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Original paper

The effects of multidirectional soccer-specific fatigue on markers of hamstring injury risk

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Abstract

The purpose of this work was to investigate the effect of multidirectional soccer-specific fatigue on hamstring muscle strength and angle of peak torque. Sixteen male semi-professional soccer players (mean ± S.D.: age: 21.3 ± 2.9 years; height 185.0 ± 8.7 cm; body mass 81.6 ± 6.7 kg) completed the $SAFT^{90}$, a multidirectional, intermittent 90-min exercise protocol based on data from English Championship soccer matches. Prior to exercise (t_0), at half-time (t_{45}) and post-exercise (t_{105}), subjects performed three maximal dominant limb isokinetic contractions (Biodex, System 3) at $120^\circ\,s^{-1}$ through a 90° range for concentric and eccentric knee flexors and concentric knee extensors. Analysis of variance revealed significant time dependant reductions in gravity corrected eccentric hamstring peak torque, and consequently in the functional hamstring:quadriceps ratio ($P < 0.01$). Eccentric hamstring peak torque decreased significantly during each half (t_0: 272.0 ± 43.2; t_{45}: 240.4 ± 43.3; t_{105}: 226.3 ± 45.7 N m). The functional hamstring:quadriceps ratio also decreased significantly during each half (t_0: 116.6 ± 21.2; t_{45}: 107.1 ± 17.6; t_{105}: 98.8 ± 20.3%). There were no significant changes in concentric hamstring or quadriceps peak torque observed during $SAFT^{90}$ ($P > 0.05$). Data analysis also revealed significant differences for Angle of Peak Torque for eccentric hamstrings ($P < 0.05$) which was significantly higher at the end of each half (t_{45}: 37 ± 15; t_{105}: 38 ± 18°) than the pre-exercise value (t_0: 28 ± 12°). There was a time dependant decrease in peak eccentric hamstring torque and in the functional strength ratio which may have implications for the increased predisposition to hamstring strain injury during the latter stages of match-play.

Keywords: Injury; Epidemiology; Soccer; Field test; Eccentric

1. Introduction

Epidemiological research in professional soccer has reported changes in injury profiles during recent years. Studies in the 1980s reported a majority of ankle and knee ligament injuries[1,2] but recent studies have reported hamstring strains as the most common injury to soccer players,[3–5] causing three competitive matches missed per injury.[5] In order to minimise the incidence of hamstring strains and associated costs; more effective injury preventive intervention programmes have been recommended.[6]

A variety of predisposing aetiological factors have been proposed relating to hamstring strain injury risk including insufficient flexibility,[7] inadequate warm-up,[8] muscle weakness,[9] previous injury,[10] strength imbalance between hamstrings and quadriceps[11] and fatigue.[6,12] Injury incidence is most likely to be the result of an interaction between multiple risk factors.[13] With half of all hamstring injuries during matches occurring within the last 15 min of each half[5] fatigue may be a predisposing factor to hamstring strain injury. Muscular fatigue is most evident towards the end of play with a 5–10% decrease in total distance covered in the second half of matches.[14] Muscle strength deficiency, due to fatigue, has been proposed to increase susceptibility to injury.[12,15] Decreased hamstring force as a result of fatigue reduces energy absorption capabilities, increasing the potential for injury.[16] Injury risk may be greatest with muscle weakness during eccentric contractions, as fatigued muscles are more susceptible to stretch injury whilst eccentrically contracting.[17]

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Rahnama et al.[12] examined the relationship between muscular imbalances and muscular fatigue associated with soccer match-play, reporting significant reductions in knee flexor and extensor peak torque, and a reduction in the functional eccentric hamstrings:concentric quadriceps strength ratio. This may imply insufficient hamstring strength to decelerate the leg during the latter part of the swing phase in sprinting, at which point eccentric overload could cause tearing in the musculo-tendinous unit.[18] These findings were further supported by Greig[15] using a 90 min treadmill protocol more closely replicating the activity profile of soccer match-play.

The studies by Rahnama et al.[12] and Greig[15] are perhaps the closest attempts at investigating the effect of soccer-specific fatigue on hamstring strength and muscular imbalance. However, the fatigue protocols employed are not truly reflective of the multidirectional nature of the sport. Both investigations have simulated either the mechanical[15] or physiological demands[12] of soccer match-play, but not both, which makes inferences about the fatigue effect to soccer match-play difficult. Furthermore, no previous study has concurrently investigated changes in the angle of peak torque as may have implications for injury potential.

Hence, the aim of this study was to investigate the effect of a 90 min multidirectional soccer-specific fatigue field test on eccentric hamstring strength and hamstring:quadriceps muscular imbalances, as well as the angles of peak torque regarding implications for hamstring injury risk.

2. Methods

Sixteen male semi-professional soccer players (mean ± S.D.; age: 21.3 ± 2.9 years; height 185.0 ± 8.7 cm; body mass 81.6 ± 6.7 kg) took part in the investigation. All players completed on average two squad training sessions and two matches per week. Subjects were included in the study if they were not injured or rehabilitating from an injury at the time of testing, and did not have a history of a previous hamstring injury within 3 months prior to testing. Written, informed consent was obtained prior to data collection from the subjects, and approval for the study obtained in accordance with Departmental and University ethical procedures.

Subjects completed a 90 min soccer-specific aerobic field test (SAFT[90]). The SAFT[90] protocol was divided into two 45 min periods interceded by a 15 min passive rest period (half-time). Prior to exercise (t_0), at half-time (t_{45}) and post-exercise (t_{105}), subjects performed three maximal dominant limb isokinetic contractions for concentric and eccentric knee flexors (conH, eccH) and concentric knee extensors (conQ).

The subjects performed no vigorous exercise 24 h prior to testing, or had consumed any caffeine or alcohol. The testing was conducted following preseason training at the start of the 2007/2008 English competitive soccer season. The training load and amount of match-play performed was as standard to the competitive season, involving two soccer training sessions and matches per week.

The SAFT[90] was based on contemporary time-motion analysis data obtained from 2007 English Championship Level match-play (Prozone®). The protocol was validated by Lovell et al.[19] to replicate the fatigue response of soccer match-play.[20] The free running protocol was designed to include multidirectional and utility movements, and frequent acceleration and deceleration as is inherent to match-play. The design of the course was based around a shuttle run over a 20 m distance, with the incorporation of four positioned poles for the subjects to navigate using utility movements (Fig. 1).

The course is performed with the subject performing either backwards running or sidestepping around the first field pole, followed by forwards running through the course, navigating the middle three field poles. The movement intensity and activity performed by the subjects whilst completing the SAFT[90] course was maintained using verbal signals on an audio CD. A 15 min activity profile was developed and repeated randomly and intermittently, six times during the full 90 min simulated soccer match. The profile incorporated 1269 changes in speed and 1350 changes in direction over the 90 min, although no contact actions such as kicking or tackling were performed. Table 1 shows the distances covered for each of the activities during the SAFT[90] and match-play data.

Isokinetic peak torque for the knee flexors and extensors (of the subjects dominant leg; their ‘kicking’ leg) was measured using a dynamometer (Biodex System 3, Biodex Medical, Shirley, NY). Prior to testing, subjects participated

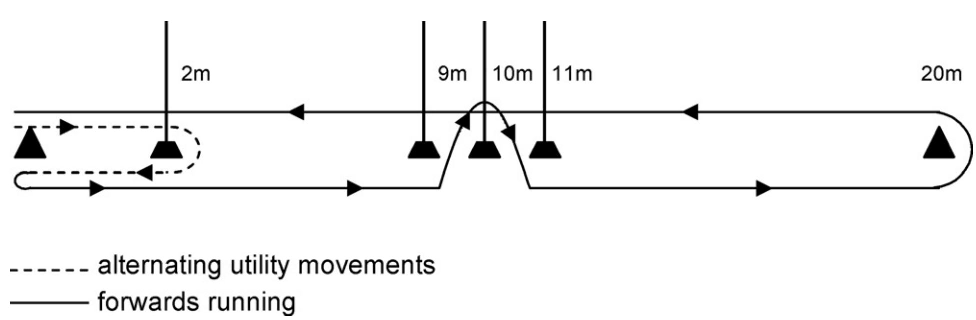

Fig. 1. A diagrammatic representation of the SAFT[90] field course.

Table 1
Distances covered of each activity during SAFT[90] and match-play data.

Activity	Distance during SAFT[90] (km)	Distance from match-play data (km)
Standing (0.0 km h^{-1})	0	0.02
Walking (5.0 km h^{-1})	3.36	3.60
Jogging (10.3 km h^{-1})	5.58	5.81
Striding (15.0 km h^{-1})	1.50	1.46
Sprinting (≥20.4 km h^{-1})	0.34	0.27
Total distance (km)	10.78	11.08

in a standardised warm-up procedure, which included, 5 min on a cycle ergometer at 60 W, 5 min of static and dynamic stretches for the major lower limb muscle groups and 5 min light jogging and familiarisation with the SAFT[90] exercise protocol.

During testing, subjects were seated on the dynamometer in an adjustable chair, with test positions recorded and repeated for each subject in subsequent trials. Subjects performed three maximal voluntary concentric quadriceps and hamstrings actions, and three eccentric hamstring muscle actions. The order of testing was standardised for subsequent testing throughout the experimental trial. All actions were performed on the subjects' dominant leg through a range of 0°–90° knee flexion and extension (with 0° being full knee extension). A one min passive recovery was allowed between each trial. The muscle actions were completed at an isokinetic angular velocity of 2.09 rad s^{-1} (120° s^{-1}). This test speed was selected as it has been shown to be acceptable as one of the fastest and safest speeds in which to reliably test eccentric hamstring muscle contractions.[12]

An analysis of variance (ANOVA) for repeated measures, with the least significant difference (L.S.D.) post-hoc test, was used to compare means and ±S.D. from muscle strength variables measured at each of the three time points: prior-to exercise (t_0), at half-time (t_{45}) and post-exercise (t_{105}).

Gravity-corrected peak torque (PT) values for concentric quadriceps, concentric hamstring and eccentric hamstring enabled calculation of the Traditional concentric hamstrings:concentric quadriceps (conH:conQ) and Functional eccentric hamstrings:concentric quadriceps (eccH:conQ) strength ratio's. The angles of peak torque (APT) were also recorded for the three muscle actions tested. All variables were analysed in respect to changes over time throughout the SAFT[90], for differences between values at the three time points: prior-to exercise (t_0), at half-time (t_{45}) and post-exercise (t_{105}).

Statistical analysis was processed using SPSS statistical software (version 14.0© Chicago, IL) with significance levels set at $P \leq 0.05$, and effect sizes were determined using the partial Eta-squared (Eta) method. When applied to ANOVA, it has been suggested than an effect size of 0.1 represents a small effect size; 0.25 a medium effect; and ≥0.4 a large effect.[21]

3. Results

The conQ PT was not significantly different ($P > 0.05$; Eta = 0.123) between t_0 (235.0 ± 20.1 N m) and t_{45} (225.0 ± 22.4 N m) or t_{105} (228.1 ± 18.5 N m). The conH PT demonstrated a decrease throughout SAFT[90], however this result was found to be non-significant (t_0 = 140.8 ± 38.0; t_{45} = 133.9 ± 27.9; t_{105} = 131.4 ± 20.8 N m, $P > 0.05$; Eta = 0.052). There was a significant difference in eccentric hamstring PT during SAFT[90] ($P < 0.01$; Eta = 0.672; Fig. 2). Post-hoc tests revealed significant reductions in eccH PT between t_0 and t_{45} by 5.2% ($P < 0.01$), and also during the second half between t_{45} and t_{105} by 6.2% ($P < 0.03$), with an overall significant decrease of 16.8% over the full 90 min ($P < 0.01$).

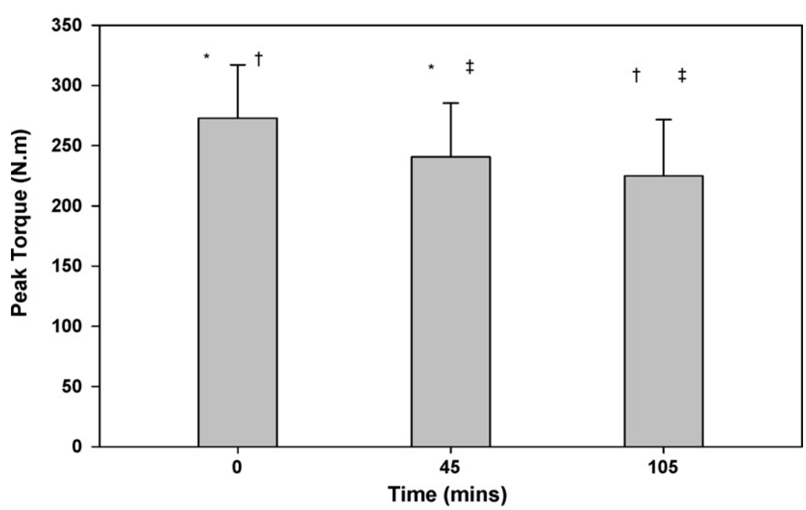

Fig. 2. Eccentric hamstring peak torque during SAFT[90]. *Significant difference between t_0 and t_{45}; †significant difference between t_0 and t_{105}; ‡significant difference between t_{45} and t_{105}.

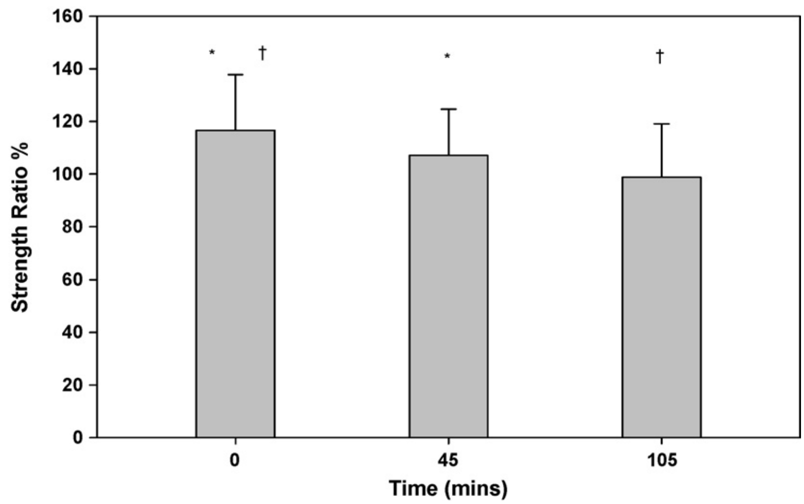

Fig. 3. Eccentric hamstring:concentric quadriceps strength ratio during SAFT[90]. *Significant difference between t_0 and t_{45}; †significant difference between t_0 and t_{105}.

The conH:conQ ratio revealed no significant changes during SAFT[90] ($P>0.05$; Eta = 0.026), however significant changes were observed with time in the Functional eccH:conQ ratio ($P<0.02$; Eta = 0.398; Fig. 3). The post-hoc tests revealed a significant decrease between t_0 and t_{45} by 8.9% ($P<0.02$), and with a significant decrease of 15.0% observed over the 90 min ($P<0.01$). Although a decrease was further observed in the Functional eccH:conQ ratio between t_{45} and t_{105} this finding was statistically non-significant ($P>0.05$).

There were significant differences in the conQ APT during SAFT[90] ($P<0.03$; Eta = 0.214; Fig. 4). Significant differences were observed between t_0 and t_{45} of 5.5% ($P<0.01$) and between t_0 and t_{105} of 5.0% ($P>0.05$). The conH APT also revealed significant changes over time ($P>0.01$; Eta = 0.297; Fig. 4). Post-hoc tests showed significant differences between t_0 and t_{45} of 20.0% ($P<0.03$) and between t_0 and t_{105} of 25.4%. Significant changes in eccH APT were also observed during SAFT[90] ($P<0.04$; Eta = 0.227; Fig. 4). Post-hoc tests identified significant differences between t_0 and t_{45} of 23.2% ($t_0 = 28.2 \pm 11.7$ vs $t_{45} = 36.7 \pm 14.5°$, $P<0.02$) and between t_0 and t_{105} of 26.2% ($t_0 = 28.2 \pm 11.7$ vs $t_{105} = 38.2 \pm 18.2$; $P<0.02$). No significant differences in APT were observed between t_{45} and t_{105} for any of the muscle actions tested ($P>0.05$).

4. Discussion

The SAFT[90] exercise protocol designed to replicate the physiological and mechanical demands of soccer match-play was shown to induce a diminished capacity of the knee flexor muscles to generate eccentric force. The SAFT[90] also impaired the functional eccH:conQ strength ratio and muscular balance. The 16.8% reduction in eccentric hamstring peak torque during our 90 min protocol, is identical

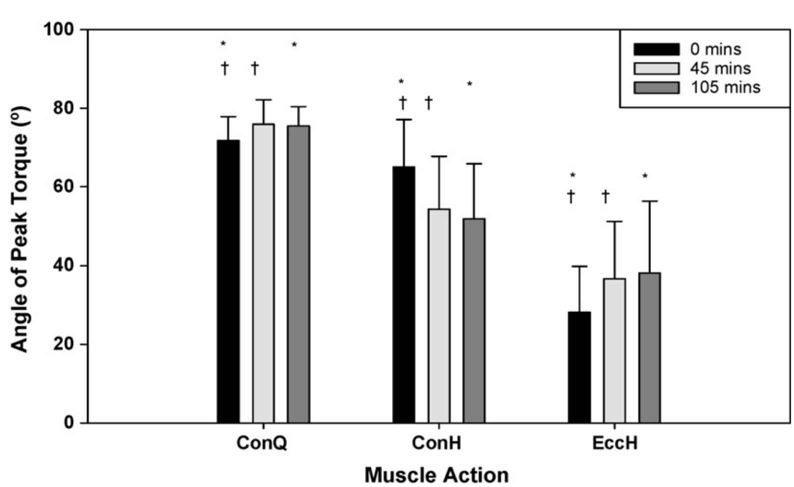

Fig. 4. Angle of peak torque for concentric quadriceps, concentric hamstring and eccentric hamstring muscle actions during SAFT[90]. *Significant difference between pre-exercise and post-exercise; †significant difference between pre-exercise and half-time.

to the decrement reported by Rahnama et al.[12] Also, our study found a 15.0% reduction in the functional eccH:conQ strength ratio, similar to the 13.0% reported by Rahnama et al.[12] following a 90 min treadmill protocol.

Rahnama et al.[12] observed significant reductions in both concentric hamstrings and quadriceps peak torque during the treadmill protocol. This contradicts our findings which observed maintained concentric muscle strength. This may potentially be explained by differences in the exercise protocols. The protocol employed by Rahnama et al.[12] was performed on a programmable treadmill, without utility movements, and comprising only 92 discrete bouts of activity during the 90 min. The greater amount of time spent in the high intensity cruising and sprinting in particular, may have created the greater physiological cost, and the additional muscular requirement to match the extra load imposed by the multidirectional and more frequently intermittent $SAFT^{90}$ protocol. Therefore, we would speculate that the results from the current study are more representative of the response associated with actual soccer match-play. However, no kicking actions were performed during the $SAFT^{90}$ protocol as may have increased the load to the quadriceps reflective of match-play, the inclusion of which may be a future progression for protocol.

Greig[15] reported no effect of the simulated match-play protocol on either concentric hamstring or quadriceps peak torque which supports our results. Greig[15] also reported significant reductions in eccentric hamstring peak torque and the functional eccH:conQ strength ratio between pre- and post-exercise values similar to findings from the current study. However, comparisons of these results to findings from the present investigation should be treated with caution due to the differing isokinetic angular velocities selected by Greig.[15] Furthermore, the more frequent contractions administered by Greig[15] may have increased the fatigue effect sustained during the exercise protocol contributing to the results observed. Although the isokinetic protocol may have also contributed to the drop in eccentric hamstring strength observed in the present investigation, as a substantially shorter and less frequent protocol was employed, the findings may be more likely to be the result of the multidirectional utility movements in the $SAFT^{90}$ at inducing the eccentric demands of match-play.

The observed decline in eccentric hamstring strength with fatigue is commonly associated with hamstring strain injury risk, since during powerful eccentric contractions the muscles are most susceptible to injury.[10,16] Sprinting is the most common mechanism for hamstring strains amongst soccer players,[5] whereby the hamstrings have a primary function to eccentrically decelerate the forward motion of the thigh and leg in the late swing phase of the cycle in preparation for foot-contact.[22] Therefore, reduced peak eccentric hamstring torque with fatigue, as observed during the $SAFT^{90}$, may help explain the reported increased predisposition to hamstring strain injury during the latter stages of match-play.[5]

The reduction in the functional eccH:conQ strength ratio also observed in this study may indicate that the hamstrings have insufficient strength to decelerate the forward moving hip and knee from the acceleration caused by the quadriceps at the latter part of the swing phase of sprinting. Small et al.[23] observed an increase in lower limb segmental velocity during the late swing phase of sprint running with fatigue associated with soccer match-play. This finding combined with our results may indicate impaired ability of the hamstrings to eccentrically decelerate the high segmental velocity of the lower limb to avoid hamstring injury. This would appear to corroborate findings of increased susceptibility to hamstring injury during the last third of the first and second halves of soccer match-play.[5]

To our knowledge, this is the first study to report changes in the knee flexor and extensor angles of peak torque associated with soccer match-play. The concentric quadriceps and hamstrings muscle actions tested revealed a shift in the optimum length for peak muscle tension in the direction of longer muscle lengths with fatigue during the $SAFT^{90}$. A number of theories have been proposed to help explain this finding, with perhaps the most widely accepted being the "popping sarcomere hypothesis".[24]

A potential consequence of this could cause a significantly greater loss of relative force to occur at shorter muscle length compared to optimal or long muscle lengths, as associated with muscle damage from eccentric contractions.[25] Furthermore, it has been suggested that at this point there may be increased susceptibility to damage, and therefore risk of injury.[26] Alternatively, LaStayo et al.[27] argued that an increase in stiffness and peak torque at longer muscle lengths may actually increase force production before failure and therefore help prevent active muscle strain injuries by improved stability, whilst possibly enhancing athletic performance. The disparity surrounding this subject area suggests that further research is warranted.

The change in APT was also significantly altered with time during the $SAFT^{90}$ in relation to the eccentric hamstring peak torque muscle action. However, contrary to the other muscle actions tested, the eccentric hamstrings APT revealed a shift towards a shorter muscle length with fatigue. This innovative finding within the research area may have important implications for injury risk, as it is believed that athletes who produce peak torque at shorter muscle lengths are at a greater risk of injury.[26,29]

It has been proposed that peak torque generation at a shorter optimum muscle length would mean that more of the muscles operating range would be on the descending limb of the length–tension curve.[28] Thereby as muscles are more likely to become injured when operating in a more lengthened position,[18] this may help explain the increased predisposition of hamstring strain injuries during the latter stages of match-play when the APT has been observed as at a shorter muscle length, and especially with the concurrent deterioration in eccentric hamstring peak torque also reported.

5. Conclusion

The SAFT^{90} produced a time dependant decrease in eccentric knee flexor strength, and subsequently in the functional eccH:conQ strength ratio, and changes in knee flexor and extensor angles of peak torque. A shift in the angle of peak torque towards longer muscle lengths during concentric knee extensor and knee flexor actions with time was observed, whereas for the eccentric knee flexor action there was a shift towards shorter muscle length.

These findings may have implications for the increased predisposition to hamstring strain injury during the latter stages of soccer match-play. Strategies that can reduce the negative effects of fatigue during match-play may help lower the risk of hamstring injury during the latter stages of soccer match-play.

Practical implications

- Reduced eccentric hamstring strength, and functional eccH:conQ ratio, and increased angle of peak torque for eccentric hamstring muscle action observed during latter stages of simulated soccer match-play.
- Higher risk of hamstring injury indicated at this time supports epidemiological match-play observations.
- Future injury prevention strategies may need to consider reducing negative effects of fatigue.

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