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The Influence of Soccer-Specific Fatigue on Peak Isokinetic Torque Production of the Knee Flexors and Extensors

Matt Greig,* MPhil, PhD
From the Medical and Exercise Science Department, The Football Association, Lilleshall, United Kingdom

Background: Epidemiological findings of higher muscular thigh strain injury incidence during the latter stages of soccer match play have been attributed to fatigue.

Hypothesis: Soccer-specific fatigue will significantly reduce peak isokinetic torque of the knee flexors and extensors.

Study Design: Descriptive laboratory study.

Methods: Ten male professional soccer players (mean age, 24.7 ± 4.4 years; body mass, 77.1 ± 8.3 kg; maximum oxygen consumption [VO₂ max], 63.0 ± 4.8 mL/kg/min) completed an intermittent treadmill protocol replicating the activity profile of match play. Before exercise and at 15-minute intervals, each player completed 1 of 2 randomized isokinetic dynamometer protocols. The first protocol quantified peak concentric knee extensor and flexor torque, while the second quantified peak concentric and eccentric knee flexor torque at isokinetic speeds of 180, 300, and 60 deg/s (3.14, 5.25, and 1.05 rad/s) with 5 repetitions at each speed.

Results: Concentric knee extensor and flexor peak torque were maintained throughout the duration of the exercise protocol, irrespective of movement speed. However, peak eccentric knee flexor torques at the end of the game (T₃₀₀eccH₁₀ = 127 ± 25 N·m) and at the end of the passive half-time interval (T₃₀₀eccH₁₀ = 133 ± 32 N·m) were significantly reduced relative to the first 15 minutes (T₃₀₀eccH₀ = 167 ± 35 N·m, P < .01; T₃₀₀eccH₁₅ = 161 ± 35 N·m, P = .02).

Conclusion: Eccentric knee flexor strength decreases as a function of time and after the half-time interval.

Clinical Relevance: This suggests a greater risk of injuries at these specific times, especially for explosive movements, in accord with epidemiological observations.

Keywords: fatigue; soccer; isokinetic; hamstring; injury

Epidemiological studies consistently report that muscular strains are a primary injury type in professional soccer.8,10,22 Injury audits in English professional soccer have classified 41% of all injuries as muscular strains.8 The thigh was reported as the most prevalent site for a strain injury, with 23% of all injuries attributed to thigh injuries (including quadriceps, hamstrings, and adductors); 81% of these were muscular strains.8

Etiological risk factors attributed to an increased risk of muscular strain injury include poor muscular strength, particularly eccentric strength deficits, and ipsilateral muscular strength imbalances.12 The temporal pattern of injury during match play also suggests fatigue to be a factor in injury causation, with 47% of match-play hamstring strains incurred during the latter stages of each half.22

Previous research has shown that concentric and, less frequently, eccentric strength of the knee flexors and extensors is impaired after exercise protocols comprising isokinetic maximal contractions,5 high-intensity cycling,11 and prolonged intermittent running.16 The nature of muscle fatigue is likely to be specific to the movement pattern of the exercise.18 Soccer is characterized by an irregular and intermittent activity profile; this intermittent nature places greater emphasis on the acceleration and deceleration phases of sprinting.

An intermittent treadmill protocol based on the activity profile of professional soccer match play has been presented previously.7 In attempting to replicate the activity profile of soccer, the authors evaluated the exercise model based on the frequency of speed change and the duration of discrete exercise bouts.7 This is in contrast to previous...
TABLE 1
Movement Activities Replicated in the Intermittent Treadmill Protocol

<table>
<thead>
<tr>
<th>Activity</th>
<th>Number of Activities</th>
<th>Mean Duration (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standing (0 km/h)</td>
<td>20</td>
<td>7.8</td>
</tr>
<tr>
<td>Walking (4 km/h)</td>
<td>55</td>
<td>6.7</td>
</tr>
<tr>
<td>Jogging (8 km/h)</td>
<td>42</td>
<td>3.5</td>
</tr>
<tr>
<td>Low speed (12 km/h)</td>
<td>46</td>
<td>3.5</td>
</tr>
<tr>
<td>Moderate speed (16 km/h)</td>
<td>20</td>
<td>2.5</td>
</tr>
<tr>
<td>High speed (21 km/h)</td>
<td>9</td>
<td>2.1</td>
</tr>
<tr>
<td>Sprint (25 km/h)</td>
<td>3</td>
<td>2.0</td>
</tr>
</tbody>
</table>

methods

Ten male professional soccer players were recruited for the present study, with a mean age of 24.7 ± 4.4 years, body mass of 77.1 ± 8.3 kg, and maximum oxygen consumption [VO₂ max] of 63.0 ± 4.8 mL/kg/min. All participants provided written informed consent in accordance with the departmental and university ethical procedures.

Experimental Design

Each participant performed all exercise periods in the afternoon between 2 and 5 o'clock to account for the effects of circadian variation and in accord with regular competition time. Each player attended the laboratory on 2 separate occasions, separated by no more than 7 days. On each occasion, players completed an intermittent treadmill (LOKO SS55, Woodway GmbH, Steinackerstraße, Germany) protocol designed to replicate the activity profile of soccer match play.

The soccer-specific intermittent protocol comprised the varying exercise intensities inherent to match play, based on a notational analysis that categorized 8 modes of activity. To provide a 15-minute activity profile, the frequency of each mode of exercise was divided by 6 (Table 1 summarizes the data set upon which the soccer-specific intermittent treadmill protocol was based). This data set was arbitrarily distributed to provide a 15-minute activity profile (Figure 1), which was repeated 6 times in the test (ie, 90 minutes). The short duration of the high-speed movements excluded consecutive stationary and sprint modes of activity. The maximum treadmill acceleration of 2 m/s² was applied for transition to and from all modes of exercise with the exception of the transition from walk to stationary (or vice versa), where an acceleration of 1 m/s² was used. The 15-minute activity profile resulted in a distance covered of 1.62 km, giving a total distance covered of 9.72 km. A constant treadmill incline of 2% to reflect the energetic cost of outdoor running was also applied. No activities such as kicking, jumping, and tackling were imposed on the exercise protocol. There was a 15-minute half-time interval, during which the participant remained seated and stationary.

Before exercise, after each 15-minute activity bout, and after the passive 15-minute half-time interval, each player completed isokinetic protocols on a Biodex isokinetic dynamometer (System 3, Biodex Medical Systems, Shirley, NY). There were 2 isokinetic protocols, randomized in delivery, quantifying either concentric knee extensor and knee flexor peak torque, or concentric and eccentric knee flexor peak torque. Both protocols were completed at isokinetic speeds of 180, 300, and 60 deg/s (3.14, 5.25, and 1.05 rad/s). This order is contrary to previous recommendations that propose progression from slowest to fastest. In familiarization trials, it was observed that the progressive increase in speed created a perception of accommodation and of increased importance of the latter trials.

Five repetitions were performed on the dominant (preferred kicking) limb at each speed with a rest period of 30 seconds between each set. Participants were instructed that each repetition should be a maximal contraction throughout the entire range of movement. No visual feedback was provided with regard to performance.

Each participant performed familiarization trials on the dynamometer in each mode of exercise, and at each test speed, in a minimum of 3 previous visits to the laboratory. On test days, the dynamometer setup was modified so as to be subject specific, following the manufacturer’s guidelines, with the setup maintained throughout the exercise protocol. The crank axis was aligned with the axis of rotation of the knee joint, and the cuff of the dynamometer’s
leverage was secured around the ankle, 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 a 90° range of flexion.

Data Analysis

The data were analyzed to quantify gravity-corrected peak torque at each of the 3 test speeds in concentric knee extension, concentric knee flexion, and eccentric knee flexion. This value was quantified as the mean peak torque over the 5 repetitions. Torque data were considered only during the isokinetic phases of the movement.

The test-retest reliability of peak torque was determined during familiarization trials. The intraclass correlation coefficients for each measure are shown in Table 2, along with an interpretation of reliability.

<table>
<thead>
<tr>
<th>Measure</th>
<th>ICC Value</th>
<th>Interpretation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concentric knee flexion: 60 deg/s</td>
<td>0.90</td>
<td>&gt;0.90 Excellent reliability</td>
</tr>
<tr>
<td>Concentric knee flexion: 180 deg/s</td>
<td>0.85</td>
<td>&gt;0.75 Good reliability</td>
</tr>
<tr>
<td>Concentric knee flexion: 300 deg/s</td>
<td>0.77</td>
<td>&gt;0.75 Good reliability</td>
</tr>
<tr>
<td>Concentric knee extension: 60 deg/s</td>
<td>0.92</td>
<td>&gt;0.90 Excellent reliability</td>
</tr>
<tr>
<td>Concentric knee extension: 180 deg/s</td>
<td>0.88</td>
<td>&gt;0.75 Good reliability</td>
</tr>
<tr>
<td>Concentric knee extension: 300 deg/s</td>
<td>0.81</td>
<td>&gt;0.75 Good reliability</td>
</tr>
<tr>
<td>Eccentric knee flexion: 60 deg/s</td>
<td>0.78</td>
<td>&gt;0.75 Good reliability</td>
</tr>
<tr>
<td>Eccentric knee flexion: 180 deg/s</td>
<td>0.78</td>
<td>&gt;0.75 Good reliability</td>
</tr>
<tr>
<td>Eccentric knee flexion: 300 deg/s</td>
<td>0.76</td>
<td>&gt;0.75 Good reliability</td>
</tr>
</tbody>
</table>

The peak torque indices were used to calculate the “traditional” strength ratio (concentric hamstring:concentric quadriceps peak torque) and the “dynamic” strength ratio (eccentric hamstring:concentric quadriceps peak torque) at each test speed. A fast:slow ratio was also calculated for each mode of exercise, quantifying the peak torque at 300 deg/s relative to the peak torque at 60 deg/s. This fast:slow ratio has previously been used as an indicator of how strength is maintained with increasing angular velocity.

In subsequent sections, the torque values are presented according to the isokinetic testing speed, the mode of exercise, the primary muscle group acting, and the time during the protocol. The testing speeds of 60, 180, and 300 deg/s are specified within the classification. Eccentric exercise is specified with the subscript “ecc,” and concentric exercise is specified with the subscript “con.” Knee flexor exercise is detailed with the subscript “H,” while knee extensor exercise is allocated the subscript “Q.” As an example, peak torque of the knee flexors at an eccentric speed of 60 deg/s would be reported as $T_{60eccH}$. Also included in the classification is the time during the protocol, with testing conducted every 15 minutes through the simulated game. The pretesting score would therefore be allocated the time subscript “00.” The time classification is cumulative and includes the passive half-time interval. The end of the first half would be specified as “45,” the start of the second half as “60,” and the end of the game as “105.” As an example, peak torque of the knee flexors at an eccentric testing speed of 60 deg/s, 15 minutes into the second half, would be reported as $T_{60eccH75}$, and at the end of the game, as $T_{60eccH105}$.

Statistical Analysis

The peak torque indices and strength ratios were determined at 15-minute intervals throughout the exercise protocol. With data satisfying the criteria for normal distribution, analysis of variance was used to investigate the influence of exercise duration on each parameter. Significant differences between means were identified using a least-squares difference post hoc test; all results are reported as the mean ± standard deviation, with significance accepted at $P < .05$.

RESULTS

Figure 2 shows the time history for peak torque generated by the knee extensors in concentric mode ($T_{conQ}$) during the soccer-specific intermittent protocol. The knee flexors at an eccentric speed of 60 deg/s would be reported as $T_{60eccH}$. Also included in the classification is the time during the protocol, with testing conducted every 15 minutes through the simulated game. The pretesting score would therefore be allocated the time subscript “00.” The time classification is cumulative and includes the passive half-time interval. The end of the first half would be specified as “45,” the start of the second half as “60,” and the end of the game as “105.” As an example, peak torque of the knee flexors at an eccentric testing speed of 60 deg/s, 15 minutes into the second half, would be reported as $T_{60eccH75}$, and at the end of the game, as $T_{60eccH105}$.
having a greater effect on peak torque as a function of eccentric movement speed.

At the slowest test speed, analysis of variance revealed no significant main effect for time at the accepted level. However, there was a trend toward reduced $T_{60eccH}$ as a function of exercise duration with $T_{60eccH105} = 144 \pm 34$ N·m, $P = .08$; $T_{60eccH15} = 144 \pm 38$ N·m, $P = .08$; $T_{60eccH30} = 145 \pm 38$ N·m, $P = .07$).

A similar pattern was observed at the eccentric speed of 180 deg/s, with $T_{180eccH105} = 125 \pm 21$ N·m significantly lower than $T_{180eccH00} = 154 \pm 37$ N·m; $P = .05$ and $T_{180eccH15} = 159 \pm 38$ N·m; $P = .02$). Also of interest was the influence of the passive half-time interval on eccentric hamstring strength, with peak eccentric torque after half-time ($T_{180eccH60} = 131 \pm 31$ N·m) significantly ($P < .05$) lower relative to $T_{180eccH00}$ and $T_{180eccH15}$.

Analysis of variance revealed a significant main effect for time at 300 deg/s, with peak eccentric knee flexor torque generally decreasing as a function of exercise duration through each half. Peak eccentric knee flexor torque at the end of the game ($T_{300eccH105} = 127 \pm 25$ N·m) was significantly reduced relative to $T_{300eccH60} = 167 \pm 35$ N·m; $P < .01$ and $T_{300eccH15} = 161 \pm 35$ N·m; $P = .02$). The influence of exercise duration was greatest at this testing speed, with a significant reduction in peak torque at the end of the first half ($T_{300eccH45} = 138 \pm 34$ N·m; $P = .04$) and a substantial reduction in $T_{300eccH90} = 143 \pm 18$ N·m; $P = .09$) relative to $T_{300eccH00}$. The detrimental effect of the passive half-time interval was even more marked at this fastest testing speed, with $T_{300eccH60} = 133 \pm 32$ N·m significantly ($P < .05$) lower than $T_{300eccH00}$ and $T_{300eccH15}$.

The traditional strength ratio of concentric hamstring:concentric quadriceps peak torque (%conH:conQ) was quantified at each test speed (Figure 5). Analysis of variance revealed no significant main effect for time for the strength ratio at any test speed.

Figure 6 shows the time history of the dynamic strength ratio (%eccH:conQ). Analysis of variance revealed no significant main effect for time in the dynamic strength ratio at the slowest test speed, but there was a significant main effect for time in %180eccH:conQ and in %300eccH:conQ ($P < .05$). Generally, the dynamic strength ratio tended to decrease as a function of exercise duration.

At 180 deg/s, the dynamic strength ratio at the end of the trial (%180eccH:conQ$_{105}$ = 81% ± 13%) was significantly lower than %180eccH:conQ$_{00}$ (105% ± 22%; $P = .01$) and %180eccH:conQ$_{15}$ (114% ± 25%; $P < .01$). The influence of
exercise duration was evident even at the end of the first half, with %180eccH:conQ45 (87% ± 16%) also significantly lower than %180eccH:conQ00 and %180eccH:conQ15.

The same pattern was evident at 300 deg/s, with the dynamic strength ratio significantly ($P < .05$) reduced at the end of the first half (%300eccH:conQ45 = 107% ± 24%) and at the end of the second half (%300eccH:conQ00 = 103% ± 23%) relative to the first 15 minutes of the exercise protocol (%300eccH:conQ00 = 133% ± 26%; %300eccH:conQ15 = 130% ± 24%). The strength ratio at the end of the passive half-time interval (%300eccH:conQ45 = 107% ± 24%) was also significantly reduced relative to %300eccH:conQ00 and %300eccH:conQ15.

No significant main effect for time was evident for the fast:slow ratio in any condition, although there was a trend toward a decreased ratio as a function of exercise duration in the eccentric hamstring condition. At each time point, the fast:slow ratio was greatest for the eccentric hamstring strength (Figure 7).

**DISCUSSION**

The aim of the present study was to investigate the time history of changes in knee flexor and extensor strength during a simulated soccer match. Direct comparisons with previous studies are difficult given the limitations of previous research in representing the activity profile of soccer match play.

In the present study, concentric quadriceps and hamstring strength was maintained throughout the exercise protocol, at all speeds. This is in contrast to the findings of impaired concentric strength in studies where fatigue has been induced using isokinetic repetitions, prolonged and intermittent free running, or treadmill running. Such contradictions may be attributed to the exercise protocol, with fatigue effect likely to be specific to both the exercise protocol and the strength-testing protocol. Fatigue-induced alterations in strength using repeated isokinetic contractions fail to replicate the functional demands of soccer. In a treadmill-based study purported to be soccer specific, there was a progressive reduction in knee flexor and extensor strength from pre-exercise, to half-time, to postexercise. However, the maximum test speed was 180 deg/s. Furthermore, the treadmill protocol used fails to replicate the activity profile of soccer, overemphasizing the contribution of high-intensity activity and with exercise bout durations much longer than observed in match play. It should also be noted that the participants used were competing at the university level but were expected to complete a treadmill protocol based on professional activity profiles. It is therefore perhaps not surprising that the authors observed a progressive decline in strength. This finding is in contrast to the results of the present study, which showed that, irrespective of isokinetic testing speed, concentric strength was maintained throughout the protocol.

In addition to replicating the short duration of discrete exercise bouts, and thereby a greater frequency of speed change, the present study offers a greater understanding of the time course of the fatigue effect. Whereas previous studies have considered changes from pre-exercise to post-exercise, the present study quantifies changes in peak torque at 15-minute intervals throughout the simulated match, in accord with the presentation of injury incidence data. It is acknowledged that this experimental design imposed a delay in the exercise protocol to undergo isokinetic testing, which might result in artificial changes that would not occur during continuous match play. In this study, while no significant main effect for time was obtained for concentric hamstring strength, there was a trend for reduced strength at the fastest speed toward the end of each half.

While concentric strength of both the knee extensors and flexors was maintained, at least within the prescribed statistical limits, a speed-dependent fatigue effect was observed for eccentric hamstring strength. The influence of exercise duration was greatest at the highest testing speed. At the higher eccentric speeds, peak eccentric torque generally decreased as a function of exercise duration through each half. At the slowest test speed, there remained a trend toward reduced eccentric hamstring strength as a function of exercise duration. This supports previous research, although in the present study, it can be observed that the fatigue effect was evident only in the final 15 minutes of the first half and for the final 30 minutes of the second half. The time history of the fatigue effect on eccentric hamstring strength supports the epidemiological data, in that more hamstring strains are likely to occur during the latter stages of match play. The susceptibility to muscular strain injury is likely to increase during explosive ballistic actions, such as the acceleration and deceleration phases during sprinting. The decline in eccentric hamstring strength might be attributed to the greater contribution of the hamstrings in controlling the running mechanics during the intermittent protocol. The hamstrings function eccentrically to slow hip flexion and knee extension, with muscle soreness and damage typically more severe following eccentric, as opposed to concentric, exercise.

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**Figure 7.** Time history of the fast:slow strength ratio during the soccer-specific intermittent protocol. EccH, knee flexor eccentric exercise; ConH, knee flexor concentric exercise; ConQ, knee extensor concentric exercise.
Also of interest was the influence of the passive half-time interval on eccentric hamstring strength. The half-time interval did not restore eccentric strength to pre-exercise values, and peak torque after half-time was lower than at the start of the half-time interval at all test speeds and significantly so at the higher speeds. This supports the increased risk of injury observed during the early stages of the second half.22

The strength indices in concentric and eccentric modes were used to investigate strength imbalances, previously reported as a risk factor for hamstring strain injuries.12,22 Because concentric strength of both the knee flexors and extensors was not significantly impaired during the exercise protocol, the traditional strength ratio was maintained at all test speeds. The concentric strength ratio increased as a function of test speed, attributed to a greater influence of isokinetic angular velocity on the knee extensors than the knee flexors.

The fatigue-induced decline in eccentric hamstring strength did produce a significant main effect for exercise duration on the dynamic strength control ratio, generally decreasing as a function of exercise duration. This ratio of eccentric hamstring strength to concentric quadriceps strength has been considered to be indicative of the joint-stabilizing effect of the hamstring muscles during knee extension.1 The time history of variation in the dynamic strength ratio reflected the temporal pattern of changes in eccentric hamstring strength. This would suggest increased susceptibility to knee-joint sprain injury,3 particularly during the latter stages of each half and the initial stages of the second half.

The fast:slow ratio has been considered to be an indicator of how strength is maintained as angular velocity increases.16 In the present study, no significant main effect for exercise duration was established in any condition. The trend toward a decreased ratio for the eccentric hamstring torque in the latter stages of each half is indicative of the greater fatigue effect at the higher test speed. The increase in angular velocity might be considered to be functionally relevant with respect to the range of running speeds used within the intermittent and irregular profile of soccer match play. The temporal pattern observed in eccentric hamstring torque might suggest an increased risk of injury with increased angular velocity, such as during sprinting activities.

The present study has quantified only peak torque, and further research might be directed toward the angle at which peak torque is attained and also the area under the torque curve time history. The small number of subjects limits the generalization of the findings; however, this limitation is tempered by the use of professional players in the present study. The small number of subjects is reflective of an ethical exclusion criteria regarding injury history. It was deemed critical to use professional players as being specific to both the injury epidemiology data and the notational analyses upon which the exercise protocol was based. Future research might consider both gender and age effects in elite populations.

The relevance of peak torque to injury incidence data should also be treated with some caution. Future research might consider the relationship between the changes observed in peak torque, particularly the decrease in eccentric hamstring strength, and functional tasks relating to the primary mechanisms of injury incidence in soccer, such as sprinting and cutting. Both the task and the exercise protocol must be specific to the demands of the game. Treadmill-based protocols are typically limited by the linear nature of the locomotion; however, with the frequency of speed change induced in the present study, there is considerable deviation from this linear gait pattern. Free-running protocols provide a means of replicating the multidirectional nature of soccer locomotion but are less able to replicate and standardize the activity profile. The added physical load associated with utility movements such as backwards running, jumping, kicking, and tackling might also be included within a free-running protocol. In the present study, the isokinetic task is planar; however, for more functional tasks such as cutting, a free-running multidirectional protocol might be more appropriate.

CONCLUSION

Eccentric hamstring peak torque was observed to deteriorate as a function of exercise duration and after the passive half-time interval. In contrast, match duration had no effect on concentric peak torque of either the quadriceps or the hamstrings, irrespective of test speed. The time history of changes in eccentric hamstring strength, and subsequently in the dynamic strength ratio, might increase the risk of injury toward the latter stages of match play and at the start of the second half. The fatigue effect increased as a function of isokinetic test speed such that any increased injury risk would be greatest during explosive movements. The function of the hamstrings musculature is such that the player may become more susceptible to both muscular strain injury and impaired joint stability. Coaches and trainers would do well to ensure that players are sufficiently warmed up before the start of the second half and that eccentric hamstring strength in players is well developed and resistant to fatigue.

REFERENCES


