PEAK HAMSTRING MUSCLE-TENDON LENGTHS DURING NON-FATIGUED AND FATIGUED ACCELERATIVE AND MAXIMAL SPEED SPRINT RUNNING IN SOCCER PLAYERS

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Fatigue is thought to be a contributing factor to hamstring injury during sprint running. Injuries can happen during acceleration or maximum speed phases between peak hip flexion and foot-strike, when the hamstring muscle-tendon unit (MTU) is at its longest. The angular displacements of the bones onto which the muscles attach influence hamstring MTU lengths, thus any fatigue-induced alterations to these displacements may be expected to influence MTU lengths, and thus injury risk. We collected 3-D kinematics and modelled hamstring MTU kinematics during the initial three steps of acceleration and two continuous steps of maximum speed sprinting before and after a 45-minute simulated soccer match. Hamstring MTUs exhibited longer lengths during maximum speed compared to acceleration. In maximum speed sprinting, an increase in peak biceps femoris long head (BFlh) length (7 mm) was observed.

KEYWORDS: sprint, soccer, fatigue, hamstring, muscle-tendon unit.

INTRODUCTION: In team-based sports, hamstring injury incidence is greatest toward the end of each quarter or half when both sprint speed and distance are reduced (Ekstrand et al., 2016), indicating the possibility that fatigue may be a contributing factor to injury, especially within the long head of the biceps femoris (BFlh) (Huygaerts et al., 2020; Kellis & Liassou, 2009; Pinniger et al., 2000; Small et al., 2009). As fatigue accumulates during the course of a match, athletes are still required, at times, to accelerate rapidly and then attain high running speeds, which requires significant physical exertion while fatigued, theoretically leaving the muscles exposed to injury (Huygaerts et al., 2020; Small et al., 2009). Two studies in which BFlh was injured during data collection (while running at 5.36 m/s and 7.44 m/s, respectively) reported a longer peak BFlh muscle-tendon unit (MTU) in the injured leg than in the contralateral uninjured leg in the running trials preceding the injury occurrence (Heiderscheit et al., 2005; Schache et al., 2009). The authors of both studies concluded that the injury therefore most likely occurred during the late swing phase (i.e., just prior to foot-ground contact) as the muscles were at their longest working length. Because the length at which muscle fibres operate, especially during eccentric contractions, is a primary factor that influences the magnitude of strain injury (Butterfield & Herzog, 2006), the peak length of MTU is also thought to be a primary predictor of hamstring injury (Schache et al., 2013). While running gait is shown to change across repeated sprint efforts when recovery time is short, it is not yet known whether kinematic changes are sufficient to evoke changes in the length of the hamstring MTU. Therefore, the purpose of this study was to use musculoskeletal modelling to estimate lengths of the three bi-articular hamstrings muscle components during fatigued and non-fatigued sprint running.

METHODS: A cohort of thirteen male intermediate-level soccer players (age: 19.1 ± 2.1 y, body mass: 72.5 ± 6.9 kg, height: 175 ± 7.7 cm) were recruited to participate in this study. All subjects maintained an injury-free status for a minimum of six months and provided written informed consent. Ethical approval was obtained from the Human Ethics Committee of Edith Cowan University.

Data Collection: The anthropometric parameters of height and body mass were recorded, and retroreflective markers were placed on specific anatomical locations. Thirteen VICON motion analysis cameras were positioned at the 35-40 m mark on a 60 m synthetic running track, captured the dynamic trajectories of these markers.

Protocol: Following a standardised warm-up, participants performed acceleration and maximum speed sprints. Dominant and non-dominant limbs were identified through force platform analysis during the single-leg vertical jumps. Three maximal sprints were performed before and after a soccer-specific fatiguing protocol, BEAST 45 (Williams et al., 2010), lasting 45 minutes.

Data Processing: Data from peak hip flexion through to toe-off for both the left and right legs were exported from Visual 3D to OpenSim software (Simtk.org, Stanford USA) for the first three steps of acceleration and two consecutive steps of maximum speed sprinting. Using the generic gait2392 three-dimensional musculoskeletal model available in OpenSim software (Delp et al., 2007), hamstring MTU kinematics were computed during acceleration and maximum speed phases in both non-fatigued and fatigued conditions. The distance (L_{MTU}) of the path between the origin and the insertion sites was taken to indicate the length of the BFlh, SM, and ST MTUs (Schache et al., 2013). The anatomical reference ($L_{0,\ MTU}$) was defined as L_{MTU} during normal standing in the static calibration trial. Changes in L_{MTU} were expressed relative to the anatomical reference $L_{0,\ MTU}$. A positive change was defined as an increase in L_{MTU} with respect to $L_{0,\ MTU,}$ whereas a decrease in L_{MTU} with respect to $L_{0,\ MTU}$ was represented as a negative value (Schache, Dorn, Wrigley, Brown, & Pandy, 2013).

Data Analysis: A two-way repeated measures ANOVA for discrete were conducted. Comparative assessments were made between limbs and conditions, with effect sizes (p = 0.05). Significant differences in joint kinematics and MTU data between non-fatigue and fatigue conditions were observed. To indicate relative timing of each variable, the continuous pelvic tilt, hip flexion, knee extension, and BFlh MTU length curves are shown in Figure 2 below.

RESULTS

Peak MTU lengths

The peak biceps femoris long head (BFlh), semimembranosus (SM) and semitendinosus (ST) MTU lengths were shorter during acceleration, reaching ~0.86-0.92 of the normal upright standing length, than the maximum speed sprint in which they were longer than normal upright standing length, reaching ~1.05-1.08 (1.00 = normal upright length – see Figure 1). After fatiguing exercise, peak SM and ST MTU lengths decreased in Step 3 but no changes were observed in Step 1 or Step 2 of the acceleration phase. No changes in peak lengths were detected in the dominant leg (DL) during maximal speed sprinting after fatiguing exercise, but an increase of ~1.3% was observed for peak BFlh length (~6.98 mm; p = 0.001, ES = 0.62) in the non-dominant leg (NDL – see Figure 1).

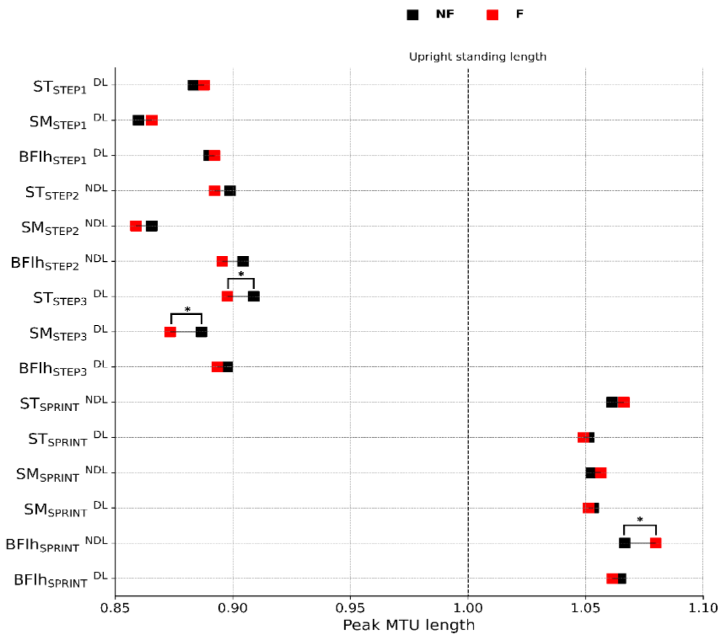

Figure 1. Peak MTU lengths relative to normal upright standing ($L_{0,\ \mathrm{MTU}}$; 1.00) during non-fatigued (black) and fatigued (red) sprinting. The Y axis shows the long head of biceps femoris (BFlh), semimembranosus (SM), and semitendinosus (ST) for lengths in DL and NDL. The STEP1, STEP2, STEP3, and SPRINT subscript denote acceleration and maximum speed sprint trials, respectively. Values > 1.00 represent an increase in MTU length compared to upright standing (vertical dashed line). *statistical difference between non-fatigued and fatigued trials ($p < 0.05$).

Timings of peak MTU lengths

In the non-fatigued condition, peak MTU lengths occurred around foot-strike for all steps during acceleration, while they were reached just prior to foot-ground contact in maximum speed sprinting (Figure 2). The timing of peak anterior pelvic tilt, hip flexion, knee extension, and BFlh MTU length remained unchanged following fatiguing exercise. Figure 2 illustrates the timing of these events exclusively during maximum speed sprinting in the non-fatigued condition (NDL).

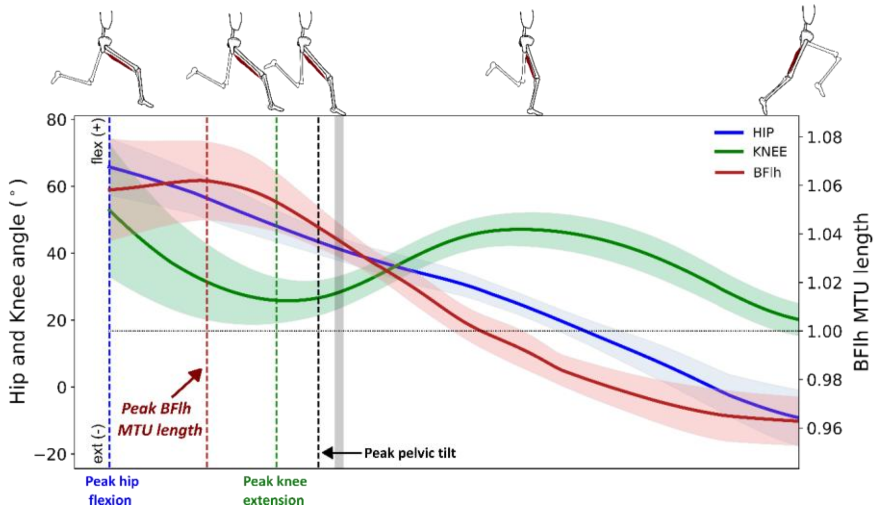

Figure 2. Shows the relative timing of peak anterior pelvic tilt, hip flexion, knee extension, and biceps femoris long head MTU length during maximum speed sprinting in the non-dominant limb (non-fatigued condition). Primary axes: hip and knee joint angles. Secondary axes: biceps femoris long head MTU length (relative to normal standing). Vertical dashed lines represent event sequence, peak hip flexion (blue), peak biceps femoris long head MTU length (maroon), peak knee extension (green), and peak anterior pelvic tilt (black); (grey) represents foot-strike.

DISCUSSION: All hamstring MTUs operated at longer lengths during maximum speed than accelerative sprinting in both non-fatigued and fatigued conditions, and this is likely explained by postural differences between the phases. Thus, if peak hamstring MTUs length is indeed a risk factor for injury, then this is speculatively unlikely to occur within the first three steps of acceleration, even after fatiguing exercise. Fatigue had a slightly greater impact on NDL than DL from both sprint technique and hamstring kinematics perspectives during maximum speed sprinting. Since the semitendinosus and BFlh moment arms are longer than semimembranosus, hip flexion causes relatively greater lengthening of these two muscles. Although knee flexion reduces muscle length, the BFlh has a smaller flexion moment arm than either the semimembranosus and semitendinosus (Schache et al., 2012). Since the hip and knee joint angle maxima do not coincide with peak BFlh MTU length (see Figure 2), peak hamstring MTU length should not be assumed to be associated with either variable. Still, it may prove useful in real-world situations for practitioners to identify lengthened hamstring MTUs during sprinting. The lengths of biarticular hamstring MTUs were approximated by adjusting an OpenSim musculoskeletal model to match the subject's anthropometric measurements. Nevertheless, this approach does not accommodate individual anatomical variations, potentially leading to misalignment between changes in peak MTU lengths and actual muscle length alterations. Furthermore, our observations were limited to the initial three steps of acceleration and two steps during maximum speed sprint running. Consequently, additional research is imperative to identify the specific point in an accelerative run where changes in sprint and MTU kinematics become discernible following fatiguing exercise.

CONCLUSION: Operating lengths of all hamstring MTUs were greater during maximum speed than accelerative sprinting, likely due to postural differences. Fatigue impacted both limb and hamstring MTU kinematics more in NDL than DL during maximum speed running. However, caution is advised when interpreting these results as the model used to obtain hamstring MTU lengths is generalised and does not account for individual anatomical differences or muscle activity.

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