EFFECT OF FATIGUE FROM REPEATED SPRINTS ON HAMSTRING MUSCLE ACTIVATION PATTERNS DURING RUNNING

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Hamstring injury has been associated with fatigue-induced reductions in activation levels during running. This study examined neuromuscular changes of the hamstring muscles as a result of fatigue following sprinting in a group of nine team sport athletes. Hamstring muscle activation, lower-limb kinematics and isokinetic eccentric hamstring strength were assessed to examine the effects of fatigue during running at five different sub-maximal speeds. As expected, there were significant increases in both Biceps Femoris (BF) and Semitendinosus (ST) activations with running speed ($P < 0.001$). After fatigue, BF activation during late swing significantly decreased by an average of 11% ($P=0.002$). There was evidence in some subjects that ST activity was increased with fatigue but the increase (4%) was non-significant for the group. There was also a tendency for reduced BF activity with fatigue to be more evident at the faster speeds of running. These findings support other evidence in the literature that the lateral hamstrings are more susceptible to fatigue. In addition, there were signs of compensatory increased ST activation levels in some subjects. These effects lend support to the potential benefit of this neuromuscular assessment of the hamstrings as a useful measure of both performance and recovery.

KEYWORDS: EMG, treadmill, running speeds, return to play

INTRODUCTION: The rate of hamstring injury re-occurrence is high, with a large number occurring within the first two weeks after return-to-sport (DeWitt and Vidale, 2014). Such immediate injury re-occurrence can cause an athlete's absence from sport participation for prolonged periods of time (Ebben, 2009; Valle *et al,* 2015; Woods *et al*, 2004; Orchard and Best, 2002). Important injury-risk factors include hamstring muscle activation and eccentric actions when the muscles are beyond their optimal length, primarily during the late swing phase (Schache *et al,* 2009). During fatigue, the hamstrings are potentially overworking to compensate for a reduction in strength to decelerate knee extension and extension of the hip joint (Pinniger *et al,* 2000)). Moreover, it has been suggested that the Biceps Femoris (BF) is more susceptible to injury with high-intensity running and has been shown to be the most commonly injured hamstring muscle (Chumanov *et al,* 2007; Dolman *et al,* 2014). A possible contributing factor are the high forces required from the BF during the late swing phase (Dolman *et al,* 2014). This study therefore aimed to explore the effects of sprinting-induced fatigue on the neuromuscular functioning of the BF and Semitendinosus (ST) muscles.

METHODS: Nine active participants took part in this study (7 males, mean age of 23.8 ± 4.6 years; height 180.4 ± 5.4 cm; body mass 76.8 ± 8.2 kg. 2 females, mean age of 23 ± 1.4 years; height 160 ± 7.1 cm; body mass 52.2 ± 5.4 kg). No participants had any history of lower limb injuries in the last 24 months. Each participant signed a written consent and completed a ready to exercise questionnaire prior to study. After a short warm up, participants performed baseline strength and running trials. Each participant's maximal hamstring strength was measured during one set of three eccentric knee extensions at 240º/s on an isokinetic dynamometer (Biodex), before and after the fatigue protocol. This measure was performed to determine the participant's changes in hamstring muscle activity patterns were due to fatigue. They then ran on a treadmill at five submaximal speeds (3.6, 3.9, 4.2, 4.5 and 4.8 m/s) during which 10-sec of right leg lower-limb kinematics and hamstring muscle activations were monitored. Lower-limb kinematics were recorded using a 38 retroreflective marker set and an eight-camera motion capture system (Qqus 300+, Qualisys, Gothenburg, Sweden) sampling at 250 Hz. Activation of the BF and ST muscles was collected using a wireless electromyography (EMG) system (Noraxon, Scottsdale, AZ) sampling at 1000 Hz. Following baseline measurements, participants performed a fatigue protocol consisting of fifteen, 30-metre sprints with short 30-second rest intervals. Immediately after this intense exercise bout, the same eccentric strength and treadmill running trials were repeated to enable pre- and post-fatigue comparisons. Peak eccentric knee extension torques allowed fatigue levels to be quantified. All marker positional data were tracked using Qualisys Track Manager Software (Qualisys, Gothenburg, Sweden) and, together with muscle EMG, exported to Visual3D (C-Motion, Germantown, MD) for further processing and analysis. EMG signals for both muscles were filtered with a fourth-order Butterworth high- and low-pass filter of 20 Hz and 500 Hz, respectively, full-wave rectified, smoothed with a moving average window of 50ms, and normalised to the maximal measured participant-muscle specific activation recorded at the fastest running speed. These rectified and smoothed bursts of activity were averaged across strides (see figure 1) and then the area under the curves (mean I-EMG) determined using the first 5-25% of the gait cycle to obtain the magnitude of the PFC phase and the last 20% to obtain the EOS phase. In addition, peak values were obtained for knee flexion and extension angles, and hip flexion and extension angles. These were monitored to provide insight on hip/knee relative changes that influence the lengthening and shortening of the hamstrings. Peak kinematic characteristics and I-EMG data were analysed in SPSS (IBM, SPSS, Chicago, IL) using a two-way repeated measures ANOVA (within-subjects) with two factors of fatigue (two levels) and speed (five levels). Maximal strength tests were analysed using a paired *t*-test to assess the difference in absolute strength of the hamstrings pre and post sprinting-induced fatigue.

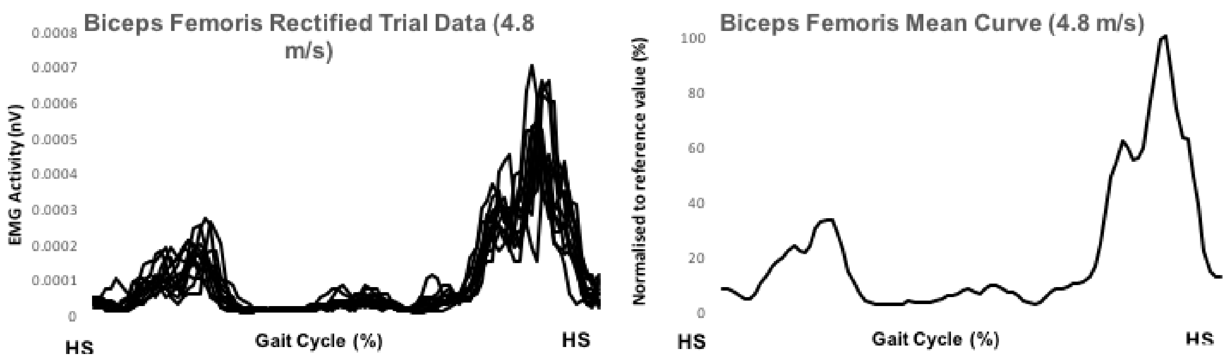

Figure 1. Activation patterns of the Biceps Femoris at one speed (4.8 m/s) for a typical subject. All strides (10-13) were aligned to heel strike (HS, 0%) (left figure), then averaged and normalised to the maximal value at the fastest speed (right figure). Consistent timing of the bursts of the BF after foot contact and towards the end of the swing phase (largest burst) can be seen.

RESULTS:

Kinematics. There were no significant interactions between speed and fatigue for kinematic variables, but there were increases in peak knee extension with both speed ($F_{4, 32} = 4.1$, $P = 0.008$) and fatigue ($F_{1, 8} = 5.7$, $P = 0.045$) prior to touch-down. Similarly, there were significant increases in peak hip extension with both speed ($F_{4, 32} = 25.1$, $P = 0.000$) and fatigue ($F_{1, 8} = 5.7$, $P = 0.044$).

I-EMG activation levels. There were no significant interactions between speed and fatigue for both the BF and ST muscles during running. There were expected significant increases in I-EMG for both BF and ST with running speed ($p<0.001$).

There were significant decreases (-11%) in BF activity level during late swing (EOS) with fatigue ($F_{1,8}$ = 20.32, P = 0.002). Although not statistically significant, there was also a tendency for BF activity to decrease after ground contact (PFC) as well ($F_{1,8}$ = 4.99, P = 0.056).

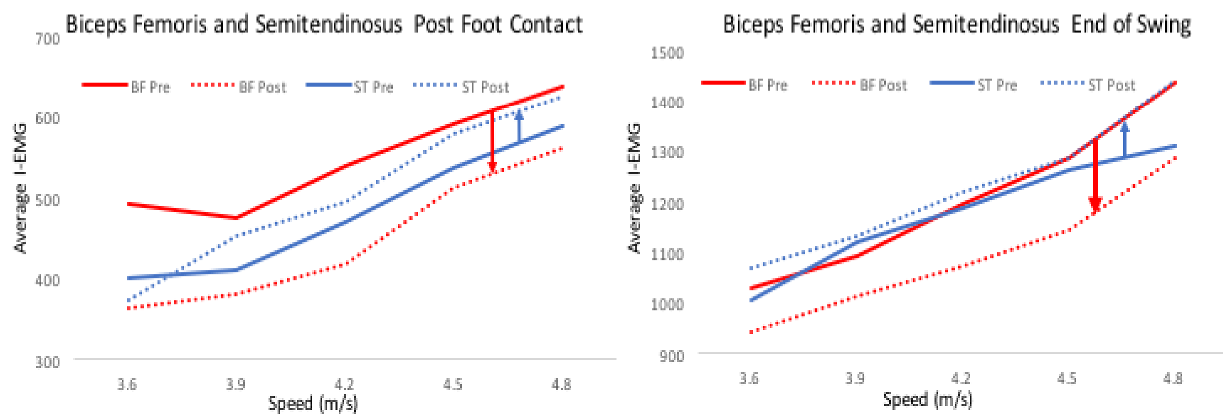

Figure 2. I-EMG values of Biceps Femoris (BF) and Semitendinosus (ST) during Post Foot Contact (PFC) and End of Swing Phase (EOS), pre and post fatigue at five increasing running speeds. Notice that BF activation levels decrease with fatigue and ST activation levels tend to increase at higher running speeds (identified using vertical arrows, where red represents BF and blue represents ST.

Table 1. Means, standard deviations and P-values from the main effects of fatigue in biceps femoris (BF) and semitendinosus (ST) during post foot contact (PFC) phase and End of Swing (EOS) phase. Significant decreases with fatigue were seen in the BF in the EOS phase (-11%), although the decrease with fatigue for biceps BF in the PFC phase (-18%) was not quite significant due to increased inter-subject variability. PFC phase and EOS phase in ST show increases in mean activity (PFC = 4.8%; EOS = 4.2%) although inter-subject differences were large.

		BF				ST			
		PFC		EOS		PFC		EOS	
Fatigue	Pre	547.10 ± 76.05	P = 0.056	1208.13 ± 54.46	P = 0.002	481.73 ± 75.84	P = 0.329	1176.65 ± 68.41	P = 209
	Post	447.54 ± 71.76		1091.04 ± 56.13		505.75 ± 73.66		1228.67 ± 83.22	

DISCUSSION: The purpose of this study was to assess the effects of a bout of fatiguing sprints on the neuromuscular functioning of the BF and ST muscles during a range of submaximal running speeds. In line with the literature, hamstring muscle activity levels and extension at the hip and knee increased alongside increases in running speed.

The main finding was that due to sprinting-induced fatigue the activation of the BF was decreased during the late swing phase of running and there was a tendency for it to decrease just after ground contact as well. In contrast, although not significant for the group, there was evidence of increases in ST activity with fatigue during faster speeds in some subjects who demonstrated higher levels of fatigue. These results suggest that with fatigue, decreases in BF activation might be compensated to some extent by an increase in ST activation. Previous studies have demonstrated these compensatory mechanisms to be emphasised after hamstring injury (Lake et al, 2018), as well as anterior cruciate ligament injury (Smeets et al, 2019).

The BF and ST reached their highest activation levels during the late swing phase for all running trials. Furthermore, the change in activity between fatigue displayed greatest values in BF and suggests that this muscle has a tendency to fatigue quicker than ST. Schache *et al,* (2012) found that during the late swing, the hamstring muscles were most active and concurs with the findings in this study. Furthermore, a variation of the characteristics in biomechanical load was detected in the muscle activity during late swing. BF was found to have the highest peak strain, while ST generated the highest lengthening velocity. One would suggest that with fatigue as BF decreased in activity, this may be an indication why ST sometimes increases activation as it is needed to compensate and help to slow down the rapid rate of knee extension before heel strike, especially at faster speeds. We found in this study that knee extension and hip extension were both increased with fatigue. This evidence suggests that during the EOS phase, the hamstrings are at a higher risk of injury and may provide some insight into BF being more susceptible to injury.

There has been a significant decrease in peak eccentric knee extension torque of the hamstring muscles after the fatigue protocol, resulting in a mean decrease of 24.3%, suggesting that the repeated sprints were the cause of fatigue. Decreased hamstring strength could be an indicator of reduced force absorption thus resulting in the BF being more susceptible to injury. Furthermore, this finding accompanies the incidence of hamstring injuries occurring more often in the latter stages of the soccer match, due to fatigue.

CONCLUSION:

The BF appeared to be more susceptible to fatigue especially at faster speeds of running. The presented neuromuscular assessment of the hamstrings during running at a range of running speeds has the potential to evaluate performance during training and also perhaps evaluate when the hamstrings are ready to meet the demands of high speed running.

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