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Effects of eccentric exercise on optimum length of the knee flexors and extensors during the preseason in professional soccer players

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A B S T R A C T

Objective: To assess the effects of eccentric exercise on optimum lengths of the knee flexors and extensors during the preseason in professional soccer.
Design: Twenty-eight athletes from a professional Spanish soccer team (Division II) were randomly assigned to an eccentric exercise intervention group (EG) or a control group (CG). Over the four-week period two athletes from the control group suffered RF injuries and two athletes were contracted by other clubs. After these exclusions, both groups (EG, $n = 13$; and CG, $n = 11$) performed regular soccer training during the four-week preseason period.
Results: After the four weeks, the optimum lengths of the knee flexors were significantly ($P < 0.05$) increased by 2.3° in the CG and by 4.0° in the EG. The change in the EG was significantly ($P < 0.05$) greater than that of the CG. The optimum lengths of the knee extensors were significantly increased only in the EG by 6.5°. Peak torque levels and ratios of quadriceps to hamstring (Q/H ratios) were not significantly altered throughout the study for either group.
Conclusion: Eccentric exercise can increase the optimum lengths of both the knee extensors and knee extensors flexors during the preseason in professional soccer.

1. Introduction

Muscle strains are the most common lower body injuries in professional soccer (Hawkins, Hulse, Wilkinson, Hodson, & Gibson, 2001; Woods et al., 2004). Particularly, the biceps femoris and rectus femoris (RF) muscles are thought to be at great risk during fast movements (i.e. sprinting, accelerating, change of direction, kicking, landing, etc.) due to their bi-articulate design (Brooks, Fuller, Kemp, & Reddin, 2006; Hoskins & Pollard, 2005a, 2005b). Previous literature indicates that hamstring injuries alone account for between 12 and 17% of all injuries reported in professional soccer (Hawkins et al., 2001; Woods et al., 2004). In addition to the prevalence of hamstring injuries there are prolonged symptoms, a poor healing response, and a high risk of re-injury (i.e. 12–31% re-injury rate) (Woods et al., 2004). Although several prospective and retrospective studies exist on the risk factors for hamstring injuries, there is no consensus on how to treat or prevent hamstring injuries (Hoskins & Pollard, 2005a, 2005b).

It has been suggested that eccentric exercise may reduce hamstring injury rates as the muscles are trained to shift the peak of the torque–angle curve in the direction of longer muscle lengths (Brockett, Morgan, & Proske, 2004; Brooks et al., 2006; Woods et al., 2004). The shift in "optimum length" is typically measured from a change in the torque–angle relationship in humans, so it should be noted that when we refer to optimum length we use it with these conventions in mind. The shift in optimum length has been reported in 11 human studies (up to 18° shift) using a variety of eccentric exercise interventions (for a recent review see Brughelli & Cronin, 2007). However, the majority of these studies have utilized an acute design (i.e. 9 of the 11 studies), where the majority of the shift was thought to be due to muscle damage (Brughelli & Cronin, 2007). There are very few studies that have reported a shift in optimum length after a period of training (Clark, Bryant, & Culgan, 2005; Kilgallon, Donnelly, & Shafat, 2007). One of these training studies was a pilot study (Clark et al., 2005) and the other study did not use an athletic population (Kilgallon et al., 2007). Thus there

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have been no previous randomized controlled training studies that have reported a shift in optimum length in an athletic population. Furthermore, there are no previous training studies that have reported a shift in optimum length of two opposing muscle groups (i.e. knee flexors and knee extensors) after eccentric exercise. This shift in optimum length has been argued to be a protective adaptation for future muscle strain injuries in sport (Brockett et al., 2004; Proske, Morgan, Brockett, & Percival, 2004). In support of this theory, several studies have reported reductions in hamstring injury rates after eccentric exercise in elite and sub-elite athletes (Arnason, Andersen, Holme, & Bahr, 2008; Askling, Karlsson, & Thorstensson, 2003; Brooks et al., 2006; Gabbe, Bennell, Finch, Wajswelner, & Orchard, 2006). It should be noted that only the training induced shift in optimum length, and not the acute muscle damage-induced shift in optimum length, has been proposed as a protective adaptation for muscle strain injuries.

Similar to the literature presented above on the knee flexors, training studies have reported shifts in optimum length of the knee extensors after eccentric exercise (up to 15.4°) (Bowers, Morgan, & Proske, 2004; Yeung & Yeung, 2008). Thus it seems possible that shifting the optimum length of the knee extensors to longer muscle lengths could protect this muscle group from future strain injury as well. RF injuries are very common in professional soccer, especially in the preseason. For example, Woods et al. (2004) reported that RF strain injuries occurred more often (29%) than hamstrings (11%) and groin strains (12%) during the preseason among 91 professional English soccer teams. However, due to a paucity of literature on RF injuries little is known about their risk factors, time lost from injury, prevention, treatment, or re-injury rates. The only study that has investigated risk factors for quadriceps injuries (n = 163) in sport has reported the following risk factors for Australian Rules football players: previous injury, player height (shorter athletes more likely to be injured), and hard ground surfaces (Orchard, 2001).

Given that the time course of the shift in optimum length has not been investigated in many longitudinal training studies, practical training methodologies for prevention or rehabilitation of hamstrings and/or RF strain injuries are yet to be developed. Accordingly, the primary objective of this blinded, randomized/controlled training study was to determine the effects of eccentric exercise on the optimum length of both the knee flexors and extensors over the preseason (i.e. 4 weeks) in professional soccer.

2. Methods

2.1. Subjects

Twenty eight members of a Spanish soccer league team (Division II) were recruited and randomly assigned to either an eccentric exercise group (EG) or a control group (CG). To reduce potential confounding, a match-pair design was used in which the athletes were matched for optimum length of the knee extensors and previous RF injuries. Thereafter, the athletes were randomly allocated to either the EG or CG. The randomization was performed by a statistician who was not involved in the intervention. The investigators were blinded to the two groups throughout the testing sessions and the training period. Two athletes (one from CG and one from EG) were dropped from the study due to being contracted by other clubs. An additional two subjects in the CG could not complete all of the training and testing sessions due to muscle strain injuries in the RF, which were confirmed by MRI. All of the remaining athletes in the EG (n = 13; age = 20.7 ± 1.6 years; height = 180.1 ± 7.0 cm; weight = 73.1 ± 6.0 kg) and CG (n = 11; age = 21.5 ± 1.3 years; height = 178.7 ± 6.5 cm; weight = 72.5 ± 7.5 kg) completed all of the training and testing sessions (i.e. 100% compliance). In addition, the total number of hours over the 4 week period during training and games were similar for the EC (41.3 ± 0.07 h and 3.5 ± 0.05 h, respectively) and the CG (43.5 ± 0.18 h and 4.3 ± 0.05 h, respectively). The only other injury that occurred throughout the study was a minor ankle sprain due to a tackle.

Both groups performed normal soccer training throughout the study, and the training period was performed during the four-week preseason of the Spanish professional soccer league. The experimental group (EG) performed additional eccentric exercises three times per week for the four weeks. All subjects provided written, informed consent within the guidelines of Edith Cowan University Human Research Ethics Committee.

2.2. Isokinetic dynamometry

A Cybex NORM® (Humac, California, USA) isokinetic dynamometer was used to measure peak torque values and torque–angle curves of both legs during knee flexion and extension. A single investigator conducted all of the isokinetic testing. The subjects were seated on the Cybex with their hip joints flexed to approximately 90°. Their upper bodies were secured with dual cross-over straps for the torso and a waist strap. The range of motion for the knee joint was set from 0 to 110°, where the full leg extension position was set as 0° for knee extension and flexion. Lateral movements of the knee were restricted with a thigh strap and an ankle strap was used to stabilize the lower leg. The subjects were instructed to grip side handles to help stabilize the upper body. Alignment between the center of rotation axis (i.e. the lateral femoral epicondyle) was monitored for each trial. Correction of gravity was obtained by measuring the torque exerted on the dynamometer lever arm by the weight of the arm.

All subjects performed six continuous maximum effort concentric contractions of the knee flexors and extensors for both legs in random order at the angular velocity of 60°/s (Brockett, Morgan, & Proske, 2001). Two warm-up sets were performed before the trial set, which were performed at 50% and 80% of the athletes perceived maximum effort. The warm-up sets and the trail set were separated by a five minute rest period in order to prevent fatigue. All subjects were instructed to give their maximum voluntary effort during the trial set, and verbal encouragement was given during each repetition. The raw data was transferred from the Cybex to a personal computer, where the data was analysed with a custom made LabVIEW 8.2 (National Instruments, Texas, USA) program. Of the six maximum effort knee flexions and extensions, the first and last contractions were excluded in the data analysis. The second, third, forth and fifth contractions were averaged for the determination of the optimum angle by fitting a 4th order polynomial curve (torque and angle arrays) (Philippou, Bogdanis, Nevill, & Maridaki, 2004). Peak torque was determined from the peak of the fitted curve. The quadriceps/hamstring ratio (Q/H ratio) was taken from the ratio of peak torque between the knee extensors and flexors. All pre-training measurements were taken at least 24 h before the training, and all post-training measurements were taken at least 48 h after the last training session. The Cybex NORM® has been shown to have high absolute (4.3–6.7%) and relative reliability (ICC = 0.89–0.98) for knee flexion and extension concentric contractions at 60°/s (Impellizzeri, Bizzini, Rampinini, Cereda, & Maffiuletti, 2008).

2.3. Eccentric training intervention

The training was performed during the Spanish professional leagues preseason. Each session lasted about 10–15 min and was performed after normal soccer training. The sessions were performed three times per week for the four-week intervention. Each session included one or two eccentric exercises for a total of four to five sets. The eccentric exercises included the following 4 exercises:

Eccentric Box Drops (see Fig. 1a and b), Lunge Pushes (see Fig. 2a and b), Forward Deceleration Steps (see Fig. 3), and the Reverse Nordic Hamstrings (see Fig. 4a and b).

It should be noted that both the EG and the CG performed the Nordic hamstring exercise during the four-week period, as it is becoming standard practice for preventing injury in professional soccer. The Nordic hamstring was the only eccentric exercise performed by the CG, which was performed once a week for a total of two sets of six repetitions. The EG also performed the Nordic hamstring exercise once a week for a total of two sets of six repetitions.

2.4. Statistical analysis

Changes in the dependent variables over time were compared between groups by a two-way repeated measures ANOVA (2 groups × 2 time points), and a Tukey post-hoc test was performed to determine significant differences between pairwise comparisons. All data are reported as means and standard deviations (SD), and the significance was set at $P < 0.05$. Since there were no significant differences found between legs for any of the variables measured ($P < 0.05$), the values for both legs were combined into a single group.

3. Results

Comparisons between the EG and CG for optimum angle, peak torque, and Q/H ratios are detailed in Table 1. It should be remembered that since the "zero angle" was set at full leg extension for both knee flexion and extension, thus a smaller knee angle represents a shorter quadriceps length and a longer hamstrings length. No significant changes in peak torque or Q/H ratios were observed after the 4-week training period for either group.

Significant increases in optimum length for knee flexion were evident in both groups (CG = 2.3°; EG = 4.0°); however, the increase was significantly greater for the EG compared with the CG.

Table 1
Mean (± SD) peak torque, Q/H ratio and optimum angle of torque development during knee flexion and extension for the control (CG) and eccentric exercise group (EG) before (Pre) and after (Post) training.

Variable	Group	Pre	Post
Knee flexion			
Optimum angle (°)	CG	30.4 ± 2.7	28.1 ± 3.5*
	EG	32.2 ± 3.6	28.2 ± 3.7*#
Peak torque (Nm)	CG	192 ± 20.9	190 ± 24.4
	EG	197 ± 22.4	193 ± 21.6
Knee extension			
Optimum angle (°)	CG	67.1 ± 7.4	68.9 ± 8.5
	EG	65.7 ± 7.1	72.2 ± 7.9*#
Peak torque (Nm)	CG	290 ± 30.3	291 ± 40.7
	EG	287 ± 34.2	293 ± 37.5
Q/H ratio's	CG	0.65 ± 0.08	0.66 ± 0.07
	EG	0.68 ± 0.07	0.67 ± 0.07

* = significantly ($P < 0.05$) different from pre-training.
# = significantly ($P < 0.05$) different from CG.

For knee extension, a significant increase in optimum length was found only for the EG of 6.5°.

4. Discussion

To our knowledge, this is the first random-controlled training study to investigate the effects of eccentric exercise on optimum length of the knee flexors and/or knee extensors in an athletic population. Eccentric based training is thought to increase the optimum length and possibly reduce muscle strain injury rates in athletic populations (Brooks et al., 2006; Proske et al., 2004). The main finding of the present study was that a group of professional male soccer players performing extra preseason eccentric exercise significantly increased their optimum lengths during knee flexion and extension in comparison to a CG. This is the first study to report a shift in optimum length of both agonist and antagonist muscle

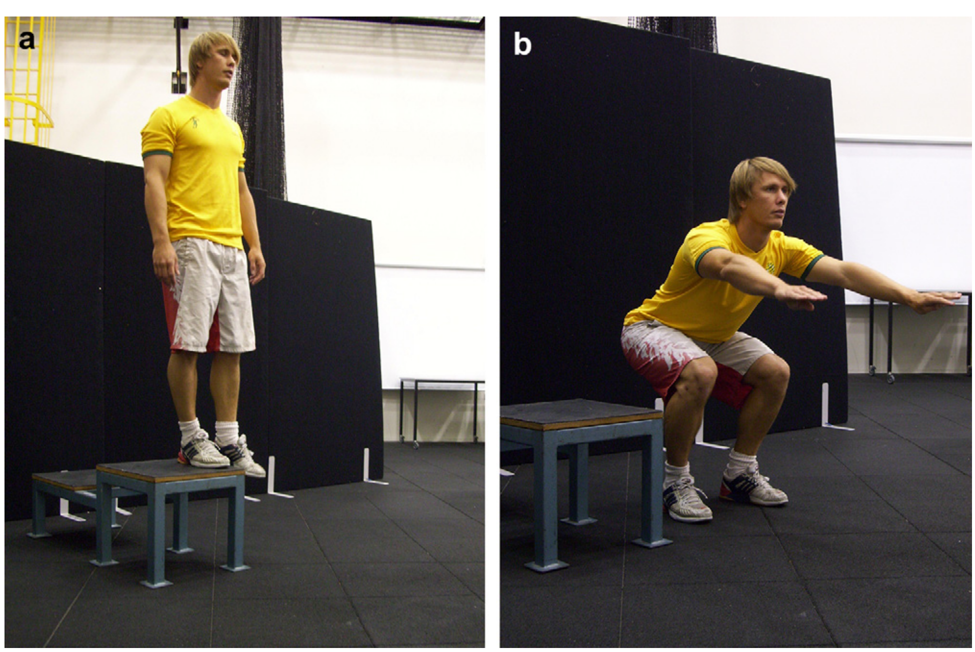

Fig. 1. Eccentric box drop. The athlete steps up onto a box (a) and then steps off the box. Upon landing the athlete bends down into a parallel squat position in one smooth and continuous motion (b).

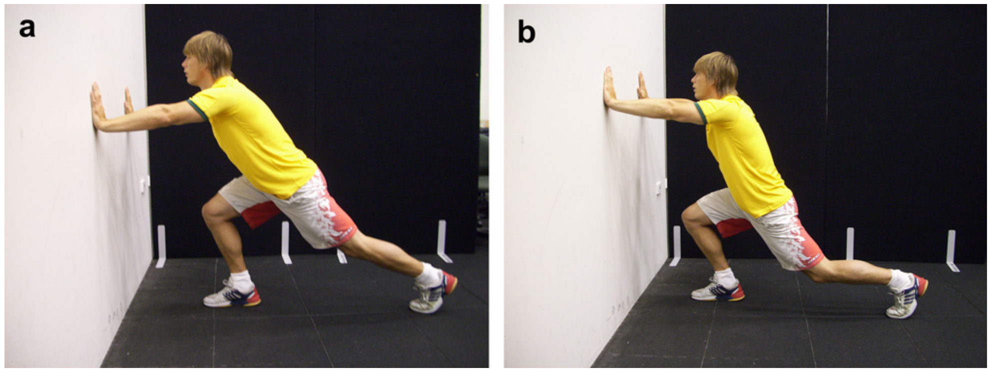

Fig. 2. Lunge pushes. The athlete assumes a lunge position with his back leg behind his center of mass (a). Then the athlete extends his arms so that pressure can be applied against a wall. Then the athlete lowers to the ground in a straight line while pushing into the wall with both legs (b).

groups. It should be noted that the athletes came from a second division soccer team in the Spanish Professional League. All of the athletes were full-time employees and performed frequent training sessions and matches. Thus it seems that the eccentric exercise intervention prescribed in this study was an adequate stimulus for adaptation.

It has been well established that eccentric exercise can shift the optimum length to longer lengths. The important factors for inducing a shift in eccentric exercise include muscle length, contraction intensity and training volume (Brughelli & Cronin, 2007). The studies reporting the greatest shifts used exercises that actively lengthened the muscles to longer lengths with maximum voluntary contractions (Brughelli & Cronin, 2007). Thus, the exercises in the present study were designed to produce high intensity eccentric muscle contractions at longer than optimum muscle lengths, especially for the knee extensors as RF injuries are very common during the preseason in professional soccer (Woods et al., 2004). The RF is a bi-articulate muscle that is actively lengthened during athletic movements that involve hip extension and knee flexion, i.e. deceleration during running, as the swing leg extends back during kicking, as the knee flexes during kicking. The eccentric exercises were designed to include active hip extension and/or knee flexion. It is impossible to determine which exercise had the greatest influence on the optimum length. However it seems that the eccentric exercise intervention was effective in changing the optimum length of the knee flexors and extensors. This approach was thought to be more specific to the training practices for professional soccer players.

Fig. 3. Forward deceleration steps. The athlete with be towed behind another athlete who is running at maximum effort. The athlete who is being towed with lean back and attempt to decelerate by extending their knees and keeping their hips fixed.

The present study was the first to investigate the training effects of eccentric exercise on the optimum length in an athletic population that was also performing normal sport training. The present study found that the optimum lengths significantly increased by 4° during knee flexion (i.e. hamstrings) and by 6.5° during knee extension (i.e. quadriceps femoris) after the four-week eccentric exercise intervention in the EG. The CG had a significant shift in the knee flexors of 2.3°, which was significantly less than the shift for the EG. The reason for this smaller shift could be due to a lower eccentric training volume. Both groups performed the Nordic hamstring exercise once per week, but the EG also performed eccentric box drops. Previous research has also reported significant shifts in optimum length for the knee flexors after eccentric based training in untrained subjects who were not participating in any other activities during the testing or training period. Clark et al. (2005) reported a shift of 6.5° in the knee flexors after four weeks of training with the Nordic Hamstring exercise. Kilgallon et al. (2007) reported a significant change in optimum length in the knee flexors of 21° after three weeks of progressive eccentric training with eccentric deadlifts and eccentric leg curls. However, the optimum lengths returned to pre-training values after 18 days of rest. Two recent studies have reported acute shifts in optimum length during knee extension after a step-down exercise, which was initiated from an elevated position and as the subjects stepped down from the box their knee extensors were contracted eccentrically. The subjects in Bowers et al. (2004) performed 240 total step-downs which induced the greater shift of 15.4°, while the subjects in Yeung and Yeung (2008) performed 150 total step-downs which induced the more modest shift of 6.9°. It should be noted that these two later studies were muscle damage studies and only one or two training sessions were performed. Given the difference between these studies and the loading parameters and longitudinal design

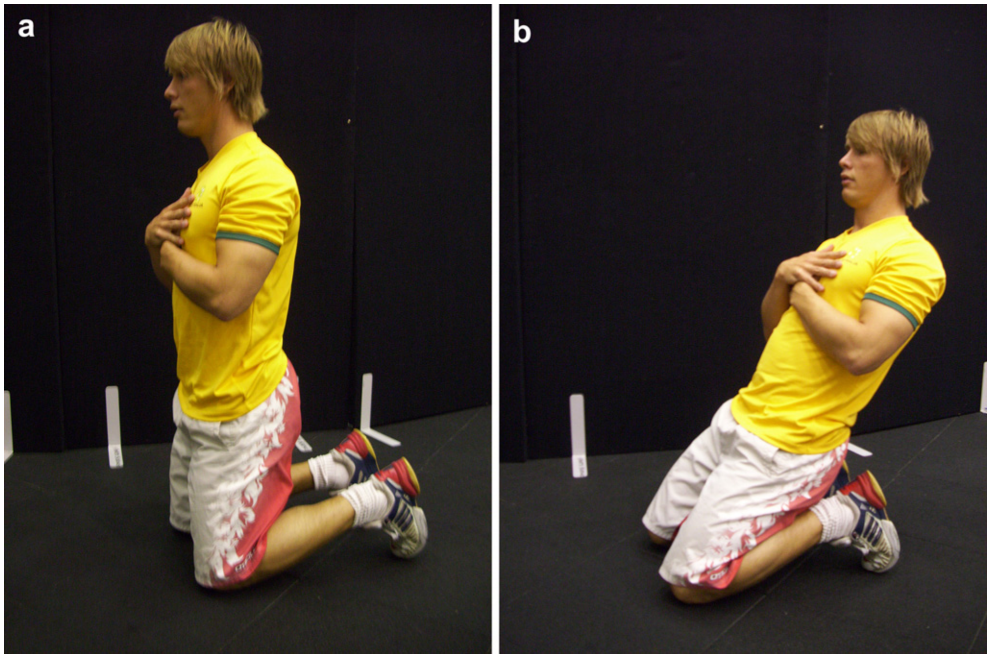

Fig. 4. Reverse nordic hamstring: This is similar to the normal Nordic hamstring exercise but in the opposite direction i.e. backwards (a and b).

of the present study, it would seem that the intervention used in the present study were still effective in shifting optimum length though eliciting less muscle damage.

It has been proposed that athletes who produce peak tension at shorter muscle lengths are more likely to suffer an acute muscle injury (Brockett et al., 2004; Brooks et al., 2006). A shorter optimum length would result in a decrease in the muscles "safe" operating range, thus increasing the risk of injury. In the only retrospective study on this topic, Brockett et al. (2004) investigated the optimum lengths in injured and non-injured hamstrings and reported that the optimum length of the injured hamstrings occurred at 12.7° less than that of the non-injured hamstrings. This was despite the fact that concentric torque was not significantly different between the injured and non-injured hamstrings. The authors concluded that a shorter than normal optimum length was a greater indicator of previous injury (and possibly future injury) than peak torque or Q/H ratios. In the present study, there was no difference in peak torque or Q/H ratio's in either group before or after the intervention.

The only form of training that has consistently been shown to decrease hamstring injury rates is eccentric exercise. Four published studies have reported drops in injury rates with bilateral and closed chain eccentric exercises, which included the Nordic hamstring and the YoYo hamstring curl (Arnason et al., 2008; Askling et al., 2003; Brooks et al., 2006; Gabbe et al., 2006). There were no hamstring injuries in the present study for either the CG or EG during the study period. However, hamstring injuries are thought to be less common as RF injuries during the preseason of professional soccer. Woods et al. (2004) is the only study to investigate both hamstring and RF injuries during the soccer preseason and reported that RF injuries occurred more often than either hamstring or groin injuries. Later in the season hamstring injuries were reported to be more common as opposed to the preseason. In addition, hamstring injury rates increase during games as opposed to training. Thus it could be speculated that eccentric exercises for RF should be emphasized more in the preseason and eccentric exercises for the hamstring and groin later in the season.

Two athletes in the CG suffered injuries to the indirect head of the RF (confirmed by MRI). Proximal RF injuries to the indirect head of the muscle–tendon complex are thought to be more severe in comparison to injuries to the distal mid-belly of the RF (Gyftopoulos, Rosenberg, Schweitzer, & Bordalo-Rodriques, 2008; Hasselman, Best, Hughes, Martinez, & Garrett, 1995). Tears to the indirect head of the muscle–tendon complex are typically longitudinal and involve a long segment of the muscle (Gyftopoulos et al., 2008). It is possible that specific interventions need to be developed for each type of RF injury. The two athletes in the present study did not receive any eccentric training for their knee extensors throughout the study.

The findings of the present study provoke several questions about future interventions. Since the present study was only performed for four weeks, it is unknown if the shifts in optimum length will increase, decrease or remain the same throughout the season. Thus, the volumes and intensities of eccentric exercise throughout a season are unknown. Further research is needed with larger sample sizes and longer training periods in order to determine appropriate training and maintenance protocols. Furthermore, prospective and retrospective studies are needed on the optimum length and RF injuries. These studies could confirm or deny the contention that a shorter than normal optimum length is a risk factor for RF injuries.

5. Conclusions

This is the first randomized controlled training study on the effects of eccentric exercise on optimum length in an athletic population. The results of this study suggest that eccentric based training can shift the optimum lengths of two apposing muscle groups i.e. the knee flexors and knee extensors. These shifts have been induced with functional eccentric exercises. In addition, the shifts have occurred with very little muscle soreness. These results suggest that four to five total sets of these eccentric exercises is the optimal volume for inducing a shift in optimum length over a four-week period.

Ethics approval

All players provided written, informed consent within the guidelines of the Ethics Committee of Edith Cowan University. The ethics review board at Edith Cowan University approved this study.

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Conflict of interest

There was no conflict of interest for this study.

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