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Cross-sectional investigation of indices of isokinetic leg strength in youth soccer players and untrained individuals

J. Iga[1] , K. George[2], A. Lees[2], T. Reilly[2]

[1]Faculty of Sport, Health and Social Care, University of Gloucestershire, Gloucestershire, UK, [2]Research Institute for Sport and Exercise Sciences, Liverpool John Moores University, Liverpool, UK
Corresponding author: Prof Keith George, Research Institute for Sport and Exercise Sciences, Liverpool John Moores University, Henry Cotton Campus, Webster Street, Liverpool, L3 2ET, UK. Tel: +44 (0) 151 231 4249, Fax: +44 (0) 151 231 4353, E-mail: K. George@ljmu.ac.uk.

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In this cross-sectional study, the differences in the isokinetic peak torque of the knee joint muscles (dominant and non-dominant) were investigated in three groups of youths ($n = 45$; age, 14.9 ± 1.1 years) with different soccer training backgrounds. Significant main effects were observed for training background on the functional hamstrings to quadriceps ratios for knee flexion (H_{CON}:Q_{ECC} ratio; $F_{2,42} = 4.023$, $P = 0.025$) and extension (H_{ECC}:Q_{CON} ratio; $F_{2,42} = 8.53$, $P < 0.001$) at 4.32 rad/s. *Post hoc* tests indicated that both ratios were significantly different between conventionally trained players compared with resistance-trained players and controls (mean $\pm$ SD; H_{ECC}:Q_{CON} ratio, dominant limb; 0.91 ± 0.10; 1.04 ± 0.12; 1.10 ± 0.22; non-dominant limb; 0.89 ± 0.09; 1.05 ± 0.19; 1.06 ± 0.15; H_{CON}:Q_{ECC} ratio, dominant limb; 0.36 ± 0.06; 0.34 ± 0.07; 0.30 ± 0.08; non-dominant limb; 0.33 ± 0.05; 0.32 ± 0.08; 0.28 ± 0.07). Results suggest that the muscle-loading patterns experienced in youth soccer may alter the reciprocal balance of strength about the knee under high-velocity conditions. The findings also indicate that these balances may be improved by incorporating resistance training into the habitual exercise routines of youth soccer players.

The identification of young talent in soccer is followed by selection into a systematic program of training designed to improve technical and tactical skills and develop specific aspects of physical fitness. Cross-sectional reports suggest that involvement in accelerated programs of soccer training may affect the strength of the knee joint muscles (Rochcongar et al., 1988; Hansen et al., 1999). For example, Rochcongar et al. (1988) found that elite young French soccer players had greater isokinetic peak torque compared with high school students, indicating that soccer training has an effect on the development of muscle strength.

While playing and training for soccer appear to increase the strength of the muscles about the knee joint, it has been suggested that the magnitude of the improvement may not be identical in both the hamstrings and the quadriceps; Cometti et al. (2001) postulated that the muscle loading patterns experienced during soccer may favor the greater development of the quadriceps muscles compared with the hamstrings, altering the reciprocal balance of strength about the knee. Additionally, soccer players seldom use both limbs with equal emphasis, often favoring the use of the dominant limb when performing game-specific activities (Zakas, 2006); it is possible that individuals exposed to advanced programs of specialized training may develop unique bilateral strength relations between the limbs (Burnie & Brodie, 1986). Currently, no research group has considered the consequence of playing and training for soccer on the reciprocal and bilateral balance of strength about the knee in youths.

The occurrence of injury may compromise the development of young talent in soccer (Price et al., 2004). Hamstring strains account for a large proportion of the injuries sustained by youth soccer players (Price et al., 2004; Le Gall et al., 2006). While the precise cause of this injury remains unclear (Croisier, 2004), it is postulated that a relative weakness in the strength of the hamstrings may predispose to this injury (Orchard et al., 1997). Injuries to the anterior cruciate ligament (ACL) are being recognized with increased frequency among youths' playing team sports such as soccer (Micheli et al., 1999). Although participation trends may contribute to these observations, these findings represent a major cause of concern (Shea et al., 2003). The exact mechanism of non-contact ACL injury remains to be elucidated (Boden et al., 2000); however, it is thought that active quadriceps pull, combined with a relative weakness in the hamstrings muscle group, may play an important role in the pathomechanism of this injury (Boden et al., 2000).

Investigations involving adults have indicated a significant reduction in the incidence and severity of musculo-ligamentous injury following appropriate resistance training (Heidt et al., 2000; Askling et al., 2003). These observations may have been mediated by an increase in the eccentric strength of the hamstrings and the improvement of muscle strength balance about the knee with resistance training (Aagaard et al., 1996). Historically, children and youths have been discouraged from participating in resistance-training programs because of fear over its safety and concern regarding its effectiveness (e.g., Vrijen, 1978). Current consensus is that when following a carefully planned and well-supervised resistance-training program, children and youths can safely and effectively train to improve their muscular strength (Stratton et al., 2004). To date, no investigation has examined the effects of resistance training on the isokinetic peak torque of the hamstrings and quadriceps muscles and the reciprocal balance of strength about the knee in youth soccer players.

The aims of the present investigation were (i) to examine the effects of playing and training for soccer on the reciprocal and bilateral balance of strength about the knee joint and (ii) to investigate the effects of resistance training in this population on isokinetic peak torque and the reciprocal balance of strength between the hamstrings and quadriceps muscles.

Materials and methods

Participants

Forty-five boys volunteered to participate in the study. This sample size was chosen on the basis of statistical power calculations (nQuery Advisor 5.0; Statistical Solution, Cork, EIRE) of the primary dependents variables (functional hamstrings to quadriceps ratios). Calculations indicated that at an α level of 0.05 (80% power), ~ 12 participants per group would be required to distinguish the minimum clinically important difference from the statistical null.

Fifteen boys were recruited from the talent development programs of a club in the English professional soccer leagues. These boys trained for 3–4 h/week and played one competitive match per week; their training focused exclusively on the development of technical and tactical soccer skills and on the improvement of game-related fitness (conventionally trained soccer players). Another fifteen boys were recruited from the training programs of another club in the English professional soccer leagues. These boys trained for 3–4 h/week to develop technical and tactical skills and improve specific aspects of game-related fitness, they played one competitive match per week, and they had performed two additional resistance-training sessions each week for the previous 8 months (resistance-trained soccer players). Their resistance-training program consisted of two to three sets of mainly lower-body exercises (back squat, leg extensions, hamstrings curls, lunges, calf raises) performed at 10–14 "repetition maximum" loading and each session lasted for approximately 30 min. Fifteen boys served as a control group; these boys participated in a range of curricular and extracurricular sporting activities but none were involved in any organized sports training programs. Table 1 illustrates the anthropometric and training characteristics of the participants. The University's Research Ethics Committee approved all procedures. The youths gave their verbal assent and signed informed parental consent was obtained before study.

Isokinetic assessments

Participants were accustomed to the dynamometer (Biodex Corporation, Shirley, New York, USA) and the test procedures 1 week before testing. As part of the familiarization process, the participants were given standard written instructions of the procedures and allowed several sub-maximal and maximal practice attempts at each test condition.

A standardized warm-up of cycling and dynamic stretching exercises preceded the formal testing. Isokinetic concentric and eccentric assessments of the flexors and extensors of the knee joint were made in both the dominant and the non-dominant limbs. Limb dominance was determined through interview and was defined as the leg preferred when kicking a ball. All measurements were performed from a seated position with the hip flexed at approximately 85°. Stabilization straps were applied across the trunk, waist, and distal femur of the leg being tested to minimize additional movements and to provide constant conditions for all participants. The axis of the dynamometer was visually aligned with the lateral femoral condyle while the knee was flexed at 90°. The length of the lever arm was individually determined and the resistance pad was placed proximal to the medial malleolus. Gravity correction procedures were applied following direct measurements of the mass of the lower limb-lever arm system at 30° knee extension.

Range of motion was from 90° knee flexion to 10° extension (0° equals full extension). Concentric assessments were made during continuous knee extension-flexion movements at 1.08 and 4.32 rad/s. Eccentric assessments were performed using the dynamometer's passive mode at 2.16 rad/s; with this approach an eccentric muscle action was followed by a passive return of the limb to the starting position. At each test condition, three sub-maximal and three maximal warm ups were followed by five maximal efforts. Standardized verbal encouragement was given before each maximal effort and visual feedback of the recorded torque was provided. Thirty seconds of rest was allowed between consecutive efforts, and 1 min between assessments at different angular velocities. To avoid the effects of acceleration and deceleration of the lever

Table 1. Anthropometric and training characteristics of the participants (mean ± SD)

	Age (years)	Stature (m)	Body mass (kg)	Soccer experience (years)
Controls	14.9 ± 1.1	1.65 ± 0.10	54.5 ± 11.3	–
Conventionally trained soccer players	15.1 ± 1.0	1.70 ± 0.07	60.4 ± 8.4	4.4 ± 1.2
Resistance trained soccer players	14.8 ± 0.9	1.71 ± 0.08	60.3 ± 11.5	4.5 ± 1.2

arm on torque output, only peak torque data obtained from the period of constant velocity, within a 5% range of the preset angular velocity, were analyzed.

Functional hamstrings to quadriceps peak torque ratios were calculated to examine the effects of involvement in soccer on the reciprocal balance of strength about the knee joint (Aagaard et al., 1998). The functional ratio representative of knee flexion was calculated as the ratio of peak concentric hamstrings torque at 1.08 and 4.32 rad/s relative to the peak eccentric quadriceps torque at 2.16 rad/s (H_{CON}:Q_{ECC} ratio). The functional ratio representative of knee extension was calculated by expressing peak eccentric hamstrings torque at 2.16 rad/s relative to peak concentric quadriceps torque (H_{ECC}:Q_{CON} ratio) at 1.08 and 4.32 rad/s. The reproducibility of indices of isokinetic leg strength using the same test protocol in youth soccer players is reported elsewhere (Iga et al., 2006).

Statistical analysis

Statistical analysis was performed in SPSS version 11 software package (Chicago, Illinois, USA). Factorial ANOVA designs were applied to examine the effects of training background on isokinetic peak torque and the reciprocal balance of strength about the knee (H_{CON}:Q_{ECC} ratios and the H_{ECC}:Q_{CON} ratios) in both the dominant and the non-dominant leg. The level of significance was set at $P<0.05$. Significant main effects were further examined using Bonferroni-corrected *post hoc* tests.

Results

Isokinetic leg strength

Non-significant interaction effects for limb by training background were observed in all test conditions; main effects for limb dominance were also non-significant. Despite apparent trends (see Table 2) the main effects for training background on the concentric peak torque of the quadriceps at 1.08 rad/s ($F_{2,42} = 2.65$, $P = 0.08$) and the eccentric peak torque of the hamstrings ($F_{2,42} = 1.861$, $P = 0.10$) and quadriceps muscles ($F_{2,42} = 1.82$, $P = 0.10$) did not reach statistical significance. Significant main effects for training background were observed for all concentric assessments for the hamstrings (1.08 rad/s, $F_{2,42} = 3.47$, $P<0.04$; 4.32 rad/s, $F_{2,42} = 7.450$, $P = 0.002$) and the quadriceps at the high concentric velocity ($F_{2,42} = 6.299$, $P = 0.004$). Bonferroni-corrected *post hoc* analysis indicated that both groups of soccer players were significantly stronger than the non-soccer players; in general, differences were greater during high-velocity assessments (25–37%) compared with assessments at low velocity (15–18%).

Reciprocal muscle strength balance

Table 3 illustrates the effects of different forms of involvement in soccer on the reciprocal balance of strength about the knee in both the dominant and the non-dominant limbs. Interaction effects for limb by training background on the reciprocal muscle strength ratios were non-significant. There were no main effects for limb dominance on any of the muscle strength ratios ($P<0.05$); non-significant main effects for training background on the H_{ECC}:Q_{CON} ratio and the H_{CON}:Q_{ECC} ratio at 1.08 rad/s were also observed. The effects for training background on the functional reciprocal muscle group ratios calculated for knee flexion ($F_{2,42} = 4.023$, $P = 0.025$) and knee extension movements ($F_{2,42} = 8.53$, $P = 0.001$) at high velocity (4.32 rad/s) were significant. Although the H_{CON}:Q_{ECC} ratio was generally higher in the soccer players compared with the controls, Bonferroni-corrected *post hoc* tests indicated that differences were significant only between the conventionally trained soccer players and the controls. *Post hoc* tests also indicated that the H_{ECC}:Q_{CON} ratio was significantly lower in the conventionally trained soccer players compared with the non-soccer group and the strength-trained soccer players.

Table 2. Mean (± SD) isokinetic concentric and eccentric peak torque (N m) of the hamstrings and quadriceps muscles in youth soccer players and controls

Angular velocity (rad/s)	Controls		Conventionally trained soccer players		Resistance-trained soccer players	
	Dominant	Non-dominant	Dominant	Non-dominant	Dominant	Non-dominant
Quadriceps CON						
1.08	148 ± 44	150 ± 54	177 ± 36	184 ± 39	189 ± 49	199 ± 38
4.32	96 ± 25	96 ± 32	131 ± 26	128 ± 26	121 ± 33	122 ± 25†
Quadriceps ECC						
2.16	179 ± 52	194 ± 64	225 ± 54	226 ± 50*	239 ± 74	237 ± 76†
Hamstrings CON						
1.08	83 ± 27	80 ± 27	98 ± 20	96 ± 23*	108 ± 35	106 ± 32†
4.32	53 ± 21	50 ± 18	79 ± 18	74 ± 17*	71 ± 20	67 ± 22†
Hamstrings ECC						
2.16	105 ± 34	102 ± 36	120 ± 28	114 ± 25	127 ± 41	129 ± 41†

*Significant differences between the controls and the conventionally trained soccer players.

†Significant differences between the controls and the resistance-trained soccer players.

Table 3. Mean (± SD) functional reciprocal muscle group ratios in youth soccer players and controls

Reciprocal muscle group ratios (rad/s)	Controls		Conventionally trained soccer players		Resistance-trained soccer players	
	Dominant	Non-dominant	Dominant	Non-dominant	Dominant	Non-dominant
H_{ECC}:Q_{CON} ratio						
1.08	0.71 ± 0.07	0.70 ± 0.10	0.68 ± 0.12	0.65 ± 0.09	0.70 ± 0.09	0.71 ± 0.12
4.32	1.10 ± 0.22	1.06 ± 0.15*	0.91 ± 0.10	0.89 ± 0.09	1.04 ± 0.12	1.05 ± 0.19†
H_{CON}:Q_{ECC} ratio						
1.08	0.45 ± 0.10	0.42 ± 0.08	0.44 ± 0.06	0.43 ± 0.07	0.50 ± 0.09	0.49 ± 0.07
4.32	0.30 ± 0.08	0.28 ± 0.07*	0.36 ± 0.06	0.33 ± 0.05	0.34 ± 0.07	0.32 ± 0.08†

*Significant differences between the conventionally trained soccer players and the controls.

†Significant differences between conventionally trained soccer players and the resistance-trained soccer players.

Discussion

The present investigation was concerned with the effect of playing and training for soccer on the reciprocal and bilateral balance of strength about the knee joint. The principal finding suggests that the muscle loading patterns experienced during youth soccer may negatively alter the reciprocal balance of strength between the hamstrings and quadriceps muscles for knee extensions performed at high velocity. The findings also support a proposal that this reciprocal strength relation may be "corrected" by incorporating resistance exercises into the habitual training routines of youth soccer players.

The primary feature of organized training for soccer is the use of systematic repetitive training techniques designed to improve technical and tactical skills and develop specific aspects of game fitness. In parallel with previous reports (Rochcongar et al., 1988; Hansen et al., 1999), the conventionally trained soccer players demonstrated higher values of peak torque compared with the controls. The magnitude of these differences appeared to be more pronounced during concentric assessments at high velocity compared with concentric assessments at low velocity; this observation may be attributable to specific adaptation of the knee joint muscles to high-velocity loadings during the accelerations, rapid changes in direction and powerful movements performed during the game (Bangsbo et al., 1991).

The resistance-trained boys generated numerically higher values of peak torque compared with the conventionally trained soccer players and the controls under most assessment conditions (see Table 2). However, some of these trends failed to reach statistical significance. These observations are likely mediated by relatively high measurement variability, impacting on the power of the statistical tests. Sample size calculations suggest that 40 participants per group would have been required to provide 80% power, to detect as statistically significant a standardized effect size of 0.5 standard deviations.

The agonist–antagonist strength relations about the knee were described by calculating the functional ratios of concentric hamstrings to eccentric quadriceps torque (flexion), and eccentric hamstrings to concentric quadriceps torque (extension). Our method of calculating these functional ratios differs from the original approaches described by Aagaard et al. (1998). We chose to perform eccentric assessments at an intermediate velocity as it has been asserted that the high-velocity lengthening of muscle imposed by isokinetic devices may prove to be an uncomfortable and sometimes painful experience (Holder-Powell & Rutherford, 1999); this may have rendered some of the boys reluctant to work maximally, compromising the acquisition of valid peak torque data.

To the authors' knowledge, no research group has considered the effect of involvement in soccer on the functional H_{CON}:Q_{ECC} ratios. Low numeric values were calculated for this ratio, suggesting that the hamstrings have a limited capacity for dynamic joint stabilization in forceful knee-flexion movements with simultaneous eccentric activation of the quadriceps muscle (Aagaard et al., 1998). Nonetheless, generally higher values for the H_{CON}:Q_{ECC} ratios were observed in the soccer players compared with the controls; particularly, the functional ratio calculated for high-velocity knee flexion was significantly higher in the conventionally trained soccer players compared with the controls. This finding is largely attributable to the higher concentric peak torque recorded for the hamstrings muscles at the high test velocity in the conventionally trained soccer players.

The reciprocal balance of strength about the knee for low-velocity knee extensions was identical between the soccer players and the controls; this finding indicates that the relative improvements in the concentric strength of the quadriceps muscles at low velocities and the eccentric strength of the hamstrings with training were monotonic, failing to alter the reciprocal balance of strength between these muscle groups in these assessment conditions compared with the controls.

The functional ratio for knee extensions at high velocity was significantly lower in the conventionally trained soccer players compared with the controls. This reduced capacity for dynamic joint stabilization was a consequence of relatively low hamstrings strength, but improved quadriceps strength in the conventionally trained soccer players. This finding suggests that the muscle-loading patterns experienced during youth soccer asymmetrically strengthen the muscles of the knee joint toward quadriceps dominance, compromising the capability for the hamstrings to provide muscular joint stabilization to the knee during high-velocity knee extensions. These notions may be altered with resistance training as a significantly higher H_{ECC}:Q_{CON} ratio was calculated for the resistance-trained boys compared with the conventionally trained soccer players. The improved muscle strength balance demonstrated by the resistance-trained boys is attributable to significant improvement in the eccentric strength of the hamstrings muscles with resistance training (Aagaard et al., 1996). The improved capacity of the hamstrings to generate torque during eccentric actions did not, however, contribute to an improved capacity for muscular joint stabilization in the resistance-trained boys compared with the controls. The broadly similar functional ratios calculated for these groups is explained by some concomitant improvement in the concentric strength of quadriceps muscles with resistance training, blunting improvement in muscle strength balance in the resistance-trained boys.

The improved strength of the hamstrings muscles in the resistance-trained boys may have important implications in reducing the threat and severity of musculo-ligamentous injury (Heidt et al., 2000; Askling et al., 2003). In soccer, hamstrings injuries are usually incurred during running or sprinting actions (Woods et al., 2004), late in the forward swing phase of the leg as the hamstrings work eccentrically to prevent hyperextension of the knee and flexion of the hip (Garrett, 1996); increasing the eccentric strength of the hamstrings may improve the capability of the hamstrings to absorb kinetic energy before failure, attenuating the risk of muscle strain injury (Stanton & Purdam, 1989). Additionally, non-contact ACL injuries commonly occur when sudden stress is applied to the knee joint while the tibia is in contact with the ground (Boden et al., 2000). It is thought that reflective eccentric quadriceps actions accompanied by an apparent weakness of the hamstrings muscle group may allow the extensor mechanism to strain the ACL (Boden et al., 2000); thus, improving the strength of the hamstrings muscles may help protect the ACL against excessive load, preventing against damage.

The reciprocal balance of strength about the knee was similar in both the dominant and the non-dominant limbs in all the groups. This observation suggests that the relative symmetry of strength between the knees joint muscles is not specifically distorted in one limb as a result of involvement in soccer. Findings for the H_{ECC}:Q_{CON} ratio are consistent with another report involving youth soccer players (Kellis et al., 2001), but are at variance with investigations involving adults (Rahnama et al., 2005). These conflicting results raise the possibility that over time, the unique muscle-loading patterns encountered in soccer, together with the preferential use of the dominant limb, may result in the asymmetrical increase of the concentric strength of the quadriceps muscles in the preferred/dominant kicking leg. Further investigation utilizing longitudinal study designs is needed to elucidate the effects of long-term involvement in soccer on hamstrings to quadriceps strength relations between the limbs.

Perspectives

The present findings suggest that youth soccer, centered on the development of technical and tactical skills and improving aspects of game-related fitness asymmetrically develops the strength of the muscles of the knee joint, altering the reciprocal balance of strength about the knee for movements performed at high velocity, thereby increasing the risk of musculo-ligamentous injury. Our results also indicate that youth soccer players can effectively perform resistance training to improve the strength of the knee joint muscles and augment the capability of the hamstrings muscles to provide dynamic joint stabilization to the knee during high-velocity knee extensions. These observations suggest a need for soccer clubs to schedule resistance-training methods into the habitual exercise routines of youth players. In making this recommendation, we concede that as training time in youth soccer is often limited, coaches may be reluctant to redirect time from technical and tactical training in particular to resistance training; however, recent evidence from Olsen et al. (2005) suggests that by carefully manipulating warmup routines, resistance-training methods may be incorporated into training schedules of youth games players without greatly impacting on the time available to train to meet other training objectives, or the need to timetable additional training sessions.

Key words: bilateral strength, hamstrings, peak torque, quadriceps, reciprocal strength, resistance training.

References

Aagaard P, Simonsen EB, Trolle M, Bangsbo J, Klausen K. Specificity of training velocity and training load on gains in isokinetic knee joint strength. Acta Physiol Scand 1996: 156: 123–129.

Aagaard P, Simonsen EB, Magnusson P, Larsson B, Dyhre-Poulsen P. A new concept for isokinetic hamstring: quadriceps muscle strength ratio. Am J Sports Med 1998: 26: 231–237.

Askling C, Karlson J, Thorstensson A. Hamstring injury occurrence in elite soccer players after strength training with eccentric overload. Scand J Med Sci Sports 2003: 13: 244–250.

Bangsbo J, Nørregaard L, Thorsøe F. Activity profile of competition soccer. Can J Sports Sci 1991: 16: 110–116.

Boden BP, Dean GS, Feagin JA, Garrett WE. Mechanisms of anterior cruciate ligament injury. Orthopedics 2000: 23: 573–578.

Burnie J, Brodie DA. Isokinetic measurement in preadolescent males. Int J Sports Med 1986: 7: 205–209.

Cometti G, Maffiuletti NA, Pousson M, Chatard J-C, Maffulli N. Isokinetic strength and anaerobic power of elite, subelite and amateur French football players. Int J Sports Med 2001: 22: 45–51.

Croisier JL. Factors associated with recurrent hamstring injuries. Sports Med 2004: 34: 681–695.

Garrett W. Muscle strain injuries. Am J Sports Med 1996: 24: S2–S8.

Hansen L, Bangsbo J, Twisk J, Klausen K. Development of muscle strength in relation to training level and testosterone in young male soccer players. J Appl Physiol 1999: 87: 1141–1147.

Heidt RS, Sweeterman LM, Carlonas RL, Traub JA, Tekulve FX. Avoidance of soccer injuries with preseason conditioning. Am J Sports Med 2000: 28: 659–662.

Holder-Powell HM, Rutherford OM. Reduction in range of movement can increase maximum voluntary eccentric force for the human knee extensor muscles. Eur J Appl Physiol 1999: 80: 502–504.

Iga J, George K, Lees A, Reilly T. Reliability of assessing indices of isokinetic leg strength in pubertal soccer players. Ped Exer Sci 2006: 18: 436–445.

Le Gall F, Carling C, Reilly T, Vandewalle H, Church J, Rochconger P. Incidence of injuries in elite French youth soccer players: a10-season study. Am J Sports Med 2006: 34: 928–938.

Kellis S, Gerodimos V, Kellis E, Manou V. Bilateral isokinetic concentric and eccentric strength profiles of the knee extensors and flexors in young soccer players. Isokin Exer Sci 2001: 9: 31–39.

Olsen O-E, Myklebust G, Engebretsen L, Holme I, Bahr R. Exercises to prevent lower limb injuries in youth sports: cluster randomised controlled trial. Brit Med J 2005: 330: 449.

Orchard J, Marsden J, Lord S, Garlick D. Preseason hamstring muscle weakness associated with hamstrings muscle injury in Australian footballers. Am J Sports Med 1997: 25: 81–85.

Micheli LJ, Metzl JD, Di Canzio J, Zurakowski D. Anterior cruciate ligament reconstructive surgery in adolescent soccer and basketball players. Clin J Sports Med 1999: 9: 138–141.

Price RJ, Hawkins RD, Hulse MA, Hodson A. The Football Association medical research programme: an audit of injuries in academy youth football. Br J Sports Med 2004: 38: 466–471.

Rahnama N, Lees A, Bambaecichi E. A comparison of muscle strength and flexibility between the preferred and non-preferred leg in English soccer players. Ergonomics 2005: 48: 1568–1575.

Rochcongar P, Morvan R, Jan J, Dassonville J, Beillot J. Isokinetic investigation of knee extensors and flexors in young French soccer players. Int J Sports Med 1988: 9: 448–450.

Shea KG, Apel PJ, Pfeiffer Anterior cruciate ligament injury in paediatric and adolescent patients: a review of basic science and clinical research. Sports Med 2003: 33: 455–471.

Stanton P, Purdam C. Hamstrings injuries in sprinting – the role of eccentric exercise. J Orthop Sports Phys Ther 1989: 10: 343–349.

Stratton G, Jones M, Fox KR, Tolfrey K, Harris J, Maffulli N, Lee M, Frostick SP. BASES position statement on guidelines for resistance exercise in young people. J Sports Sci 2004: 22: 383–390.

Vrijen J. Muscle strength development in the pre- and post-pubescent ages. Med Sport 1978: 11: 152–158.

Woods C, Hawkins RD, Maltby S, Hulse M, Thomas A, Hodson A. The football association medical research programme: an audit of injuries in professional football – analysis of hamstrings injuries. Br J Sports Med 2004: 38: 36–41.

Zakas A. Bilateral isokinetic peak torque of quadriceps and hamstrings muscles in professional soccer players with dominance on one or both two sides. J Sports Med Phys Fitness 2006: 46: 28–35.