MUSCLE ACTIVATION STRATEGIES DURING AN UNANTICIPATED STOPPING TASK

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The purpose of this study was to determine how time constraints during stopping in sports affect lower limb muscle activation strategies in both the termination and stability steps. Rapid deceleration is common in both recreational and professional sport and has previously been associated with lower limb injury. To investigate control differences between anticipated and unanticipated stopping, total muscle activation and directed co-contraction ratios were used to analyse lower limb muscle activation. Increased plantar flexor and knee flexor activity was found during the pre-contact and weight acceptance phases of unanticipated stopping compared with anticipated stopping. These results support the hypothesis that lower limb muscle activity is altered when the task is unanticipated, which may place athletes at higher risk of lower limb injury in sport.

KEY WORDS: unanticipated stop, EMG, total muscle activation.

INTRODUCTION: Team sports require athletes to rapidly accelerate, decelerate and change direction, often under significant time constraints, in response to an opposing player or to gain possession of a ball. Injuries in these athletes are prevalent, with more than 50% of observed injuries in collegiate sport sustained to the lower extremity (Hootman, Dick, & Agel, 2007). The mechanism of injury to ligamentous and other soft tissues is the inability to withstand the load applied to them in acute instances (Lloyd & Buchanan, 2001). Much work has characterized the net external moments experienced during running and cutting manoeuvres in an attempt to understand the mechanisms of these resulting non-contact, traumatic lower limb injuries, such as anterior cruciate ligament tears (Besier, Lloyd, Ackland, & Cochrane, 2001; Dempsey et al., 2007; Fong et al., 2009). In addition, the effects of unanticipated movements relative to their anticipated counterparts have been investigated as many of the movements that occur during sport are unplanned. Knee moments in the frontal and transverse planes have been found to double during unanticipated sidestepping when compared to their anticipated counterparts (Besier et al., 2001).

In order to reduce strain on the tissues within the knee joint, we must reduce or counter the applied external forces. This can be achieved in two ways: 1) modify an athlete's technique during injurious sporting tasks; or 2) improve the muscular support and activation around the joint to counter external loads. In-vivo, in-silico and ex-vivo research have identified combined applied flexion, valgus and internal rotation moments to elevate ACL strain (Besier et al., 2001; Hashemi et al., 2011; McLean, Huang, Su, & Van Den Bogert, 2004). Consequently, it would be desirable to activate muscles and muscle groups which have anatomical moment arms capable of creating internal moments to counteract elevated external moments, leading to increased joint stability. However, the ability of the central nervous system (CNS) to adjust muscle activation patterns to oppose external joint loading during unanticipated stopping remains unclear. Previous work has reported differences in muscle activation of both limbs during unanticipated stopping during a walking task, finding greater muscle activation during stance in the lead limb likely in an effort to increase limb stiffness and maintain stability (Bishop et al., 2003). The purpose of this study was to quantify the mean total muscle activation (TMA) and directed co-contraction ratios (DCCR) of lower limb muscles that cross the knee joint in both the right leg (termination step) and left leg (stability step) during anticipated and unanticipated stopping for both pre-contact (PC) and the weight acceptance (WA) phase of stance. We hypothesized that: 1) TMA of both limbs would be lower in the unanticipated stopping during PC, while both TMA of the right and left leg would be higher during WA; and 2) DCCRs would shift towards zero in the unanticipated task, indicating increased co-contraction between agonist/antagonist muscle groupings due to the lack of time available for appropriate coordination.

METHODS: Five male (25.4±4.2 years, 1.77±0.05 m, 72.7±6.4 kg) recreational team sport athletes were asked to complete a series of anticipated and unanticipated straight line run-stop tasks (Figure 1). Participants were instructed to run at 4.5 m.s^{-1} along a 20 m runway and stop upon reaching a force plate with the right leg (termination step). Final gait termination occurred on the subsequent contact on a second force platform with their left leg (stabilization step). During these tasks, a large television screen displayed either a stop signal at initiation of the run (anticipated) or after ipsilateral limb toe off (unanticipated). Surface electromyographic (sEMG) data were collected from 12 lower limb muscles (6 right, 6 left): semitendonisis (ST), biceps femoris (BF), rectus femoris (RF), vastus medialis (VM), and medial and lateral gastrocnemius (MG, LG). Sites for wireless electrode placement (Delsys Trigno, Delsys, Inc., Natick, MA, USA) were located and prepared according to SENIAM guidelines (Hermens et al., 1999). Force data were collected from both plates at 1200 Hz while sEMG were collected at 2000 Hz.

Five successful trials (trials in which the participant was able to come to a complete stop with each foot on the correct platforms) were recorded for each condition. A custom MATLAB program (The MathWorks, Inc., Natick, MA, USA) was used to identify the following phases: PC (50 ms before foot contact) and WA (identified as the time from contact to the first trough in the vertical ground reaction force trace) (Dempsey et al., 2007). Once these phases were identified, corresponding periods of muscle activity were segmented from the recorded sEMG data. All sEMG signals were processed in the following manner: 1) the DC bias was removed by subtracting the mean of the signal; 2) a bandpass filter (20-500 Hz) was applied; 3) sEMG were full-wave rectified; 4) a 6 Hz low-pass filter was applied to create a linear envelope; and 5) all EMG were normalized to peak values for each muscle across all trials recorded, respectively. Following signal processing, mean total muscle activation (TMA) for each muscle was calculated (Heiden, Lloyd, & Ackland, 2009). The following muscle groupings were calculated for statistical analysis on the basis of their ability to support the knee joint owing to their anatomical moment arms: quadriceps (TMA-QUAD), gastrocnemii (TMA-GAS), knee flexors (TMA-FLEX, BF and ST), and all muscles crossing the knee joint (TMA-KJ). Directed co-contraction ratios (DCCR) were calculated for the following groupings: flexion-extension (DCCR-FE), medial-lateral (DCCR-ML), and ST-BF (DCCR-STBF). These ratios are constrained between -1 and 1, with 0 values indicating equivalent agonist-antagonist activation (Heiden et al., 2009).

Statistical tests were performed separately for PC and WA. Two-way mixed ANOVAs were used to test for significant differences in task (anticipated vs. unanticipated) as well as the relationship between task and limb. When significant results were found, additional post-hoc tests with a least-squares difference factor were performed to test for differences in limb activation between tasks as well as between limbs within the same task. Statistical analyses were conducted in SPSS (IBM SPSS Statistics 22, SPSS Inc., Chicago, IL) with an α = 0.05.

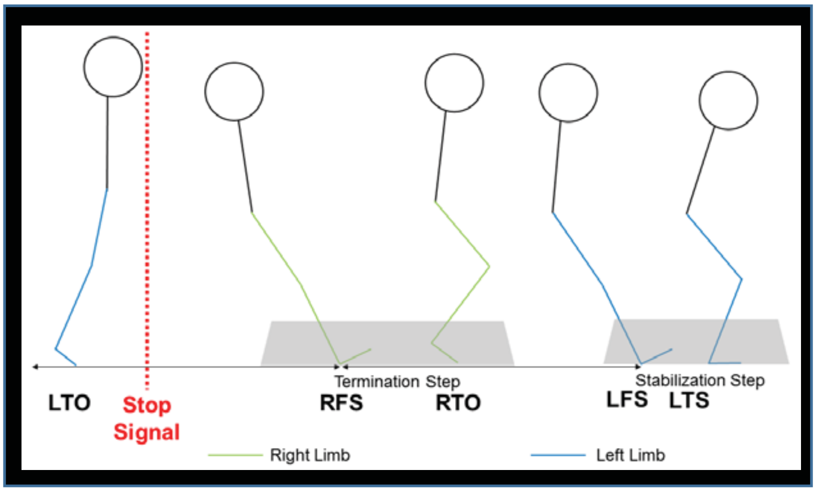

Figure 1. Diagram of unplanned stop condition. Stop signal was triggered at left toe off and the termination step and stabilization step occurred on separate force plates.

RESULTS AND DISCUSSION: During PC, there was a significant increase in TMA-GAS (+Δ17.1%, p=0.032) accompanied by a significant decrease in TMA-FLEX (-Δ5.2%, p=0.036) in unanticipated stopping compared with anticipated stopping (Figure 2a). The increase in TMA-GAS was unexpected. This may be due to altered limb posture at foot contact, causing the contact point to occur more anteriorly on the foot. A significant interaction between limb and task was found in TMA-KJ (p=0.036) and TMA-FLEX (p=0.004) (Figure 2), with TMA-FLEX for the right limb significantly lower during the unanticipated task. During both tasks, DCCRs were shifted toward flexion, medial and external rotation muscles; however, DCCR-FE shifted closer to zero during the unanticipated stop task indicating more generalized co-contraction occurs when time constraints are applied to stopping in sport (p=0.028) (Figure 2c).

In support of our hypotheses, TMA-FLEX decreased during PC in the unanticipated stopping. This is likely due to the reaction time for force generation not being sufficient for pre-activation prior to foot contact. This is especially important during the unanticipated task given the role of the hamstrings during gait is to decelerate the swing limb prior to foot contact (Hamner, Seth & Delp, 2010). It was surprising, however, that only TMA-FLEX of the right limb was significantly different between tasks and not the left limb as well. This may be indicative that the majority of the adaptations to the unanticipated stop occur with the termination step and not the stability step.

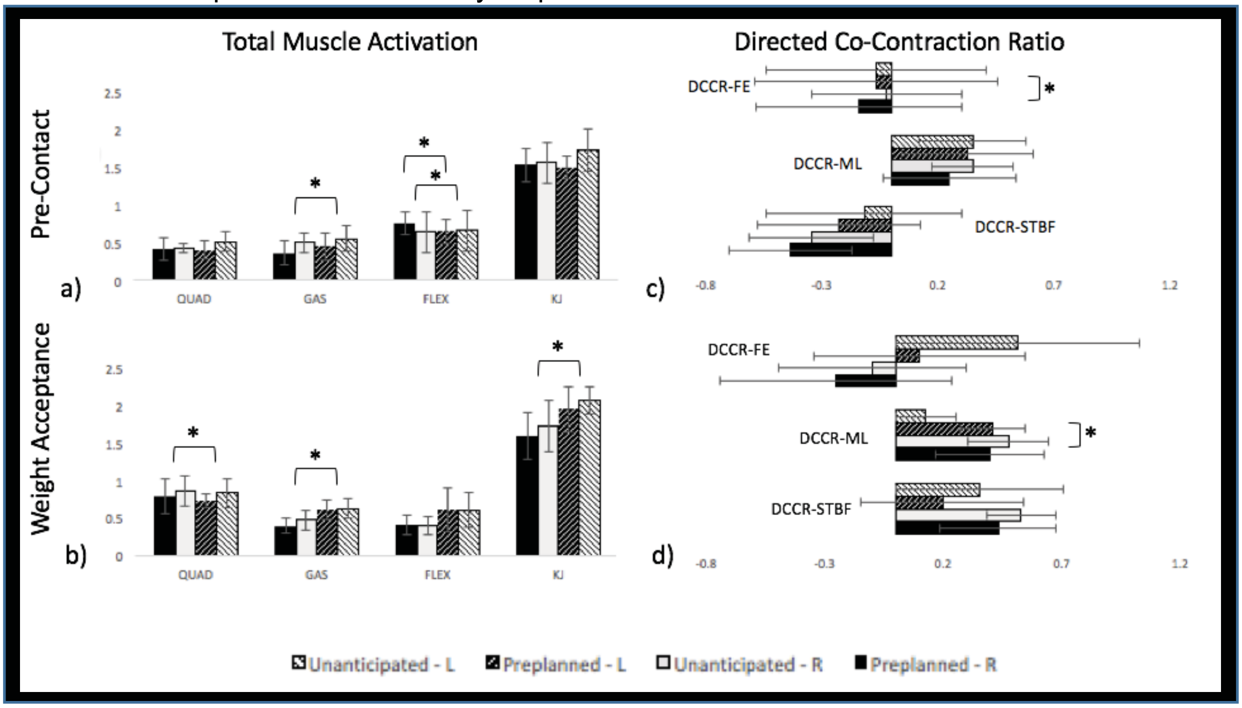

Figure 2. a-b. Mean (SD) total muscle activation (TMA) of muscles crossing the knee joint for right and left limbs during anticipated and unanticipated stopping. Figure 2 c-d. Mean directed co-contraction ratios and SD error bars for R/L limb pairings during anticipated and unanticipated. A DCCR>0 indicated co-contraction was directed toward muscles with flexion and/or medial moment arms, while a DCCR<0 indicated co-contraction was directed toward muscles with extension and/or lateral moment arms.

In support of our first hypothesis, during WA, TMA-QUAD (+Δ11.4%, p=0.041), TMA-GAS (+Δ7.5%, p=0.045) and TMA-KJ (+Δ6.4%, p=0.036) were significantly greater during unanticipated stopping across both legs (Figure 2b). There were no differences in TMA-FLEX between conditions (p=0.728). The increased TMA of most muscle groups may be due in part to potentially increased loads experienced about the knee during the unanticipated stopping. This has been observed during unanticipated sidestepping where increases in frontal and transverse plane knee moments were 70% higher than anticipated conditions (Besier et al., 2001). The lack of differences in knee flexor activation may be caused by the difference in landing strategy and position that occurs during the unanticipated stop. This is supported by the result of TMA-QUAD being higher in the right leg during anticipated relative to the unanticipated stop. Finally, the DCCR-ML shifted closer to 0 during the unanticipated stop in weight acceptance (p=0.050, Figure 2d), indicating greater reliance on co-contraction for joint stability.

CONCLUSION: During unanticipated stopping tasks, athletes adopt a more generalised co-contraction strategy. These findings indicate that the CNS does not provide sufficient muscle coordination when time constraints are placed on sudden stopping in sport which has implications for non-contact injury. Initial results also support the hypothesis and previous research in sidestepping (Besier, Lloyd, & Ackland, 2003) that net muscle activation increases during unanticipated sporting tasks, which may likely be in response to elevated external knee joint loading. We expect further investigation into full body kinematics and lower limb kinetics during these tasks to provide more valuable insight into the reasons for these observed changes.

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