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Effect of Timing of Eccentric Hamstring Strengthening Exercises During Soccer Training: Implications for Muscle Fatigability

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Abstract

Small, K, McNaughton, L, Greig, M, and Lovell, R. Effect of timing of eccentric hamstring strengthening exercises during soccer training: implications for muscle fatigability. *J Strength Cond Res* 23(X): xxx–xxx, 2009—The purpose of this study was to examine the effects of a field-based injury prevention exercise on eccentric hamstring strength during simulated soccer match play. Sixteen semiprofessional soccer players (age 21.3 ± 2.9 years; height 185.0 ± 8.7 cm; body mass 81.6 ± 6.7 kg) completed the Soccer-specific Aerobic Field Test ($SAFT^{90}$), a multidirectional 90-minute exercise protocol representative of soccer match play. Subjects performed 3 maximal dominant-limb isokinetic contractions at $120°·s^{-1}$ for concentric knee extensors (conQ) and flexors (conH), and eccentric knee flexors (eccH) before $SAFT^{90}$ (t_0), at half-time (t_{45}), and immediately after the $SAFT^{90}$ (t_{105}). After baseline testing, subjects were divided into 2 groups, either performing Nordic hamstring eccentric strengthening exercises during the cool-down (CD) or warm-up (WU) of twice-weekly training sessions. After an 8-week intervention program, the baseline testing was repeated. The WU group displayed a significant increase postintervention in eccH gravity-corrected peak torque (PT) and the functional eccH:conQ ratio at t_0 ($p < 0.01$), a significantly greater improvement compared with CD group ($p < 0.05$). Conversely, the CD group displayed a significant increase in both eccH PT and the functional eccH:conQ ratio postintervention at t_{45} ($p < 0.05$) and at t_{105} ($p < 0.05$), which were significantly greater increases compared with the WU group ($p < 0.05$). These findings indicate that the training intervention had a time-dependent beneficial effect on eccentric hamstring strength and that strength training conducted posttraining significantly reduced the negative influence of fatigue.

Key Words fatigue, injury prevention, muscle strain

Introduction

Hamstring strains are currently the most common injury in professional soccer (2,11,21), incurring considerable financial and lost playing time costs to both club and players. Despite the high incidence of hamstring strains in soccer, research into injury prevention programs is limited. AU2

Eccentric hamstring strength is a fundamental etiological factor associated with hamstring muscle strains. Eccentric muscle contractions are seen not only as an integral part of the functional repertoire of the hamstring muscle group but also as a key factor related to injury potential (14). Hamstring strain injuries are most likely the result of an interaction between multiple risk factors (12). The interaction between eccentric hamstring strength and fatigue has been the subject of more recent investigation (10,17,19).

Research has shown that reductions in eccentric hamstring strength occur during the later stages of simulated soccer match play (10,17,19). Consequently, greater muscular strength imbalance between eccentric hamstring and concentric quadriceps strength has also been observed at this time (10,17,19) and implicated as an additional factor for hamstring injury risk (5). Furthermore, epidemiological data have indicated an increased incidence of hamstring strains during the later stages of actual soccer match play (21). Therefore, an increased hamstring injury risk would seem logical from reduced eccentric hamstring strength attributable to fatigue experienced during soccer match play.

Research has shown that eccentric hamstring strengthening exercises improve eccentric hamstring strength (15), and this exercise strategy has subsequently been used to investigate the prevention of hamstring strains in soccer (1). The findings revealed that an intervention strategy incorporating eccentric hamstring strength training during the warm-ups before training sessions significantly reduced the incidence of hamstring strains during total training and competition exposure compared with baseline data and other interventions. However, during matches there was no significant difference in hamstring injury rates in the

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intervention teams between the baseline and the intervention period (1). Therefore, it would seem that eccentric hamstring strength training conducted during warm-up was actually ineffective at reducing hamstring strain injury risk during match play.

However, during previous research, all strength testing and training has been conducted in a nonfatigued state. Therefore, it is unknown whether players are able to maintain increased eccentric hamstring strength when experiencing fatigued situations, which is associated with increased susceptibility to hamstring strain injury (21). Furthermore, it would be intriguing to investigate whether the conditions under which the exercises are performed have additional connotations in improving and/or maintaining eccentric hamstring strength because this may have important implications for injury prevention.

The objective of this study, therefore, was to compare the effects of performing eccentric hamstring strengthening exercises during either the warm-up or cool-down of soccer training sessions on hamstring muscle strength fatigability during simulated soccer match play.

Methods

Experimental Approach to the Problem

At the beginning and end of an 8-week intervention period, subjects completed a 90-minute version of the Soccer-specific Aerobic Field Test ($SAFT^{90}$) protocol indicative of soccer match-play demands. The simulation is divided into 2 × 45-minute periods separated by a 15-minute passive rest period (half-time). Before exercise (t_0), at half-time (t_{45}), and postexercise (t_{105}), subjects performed 3 maximal dominant-limb isokinetic contractions for concentric knee extensors (conQ), concentric knee flexors, and eccentric knee flexors (eccH).

Subjects performed no vigorous exercise 24 hours before testing and had consumed no caffeine or alcohol. Baseline and postintervention testing was conducted during the first 3 months of the 2007/2008 English competitive soccer season. The training load and amount of match play performed was standard for the competitive season, involving 2 soccer training sessions and matches per week.

Subjects

Sixteen male semiprofessional soccer players (mean ± *SD*; age 21.3 ± 2.9 years; height 185.0 ± 8.7 cm; body mass 81.6 ± 6.7 kg) took part in the investigation. Subjects were only included in the study if they were not injured or rehabilitating from an injury at the time of testing, either at baseline or postintervention, and did not have a history of a previous hamstring injury within 3 months before baseline testing. Subjects were informed of the experimental risks and signed an informed consent document before the investigation. The investigation was approved by an institutional review board for use of human subjects and in accordance with departmental and university ethical procedures.

Procedures

During each testing session, along with isokinetic muscle strength profiling, subjects completed a 90-minute fatiguing exercise protocol reflective of soccer match play ($SAFT^{90}$). The $SAFT^{90}$ was developed based on contemporary time-motion analysis data obtained from 2007 English Championship Level match play (Prozone). The $SAFT^{90}$ has been shown to induce both the typical activity profile and physiological demands (13), and to replicate the fatigue response, of soccer match play (8). The field test was designed to include multidirectional and utility movements and frequent acceleration and deceleration, as is inherent to soccer match play. The design of the course was based around a shuttle run for a 20-m distance, with the incorporation of 4 positioned poles for the subjects to navigate using utility movements (Figure 1). F1

A 15-minute activity profile was developed and repeated 6 times during the full 90-minute simulated soccer match. The movement intensity and activity performed by the subjects while completing the SAFT course were maintained using verbal signals from an audio CD. This enabled the exercise intensity and duration to be standardized between pre- and postintervention testing.

Isokinetic peak torque (PT) for the knee flexors and extensors (of each subject's dominant leg–the "kicking" leg) was measured using a dynamometer (Biodex System 3, Biodex Medical, Shirley, NY). This equipment was selected because it has been shown to provide mechanically reliable measures of torque, position, and velocity on repeated trials performed on the same day and on different days (7).

Before testing, subjects participated in a standardized warm-up procedure, which included 5 minutes on a cycle ergometer at 60 W, 5 minutes of static and dynamic stretches for the major lower-limb muscle groups, and 5 minutes of light jogging and familiarization with the $SAFT^{90}$ exercise protocol.

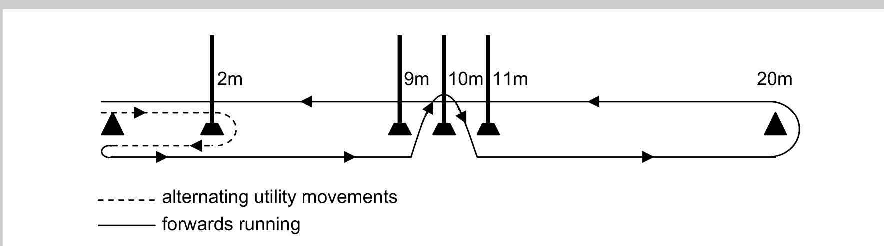


Figure 1. A diagrammatic representation of the Soccer-specific Aerobic Field Test ($SAFT^{90}$) field course.

The isokinetic testing procedure was conducted as described in a previous study (17). All actions were performed at an angular velocity of 2.09 rad·s^{-1} (120°·s^{-1}) and through a range of 0–90° of knee flexion and extension (with 0° being full knee extension). A 1-minute passive recovery was allowed between each trial.

The dependent variables extracted from the isokinetic strength indices were gravity-corrected (PT) values for concentric quadriceps, concentric hamstring, and eccentric hamstring, which enabled calculation of the traditional concentric hamstrings:concentric quadriceps (ConH:ConQ) and functional eccentric hamstrings:concentric quadriceps (EccH:ConQ) strength ratios.

After baseline testing, the subjects were randomly allocated into 1 of 2 training groups: a warm-up group (WU; $n = 8$) or a cool-down group (CD; $n = 8$). Both groups incorporated a program of Nordic hamstring exercises (14) into biweekly soccer training sessions for the 8-week intervention period. The CD group performed the Nordic hamstring exercises during the cool-down of training sessions (i.e., in an exercised state), whereas the WU group performed the exercises during the warm-up (i.e., in a resting state).

The training protocol and load for the Nordic hamstring exercises followed that as employed by Mjølsnes et al. (15). This exercise program has been shown to increase eccentric hamstring strength and to be a safe exercise in this player population, resulting in no injuries during a 10-week period (15).

During the 8-week intervention, match and training exposure, along with compliance rate with the prescribed exercise program, were logged by the players. After the intervention period, subjects were invited back for retesting using identical methods previously employed.

Statistical Analyses

An analysis of variance (ANOVA) for repeated measures was used to assess differences in strength variables measured between groups at each of the 3 time points: before exercise (t_0), at half-time (t_{45}), and postexercise (t_{105}). In addition, 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 represents a medium effect, and ≥0.4 represents a large effect (16). Paired-samples t-tests were subsequently used to analyze within-group differences at individual time points (i.e., t_0, t_{45}, and t_{105}). Effect sizes were determined using the Cohen (4) method, which defines 0.02, 0.15, and 0.35 as small, medium, and large effect sizes, respectively. Statistical analysis was processed using SPSS statistical software with significance levels set at $p \leq 0.05$.

Results

During the 8-week intervention, the WU and CD groups had rates of compliance with the intervention programs of 91.2 and 89.7%, respectively. No significant differences were observed in the compliance rates or total amounts of soccer training and match play between groups ($p > 0.05$).

Cool-Down Group

In the CD group ($n = 8$), a significant increase was observed in the postintervention conH PT at t_{45} (pre t_{45}: 129.6 ± 21.8 N·m vs. post t_{45}: 153.6 ± 33.9 N·m; $p < 0.03$; Cohen $d = 0.66$; 95% CI 0.39–1.71) and t_{105} (pre t_{105}: 133.8 ± 23.3 N·m vs. post t_{105}: 151.1 ± 27.7 N·m; $p < 0.01$; Cohen $d = 0.79$; 95% CI 0.24–1.83). Significant differences were also observed between pre- and postintervention eccH PT at t_0, t_{45}, and t_{105} ($p < 0.01$; eta = 0.71; Figure 2). Post hoc tests revealed significant increases in eccH PT at t_{45} (pre t_{45}: 250.9 ± 36.8 N·m vs. post t_{45}: 282.3 ± 43.4 N·m; $p < 0.02$; Cohen $d = 1.03$; 95% CI 0.09–1.98) and t_{105} (pre t_{105}: 237.9 ± 30.7 N·m vs. post t_{105}: $p < 0.01$; Cohen $d = 0.75$; 95% CI 0.28–1.78). Consequently, a significant difference was observed between the pre- and postintervention eccH:conQ strength ratios at t_0, t_{45}, and t_{105} ($p < 0.02$; eta = 0.44; Figure 3).

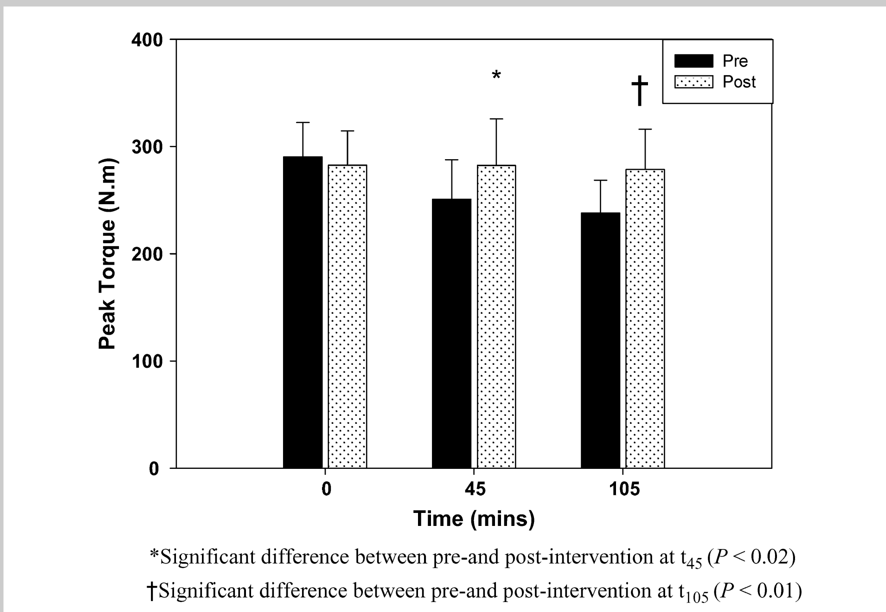


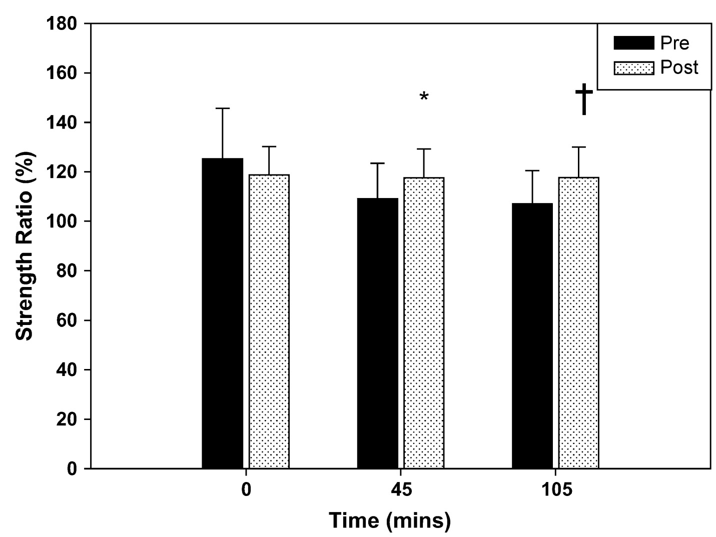
Figure 2. Comparison of eccentric hamstring peak torque between pre- and postintervention for the cool-down group. *Significant difference between pre- and postintervention at halftime (t_{45}; $p < 0.02$); †significant difference between pre- and postintervention after exercise (t_{105}; $p < 0.01$).

Warm-up Group

In the WU group ($n = 8$), a significant increase was observed postintervention in eccH PT at t_0 (pre t_0: 255.1 ± 50.0 N·m vs. post t_0: 272.5 ± 50.4 N·m; $p < 0.01$; Cohen $d = 0.35$; 95% F4 CI −0.75 to 1.45; Figure 4). A significant difference was also observed between pre- and postintervention eccH:conQ F5 strength ratio at t_0, t_{45}, and t_{105} ($p < 0.05$; eta = 0.38; Figure 5). Post hoc tests revealed a significant increase in eccH:conQ ratio at t_0 (pre t_0: 108.0 ± 19.3% vs. post t_0: 113.1 ± 17.4%; $p < 0.03$; Cohen $d = 0.29$; 95% CI −0.82 to 1.39).

Differences Between Groups (CD vs. WU)

There was a significant difference between groups in conH PT at t_0, t_{45}, and t_{105} ($p < 0.03$; eta = 0.30). Post hoc tests revealed significant increases in conH PT for the CD group compared with the WU group at t_{45} (difference [D]−CD t_{45}: 24.0 ± 24.0% vs. D-WU t_{45}: −4.9 ± 21.0%; $p < 0.03$; Cohen $d = 1.03$; 95% CI 0.17–1.90) and t_{105} (D-CD t_{105}: 17.3 ± 13.7% vs. D-WU t_{105}: 2.1 ± 11.1%; $p < 0.03$; Cohen $d = 0.26$; 95% CI −0.43 to 0.94). Significant differences between groups were also observed in eccH PT at t_0, t_{45}, and t_{105} ($p < 0.04$; eta = F6 0.28; Figure 6). At t_0, the WU group displayed a significant increase in eccH PT compared with the CD group (D-CD t_0: −7.9 ± 24.7% vs. D-WU t_0: 17.4 ± 9.7%; $p < 0.03$; Cohen $d = 0.57$; 95% CI 0.09–1.04). Conversely, the CD group displayed significant increases in eccH PT at t_{45} (D-CD t_{45}: 31.5 ± 25.7% vs. D-WU t_{45}: −4.9 ± 25.0%; $p < 0.02$; Cohen $d = 0.81$; 95% CI 0.21–1.42) and t_{105} (D-CD t_{105}: 40.7 ± 24.4% vs. D-WU t_{105}: −6.4 ± 23.2%; $p < 0.02$; Cohen $d = 1.01$; 95% CI 0.47–1.55). Subsequently, the CD group had a significant increase in the eccH:conQ strength ratio (Figure 7) com- F7 pared with the WU group at t_{45} (D-CD t_{45}: 8.4 ± 10.7% vs. D-WU t_{45}: -9.7 ± 14.8%; $p < 0.02$; Cohen $d = 1.02$; 95% CI 0.24–1.81) and t_{105} (D-CD t_{105}: 10.7 ± 14.1% vs. D-WU t_{105}: −3.5 ± 10.4%; $p < 0.04$; Cohen $d = 0.70$; 95% CI 0.04–1.36).



*Significant difference between pre-and post-intervention at t_{45} ($P < 0.05$)

†Significant difference between pre-and post-intervention at t_{105} ($P < 0.05$)

Figure 3. Comparison of the functional eccentric hamstring:concentric quadriceps ratio between pre- and postintervention for the cool-down group. *Significant difference between pre- and postintervention at halftime (t_{45}; $p < 0.05$); †significant difference between pre- and postintervention after exercise (t_{105}; $p < 0.05$).

Discussion

The findings indicate that the timing of eccentric hamstring strengthening exercises during soccer training sessions affects the temporal pattern of strength gains during simulated soccer match play. After the intervention period, the group performing the Nordic hamstring exercises during the warm-up significantly increased their resting eccentric hamstring muscle strength and, subsequently, their functional eccH:conQ strength ratios. However, no significant changes were observed postintervention at either half-time or post-$SAFT^{90}$. This indicates no improvements in eccentric hamstring fatigability in terms of maintaining strength and reducing the negative effects of fatigue associated with simulated soccer match play. For the CD group after the intervention, the results demonstrated maintained eccentric hamstring strength and preserved functional eccH:conQ strength balance during $SAFT^{90}$. The findings should be considered, however, in light of the absence of a control group during the intervention period, which was attributable to a relatively low subject number.

The initial gain in preexercise eccentric hamstring PT and eccH:conQ strength ratio after the intervention period supports previous research (15). However, the current study administered higher isokinetic test speeds than previous work had (15), and because these are more specific to high-velocity functional movements (6), such as sprinting, the primary hamstring injury mechanism (21), our findings may be more valid in relation to hamstring injury risk.

The increased eccentric hamstring PT in a nonfatigued state may imply that such gains in eccentric hamstring strength could potentially prevent hamstring strains, which are principally thought to occur during eccentric muscle contractions (9). However, in the present study, no improvements were observed postintervention in eccentric hamstring strength for the WU group at either half-time or post-$SAFT^{90}$. Given that epidemiological research has observed players to be at

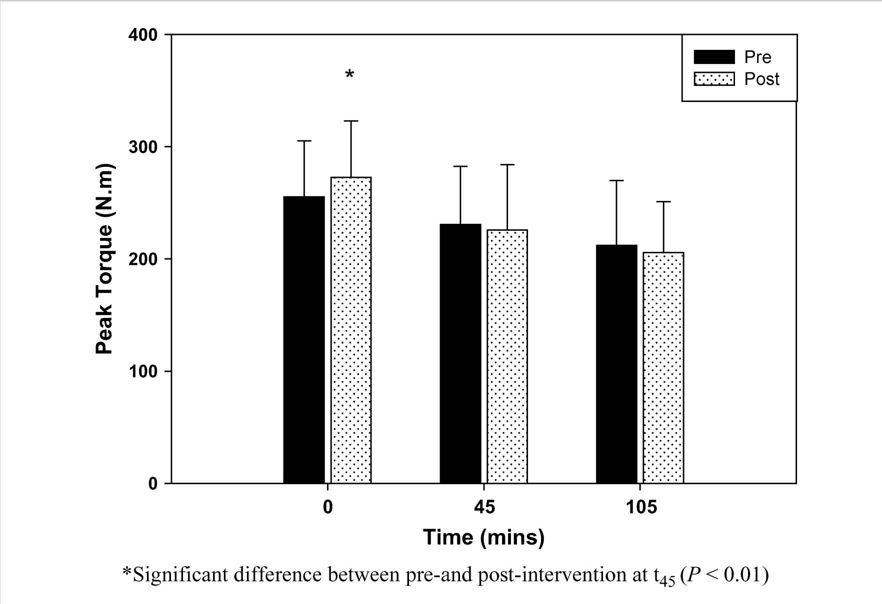


Figure 4. Comparison of eccentric hamstring peak torque between pre- and postintervention for the warm-up group. *Significant difference between pre- and postintervention at halftime (t_{45}; $p < 0.01$).

increased risk of hamstring injuries at this time (21), the potential reduction in injury risk when fatigued during soccer match play seems to be more doubtful.

Research has investigated the prevention of hamstring strains in elite soccer players registering hamstring strains and player exposure time across 4 consecutive soccer seasons (1). The main findings revealed that the Nordic hamstring exercises combined with warm-up stretching reduced the incidence of hamstring strains by 65% compared with teams that did not use the training program.

However, the results also revealed no significant difference in the rate of hamstring strains observed for the intervention teams between the baseline and intervention period during actual match play. Therefore, the training program conducted in a nonfatigued state seems to have been ineffective at reducing match-play injury risk, although the authors did not speculate on the mechanism of this unanticipated finding. It may be postulated that although players experienced initial strength gains while nonfatigued, this strength may not have been preserved during the later stages of match play, at which point players are at increased susceptibility to injury (21).

In a similar investigation to that of Árnason et al. (1), Verrall et al. (20) assessed the effectiveness of introducing sport-specific training on reducing hamstring injuries in professional Australian Rules football players. The intervention program incorporated flexibility exercises, high-intensity anaerobic interval running/acceleration drills, and a specific football drill involving running while in a forward-flexed trunk position (therefore increasing the eccentric load imposed on the hamstring muscles) that was performed in a fatigued state at the end of the training period. Postintervention hamstring injury incidence rate was significantly lower than during the preintervention period. Hence, the findings by Verrall et al. (20) suggest that the incorporation of sport-specific drills (emphasizing eccentric hamstring strength) performed under fatigued conditions aided in lowering the risk of hamstring injury.

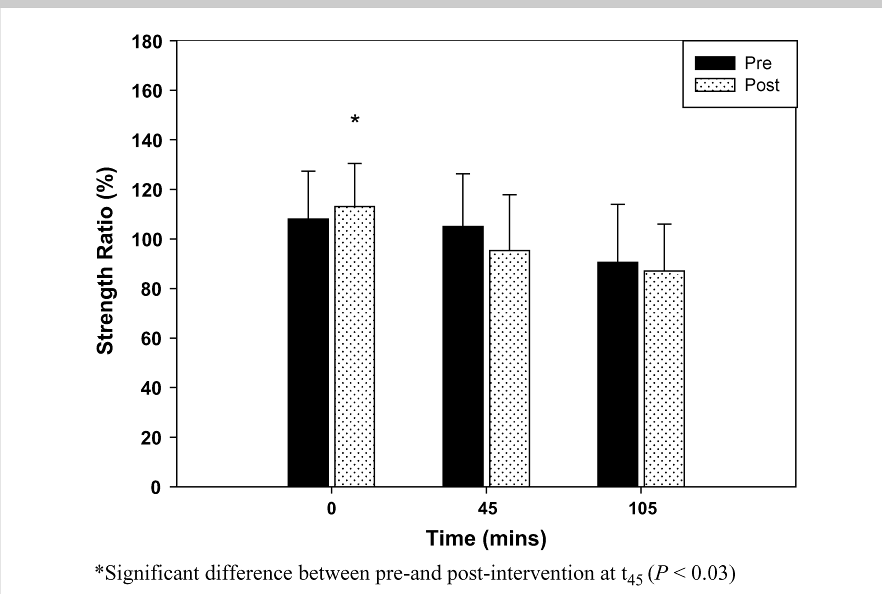


Figure 5. Comparison of the functional eccentric hamstring:concentric quadriceps ratio between pre- and postintervention for the warm-up group. *Significant difference between pre- and postintervention at halftime (t_{45}; $p < 0.03$).

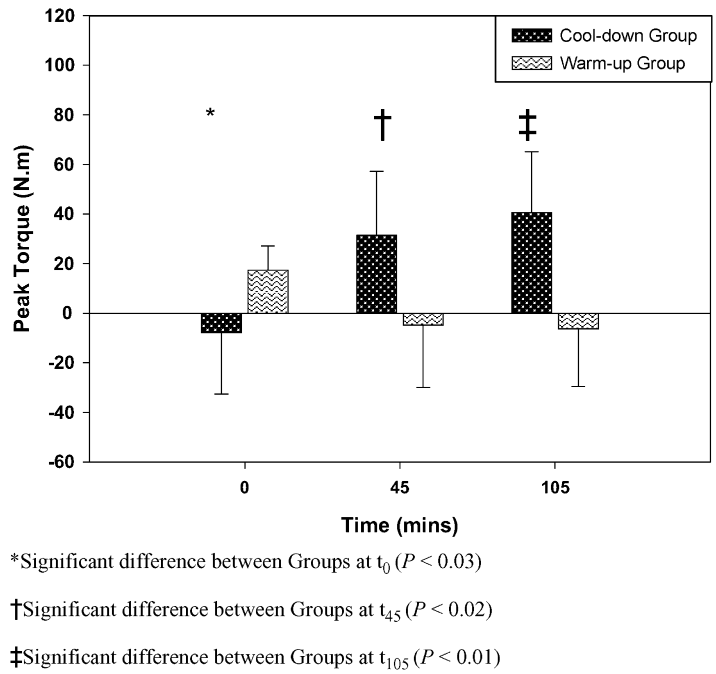


Figure 6. Changes in eccentric hamstring peak torque between pre- and postintervention for cool-down and warm-up groups. *Significant difference between groups before exercise (t_0; $p < 0.03$); †significant difference between groups at halftime (t_{45}; $p < 0.02$); ‡significant difference between groups after exercise (t_{105}; $p < 0.01$).

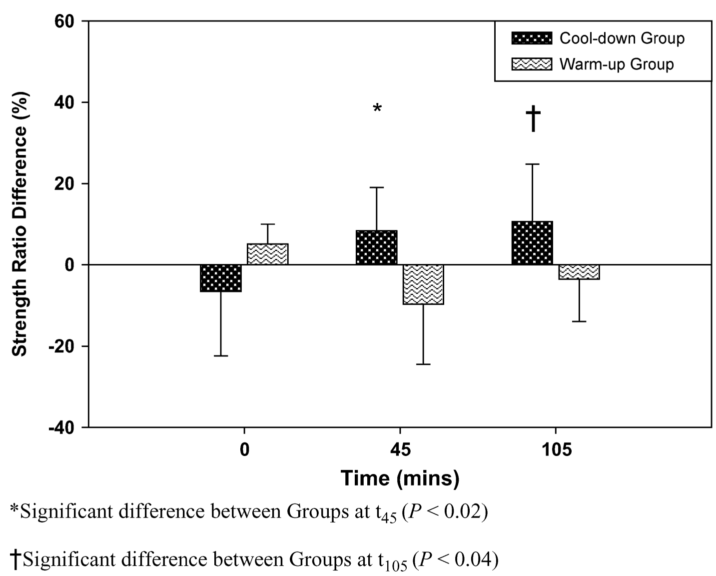


Figure 7. Changes in functional eccentric hamstring:concentric quadriceps ratio between pre- and postintervention for cool-down and warm-up groups. *Significant difference between groups at halftime (t_{45}; $p < 0.02$); †significant difference between groups after exercise (t_{105}; $p < 0.04$).

In the CD group, postintervention results displayed better-maintained eccentric hamstring strength and preserved eccH:conQ muscular balance at halftime and post-SAFT^{90}, especially when compared with the warm-up. Therefore, the players demonstrated reduced negative fatigue effects on markers of hamstring strain injury risk during the later stages of simulated soccer match play when reportedly at greatest susceptibility to strain injury (21).

To our knowledge, these findings are unique, not least concerning soccer-specific fatigue and hamstring injury risk. However, they may be explained in terms of the law of specificity, whereby the nature of the training load produces specific responses and adaptations to that load. Therefore, it is conceivable that training in a fatigued state may improve performance in a fatigued state. This response may relate to the concept of postactivation potentiation, whereby a motor learning component could be involved to create training-induced neuromuscular adaptations of alternate muscle recruitment strategies according to the specific mode of exercise training.

Alternatively, theories regarding principles of myoplasticity, increased mitochondrial mass, increased free fatty acid use, and increased capillary density have been proposed as positive adaptations after fatigued resistance training (3). However, because little research has investigated these hypotheses, additional research is warranted to examine muscular adaptations after strength training in a fatigued state. This information could hold vital knowledge to be used in the future planning of injury prevention programs.

The CD group also displayed a significant increase in concentric hamstring muscle strength after the intervention at half-time and post-SAFT^{90} protocol. This finding may be explained by the mechanics and muscle actions involved in performing the Nordic hamstring exercise. After controlling forward motion to the ground, to return to the starting vertical position subjects forcefully push with their hands on the ground while at the same time exerting some concentric contraction of the hamstrings (15). Therefore, as the CD group performed the exercise during the cool-down of training sessions, the results indicate that they were able to increase their fatigability of concentric hamstring strength. Although this did not alter the traditional conH:conQ ratio, which may have injury prevention implications, it could aid performance in maintaining players' ability to run, sprint, jump, and tackle vigorously under fatigued conditions, especially during the later stages of soccer match play (17).

This is perhaps the first study to investigate the effect of timing of eccentric hamstring strengthening exercises during soccer training, but the results could potentially be significant for hamstring injury prevention programs in a variety of related sports. Considering the acknowledged relationship between reduced eccentric hamstring strength and increased injury potential, the strength benefits reported by performing eccentric hamstring strengthening exercises in a fatigued state may help reduce the risk of hamstring strain injuries, especially during the later stages of soccer match play. To confirm this, the next logical step could be to investigate the effect of the timing of eccentric hamstring strengthening exercises during soccer training sessions on the incidence of hamstring strain injuries in soccer. Furthermore, because a variety of common soccer injuries have been shown to have an increased incidence during the later stages of match play (11,18), future research could investigate additional injury prevention programs conducted during fatigued conditions and the effect this may have on reducing injury risk.

Practical Applications

The findings from the present study indicate that performing eccentric hamstring strengthening exercises during the cool-down rather than warm-up of soccer training sessions more effectively maintains eccentric hamstring strength and preserves the functional eccH:conQ strength ratio throughout simulated soccer match play. These findings may have implications for future injury prevention programs aiming to reduce hamstring strain injury risk, particularly during the later stages of soccer match play. Furthermore, it may be hypothesized that such a strategy of fatigued training for injury prevention may have wider applications for preventing additional injuries displaying a similar temporal pattern of incidence during competition, and also across multiple sports.

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