, 70.1 ± 6.9 kg) of similar low-to-moderate levels of habitual physical activity were recruited for the study. Participants were required to not have experienced Achilles tendon pain or injury in the previous six months. Female participants were required to be taken the combined monophasic oral contraceptive pill for ≥6 months and were only tested between days 7-21 of pill consumption to limit fluctuations in endogenous gonadal hormones (Onambele, Burgess, & Pearson, 2007). This helped control for the possibility of menstrual cycle phase influencing neuromuscular function.

Overview: Participants were required to complete a series of isometric explosive (voluntary) and involuntary (twitch) contractions of the plantarflexors of their right leg. Both contraction types were performed at three ankle joint angles (-10° plantarflexion (PF), 0° (NE), 10° dorsiflexion (DF)). Participants were secured in a calibrated dynamometer (Con-trex, Dubendorf, Switzerland) in a lying prone position. The dynamometer fulcrum was perpendicular to the lateral malleolus of the ankle and the knee was at 180° (full extension). The ankle was securely fastened with two ankle straps. A waist belt and shoulder straps were used to secure the upper body. The torque signal from the dynamometer was sampled at 2000 Hz using an external A/D converter and interfaced with LabChart 8 software (AD Instruments, Sydney, Australia) through a personal computer. Surface EMG was recorded from the lateral gastrocnemius, medial gastrocnemius and soleus muscles using a DELSYS Trigno EMG-system (Delsys, Boston, MA). A reference electrode was placed over the lateral epicondyle of the femur. SENIAM guidelines guided the placements for muscle electrodes. Ultrasonography was then used to identify the largest muscle belly and the orientation of the muscle fibres. Following skin preparation (dry shaving, gentle abrading, cleaning with 70% ethanol), EMG sensors were attached on the identified muscle sites. EMG signals were amplified and interfaced with LabChart 8 software using wireless software. The EMG was sampled at 2000 Hz. To elicit single-pulse twitch contractions and measure involuntary EMD, the tibial nerve was electrically stimulated with square wave pulses (0.1 ms duration) delivered by a constant current variable voltage stimulator (model DS7AH, Digitimer Ltd, Hertfordshire, UK). The anode was attached to the skin superior to the patella and the cathode was attached to the skin over the tibial nerve in the popliteal fossa.

Protocol: EMD measures were completed in the following order:
1) Electrically evoked twitch contractions: A series of twitch contractions at incremental electrical currents were delivered until a plateau in the M-wave was observed. This was then increased by 20% to ensure a supramaximal current stimulus was used. Three supramaximal pulses were delivered at 12-second intervals, and repeated at three joint angles (10° PF, 0° NE, 10° DF) in a randomly assigned order.
2) Explosive contractions: Explosive contractions were performed similarly to a previously published protocol, with slight adjustments to align with this study's objectives (Tillin, Jimenez-Reyes, Pain, & Folland, 2010). Participants performed a series of submaximal plantarflexor contractions as warm-up before the explosive contractions. Next, 5 explosive isometric contractions were performed, separated by 30 seconds rest. For each contraction, participants were instructed to relax and following an auditory electronic signal, plantarflex their ankle as "fast and hard" as possible with the emphasis on "fast" for approximately 1-1.5 seconds. A series of 5 contractions were performed at each of the ankle joint angles. The three contractions at each joint angle with the largest peak slope and no countermovement were used for analysis.

Data analysis: EMG and torque signals were processed using a custom-written code in Matlab (R2019a, MathWorks, Massachusetts, USA). The EMG signal was band-pass filtered in both directions between 10 and 400 Hz using a fourth-order Butterworth digital filter. Torque signal was low-pass filtered at a cut off frequency of 20 Hz using a zero-lag fourth-order Butterworth filter. Identification of the EMG and force onsets were made manually. Manual identification of onsets is considered the most sensitive and accurate for detecting onsets (Tillin et al., 2010). Pilot testing comparing visual detection and SD thresholds on the band-pass filtered signals and band-pass and low-pass smoothed signals confirmed manual as the most sensitive in detecting EMG onsets. Threshold detection method tended to detect signal onset late when baseline noise was minimal, and detected signal onset early (up to 80 ms) when high baseline noise was present. EMD time was calculated as the difference between the onset of EMG (M-wave onset) and force identified for each of the superficial plantarflexor muscles. Signal onset was determined as the last peak/trough before the signal deflected away from its baseline noise. The largest EMD value of each contraction was defined as the EMD value for the entire muscle group. Three contractions were averaged to provide a mean plantar flexor value for each joint angle across contraction types.

Statistical analysis: Means and standard deviations were calculated for all EMD values across contraction type and ankle joint angles. The effect of contraction type and ankle joint angle on EMD was examined on SPSS V26.0 (SPSS Inc., Chicago, IL) using a two-way repeated-measures ANOVA. Pairwise comparisons with Bonferroni correction were performed when a significant interaction was detected. Statistical significance was set at $P < 0.05$.

RESULTS: The results of the two-way repeated-measures ANOVA revealed that for EMD, there was a significant main effect for contraction type ($F(1,13) = 82.16$, $P < 0.05$). Additionally for EMD, there was a significant main effect for angle ($F(2,26) = 13.00$, $P < 0.05$). There was no significant interaction between contraction type and angle. Involuntary EMD decreased as the ankle joint angle increased from PF toward DF. Post hoc analyses revealed a significant decrease in involuntary EMD from PF to NE (3.7 ± 3.6; 95% CI 1.8-6.1, $P < 0.05$). Involuntary EMD was also significantly lower from PF to DF (5.0 ± 5.2; 95% CI 1.3-9.2, $P < 0.05$). There was no significant difference in involuntary EMD from NE to DF. Explosive EMD followed a similar trend with a significant decrease from PF to NE (5.2 ± 7.1; 95% CI 0.8-11.1, $P < 0.05$). However, there was no significant difference between PF and DF, or between NE and DF. Figure 1 displays the average trend of EMD values across contraction type and ankle angle.

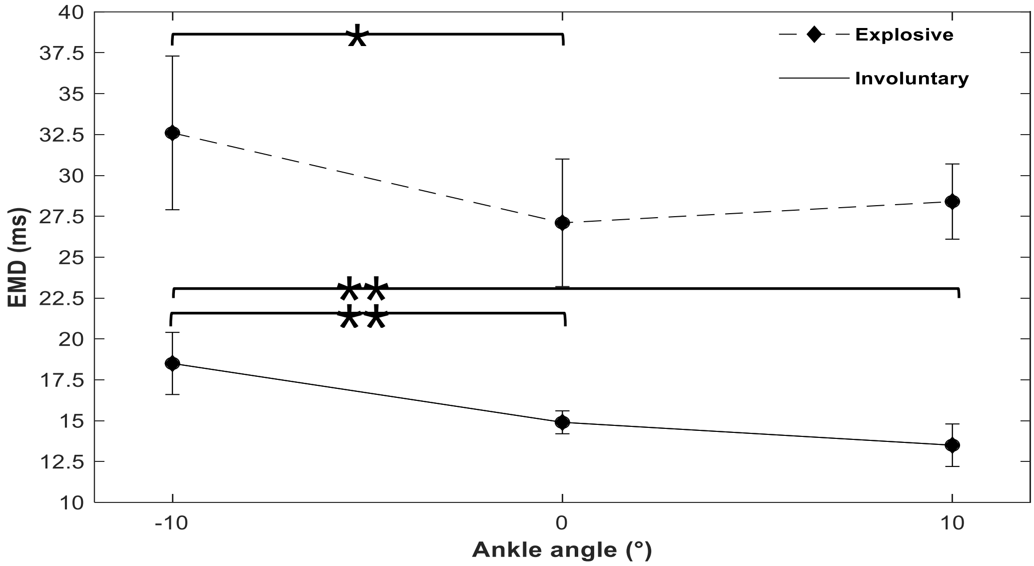

Figure 1. EMD as a function of contraction type and ankle joint angle: Plantarflexion (-10°), neutral (0°) and dorsiflexion (10°). Values are mean ± SD. Significant difference between values: ** $P < 0.01$; *$P < 0.05$.

DISCUSSION: The aim of this study was to quantify differences in plantarflexor EMD across muscle modes of contraction and MTU lengths. The main findings are: (1) Involuntary EMD decreases as MTU length increases. (2) Involuntary EMD is similar between MTU lengths where tendon slack is taken up (neutral and dorsiflexion). (3) Explosive EMD decreased as MTU length increased from plantarflexion to neutral. (4) Explosive EMD is similar between MTU lengths where tendon slack is taken up. (5) Explosive EMD was lower at dorsiflexion compared to plantarflexion but they did not differ significantly. Explosive EMD at the neutral angle in the current study is comparable to previous values in male athletes (lateral gastrocnemius (26.5 ± 6.1 ms), medial gastrocnemius (26.6 ± 6.0 ms) (Wang et al., (2012)). There is limited research investigating explosive plantarflexion EMD at angles other than neutral. In the present study, involuntary EMD values are comparable with previously published values by Muraoka et al. (2004) for neutral and dorsiflexion angles (0°: 15.0 ± 1.4 ms, 5°: 14.8 ± 1.4 ms). The plantarflexion angle in the current study (18.5 ± 1.9 ms) slightly differed from this previous research (16.0 ± 2.3 ms), potentially due to differences in tendon slack length between participants in the studies. Across both contraction conditions, EMD tended to decrease while the MTU length increased. The mechanism for this decrease may be explained by the potential presence of tendon slack at the plantarflexion angle. When the length of the series elastic component is below a slack length in a muscle-tendon complex whereby the series elastic component can transmit muscle contraction forces to the bone, the series elastic component needs to be stretched beyond the slack length to transmit muscle force (Muro and Nagata, 1985). The time taken to stretch the series elastic component is therefore prolonged in the plantarflexion condition if tendon slack is present, increasing the EMD. Previous research found no significant difference in involuntary EMD among joint angles of -10°, 0° and 5°, potentially explained by tendon slack being removed at these angles (Muraoka et al., 2004). Contrary to past reports (Muraoka et al., 2004) on involuntary EMD, the current study suggests an increase in MTU length from the plantarflexion angle (-10°) to neutral (0°) and the dorsiflexion angle (10°), results in a significant decrease in EMD. While tendon slack was not measured in the current study, the results suggest that tendon slack may still be present in the MTU at a plantarflexion angle of -10°, evidenced in the differences in EMD between the plantarflexion and neutral angle for both contraction types. Explosive EMD values decreased between plantarflexion and dorsiflexion angles, however the absence of a significant difference may be attributed to high variability in explosive EMD, particularly for the plantarflexion angle (Figure 1).

EMD is an important descriptor of explosive muscular contractions, evidenced by its relationship with maximal explosive contraction force and rate of force development (Bell & Jacobs, 1986). Theoretically, a reduced EMD should enhance the neuromuscular response time to a stimulus, and improve explosive performance. Understanding the determinants of this fundamental measure may have implications for improving explosive neuromuscular performance. This investigation suggests that enhanced explosive neuromuscular performance of the plantarflexors may be achieved as muscle length increases from plantarflexion toward dorsiflexion. This has implications across sports where rapidly producing muscular force is a prerequisite for improved movement outcomes, such as the sprint start. Examination of how these delays may influence performance in activities such as the sprint start hence seem pertinent to inform both strength and conditioning and coaching practice.

CONCLUSION: EMD of the plantarflexors is influenced by both the muscle mode of contraction and the initial MTU length. Across both modes of contraction, EMD decreased while MTU length increased. The results suggest that MTU length is an important determinant of plantarflexor EMD, and may have important implications for sporting performance where the ability to rapidly produce muscular force is crucial e.g. sprinting, cycling.

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