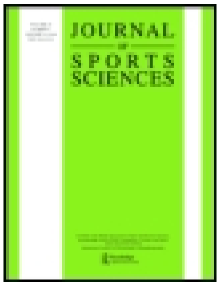

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Differences in thigh muscularity and dynamic torque between junior and senior soccer players

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Abstract

The aim of the present study was to examine differences in thigh muscularity and dynamic torque between elite junior (15.7 ± 0.2 years) and senior (22.6 ± 2.4 years) soccer players. Cross-sectional areas of the total muscle compartment, quadriceps femoris, and hamstrings + adductors were determined using magnetic resonance imaging. Knee extension and flexion torque were also measured at 1.05 and 3.14 $rad \cdot s^{-1}$. Neither junior nor senior players showed significant differences in cross-sectional area or torque between the dominant and non-dominant leg. The quadriceps femoris and hamstrings + adductors were significantly greater in the senior than junior players at all thigh-slice sites. The percentage of quadriceps femoris to total muscle compartment was significantly higher in the junior than the senior players, and the corresponding value of hamstrings + adductors was significant in the reverse direction. The senior players showed greater torque than the juniors regardless of motion and velocity, even in terms of torque relative to the product of the cross-sectional area and height. The present results indicate that (1) senior players are characterized by the predominant development of hamstrings and adductors and a higher dynamic torque relative to muscle size, and (2) elite soccer players did not show asymmetry in terms of the muscularity or dynamic torque of the thigh muscles irrespective of age.

Keywords: *Lateral dominance, quadriceps femoris, hamstrings, adductors, cross-sectional area*

Introduction

Compared with other sports, there have been many studies of the profiles of muscular strength in not only senior but also junior soccer players. Considerable research effort has been made to assess the strength capabilities of the hamstrings and quadriceps femoris and the strength ratio between the two muscle groups (hamstrings-to-quadriceps strength ratio) and between the dominant and non-dominant legs (Ahmad et al., 2006; Cometti, Maffiuletti, Pousson, Chatard, & Maffulli, 2000; Gur, Akova, Punduk, & Kucukoglu, 1999; Kearns, Isokawa, & Abe, 2001; Leatt, Shephard, & Plyley, 1987; Magalhaes, Oliveira, Ascensao, & Soares, 2004; McLean & Tumilty 1993; Oberg, Moller, Gillquist, & Ekstrand, 1986; Rahnama, Lees, & Bambaecichi, 2005; Rochcongar, Morvan, Jan, Dassonville, & Beillot, 1988; Rosene, Fogarty, & Mahaffey, 2001; Zakas, 2006; Zakas, Mandroukas, Vamvakoudis, Charistoulas, & Aggelopoulou, 1995). In spite of the highly aerobic nature of soccer, it is generally accepted that anaerobic capacity, power, and strength differentiate successful players from their less able counterparts (Tumilty, 1993). Superior leg strength in elite soccer players has been reported in many studies (Cometti et al., 2000; Oberg et al., 1986; Wisloff, Helgerud, & Hoff, 1998), and the strength capability of leg muscles determines sprint performance and jumping height in high-level soccer players (Wisloff, Castagna, Helgerud, Jones, & Hoff, 2004). In junior populations, also, elite soccer players can be characterized by the development of leg muscle strength (Hansen, Bangsbo, Twisk, & Klausen, 1999; Leatt et al., 1987).

Although the development of both the hamstrings and quadriceps is important for soccer players, these muscles are at a high risk of injury and are also implicated in injuries of the knee joint (Ergun, Islegen, & Taskiran, 2004; Fried & Lloyd, 1992).

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The quadriceps femoris plays an important role in jumping and ball kicking, while the hamstrings control these activities and contribute to joint stabilization (Fried & Lloyd, 1992). Regardless of age, therefore, strength assessments of reciprocal muscle groups in the thigh are of particular importance for soccer players to design training programmes to improve their performance and prevent injuries.

No previous study, however, has compared thigh muscularity in junior and senior soccer players. Several studies have examined age-related differences in the hamstrings-to-quadriceps strength ratio (Ahmad et al., 2006; Cometti et al., 2000; Gur et al., 1999; Rochcongar et al., 1988), although their findings are equivocal. While Cometti et al. (2000) provided evidence to suggest predominant strength development of the hamstrings in elite adult soccer players, Gur et al. (1999) and Ahmad et al. (2006) found no such age-related effect regarding the concentric and isometric hamstrings-to-quadriceps strength ratio. We have been unable to identify reasons for these discrepancies among previous findings.

The force generation capability of a muscle is related to its cross-sectional area (Fukunaga, Roy, Shellock, Hodgson, & Edgerton, 1996). High loads and few repetitions with high movement velocities have been proposed for strength training for elite professional soccer players (Hoff, 2005; Wisloff et al., 2004). However, this type of strength training is known to increase muscle strength with minimal hypertrophy or body mass gain (Sale, 1988). Thus, quantification of cross-sectional area as well as strength will provide more detailed information on the growth trends of these two muscle groups in soccer players.

Lateral dominance in the leg strength of soccer players has also been studied extensively, although the results have been inconsistent. Several researchers indicated no imbalance in the knee strength of soccer players (Agre & Baxter, 1987; Rochcongar et al., 1988; Rosene et al., 2001; Zakas, 2006), while others reported the presence of asymmetry (Ergun et al., 2004; Gur et al., 1999; Magalhaes et al., 2004; McLean & Tumilty, 1993). Since several factors may be responsible for this discrepancy, quantification of cross-sectional area can lead to a better understanding of lateral dominance. To our knowledge, however, few studies have examined leg muscularity directly with respect to lateral dominance in soccer players (Kearns et al., 2001; Masuda, Kikuhara, Takahashi, & Yamanaka, 2003). Kearns et al. (2001) identified asymmetry in the muscle thickness of the medial gastrocnemius of junior soccer players, while Masuda et al. (2003) reported that differences in cross-sectional area between the dominant and non-dominant thigh were negligible in adult soccer players. Thus, we hypothesize that there is an age-related effect on the lateral dominance of thigh muscularity in soccer players.

In the present study, the dynamic torque during knee extension and flexion and cross-sectional area of the quadriceps femoris, hamstrings, and adductors were determined in junior and senior soccer players using an isokinetic dynamometer and magnetic resonance imaging. The maim aim of the study was to examine thigh muscle development in soccer players in terms of both strength and muscularity in relation to the flexion-to-extension ratio and lateral dominance. In addition, since it was anticipated that torque would be higher in seniors, we also investigated whether differences in torque between the age groups were due to differences in cross-sectional area.

Methods

Participants

The participants were 26 junior (age 15.7 ± 0.2 years; height 1.71 ± 0.05 m; body mass 62.3 ± 5.8 kg; mean $\pm$ *s*) and 20 senior (age 22.6 ± 2.4 years; height 1.76 ± 0.05 m; body mass 69.6 ± 5.9 kg) soccer players. Compared with the juniors, the senior players were significantly taller ($P = 0.003$) and heavier ($P = 0.0001$).

All senior players were professionals and played in the first division of the Japan league. The testing of senior players was carried out in the second week of the pre-season period. Before testing, the senior players had performed at least five physical training programmes in addition to 10–12 soccer training sessions (each session lasting 1.5–2.0 h). The physical training programme in the first week consisted mainly of aerobic running with combined anaerobic–aerobic exercises (middle-distance running and interval training). Junior players were academy trainees from one of the most successful clubs in Japan. They had been engaged in organized soccer training for at least 4 years and had recently undergone physical and soccer training programmes for 3 h a day, 6 days per week. The physical training for the junior players consisted mainly of long-distance running, interval training, and circuit training using their own body masses as a load. Of the participants, nine junior and seven senior players were forwards and the remainder were midfield players. The percentage of the forward players was similar (35%) in the two age groups. All testing was performed at least 24 h after the completion of a training session.

This study was consistent with institutional ethical requirements for human experimentation in accordance with the Declaration of Helsinki. The participants and parents of the junior players were fully informed of the study procedures as well as the purpose of the study, and gave their informed written consent.

Measurement of muscle cross-sectional area

Magnetic resonance images were obtained separately for both thighs using a 0.2-T scanner (Signa Profile, General Electric Medical System) with a body coil to determine the cross-sectional area of the total muscle compartments (TMC) and quadriceps femoris (QF), hamstrings (Ham), and adductors (Add). First, longitudinal images were obtained to identify the greater trochanter and lower edge of the femur. Second, transverse scanning of T1-weighted images of 10 mm thickness was performed from the greater trochanter to the lower edge with a 10-mm gap (TR 350 ms, TE 21ms, matrix 256 × 256, field of view 40 × 40 cm, 2 NEX). Similar to the method of Masuda et al. (2003), images located nearest to 30% (proximal to the knee), 50%, and 70% of femur length, from the lower edge of the femur to the greater trochanter, were selected for the determination of cross-sectional area (Figure 1). For each of the transverse images, a single experienced observer, blinded to the participants' characteristics, outlined the areas of the total muscle compartment and three muscle groups – the quadriceps femoris (rectus femoris, vastus lateralis, vastus medialis, and vastus intermedius), hamstrings (biceps femoris, semitendinosus, and semimembranosus), and adductors (adductor brevis, adductor longus, adductor magnus, and adductor minimus) – using a computer mouse. Cross-sectional area was then calculated by summing the pixels surrounded by the outlines. In addition to the absolute value, the cross-sectional areas of each of the three muscle groups and the sum of the hamstrings and adductors (Ham + Add) were expressed as the percentage of the total muscle compartment and are referred to as %QF, %Ham, %Add, and %Ham + Add, respectively. Intra-observer differences in the calculation of muscle cross-sectional area were addressed by repeating the measurements ten times in a pilot study with three young men. The coefficient of variation (%CV) for the determination of cross-sectional area was less than 1%.

Measurement of dynamic strength

Isokinetic torque during maximal concentric knee extension and flexion in both legs was determined using a dynamometer (Biodex System 3, Biodex Co., USA). For an appropriate evaluation of dynamic strength in soccer players, it is preferable to perform measurements over a wide range of angular velocities (Cometti et al., 2000; Leatt et al., 1987). However, this was impossible due to the limited time schedule of the study. Gur et al. (1999) reported that adult soccer players showed higher knee torque than

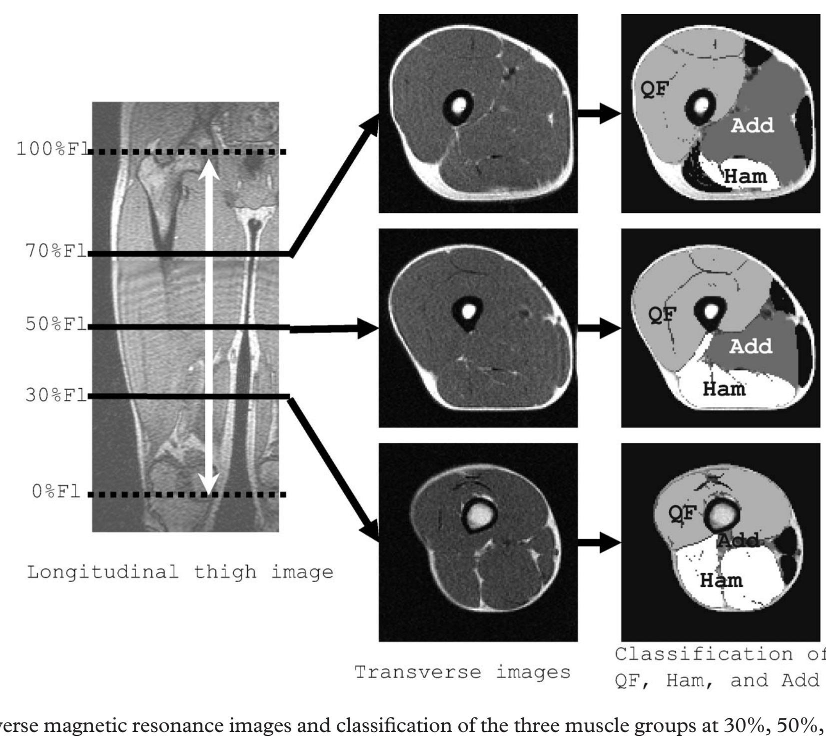

Figure 1. Sample transverse magnetic resonance images and classification of the three muscle groups at 30%, 50%, and 70% of femur length. Fl = femur length; QF = quadriceps femoris; Ham = hamstrings; Add = adductors.

younger players above 3.14 rad · s^{-1}, in spite of showing a similar torque at a lower angular velocity. Thus, the measurement of dynamic strength in this study was conducted at low and moderately high angular velocities (1.05 and 3.14 rad · s^{-1}, respectively).

For torque measurements, the participants were seated in an upright chair with arms folded over the chest and stabilized firmly at the shoulder, chest, hip, and mid-thigh via straps. The rotational axis of the dynamometer was visually aligned to the anatomical axis of the knee joint with the knee at a 1.57 rad of flexion, and the lower leg of the participant was attached to the lever arm of the dynamometer. The order of the leg examined and velocity set was randomized for each participant. After a standardized warm-up of 5 min of jogging and 5 min of stretching the leg muscles, participants were asked to take the prescribed position for torque measurements. The warm-up practice consisted of five submaximal repetitions of the task movements at each test speed to familiarize the participants with the test protocol. The standardized gravity correction procedure was performed before each trial. The participants performed maximal torque exertions in knee extension and flexion three times at 1.05 rad · s^{-1} and five times at 3.14 rad · s^{-1}, and rest periods of at least 2 min were allowed between trials. The reason for performing five repetitions at 3.14 rad · s^{-1} was that a few participants showed the highest torque on the fourth or fifth repetition in a preliminary experiment. The highest torque value was used for later analysis.

Data analyses

Limb dominance was reported by the participants based on the leg preferentially used for ball kicking, and confirmed by an experimenter observing the participants playing in official games. In the present study, dynamic strength was assessed as torque. Muscle volume is a major determinant of joint torque in humans (Fukunaga et al., 2001). Therefore, torque values at both test velocities were correlated to the product of the average value of the cross-sectional areas at the three slice levels and body height (CSA*ht, where CSA = cross-sectional area and ht = height). Since significant correlations [$r = 0.655$ ($P < 0.0001$) to 0.834 ($P < 0.0001$)] were observed between the two variables, the ratio of torque (T) to CSA*ht [T/(CSA*ht)] was calculated as an index to represent dynamic strength relative to muscle size.

Descriptive data are presented as means and standard deviations (s). A simple linear regression analysis was used to calculate the correlation coefficients between the measured variables. A two-way repeated-measures analysis of variance (ANOVA) with Scheffé's test was used to examine differences in cross-sectional area and torque between the dominant and non-dominant leg. Moreover, two-way ANOVA with Scheffé's test was used to examine differences in cross-sectional area and torque between the junior and senior players. If a significant interaction between age and thigh-slice level or test velocity was found, one-way ANOVA with Scheffé's test was used to identify the thigh-slice level or test velocity at which the difference between the two age groups lay. Statistical significance was set at $P < 0.05$.

Results

For all cross-sectional area and torque values, there were no significant effects of leg in junior ($F_{1,25} = 0.0001$ to 2.744, $P = 0.108$ to 0.991) or senior ($F_{1,19} = 0.539$ to 3.559, $P = 0.075$ to 0.415) players. In the following descriptions, therefore, only the effect of age on the measured variables was focused on.

In both the dominant and non-dominant leg, the total muscle compartment and quadriceps femoris were significantly greater in the senior than in the junior players ($F_{1,132} = 17.542$ to 47.115, $P < 0.0001$), with no significant interaction between age and thigh-slice level ($F_{2,132} = 0.902$ to 2.194, $P = 0.116$ to 0.408) (Table I). In contrast, the hamstrings and adductors showed significant interactions between age and thigh-slice level in both legs ($F_{2,132} = 3.929$ to 13.819, $P = 0.022$ to < 0.0001). One-way ANOVA indicated that the hamstrings at 30% ($P = 0.002$) and 50% of femur length ($P = 0.004$) and the adductors at 70% of femur length ($P < 0.0001$) in the dominant leg, and the hamstrings at 30% ($P < 0.0001$) and the adductors at 50% ($P = 0.011$) and 70% of femur length ($P < 0.0001$) in the non-dominant leg, were significantly greater in the senior than the junior players (Table I). In both legs, the hamstrings + adductors were significantly greater for the senior than for the junior players (dominant leg: $F_{1,132} = 44.557$, $P < 0.0001$; non-dominant leg: $F_{1,132} = 58.560$, $P < 0.0001$), with no significant interaction between age and the thigh-slice level (dominant leg: $F_{2,132} = 1.942$, $P = 0.147$; non-dominant leg: $F_{2,132} = 1.894$, $P = 0.155$).

In both legs, the differences between the two age groups in the percentage of each muscle group to total muscle compartment were small (Table II). In both legs, however, %QF was significantly greater in the junior than the senior players (dominant leg: $F_{1,132} = 9.319$, $P = 0.003$; non-dominant leg: $F_{1,132} = 11.735$, $P = 0.0008$), while %Ham + Add

Table I. Cross-section area (cm^2) in junior and senior players (mean ± *s*).

			Thigh slice levels			Two-way ANOVA	
Variable	Leg	Group	30% Fl	50% Fl	70% Fl	Scheffé test on group difference[a]	Interaction with thigh slice level
TMC	D	Junior	104.1 ± 11.7	148.3 ± 15.1	153.0 ± 16.4	J < S	n.s.
		Senior	112.7 ± 10.1	165.6 ± 14.1	171.6 ± 17.2		
	ND	Junior	106.2 ± 13.6	147.2 ± 14.3	149.6 ± 15.2	J < S	n.s.
		Senior	115.6 ± 9.1	165.8 ± 12.6	170.5 ± 16.2		
QF	D	Junior	57.7 ± 7.4	74.9 ± 7.7	69.3 ± 6.3	J < S	n.s.
		Senior	60.7 ± 5.9	81.7 ± 8.8	76.0 ± 8.0		
	ND	Junior	59.8 ± 5.9	74.1 ± 7.7	67.9 ± 6.3	J < S	n.s.
		Senior	62.7 ± 4.8	82.1 ± 7.4	75.7 ± 8.4		
Ham	D	Junior	37.5 ± 4.2	36.6 ± 4.4	15.4 ± 3.7	30%,50%Fl:J < S	$P = 0.0220$
		Senior	43.1 ± 5.0	40.8 ± 3.0	16.2 ± 4.4		
	ND	Junior	37.3 ± 4.6	36.0 ± 4.4	14.5 ± 3.3	30%Fl:J < S	$P = 0.0089$
		Senior	43.8 ± 4.3	40.0 ± 3.3	15.7 ± 4.1		
Add	D	Junior	1.8 ± 1.5	26.9 ± 5.4	58.2 ± 7.4	70%Fl:J < S	$P < 0.0001$
		Senior	1.3 ± 1.7	32.1 ± 6.8	68.4 ± 6.7		
	ND	Junior	1.8 ± 1.5	26.9 ± 4.4	57.3 ± 6.8	50,70%Fl:J < S	$P < 0.0001$
		Senior	1.6 ± 1.6	32.8 ± 6.5	68.2 ± 6.3		
Ham + Add	D	Junior	39.4 ± 4.4	63.4 ± 7.3	73.6 ± 9.5	J < S	n.s.
		Senior	44.5 ± 5.7	72.9 ± 7.2	84.6 ± 9.3		
	NDJ	Junior	39.1 ± 5.0	63.0 ± 7.2	71.8 ± 8.8	J < S	n.s.
		Senior	45.3 ± 5.0	72.8 ± 7.3	83.8 ± 8.5		

Note: Fl = femur length; TMC = total muscle compartment; QF = quadriceps femoris; Ham = hamstrings; Add = adductors; D = dominant; ND = non-dominant; J = junior; S = senior.
[a]Significant difference between mean values for junior and senior players ($P < 0.05$).

Table II. Percentage of each muscle cross-sectional area to total muscle compartment in junior and senior players (mean ± *s*).

			Thigh slice levels			Two-way ANOVA	
Variable	Leg	Group	30% Fl	50% Fl	70% Fl	Scheffé test on group difference[a]	Interaction with thigh slice level
%QF	D	Junior	55.4 ± 2.4	50.5 ± 2.1	45.3 ± 2.1	J > S	n.s.
		Senior	53.9 ± 2.9	49.3 ± 2.7	44.2 ± 2.1		
	ND	Junior	56.2 ± 2.3	50.4 ± 2.4	45.5 ± 2.1	J > S	n.s.
		Senior	54.3 ± 2.1	49.5 ± 2.5	44.4 ± 1.8		
%Ham	D	Junior	36.1 ± 2.4	24.7 ± 2.0	10.0 ± 2.0	n.s.	$P = 0.0107$
		Senior	38.3 ± 2.8	24.7 ± 1.9	9.4 ± 2.1		
	ND	Junior	35.2 ± 2.2	24.5 ± 1.5	9.6 ± 1.6	30%Fl:J < S	$P < 0.0001$
		Senior	37.9 ± 2.1	24.2 ± 1.7	9.1 ± 1.9		
%Add	D	Junior	1.7 ± 1.5	18.1 ± 2.6	38.0 ± 2.1	n.s.	$P = 0.0220$
		Senior	1.1 ± 1.4	19.3 ± 3.3	39.9 ± 2.2		
	ND	Junior	1.7 ± 1.3	18.3 ± 2.2	38.3 ± 2.2	n.s.	$P = 0.0457$
		Senior	1.3 ± 1.3	19.7 ± 3.3	40.0 ± 2.1		
%Ham + Add	D	Junior	37.9 ± 2.1	42.8 ± 1.8	48.0 ± 1.9	J < S	n.s.
		Senior	39.4 ± 3.1	44.1 ± 2.7	49.3 ± 2.2		
	ND	Junior	36.9 ± 2.0	42.8 ± 1.9	47.9 ± 1.9	J < S	n.s.
		Senior	39.2 ± 2.2	43.9 ± 2.5	49.2 ± 1.7		

Note: Fl = femur length; TMC = total muscle compartment; QF = quadriceps femoris; Ham = hamstrings; Add = adductors; D = dominant; ND = non-dominant; J = junior; S = senior.
[a]Significant difference between mean values for junior and senior players ($P < 0.05$).

was significantly greater in the senior than the junior players (dominant leg: $F_{1,132} = 12.562$, $P = 0.0005$; non-dominant leg: $F_{1,132} = 20.449$, $P < 0.0001$). The %Ham and %Add tended to be higher in the senior than in the junior players at 30% and 70% of femur length, respectively, and these showed significant interactions with age and thigh-slice level ($F_{2,132} = 3.160$ to 10.552, $P = 0.046$ to < 0.0001). One-way ANOVA indicated that only %Ham at 30% of femur length in the non-dominant leg was significantly higher ($P = 0.0005$) in the senior than the junior players.

The senior players showed significantly greater torque than the juniors in the two motions with both legs ($F_{1,88} = 24.907$ to 42.353, $P < 0.0001$), with no significant interaction with test velocity ($F_{1,88} = 0.105$ to 1.009, $P = 0.318$ to 0.764) (Table III). Moreover, the ratios of knee flexion to knee extension regarding torque for both legs were also significantly higher in the senior than in the junior players (dominant leg: $F_{1,88} = 7.992$, $P = 0.006$; non-dominant leg: $F_{1,88} = 6.262$, $P = 0.014$), with no significant interactions with test velocity (dominant leg: $F_{1,88} = 0.470$, $P = 0.495$; non-dominant leg: $F_{1,88} = 0.280$, $P = 0.598$), although the differences were small (Table IV). The significance of differences in torque between the junior and senior players remained when expressed as T/(CSA*ht) ($F_{1,88} = 4.121$ to 13.176, $P = 0.045$ to 0.0005) (Table V).

Discussion

Lateral dominance

In both the junior and senior players, no significant difference in muscle cross-sectional area or torque was observed between the dominant and non-dominant leg. An imbalance in the strength of soccer players related to lateral dominance has been studied extensively, but the findings are equivocal. In terms of concentric strength, a similarity between the dominant and non-dominant leg has been reported in junior (Rochcongar et al., 1988) and senior (Agre & Baxter, 1987; Rosene et al., 2001; Zakas, 2006) players, as observed here. However, others have reported an imbalance related to lateral dominance in the strength of either the knee flexors or extensors (Ergun et al., 2004; Gur et al., 1999; Magalhaes et al., 2004; McLean & Tumilty, 1993). In addition, in a study of junior soccer players, Kearns et al. (2001) reported that the thickness of the medial gastrocnemius was greater in the dominant than the non-dominant leg. The present results for junior players contradict this finding. In terms of cross-sectional area, however, our results are in line with those of Masuda et al. (2003), who examined the cross-sectional area of the quadriceps femoris, hamstrings, and adductors in university soccer players. The discrepancy between the results of Kearns et al. (2001) and those of the present study could be due to differences in the variables analysed and muscle groups examined. In addition, the fact that the participants were elite junior and senior soccer players would also suggest a lack of an imbalance in muscle cross-sectional area and torque between the dominant and non-dominant leg. Zakas (2006) did not identify any influence of lateral dominance in the knee extension and flexion strength of professional soccer players. Zakas noted that the training sessions and matches undertaken by professional soccer players appear to have resulted in a balance of strength between the left and right sides of the body, and that it is reasonable to assume that a high degree of skill in using both legs improves the ability to execute motor performances in soccer (Zakas, 2006). In addition, even at a young age, well-trained soccer players show no

Table III. Torque (N · m) in junior and senior players (mean ± *s*).

Movement	Leg	Group	Velocity: $1.05\ \text{rad} \cdot \text{s}^{-1}$	Velocity: $3.14\ \text{rad} \cdot \text{s}^{-1}$	Two-way ANOVA: Scheffé test on group difference[a]	Two-way ANOVA: Interaction with test velocity
Knee extension	D	Junior	182.0 ± 28.4	137.7 ± 17.2	J < S	n.s.
		Senior	214.4 ± 31.7	161.1 ± 21.9		
	ND	Junior	179.0 ± 29.2	133.5 ± 19.3	J < S	n.s.
		Senior	211.3 ± 34.2	156.3 ± 20.0		
Knee flexion	D	Junior	96.2 ± 18.2	79.1 ± 15.5	J < S	n.s.
		Senior	122.7 ± 24.1	103.0 ± 19.6		
	ND	Junior	88.2 ± 20.4	79.5 ± 15.6	J < S	n.s.
		Senior	117.8 ± 20.7	101.2 ± 18.2		

Note: D = dominant; ND = non-dominant; J = junior; S = senior.
[a]Significant difference between mean values for junior and senior players ($P < 0.05$).

Table IV. Torque ratio of knee flexion to knee extension (mean ± *s*).

		Velocity		Two-way ANOVA	
Leg	Group	1.05 rad · s^{-1}	3.14 rad · s^{-1}	Scheffé test on group difference[a]	Interaction with test velocity
D	Junior	0.53 ± 0.07	0.58 ± 0.11	J < S	n.s.
	Senior	0.57 ± 0.06	0.64 ± 0.08		
ND	Junior	0.49 ± 0.07	0.60 ± 0.18	J < S	n.s.
	Senior	0.56 ± 0.08	0.65 ± 0.08		

Note: D = dominant; ND = non-dominant; J = junior; S = senior.
[a]Significant difference between mean values for junior and senior players ($P < 0.05$).

Table V. Torque (kN · m^{-2}) relative to the product of mean muscle cross-sectional area and height (mean ± *s*).

			Velocity		Two-way ANOVA	
Movement	Leg	Group	1.05 rad · s^{-1}	3.14 rad · s^{-1}	Scheffé test on group difference[a]	Interaction with test velocity
Knee extension	D	Junior	15.85 ± 2.12	11.89 ± 1.14	J < S	n.s.
		Senior	16.79 ± 2.12	12.59 ± 1.18		
	ND	Junior	15.54 ± 1.84	11.58 ± 0.99	J < S	n.s.
		Senior	16.32 ± 1.91	12.10 ± 1.06		
Knee flexion	D	Junior	18.81 ± 2.50	15.46 ± 2.43	J < S	n.s.
		Senior	20.82 ± 3.19	17.47 ± 2.44		
	ND	Junior	17.58 ± 3.50	15.92 ± 3.06	J < S	n.s.
		Senior	20.17 ± 2.79	17.34 ± 2.49		

Note: D = dominant; ND = non-dominant; J = junior; S = senior.
[a]Significant difference between mean values for junior and senior players ($P < 0.05$).

difference in force between the preferred and non-preferred leg (Shephard, 1999). Based on the above, it would appear that for the participants examined here, their own training programmes and/or soccer skills might have resulted in a balance in both muscularity and strength of the left and right sides of the body regardless of age.

Development of thigh muscularity

In both the dominant and non-dominant leg, cross-sectional area of the total muscle compartment, quadriceps femoris, and hamstrings + adductors were significantly higher in the senior than junior players, regardless of thigh-slice level. These differences might be explained in part by the fact that the senior players were significantly heavier than the junior players. However, significant differences in the hamstrings were only found at 30% and 50% of femur length, and at 50% and 70% of femur length for the adductors. Along the thigh, the cross-sectional area of the quadriceps femoris is maximal at about mid-thigh level (Akima et al., 2000). In contrast, the cross-sectional area of the hamstrings and adductors becomes greater at points proximal to the knee and hip joints, respectively. The present observations also indicated that the hamstrings and adductors were largest at 30% and 70% of femur length, respectively, on average. Thus, the differences in the hamstrings and adductors between the junior and senior players were significant at the slice level where the anatomical cross-sectional area of each muscle group becomes greater along the thigh.

Compared with the cross-sectional area of the quadriceps femoris at mid-thigh level in untrained, young adult Japanese men (74 cm^2) (Kanehisa, Ikegawa, & Fukunaga, 1994) and boys aged 14–16 years (56 cm^2) (Kanehisa, Ikegawa, Tsunoda, & Fukunaga, 1995), the corresponding values in the present study were about 17% and 34% greater for the junior and senior players, respectively. Although the cross-sectional areas of the hamstrings and adductors were not reported in these previous studies, when percentage of quadriceps femoris to total muscle compartment is calculated, one finds higher values in both the untrained young adult men (55%) and boys (56%) compared with the senior and junior soccer players (49–50%) in the present study. In addition, the %QF of an untrained population was reported to be almost constant after adolescence (Kanehisa et al., 1995). However, the %QF was slightly but significantly higher in the junior than the senior players regardless of the thigh-slice level in the present study, with the reverse being the case for %Ham + Add. Therefore, compared with untrained populations, the soccer players can be characterized by a predominant development of the hamstrings and/or adductors rather than of the quadriceps femoris, and a tendency towards hamstring and adductor development becomes more apparent through the continuation of soccer training from the junior to senior stage at a highly competitive level.

Implications of hamstring and adductor development

Why a significant difference existed in %QF and %Ham + Add between the two age groups remains unclear. However, it might be associated with the higher torque ratio of knee flexion to knee extension in the senior than in the junior players. Many studies have suggested that elite senior soccer players are likely to show higher knee flexion strength than younger or sub-elite players (Cometti et al., 2000; Gur et al., 1999; Oberg et al., 1986). Thus, the predominant development of the hamstrings and adductors in soccer players may be an advantage for attaining high-level soccer playing standards. In particular, such a predominant development would be beneficial for improving running speed. The hamstrings together with the adductor magnus and gluteus maximus are considered to make the most important contribution to maximal running speed (Delecluse, 1997). Previous reports of electromyograms recorded during sprinting have provided evidence that the hamstrings play a primary role in the propulsion phase (Mero, Komi, & Gregor, 1992). Also, Simonsen and colleagues (Simonsen, Thomsen, & Klausen, 1985) suggested that the adductor muscles of the thigh may be the most important movers of the flexor moment about the hip, which acts to balance the upper body during the powerful hip and knee joint extension in the ground phase of sprinting. We did not evaluate adductor strength (hip adduction) in the present study. A further study should be conducted to examine the possible association between sprinting ability and the muscularity and strength of the hamstrings and adductors in soccer players.

The hamstrings also contribute to stabilization of the knee joint in sprinting (Aagaard, Simonsen, Magnusson, Larsson, & Dyhre-Poulsen, 1998; Osternig, Hamill, Lander, & Robertson, 1986), jumping, and ball kicking (Fried & Lloyd, 1992). During a powerful kick in soccer, the hamstrings are active in knee flexion in the backswing phase and in the downswing phase nearer to when the ball is struck (Wahrenberg, Lindbeck, & Ekholm, 1978). Hamstring activity in the latter phase causes a reduction in the rate of knee extension and acts to prevent hyperextension and possible damage to the knee (Robertson & Mosher, 1985). Thus, the greater development of the hamstrings compared with the quadriceps femoris may be assumed to be an advantage for not only achieving high-level performance but also for preventing injuries in senior players.

Torque relative to muscle size

As anticipated, the isokinetic torque was higher in the senior than in the junior players. The torque measured by the isokinetic dynamometer is a product of the applied force and the length of the lever arm of the dynamometer. In the present study, the seniors were significantly taller than the juniors, so it could be assumed that the senior players would have a longer lower leg length. Hence, the observed differences in torque might be simply attributable to the difference in lower leg length between the two groups. However, it should be noted that the senior players also showed higher values of T/(CSA*ht) than the juniors, regardless of the motion and test velocity.

As a possible explanation for this, we speculate that neuromuscular function relating to torque development in knee extension and flexion would differ between the two age groups. It has been suggested that a training programme involving a heavy-resistance, low-repetition system or ballistic movement can greatly improve neural activation during maximum voluntary contractions (Hoff, 2005; Sale, 1988; Wisloff et al., 2004). This can be an important factor in increasing muscle strength relative to muscle size (Sale, 1988). In addition, the key training stimuli for improving torque output on high-velocity contractions are repeated attempts to perform ballistic contractions and the high rate of force development of the ensuing contraction (Behm & Sale, 1993). The junior players examined in the present study had not been exposed periodically to systematic resistance exercises in their own training programmes. In contrast, the senior players had great experience of high-resistance and ballistic training as a part of their muscular fitness programmes. Considering that the ratio of knee strength to muscle size remains unchanged with age in untrained populations after late adolescence (Kanehisa et al., 1994, 1995), it might be assumed that the training background of senior players, rather than their age, is the reason why their T/(CSA*ht) values are higher than those of junior players.

Another possible reason for the age-related difference in T/(CSA*ht) is the influence of the percentages of the number and/or area of type II fibres on dynamic torque relative to muscle cross-sectional area. Ryushi and Fukunaga (1986) reported that isokinetic knee extension torque relative to the cross-sectional area of the quadriceps femoris was correlated with the percent number and percent area of type IIa fibres in the vastus lateralis muscle. Therefore, there is a possibility that, as a result of longer soccer training experience or selection processes, the proportions of the number and/or area of type IIa fibres may predominate in senior players, leading to a higher T/(CSA*ht) than in junior players.

In summary, the present study indicate that: (1) compared with junior players, senior players were characterized by a predominant development of the hamstrings and adductors and showed a higher dynamic torque relative to muscle size; and (2) neither junior nor senior players showed a significant influence of lateral dominance on the cross-sectional area of the thigh muscles or dynamic torque during knee extension and flexion.

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