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original research

Soccer-Specific Fatigue and Eccentric Hamstrings Muscle Strength

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Context: Epidemiologic findings of higher incidences of hamstrings muscle strains during the latter stages of soccer match play have been attributed to fatigue.

Objective: To investigate the influence of soccer-specific fatigue on the peak eccentric torque of the knee flexor muscles.

Design: Descriptive laboratory study.

Setting: Controlled laboratory environment.

Patients or Other Participants: Ten male professional soccer players (age = 24.7 ± 4.4 years, mass = 77.1 ± 8.3 kg, $\dot{V}O_{2max}$ = 63.0 ± 4.8 mL·kg^{-1}·min^{-1}).

Intervention(s): Participants completed an intermittent treadmill protocol replicating the activity profile of soccer match play, with a passive halftime interval. Before exercise and at 15-minute intervals, each player completed isokinetic dynamometer trials.

Main Outcome Measure(s): Peak eccentric knee flexor torque was quantified at isokinetic speeds of 180° · s^{-1}, 300° · s^{-1}, and 60° · s^{-1}, with 5 repetitions at each speed.

Results: Peak eccentric knee flexor torque at the end of the game ($T_{300eccH105}$ = 127 ± 25 Nm) and at the end of the passive halftime interval ($T_{300eccH60}$ = 133 ± 32 Nm) was reduced relative to $T_{300eccH00}$ (167 ± 35 Nm, $P < .01$) and $T_{300eccH15}$ (161 ± 35 Nm, $P = .02$).

Conclusions: Eccentric hamstrings strength decreased as a function of time and after the halftime interval. This finding indicates a greater risk of injuries at these specific times, especially for explosive movements, in accordance with epidemiologic observations. Incorporating eccentric knee flexor exercises into resistance training sessions that follow soccer-specific conditioning is warranted to try to reduce the incidence or recurrence of hamstrings strains.

Key Words: athletic injuries, isokinetic activity

Key Points

- Eccentric peak hamstrings torque decreased during the match and after halftime.
- The fatigued player may be more susceptible to both muscle strain and joint injuries.
- Developing fatigue-resistant eccentric hamstrings strength and rewarming properly may help to reduce the risk of injury.

Hamstrings muscle strains are frequent injuries in professional soccer players.[1–4] In an epidemiologic study of English professional soccer athletes, the thigh was the most prevalent site for injury, with 81% of thigh injuries classified as muscular strains.[2] In US Major League Soccer, hamstrings strains incurred during matches and training sessions accounted for 42% of all strain injuries.[4] An etiologic risk factor commonly attributed to the high incidence of thigh strain injuries is poor eccentric muscular strength.[5,6] The temporal pattern of injury during match play also indicates that fatigue might be a factor.[2] In English professional soccer players, 47% of match-play hamstrings strains were incurred during the final 15 minutes of each half.[3] The fatigue associated with soccer match play is specific to the characteristic activity profile. Soccer has an irregular and intermittent activity profile[7–10] and, thus, when considering soccer-specific fatigue, we should account for both physiologic and mechanical load. A soccer-specific fatigue protocol, based on the activity profile of match play,[7,11] has been previously evaluated[12] based on the duration of exercise bouts and, therefore, the frequency of changes in speed. This effort contrasted with previous attempts to replicate the demands of soccer using treadmill or free-running protocols, which have only been evaluated against the physiologic response.[13,14]

Our aim was to quantify the temporal influence of soccer-specific fatigue on changes in peak eccentric isokinetic torque of the knee flexors. If eccentric hamstrings strength is impaired as a result of fatigue, then the risk of hamstrings strain injury is likely to increase. We tested a range of speeds to represent the varied stimuli presented in soccer match play and to further consider whether any fatigue effect was speed dependent.

METHODS

We selected 10 male professional soccer players (age = 24.7 ± 4.4 years, mass = 77.1 ± 8.3 kg, $\dot{V}O_{2max}$ = 63.0 ± 4.8 mL·kg^{-1}·min^{-1}). All players provided written informed consent in accordance with the departmental and university ethical procedures and following the principles outlined in the Declaration of Helsinki.

Experimental Design

Players were tested at 1500 hours in accord with regular playing time and to account for the effects of circadian variation,[15] completing an intermittent treadmill (model LOKO S55; Woodway GmbH, Steinackerstraße, Germany) protocol replicating the activity profile of soccer match play.[12]

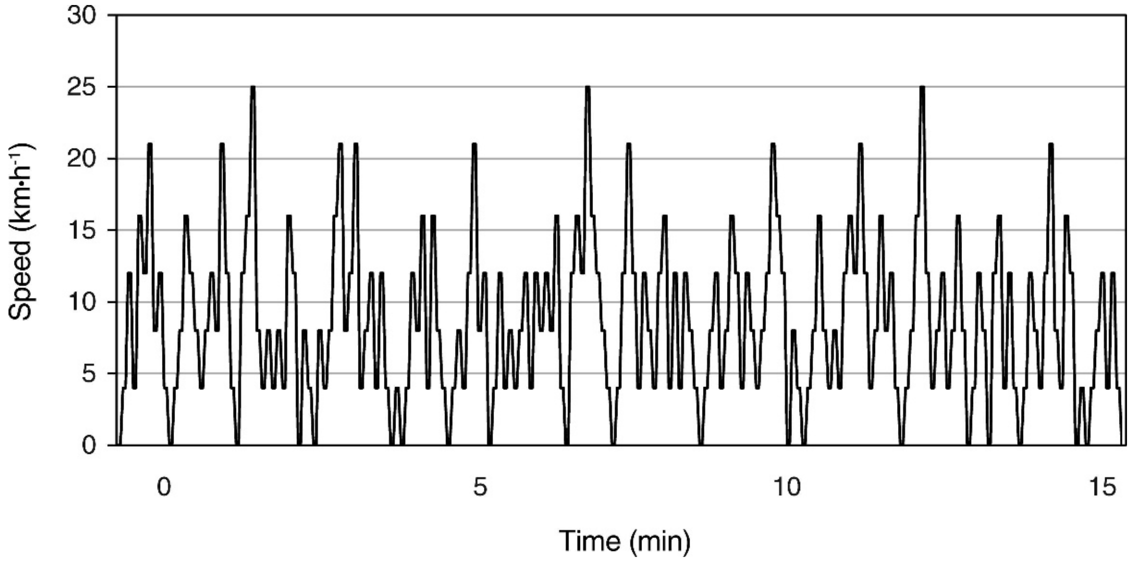

Figure 1. The soccer-specific intermittent treadmill protocol.

The soccer-specific intermittent protocol was based on notational analysis categorizing 8 modes of activity.[11] The 15-minute intermittent activity profile is shown in Figure 1, and this exercise bout was completed 6 times in the 90-minute test, with a 15-minute passive halftime interval. The maximum treadmill acceleration of 2 $m \cdot s^{-2}$ was used to transition between all modes of exercise except for that from walking to stationary (or vice versa), when an acceleration of 1 $m \cdot s^{-2}$ was used. A constant 2% gradient accounted for the energetic cost of outdoor running.[16] The activity profile resulted in a distance covered of 1.62 km, for a total distance covered of 9.72 km, which is slightly less than the average distance covered in a match (Figure 1).[7]

Before exercise and at 15-minute intervals, each player completed isokinetic protocols on an isokinetic dynamometer (System 3; Biodex Medical Systems, Shirley, NY). The same protocol was applied for each player and at each time interval (ie, the protocol was neither changed nor counterbalanced among participants). Peak eccentric knee flexor torque was quantified at isokinetic speeds of $180° \cdot s^{-1}$, $300° \cdot s^{-1}$, and $60° \cdot s^{-1}$. This testing order, although contrary to recommendations for progression from slowest to fastest,[17] was based on observations during familiarization trials that the progressive speed increase was perceived by the players as representing a process of accommodation, with increased importance attached to the latter trials. We used a range of test speeds to represent the varied stimuli presented in soccer match play (eg, from walking to sprinting and kicking) and to further consider whether any fatigue effect depended on speed.

Five repetitions were performed at each speed with the dominant (defined as the preferred kicking) leg with a rest period of 30 seconds between sets. Each repetition was required to be a maximal contraction throughout the entire range of movement. Communication during the testing was restricted to ensuring that the participant was aware of the test speed to follow, and no visual feedback was provided with regard to performance.

All players had performed familiarization trials on the dynamometer at each test speed on a minimum of 3 previous visits to the laboratory. The dynamometer set-up was modified to be participant specific, following the manufacturer's guidelines, and was maintained throughout the exercise protocol. The crank axis was aligned with the axis of rotation of the knee, with the cuff of the dynamometer's lever arm secured around the ankle and the base of the cuff approximately 5 cm proximal to the malleoli. Restraints were applied across the test thigh, proximal to the knee joint so as not to restrict movement, and across the chest. The range of motion was preset from full extension to 90° of flexion.

Statistical Analysis

Gravity-corrected peak torque at each test speed was calculated as the mean peak torque over the 5 repetitions. Only torque data obtained during the isokinetic phases of the movement were included in the analysis. The test-retest reliability of peak torque was determined during familiarization trials. The intraclass correlation coefficients for each speed were between 0.76 and 0.78, reflecting good reliability.[18]

The peak torque indices at each speed and the fast:slow ratio were determined at 15-minute intervals throughout the exercise protocol. A 2-way, repeated-measures analysis of variance was used to investigate the temporal influence of exercise duration on each factor. Differences between means were identified using a least squares difference post hoc test. All results are reported as the mean ± SD, with significance set at ≤ .05. All statistical tests were performed with SPSS software (version 10; SPSS Inc, Chicago, IL).

RESULTS

At $60° \cdot s^{-1}$, no main effect for time was noted ($P >$ .05), although the peak torque at the end of the exercise protocol ($T60_{105}$ = 118 ± 23 Nm) was reduced relative to the first 30 minutes of exercise ($T60_{00}$ = 144 ± 34 Nm, P = .08; $T60_{15}$ = 144 ± 38 Nm, P = .08; $T60_{30}$ = 145 ± 38 Nm, P = .07) (Figure 2). At $180° \cdot s^{-1}$, a similar temporal pattern was evident, with $T180_{105}$ (125 ± 21 Nm) lower than $T180_{00}$ (154 ± 37 Nm, P = .05) and $T180_{15}$ (159 ± 38 Nm, P = .02).

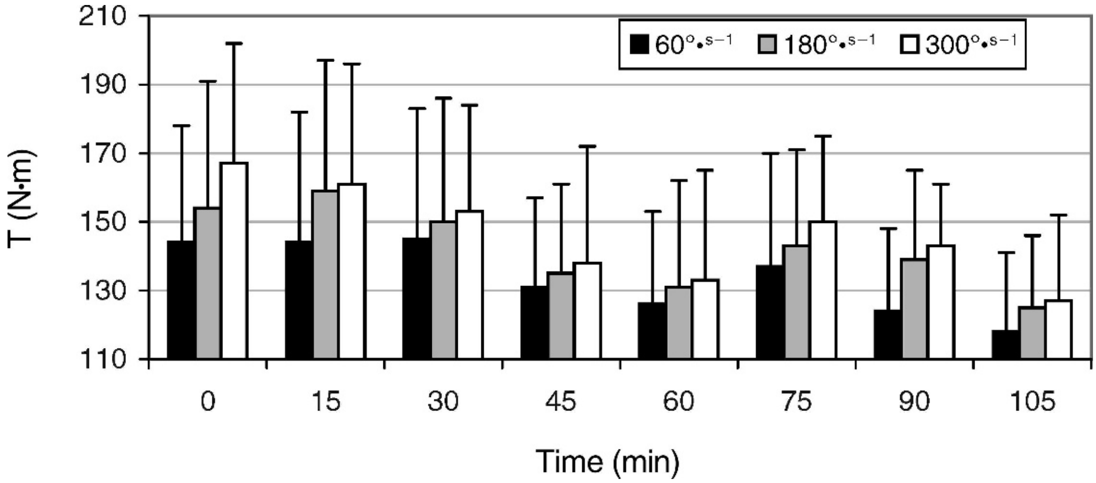

Figure 2. Time history of peak eccentric hamstrings torque (T) during the soccer-specific intermittent protocol.

A main effect for time at 300° · s−1 was revealed, as peak eccentric torque generally decreased as a function of exercise duration through each half, with $T300_{105}$ (127 ± 25 Nm) lower than $T300_{00}$ (167 ± 35 Nm, $P < .01$) and $T300_{15}$ (161 ± 35 Nm, $P = .02$). The temporal pattern of the fatigue effect was most evident at this testing speed, with a decrease in peak torque also observed at the end of the first half ($T300_{45}$ = 138 ± 34 Nm, $P = .04$) and earlier in the second half, with $T300_{90}$ (143 ± 18 Nm) reduced ($P = .09$) relative to the pre-exercise measure. Aside from the fatigue effect, the temporal pattern of change in eccentric peak torque also highlighted the potential negative influence of the passive halftime interval. At testing speeds of 180° · s−1 and 300° · s−1, the peak torque after the passive halftime interval was reduced relative to the end of the first half ($P < .05$, Figure 2).

DISCUSSION

The aim of our study was to investigate the temporal changes in peak eccentric hamstrings strength during a simulated match, given epidemiologic observations of increased hamstrings strain incidence during the latter stages of match play.[3] Direct comparisons with previous studies are difficult, because a fatigue effect is specific to the exercise protocol, and previous authors have typically failed to represent the intermittent activity profile of soccer match play.[13,14]

We used a protocol that considers the mechanical demands of the intermittent running characteristic of soccer, replicating the short duration of exercise bouts, and subsequently providing a valid frequency of speed change. The protocol also provided a more detailed understanding of the temporal pattern of any fatigue effect. Whereas previous investigators have considered changes from pre-exercise to postexercise,[19] we quantified changes in peak eccentric hamstrings strength at 15-minute intervals throughout the simulated match. This temporal pattern allows us to consider injury incidence data in parallel.[2,3]

Peak eccentric torque generally decreased as a function of exercise duration through each half. The fatigue effect was speed dependent, with the influence of exercise duration on the absolute decrease in peak torque greatest at the fastest testing speed. The time history of eccentric hamstrings strength supports the epidemiologic data,[3] with hamstrings strains more likely to occur during the latter stages of match play. The influence of testing speed on the temporal pattern indicates that the risk of muscle strain injury increases during explosive actions such as sprinting and may be crucial during the late-stance phase for propulsion.[20]

The mechanism underpinning the temporal pattern of change in eccentric hamstrings strength is worthy of further consideration. In the same exercise protocol involving the same professional players, the electromyographic activity of the biceps femoris muscle increased during the latter stages of each half.[12] Over a standardized 30-second bout during each repetition of the 15-minute activity profile, the electromyographic activity of the rectus femoris muscle was not affected by exercise duration. However, the integrated electromyographic activity of the biceps femoris increased progressively during each half and more markedly during the second half.[12] It should be noted that running speed is dictated by the treadmill and, as such, this finding indicates greater muscular contribution is required to maintain the same level of performance.

The observed decline in eccentric hamstrings strength might therefore be attributed to the greater contribution of the hamstrings in controlling the intermittent running profile. Additionally, as sprinting has previously been observed as a primary mechanism of injury,[2] the frequency of speed changes places greater emphasis on the acceleration and deceleration phases of the running cycle. The increased muscle contribution from the biceps femoris in maintaining running mechanics during the intermittent protocol, in parallel with the decrease in peak eccentric strength, may further increase the risk of injury.

Although our primary focus was the influence of fatigue on eccentric hamstrings strength, an interesting observation was the negative influence of the passive halftime interval. During the halftime interval, players remained seated and passive, reflecting typical behavior during competition. They failed to recover eccentric strength to pre-exercise values and, thus, failed to mediate the fatigue effect imposed during the first half. The peak torque after halftime was lower than at the start of halftime at all test speeds and significantly so at the higher speeds. This finding indicates that consideration should be given to active re–warm-up strategies during the halftime interval, which, as recently shown,[21] would complement the physiologic benefits associated with activity before the second half. Additionally, an active re–warm-up may reduce the increased risk of injury observed during the very early stages of the second half.[3]

Clinical Relevance

Our study provides informative data for the practitioner, highlighting not only the susceptibility of eccentric hamstrings strength to fatigue but also the influence imposed by movement speed. Strength work is acknowledged as a fundamental component of a generic conditioning program in professional soccer. However, strength and speed training tend to be addressed only in the resting state. Such practices may not provide the best mode of intervention for the increased injury incidence observed late in the game. Resistance to fatigue and eccentric strength, particularly at high speeds (as we have noted, the largest strength decrement was at $300° \cdot s^{-1}$) should be given greater consideration in conditioning for soccer.

The consideration for eccentric fatigue, again at higher speeds, should also be considered during functional, return-to-play evaluation. Hagglund et al,[22] following an elite group of soccer players over a 2-year period, documented that athletes returning from hamstrings injuries were almost 3 times as likely to experience an identical injury the next season.[22] Using a prospective approach, others[1,5,23,24] have shown decreased rates of hamstrings strain after implementing multimodal intervention programs. The principal focus of the resistance exercises should be to impose an increased eccentric demand on the knee flexors and, after attaining sufficient strength, to incorporate a speed component (ie, power and endurance) into the progression.[23,24] Specific examples, such as Nordic hamstrings curls, which require an individual to resist a forward-falling motion by using the hamstrings,[5] potentially induce near-maximal neuromuscular involvement during the eccentric phase of contraction. Additionally, performing these exercises after a series of short-sided games would maximize the practical application of soccer-specific fatigue, as these drills have been shown to assimilate both match-related fatigue and soccer-specific movement patterns.[25]

Recommendations for Future Research

The small number of participants limits the global generalization of our findings. However, this limitation is tempered by the inclusion of professional players in our study. The small number of volunteers reflects our ethical exclusion criteria regarding injury history. We deemed it critical to study professional players, as they were specific to both the injury epidemiology data and the notational analyses upon which the exercise protocol was based. Future researchers might consider both sex and age effects in elite populations.

With regard to data analysis, investigators using soccer-specific fatiguing protocols might consider the angle at which peak torque is attained and, in more detail, the torque curve time-history, as others[26] have shown discrepancies among angles with single-leg pedaling exercises. The relevance of peak torque to injury incidence data should naturally be treated with some caution. Authors might consider the relationship between the changes observed in eccentric hamstrings strength and functional tasks relating to the primary mechanisms of injury incidence in soccer, such as sprinting, cutting, etc. Both the exercise protocol and the functional task must be specific to the demands of the game. Treadmill-based protocols are inherently limited by the linear nature of the locomotion; however, the frequency of speed changes induced in our study resulted in considerable deviation from a linear gait pattern. Free-running protocols have merit in replicating the multidirectional nature of soccer activity but are hindered in their ability to replicate and standardize the activity profile. In the present study, the isokinetic task is planar; yet for more functional tasks, such as cutting, a free-running, multidirectional protocol might be more appropriate. Such design issues arising in the development of an exercise protocol for research studies might also be considered by the practitioner faced with the dilemma of when a player is ready to return to play.

CONCLUSIONS

Eccentric peak hamstrings torque deteriorated as a function of exercise duration throughout the simulated match and after the passive halftime interval. The temporal pattern of changes in eccentric hamstrings strength supports injury epidemiology data indicating an increased risk of injury in the latter stages of match play and at the start of the second half. The higher injury risk in the fatigued player during explosive movements such as sprinting is consistent with the increased fatigue effect.

The function of the hamstrings musculature is such that the fatigued player may become more susceptible to both muscular strain injury and impaired joint stability. Coaching and medical staffs would do well to ensure that players are sufficiently warmed up before the start of the second half and that their eccentric hamstrings strength is well developed and resistant to fatigue. Incorporating eccentric hamstrings exercises into off-season or preseason resistance training sessions decreases the incidence of muscle strains[23,24] and may be especially important if the athlete has a history of injury. Finally, consistent evaluation and reevaluation of eccentric strength and functional power (such as functional hamstrings to quadriceps muscle strength ratios[27]) may provide critical information as to the effectiveness of the intervention and any potential relationship to the incidence of hamstrings injury.

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