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Effects of age on the reciprocal peak torque ratios during knee muscle contractions in elite soccer players

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To investigate the effects of age on the reciprocal peak torque ratios during knee muscle contractions, 25 elite male soccer players, aged 22.3±3.8 yr (18–28), volunteered for the present study. The players were grouped as adult (>21 years, $n=13$) and young players (≤ 21 years, $n=12$). Maximal concentric (CON) and eccentric (ECC) isokinetic thigh muscle strength was measured at angular velocities of 30°, 180°, 240° and 300°/s. ECC and CON peak torques of knee flexors (hamstring, HAM) and CON peak torques of knee extensors (quadriceps, QUA) in the dominant knee were greater ($P<0.05$) in adult players than in young players at 180, 240 and 300°/s. ECC HAM/CON QUA peak torque ratio at 300°/s was greater ($P<0.05$) for adult players compared to young players in the dominant knee but not in the nondominant knee. Furthermore, conventional HAM/QUA peak torque ratios of the dominant knee at all angular velocities for ECC contraction were higher ($P<0.05$) in adult players than in young players. In conclusion, the findings of the present study indicate that the reciprocal torque ratio is influenced by age in the dominant knee of elite soccer players. Because there was no effect of age for the nondominant leg, the findings of the present study are more likely to be the result of the training background of the players than their age.

Key words: soccer; reciprocal HAM/QUA ratio; age

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The isokinetic strength of knee extensor (quadriceps, QUA) and flexor (hamstring, HAM) muscles of soccer players has been investigated in previous studies in association with playing position (1), age (2) and activity level (3). Since the importance of the strength ratio between HAM and QUA with regard to injuries has been suggested previously (4, 5), the ratio between the peak torque values at different angular velocities was also determined in these studies (1–3). While HAM/QUA ratio for soccer players was found to be greater than for the reference group at 30°/s, there was no significant difference between groups of soccer players based on activity level (3). The ratio was also found to be significantly higher for forward players than for goalkeepers and defenders at 30°/s (1). However, there was no such difference of ratio at an angular velocity of 180°/s either related to activity level or related to playing position (1, 3).

Recently, Aagaard et al. (6, 7) have suggested a new method to calculate HAM/QUA ratio in order to evaluate dynamic knee joint stability as maximal eccentric (ECC) HAM strength divided by maximal concentric (CON) QUA strength. Moreover, they have introduced the ECC HAM/CON QUA ratio as an indicator of the extent to which HAM is capable of counteracting the anteriorly directed shear force exerted on the tibia by contraction of the quadriceps muscle, especially at high levels of muscle force. Kellis and Baltzopoulos (8) have also suggested that ECC antagonist/CON agonist moment ratio may be a more valid indicator of muscular imbalance than ECC (ECC/ECC) or CON (CON/CON) reciprocal parameters. In addition, it has been reported that injuries may be related to ECC antagonist/CON agonist moment deficits at a given velocity (9). The findings of Jönhagen et al. (10), who have investigated the role of HAM strength and flexibility on HAM injuries in sprinters, support this idea. In their study, Jönhagen et al. measured CON torque at 30, 180 and 270°/s and ECC torque at 30, 180 and 230°/s for knee muscles and found that ECC HAM torques at all angular velocities and CON HAM torque at 30°/s were significantly weaker in injured sprinters than in non-injured sprinters. Interestingly, by roughly calculating ECC HAM/CON QUA torque ratios based on the mean values on the injured and non-injured sprinters given in their study, values of 0.54, 0.78 and 0.92 can be seen for the injured sprinters, which appear to be lower than the values of 0.55, 0.90 and 1.04 seen in the non-injured sprinters at 30, 180 and 270°/s, respectively. Although Jönhagen et al. (10) have not examined the reciprocal ratio in relation to injuries, lower values of ratio for injured sprinters, particularly for faster angular velocities, might also indicate the importance of the ratio for injury preventation.

Influence of age on the isokinetic QUA and HAM strength was previously investigated in four groups of soccer players: three young (mean age 17.0, 15.3, 13.8 yr) and one adult (mean age 24.0 yr) by Rochcongar et al. (2). In their study the largest gain in strength was observed in the age group of 16–17 years together with the lowest HAM/QUA ratio. The increase in muscle strength was also found to be greater at low velocity than at high velocity after reaching 16 years of age. In a previous study carried out in our laboratory, we found age- and sex-related differences in CON QUA/ECC HAM torque ratio of the knee in sedentary individuals (11). According to results of our previous study (11), the CON QUA/ECC HAM ratio was lower for older than for younger men.

In the light of the previous findings on the effects of age upon the conventional HAM/QUA ratio and CON QUA/ECC HAM ratio in soccer players and sedentary individuals, respectively, we decided to investigate the effects of age on the reciprocal torque ratio in elite soccer players. Furthermore, because the differences for conventional HAM/QUA ratios were thought to be associated with playing position by Öberg et al. (1), we also examined the influence of playing position on the ECC HAM/CON QUA ratio in elite soccer players. Since isokinetic strength tests were used to identify muscle weakness and functional imbalance between the legs, the weaker side being most liable to injury (12), the measurements were conducted for both legs in the present study.

Material and methods

Twenty-five elite male soccer players who were playing in the first division of the National League, aged 22.3±3.8 yr (18–28), volunteered for this study. Subjects were grouped according to UEFA (European Union Football Association) age bracket classification criteria as adult (>21 years, 5 defenders, 4 midfielders and 4 forwards), and young players (≤21 years, 3 defenders, 5 midfielders, 4 forwards). The players were also divided into three groups according to their playing position as defenders ($n=8$), midfielders ($n=9$) and forwards ($n=8$). Physical characteristics of the subjects are summarized in Table 1.

The subjects were interviewed about their training and injury backgrounds and limb dominance. The preferred kicking leg was chosen as the dominant leg and the support leg was chosen as the nondominant leg. Three of the adult players and 4 of the young players were using the left leg as the dominant leg. The subjects had been engaged in soccer training for 6–18 years. Furthermore, all subjects were healthy and they had no history of musculoskeletal disease or knee joint surgery. After being informed of the testing procedures, possible risks and discomforts that might ensue, all subjects gave their written informed consent to participate in the study. All tests were performed following the season.

Skinfolds were measured at three sites, namely triceps, suprailiac and subscapular using Lange calipers (England). Then body fat percentage of each player was calculated from the formula suggested by Durnin and Rahaman (13). Lean body mass was calculated as [body weight – (body weight × body fat percentage)].

In order to evaluate the maximal oxygen consumption, subjects performed a maximal test following warm-up. Treadmill running speeds were such that the subject became exhausted in 7 to 10 min. The inclination of the treadmill was increased 3.5% every 3 min from an initial position of 2.5%. Oxygen consumption and carbon dioxide production were measured breath by breath using the metabolic analyzer of SensorMedics 2900C (USA) throughout the tests.

All muscle strength tests were carried out using the Cybex 6000 (Lumex Division, USA) computer-controlled isokinetic dynamometer. Subjects were positioned sitting with the backrest at a 90° angle and were instructed to grip the sides of the seat during testing. An adjustable lever arm was attached to the leg by a padded cuff just proximal to the lateral malleolus. Passive reference gravity torque was determined separately for each subject at 45° (0°=straight leg). Subsequently, this allowed the computer software to calculate the amount of passive gravity torque at every knee joint angle in the range of motion for each subject. The calculated gravity torques were then added to QUA torques and subtracted from HAM torques for each trial performed to correct the gravity effect.

Maximal voluntary strength of QUA and HAM was measured with constant angular velocity during the CON and ECC tests. After being familiarized with testing procedures by performing several light contractions, subjects performed 3 consecutive submaximal warm-up trials, rested for 20 s, and then completed 4 consecutive maximal contractions of

Table 1. Selected physical characteristics of subjects

	Adult (n=13)	Young (n=12)
Age (yrs)	25.1±2.6[1]	18.6±0.8
Training Age (yrs)	14.2±3.0[1]	9.4±1.9
Height (cm)	177±5	175±6
Body Weight (kg)	72.1±4.2[1]	64.3±4.5
Body Fat (%)	10.9±2.4[1]	4.6±0.1
Lean Body Mass (kg)	64.2±3.3[1]	61.3±4.3
$\dot{V}O_2$ max (ml · min^{-1})	3837±339[1]	3452±290
$\dot{V}O_2$ max (ml · kg^{-1} · min^{-1})	53.4±5.0	53.8±3.4

[1] indicates differences (P<0.05) between adult and young players.

QUA and HAM at 30°, 180°, 240 and 300°/s for CON and ECC tests. The knee moved through the whole range of motion between 10° and 90° (0°=straight leg) during the CON and ECC tests. During the tests the subjects were verbally encouraged to produce maximal effort. The sequence of the tests was first CON then ECC with a 20-min rest allowed between the tests and a 20-s rest between each contraction speed. ECC tests were performed following CON tests.

The comparisons between young and adult players, and between dominant and nondominant leg were tested by the Student *t*-test and paired *t*-test, respectively. To investigate the effects of playing position on the tested variables, analysis of variance (ANOVA) was used. All data were pooled, and Pearson Product Moment correlation coefficients between the different strength variables and age were then calculated to determine the relationship between age and the ratios of reciprocal knee muscle strength. The 0.05 probability level was accepted to denote statistical significance. All values are given as mean±SD.

Results

Chronological and training ages, and body weight of adult players were greater (P<0.001) than young players (Table 1). However, young players had lesser body fat (P<0.001) and lean body mass (P<0.05) than adult players (Table 1). In addition, young players had lower (P<0.05) $\dot{V}O_2$ max (ml · min^{-1}) than adult players. However, $\dot{V}O_2$ max was similar between two groups when it was expressed relative to body weight. Chronological (training) age for defenders (n=8), midfielders (n=9) and forwards (n=8) were 22.7±3.7 (12.8±2.7), 21.7±4.3 (11.0±4.0) and 22.5±3.9 (12.3±3.5) years respectively, and there was no significant difference among the groups for age by ANOVA.

For all angular velocities, ECC peak torques of QUA in dominant and nondominant knee were not significantly different between the two age groups (Table 2). While CON peak torques of QUA in the nondominant knee were not significantly different between the two age groups for for all angular velocities, it was greater (P<0.05) in adult players than young players in the dominant knee for the angular velocities of 180°/s, 240°/s and 300°/s (Table 2). For all angular velocities, ECC and CON peak torques of HAM were not significantly different between the two

Table 2. Eccentric (ECC) and concentric (CON) peak torque (Nm) in dominant and nondominant knees of adult and young players

	Angular velocity (°/s)	Dominant		Nondominant	
		Adult (n=13)	Young (n=12)	Adult (n=13)	Young (n=12)
Quadriceps					
ECC	30	245±48	272±38	247±45	263±44
	180	242±44	249±40	255±43	239±43
	240	242±41	246±40	250±35	241±40
	300	254±40	249±43	257±40	248±38
CON	30	234±29	229±24	233±31	223±22
	180	159±23[1]	144±14	155±20	146±11
	240	145±24[1]	131±14	143±20	134±12
	300	133±18[1]	121±13	131±18	122±14
Hamstring					
ECC	30	142±28	140±23	145±43	136±32
	180	158±21[1]	136±17	151±35	140±24
	240	164±23[1,2]	136±17	148±35	138±24
	300	165±23[1,2]	139±22	151±25	143±23
CON	30	133±21	127±14	128±16	122±14
	180	98±16[1]	86±16	96±15	88±14
	240	91±16[1,2]	74±9	84±15	78±8
	300	84±15[1]	71±10	80±20	72±8

[1] indicates differences (P<0.05) between adult and young players, [2] indicates differences (P<0.05) between dominant and nondominant legs.

Table 3. The reciprocal HAM / QUA peak torque ratios in dominant and nondominant knees of adult and young players

Angular velocity (°/s)	Dominant		Nondominant	
	Adult (n=13)	Young (n=12)	Adult (n=13)	Young (n=12)
CON HAM/CON QUA				
30	0.56±0.05	0.57±0.06	0.55±0.06	0.56±0.08
180	0.61±0.07	0.60±0.09	0.61±0.08	0.61±0.09
240	0.62±0.08	0.58±0.06	0.61±0.08	0.60±0.06
300	0.63±0.08	0.60±0.06	0.60±0.09	0.62±0.08
ECC HAM/ECC QUA				
30	0.60±0.12[1]	0.52±0.08	0.57±0.13	0.53±0.10
180	0.63±0.10[1]	0.55±0.09	0.63±0.13	0.58±0.12
240	0.66±0.13[1,2]	0.58±0.10	0.61±0.10	0.60±0.15
300	0.64±0.10[1]	0.57±0.09	0.60±0.10	0.59±0.14
ECC HAM/CON QUA				
30	0.61±0.09	0.62±0.11	0.62±0.14	0.59±0.14
180	0.97±0.20	0.94±0.18	0.99±0.18	0.97±0.22
240	1.15±0.14[2]	1.13±0.35	1.04±0.22	1.06±0.20
300	1.27±0.19[1,2]	1.19±0.26	1.15±0.18	1.14±0.19

[1] indicates differences ($P<0.05$) between adult and young players, [2] indicates differences ($P<0.05$) between dominant and nondominant legs.

age groups for the nondominant knee (Table 2). However, ECC and CON peak torques of HAM in the dominant knee at the angular velocities of 180°/s, 240°/s and 300°/s were greater ($P<0.05$) in adult players than in young players (Table 2). ECC peak torques of HAM at 240°/s and 300°/s, and CON peak torques of HAM at 240°/s were greater ($P<0.05$) for the dominant leg compared to the nondominant leg in adult players (Table 2). In contrast, there were no significant differences in ECC and CON peak torques of QUA and HAM between the dominant and nondominant leg of the young players. Although we have not presented peak torque values of our subjects according to playing position, there were no significant differences between groups based on playing position for peak torque.

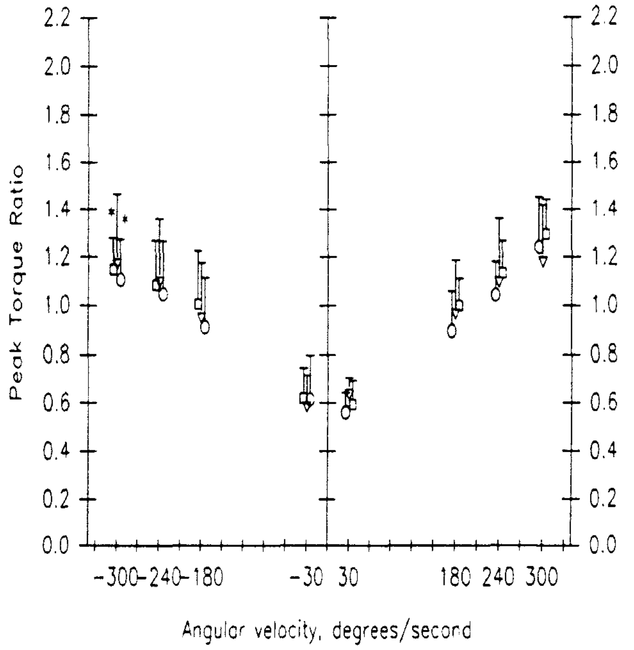

Fig. 1. ECC HAM/CON QUA peak torque ratios for defenders (open circle), midfielders (open triangle) and forwards (open square). Negative and positive angular velocities indicate nondominant and dominant knee, respectively. Error bars: ±SD. No significant differences were observed between groups. * denotes difference ($P<0.05$) between dominant and nondominant knee for defenders and forwards.

While ECC HAM/CON QUA ratios were not different between the two age groups in the nondominant knee for all angular velocities, it was greater ($P<0.05$) in adult players compared to young players for peak torque at 300°/s in the dominant knee (Table 3). When we compared the dominant with the nondominant leg, ECC HAM/CON QUA ratio in the dominant leg was greater ($P<0.05$) than the nondominant leg in adult players only at 240°/s and 300°/s (Table 3). In addition, for all angular velocities, it was not significantly different among the groups based on playing position either for the dominant or for the nondominant knee (Fig. 1). However, ECC HAM/CON QUA ratio at 300°/s was greater in the dominant knee compared to the nondominant knee in defenders and forwards (Fig. 1).

While conventional HAM/QUA peak torque ratios in the dominant knee at all angular velocities for ECC contractions were greater ($P<0.05$) in adult players than in young players, it was not significantly different for CON contractions (Table 3). However, conventional HAM/QUA ratios in the nondominant knee were not significantly different between the two age groups, either for ECC or for CON contractions. There was also no significant difference between the

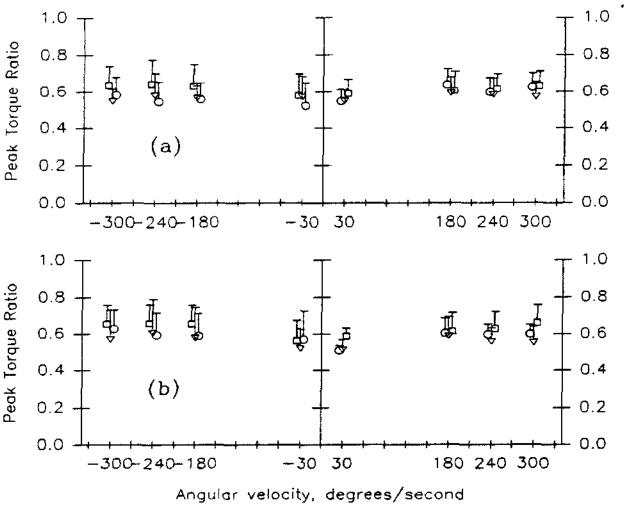

Fig. 2. Conventional HAM/QUA peak torque ratios for defenders (open circle), midfielders (open triangle) and forwards (open square) for dominant knee (a) and nondominant knee (b). Negative and positive angular velocities indicate eccentric and concentric muscle contractions, respectively. Error bars: ±SD. No significant differences were observed between groups and between dominant and nondominant knee.

dominant and nondominant leg for CON and ECC contractions except for ECC HAM/ECC QUA peak torque ratio at 240°/s, which was greater ($P<0.05$) in the dominant knee than the nondominant knee for adult players. Furthermore, there were no significant differences between defenders, midfielders and forwards, and between the dominant and nondominant knee for conventional HAM/QUA ratios (Fig. 2). In addition, age was not significantly correlated to the reciprocal peak torque ratios.

Discussion

The main findings of this study were: 1) ECC and CON peak torques of the hamstring muscles and CON peak torques of the quadriceps muscle at the angular velocities of 180°/s, 240°/s and 300°/s were greater for adult players compared to young players in the dominant knee; 2) ECC peak torques of the hamstring muscles at 240°/s and 300°/s, and CON peak torques of the hamstring muscles at 240°/s were greater for the dominant leg compared to the nondominant leg in adult players; 3) adult players had greater ECC HAM/CON QUA torque ratio only at 300°/s for the dominant knee; 4) conventional HAM / QUA peak torque ratios at all velocities examined for ECC contractions were also greater in adult players compared to young players in the dominant knee; 5) ECC HAM/CON QUA ratios at 240°/s and 300°/s were greater in the dominant leg compared to the nondominant leg in adult players; 6) the ratios did not show a significant variation related to playing position of the players either for the dominant or for the nondominant knee. However, ECC HAM/CON QUA torque ratio at 300°/s was greater in the dominant knee than the nondominant knee in defenders and forwards.

It is clear that the muscles associated with a joint have a significant role in preserving its stability. During open chain knee extension, the hamstring muscles contract eccentrically and may pull the tibia posteriorly to prevent its anterior-rotatory displacement (14). Thus, with co-activation of the hamstring muscles during knee extension, it is possible to improve stiffness of the joint and to counteract excessive anterior tibial translation. Therefore, we can speculate that a greater reciprocal ratio and hamstring muscle strength in adult players compared to younger players found in the present study may indicate a greater potential for muscular joint stabilization in adult players than in young players. However, if it were correct, we would expect similar findings for the nondominant knee of the players. Since this was not observed, and since training age is normally a function of chronological age, greater ratio and hamstring muscle strength in the dominant knee of adult players might be a result of the training background more than the age.

Solomonow et al. (15) suggested that skill acquisition may result in a reduced amount of antagonist co-activation. In speculative terms, it should be possible to restore co-activation by training of the antagonist. Findings of Aagaard et al. (16), who investigated the effects of three different strength training regimes (high- and low-resistance strength training and kicking training) on the reciprocal ratio, indicate an enhanced capacity for muscular knee joint stabilization via strengthening of the hamstrings. In their study, although kicking performance was not changed in any of the three training groups, ECC HAM/CON QUA ratio was increased (15%) significantly in the heavy resistance training group at an angular velocity of 240°/s. They also found that conventional HAM/QUA ratio increased at 240°/s for CON contraction and decreased at 30°/s for ECC contraction in the heavy resistance training group. However, Aagaard et al. (16) did not address the influence of players' age. In addition, in terms of limb dominance, Aagaard et al. examined the preferred kicking leg of the subjects. In the light of Aagaard and co-workers' findings, the greater reciprocal ratios in adult players compared to young players observed for the dominant leg in the present study could be the result of heavy resistance strength training performed previously by the players. Since in this case both legs would have been exposed to training, similar results should be expected to occur for the nondominant leg. However, for the nondominant leg no differences were observed. Therefore, the specific muscle loading patterns experienced during soccer training and matches may have caused the results observed. It is furthermore possible that the specific muscle loading patterns associated with top level soccer sports could induce gains in eccentric hamstring strength, particularly in the dominant leg (or kicking leg). Supporting this coupling between functional soccer performance and isolated muscle strength, it was previously reported by Cabri et al. (17) and DeProft et al. (18) that the kicking performance (maximal ball flight length) of elite soccer players was positively related to maximal ECC hamstring strength.

In our data, ECC HAM/CON QUA ratio increased with increase in joint angular velocity in both legs and in both groups of subjects. However, this increment was more pronounced in the dominant leg of adult players compared to young players. Hagood et al. (19) found that the hamstring muscles and the quadriceps muscle demonstrate a significant increase in their antagonist co-activation pattern during the final 40° of fast extension and flexion movements, respectively, as limb velocity increases. According to these findings, they concluded that as limb velocity is increased, there is a substantial reflexive increase in the contribution of the antagonist musculature to joint stiffness and reduction of laxity. Solomonow et al. (15) also suggested that antagonist co-activation is sensitive to joint velocity. Renström et al. (20) reported that skill acquisition in high-performance sports associated with lowered hamstring muscle co-activation may overstrain the anterior cruciate ligament (ACL) and render it open to high risk of injuries, especially in contact sports. In addition, it was suggested by Baratta et al. (21) that the reduced co-activation pattern of antagonist muscle may likely increase the risk of knee ligament damage and so co-activation of the antagonist muscle is necessary to aid the ligaments in maintaining joint stability and regulating the joint's mechanical impedance. They have also pointed out that high skill and performance of the quadriceps muscle developed by training may be associated with a depressed antagonist co-activation of the hamstring muscles. It may be speculated that such reduced antagonist activity diminishes the total stabilizing force available to the joint during extension loading, thereby exposing the ACL to an increased tensile stress. Therefore, high-performance athletes with overdeveloped quadriceps muscle and absence of hamstring muscle co-activation may face an increased risk of ACL injuries, as is also speculated in the above study (15).

Analysis of soccer training and the positional role of players during the game showed that there was a difference in training background of players according to playing position (22). Therefore, the difference in the reciprocal torque ratio related to playing position has previously been explained with the training background of subjects by Öberg et al. (1). Contrary to these findings of Öberg et al., we could not observe the influence of playing position on the reciprocal torque ratios. However, although the players had a wide range of age (17–38 years), the effect of age on the tested parameters was not addressed in the study of Öberg et al. (1). Finally, from the present data it seems that inter-positional differences between the players involved in the age groups does not account for the greater reciprocal torque ratios found in the adult players.

In conclusion, the findings of the present study indicate that the reciprocal torque ratio obtained at the dominant knee (the kicking leg) of elite soccer players is influenced by age. Because this was not seen for the nondominant knee, it is more likely to be the result of training background of the players than their age. Furthermore, in light of our data and those of others, it might be interesting to investigate whether the differences observed in reciprocal torque ratio between young and adult soccer players are associated with corresponding differences in maximal kicking performance or altered incidences of knee joint injury.

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