Isokinetic Strength and Anaerobic Power of Elite, Subelite and Amateur French Soccer Players

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Information about the influence of different practice levels on physical characteristics of a large number of soccer players is lacking. Therefore we assessed muscular strength and anaerobic power of elite, subelite and amateur soccer players to clarify what parameters distinguish the top players from the less successful. We tested 95 soccer players from the French first division (elite), second division (subelite), and amateurs and determined the isokinetic strength of the knee extensor and flexor muscles at angular velocities from $-120^\circ \cdot s^{-1}$ to $300^\circ \cdot s^{-1}$. Vertical jump, 10 m sprint, 30 m sprint and maximum ball speed during shooting were also measured. The elite players had higher knee flexor torque than the amateurs at all angular velocities ($p < 0.05$), except at $300^\circ \cdot s^{-1}$. The hamstring/quadriceps ratios proposed with two different methods were significantly lower in the amateur group than in the elite group ($p < 0.05$), except at $300^\circ \cdot s^{-1}$. Maximum ball speed during shooting and speed over 30 m sprint were not different between elite, subelite, and amateur players while speed over a 10 m sprint was significantly slower in amateur players and faster in the elite group ($p < 0.05$). Although performance in soccer is not determined only by measurable variables, professional players differ from amateurs in terms of knee flexor muscle strength and short-distance sprinting speed. Based on these findings we conclude that hamstring strength is extremely important in soccer players for joint stabilization during various tasks, notably in eccentric action. Further, short-sprinting performance may mirror actual game situations at high level and could be an important determinant of match-winning actions.

Key words: Isokinetic dynamometer, hamstring/quadriceps ratio, sprint running, kicking performance, vertical jump.

Introduction

Soccer requires intermittent physical activity in which sequences of actions requiring a variety of skills of varying intensities are strung together. Running is the predominant activity, yet explosive type efforts such as sprints, jumps, duels, and kicking are important factors for successful soccer performance. These efforts depend on maximal strength and anaerobic power of the neuromuscular system, more particularly of the lower limbs. Maximal strength refers to the highest force that can be perfomed during one maximum voluntary contraction, and is considered important for soccer performance [8–11,15, 20,21,26]. By increasing the available force of muscular contraction in appropriate muscles or muscle groups, acceleration and speed in skills critical to soccer such as turning, sprinting, jumping, and changing pace may improve [5]. The evaluation of muscle strength of the lower extremities in soccer has been performed using isokinetic peak torque [21,30] and free weights [29]. Anaerobic power refers to the ability of the neuromuscular system to produce the greatest possible impulse in a given time period. Sprint performance [8,13,22], vertical jumps [7,16,23,28,29], and kicking performance [1,3,12, 19,25] have been used to test the anaerobic power of soccer players. Indeed, in many studies some strength and anaerobic power characteristics differentiated elite from non-elite soccer players [8,16].

Öberg et al. [21] reported differences in concentric isokinetic peak torque of the quadriceps (Q) and hamstring (H) muscles between the highest and the lowest Swedish soccer divisions. They concluded that high-level soccer players had greater strength because training intensity increased with increasing playing category. Expressing hamstring strength relative to quadriceps strength gives the H/Q ratio, a measure of normal knee function and stability. Scarce information exists on the H/Q ratio between different levels of practice, more particularly in eccentric action. Although the H/Q ratio was not significantly different between four divisions of Greek soccer players [30], measurements were performed only at $60^\circ \cdot s^{-1}$ and $180^\circ \cdot s^{-1}$ in concentric conditions. Probably not only the conventional H/Q ratio calculated during concentric and eccentric muscle contractions but also the ratio of eccentric hamstring strength relative to concentric quadriceps strength (H_{ecc}/Q_{con}) is important for describing the muscular relationship about the knee joint [2]. Since this ratio was suggested to reflect the potential for providing muscular stabilization at knee joint

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during active knee extension [2], it is of relevance to assess the H_{ecc}/Q_{con} ratio of soccer players of different levels. In Brewer and Davis [8] comparative study the main physical difference between elite and non-elite English soccer players was the faster sprinting times over 15 and 40 m of the elite players. Moreover the results of Gauffin et al. [16] showed that first and second division teams had better performance in vertical jump compared with lower level teams while Wisloff et al. [29] found no difference between the first and the last classified team in Norwegian elite soccer league.

To our knowledge no study investigated simultaneously the influence of different practice levels on the muscular strength and anaerobic power of a large number of soccer players. We therefore evaluated concentric and eccentric isokinetic peak torque of the knee flexor and extensor muscles, 10 m and 30 m sprint performances, maximum ball speed during shooting, and vertical jumps of a group of 95 French soccer players. Isokinetic testing was preferred to free weights to investigate both knee extensor and flexor torque in concentric and eccentric conditions at different angular velocities and to establish H/Q ratios. A more complete isokinetic test procedure was used in comparison with earlier studies. Data were collected to verify whether differences existed between elite, subelite, and amateur soccer players in muscle strength and/or anaerobic power of the lower limb and to study any possible correlations between the various variables, by attempting to clarify which one(s) distinguish the top players from the less successful. A secondary aim was to establish normative data for French soccer players since little recent information exists on both professional and amateur teams.

Methods and Materials

All procedures described in this study were approved by the Committee on Human Research of the University of Dijon. All subjects agreed to participate in the study on a voluntary basis and signed an informed consent.

Subjects

The 95 soccer players who participated in the study included 29 professional first division (D1) players (10 defense players, 12 midfield players, and 7 forward players), 34 professional second division (D2) players (14 defense players, 12 midfield players, and 8 forward players), and 32 amateur (AM) players of regional standard (13 defense players, 12 midfield players, and 7 forward players). The percentage of defense, midfield, and attack players was comparable between the three tested groups. Descriptive anthropometric data of the subjects are shown in Table **1**. On average, D1 and D2 players had trained 12 to 14 hours per week and had played one or two games per week for the previous 5 years. Amateur players had practiced up to 6 hours per week and had played up to one game per week in the last season. None of the players tested had had any prior experience in isokinetic practice before the tests.

Table 1 Main characteristics of the subjects (Means values ± SD)

	Age (years)	Height (cm)	Weight (kg)
D1 (n = 29)	26.1 ± 4.3	179.8 ± 4.4	74.5 ± 6.2
D2 (n = 34)	23.2 ± 5.6	178.0 ± 5.8	73.5 ± 14.7
AM (n = 32)	25.8 ± 3.9	177.7 ± 5.1	76.5 ± 18.1

Testing

All measurements were performed one month before the end of the competitive season. All the tests were completed over two different sessions, 7 days apart.

Leg Muscle Strength. In the first testing session muscular strength was measured with an isokinetic ergometer (Biodex, Biodex Corporation, Shirley NY, USA), which recorded instantaneous muscular torques at various preset constant angular velocities [27]. The motor axis was visually aligned with the axis of the knee joint. The subject was seated and stabilised by straps so that only the knee to be tested was moving with a single degree of freedom. After a standardized warm-up consisting of 3 to 5 submaximal (~ 50 %) and one maximal concentric contraction of the quadriceps and hamstring muscles at the five experimental velocities, the subjects were asked to extend and to flex the knee maximally through 90°, starting from 90° of flexion. Three consecutive trials were performed at each angular velocity. Concentric (con) actions were performed at angular velocities of 60°, 120°, 180°, 240°, and $300° \cdot s^{-1}$, and eccentric (ecc) actions at angular velocities of 60° and $120° \cdot s^{-1}$. A 3 min rest period was allowed between series. Only the highest peak torque values of the flexors and extensors of the dominant leg were used in the analysis. The velocity throughout each repetition was analysed, and it was also verified that at higher angular velocities peak torque was developed during the constant velocity period. Torques were gravity-corrected at each joint angle where the gravity effect was greatest [27]. The H/Q ratio is given as H_{ecc}/Q_{ecc} and H_{con}/Q_{con}, at the corresponding angular velocities and by the method of Aagaard et al. [2], in which an H/Q ratio is associated with knee extension or flexion (H_{ecc}/Q_{con} for knee extension; H_{con}/Q_{ecc} for knee flexion) at the same angular velocity (60° and $120° \cdot s^{-1}$).

Anaerobic Power. The second testing session consisted of three main parts. Sprint, vertical jump, and kicking performance were assessed on the same soccer field. A full recovery (30 min) was allowed between different measurements, and tests were performed in the same order. Prior to testing, each subject underwent a 10 min warm-up period on a bicycle ergometer followed by supervised static stretching of the lower limbs. The soccer players performed three 30 m sprints, separated by a 5 min recovery period. Speeds were measured with infrared photoelectric cells (TEL.SI. s.r.l., Vignola, Italy) positioned 10 and 30 m from the start line and controlled by T.A.C. (Test Atletici Computerizzati, TEL.SI. s.r.l. Vignola, Italy) software. The players started on a visual signal from a standing position and ran the 30 m distance as fast as possible. The fastest of three trials was used for subsequent analysis. The jumping ability of the soccer players was evaluated with a Bosco's jumping mat (Ergojump, Globus Italia, Codogne, Italy). The players performed two different jumps, a squat jump (SJ) and a counter movement jump (CMJ) with the arms kept in the akimbo position to minimize their contribution [6]. Three tests were carried out for each type of jump, and the best result was used. A 2 min rest was allowed between jumps to minimize the effect of fatigue. Kicking performance was estimated from maximum ball speed during shooting. The speed, in $km \cdot h^{-1}$, was measured with a Stalker's type hyperfrequency radar (Stalker Professional Radar, Radar Sales, Plymouth MN, USA). The radar was set up behind the goal, and the soccer ball placed on the 6 yard line. It was then struck by the dominant leg after a free run-up. The best of five attempts was used for analysis.

Statistical analysis

Descriptive statistics were calculated. One-way analysis of variance (ANOVA) was used to investigate differences in strength and power variables between elite, subelite, and amateur soccer players. When significant treatment effect (group) occurred, Newman-Keuls post hoc comparisons were used to test differences among means. For all procedures a level of $p \leq 0.05$ was selected to indicate statistical significance.

Results

Leg muscle strength

In Fig. **1** the torque/angular velocity relationship of the knee flexors showed significant differences among the three groups. D1 players' hamstrings were significantly stronger than those of amateur players at every angular velocity ($p < 0.05$), except at $300° \cdot s^{-1}$ (Table **2**). This difference was greater in eccentric muscle action. The peak torque of D2 players was significantly higher than in the AM group, but only at the angular velocities from $-120° \cdot s^{-1}$ up to $60° \cdot s^{-1}$. The difference was greater under eccentric conditions at $-120° \cdot s^{-1}$ ($p < 0.05$). Fig. **2** shows the torque/angular velocity relationship of the knee extensor muscles. The three groups of players had comparable concentric strength. Conversely the quadriceps peak torque of amateurs was higher than that of the other two groups at $-60° \cdot s^{-1}$ and $-120° \cdot s^{-1}$ ($p < 0.01$; Table **2**). The overall H/Q ratio was higher for professionals (D1 and D2 players) than for amateurs, except at $300° \cdot s^{-1}$ (Figs. **3** and **4**; Table **2**). This difference was greater in eccentric contraction with the conventional computation method ($p < 0.05$). The H/Q ratio realized with Aagaard's method [2] showed statistically significant differences at every

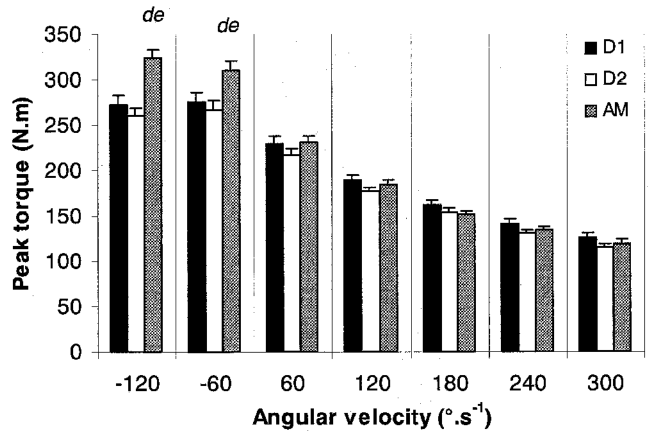

Fig. 2 Peak torque developed by the three groups for knee extensors, from $120° \cdot s^{-1}$ eccentric to $300° \cdot s^{-1}$ concentric. Values are means (± SE). *d* values for AM significantly higher than for D1 ($p < 0.05$). *e* values for AM significantly higher than for D2 ($p < 0.05$).

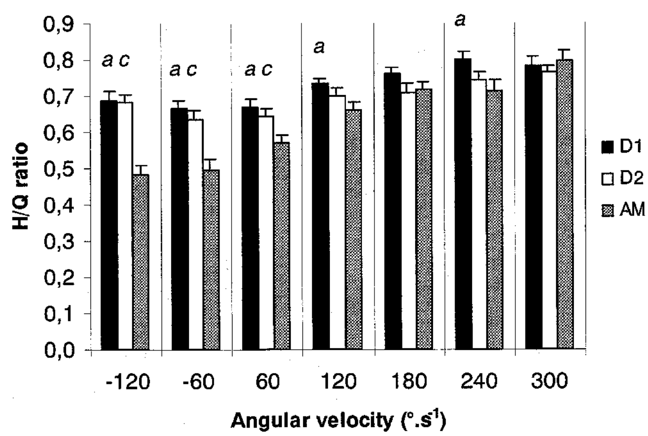

Fig. 3 Conventional H/Q ratio based on peak torque for the three groups of players. Negative angular velocity: H_{ecc}/Q_{ecc}; positive angular velocity: H_{con}/Q_{con}. Values are means (± SE). >*a* values for D1 significantly higher than for AM ($p < 0.05$). *c* values for D2 significantly higher than for AM ($p < 0.05$).

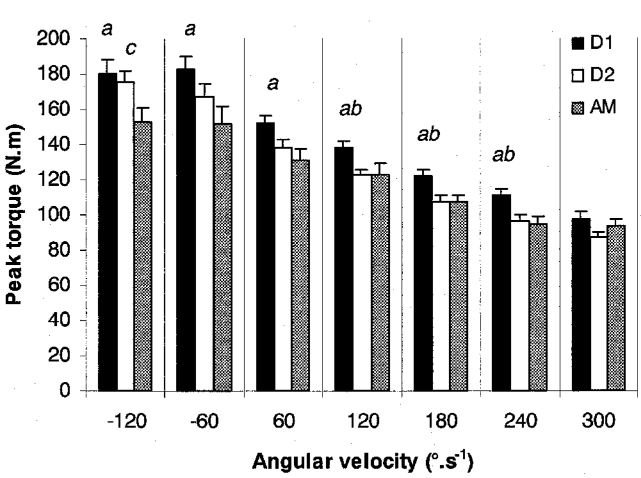

Fig. 1 Peak torque developed by the three groups for knee flexors, from $120° \cdot s^{-1}$ eccentric to $300° \cdot s^{-1}$ concentric. Values are means (± SE). *a* values for D1 significantly higher than for AM ($p < 0.05$). *b* values for D1 significantly higher than for D2 ($p < 0.05$). *c* values for D2 significantly higher than for AM ($p < 0.05$).

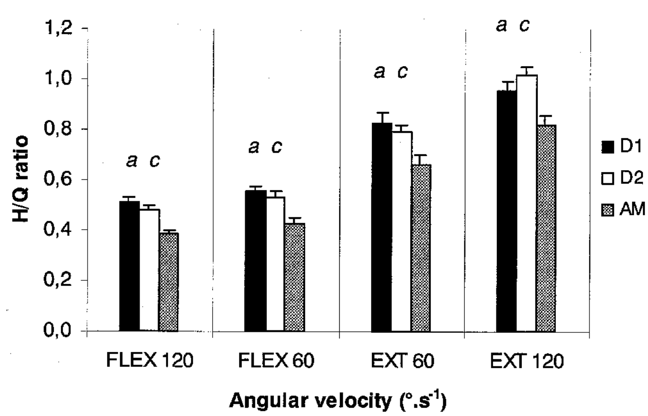

Fig. 4 H/Q ratio proposed by Aagaard et al. [2] based on peak torque data for the three groups of players. Knee flexion (FLEX): H_{con}/Q_{ecc}; knee extension (EXT): H_{ecc}/Q_{con}. Values are means (± SE). *a* values for D1 significantly higher than for AM ($p < 0.05$). *c* values for D2 significantly higher than for AM ($p < 0.05$).

Table 2 F ratios and p values from one-way analysis of variance and post hoc comparisons referred to isokinetic data for three groups of subjects

	ANOVA main effect		Newman-Keuls post hoc comparisons		
Hamstrings	F ratio	p	D1 vs D2	D1 vs AM	D2 vs AM
$-120° \cdot s^{-1}$	3.49	$p < 0.05$	0.65	$p < 0.05$	$p < 0.05$
$-60° \cdot s^{-1}$	3.17	$p < 0.05$	0.19	$p < 0.05$	0.22
$60° \cdot s^{-1}$	4.15	$p < 0.05$	0.06	$p < 0.05$	0.32
$120° \cdot s^{-1}$	3.63	$p < 0.05$	$p < 0.05$	$p < 0.05$	0.96
$180° \cdot s^{-1}$	5.19	$p < 0.01$	$p < 0.01$	$p < 0.05$	0,95
$240° \cdot s^{-1}$	5.84	$p < 0.01$	$p < 0.01$	$p < 0.01$	0.67
$300° \cdot s^{-1}$	2.02	0.14	–	–	–
Quadriceps	F ratio	p	D1 vs D2	D1 vs AM	D2 vs AM
$-120° \cdot s^{-1}$	13.76	$p < 0.001$	0.35	$p < 0.001$	$p < 0.001$
$-60° \cdot s^{-1}$	5.69	$p < 0.01$	0.49	$p < 0.05$	$p < 0.01$
$60° \cdot s^{-1}$	1.28	0.28	–	–	–
$120° \cdot s^{-1}$	1.44	0.24	–	–	–
$180° \cdot s^{-1}$	1.29	0.28	–	–	–
$240° \cdot s^{-1}$	1.37	0.26	–	–	–
$300° \cdot s^{-1}$	1.63	0.20	–	–	–
H/Q – Fig. **3**	F ratio	p	D1 vs. D2	D1 vs AM	D2 vs AM
$-120° \cdot s^{-1}$	18.55	$p < 0.01$	0.93	$p < 0.001$	$p < 0.001$
$-60° \cdot s^{-1}$	12.09	$p < 0.001$	0.45	$p < 0.001$	$p < 0.001$
$60° \cdot s^{-1}$	5.88	$p < 0.01$	0.39	$p < 0.001$	$p < 0.05$
$120° \cdot s^{-1}$	3.17	$p < 0.05$	0.26	$p < 0.05$	0.19
$180° \cdot s^{-1}$	1.52	0.22	–	–	–
$240° \cdot s^{-1}$	3.20	$p < 0.05$	0.11	$p < 0.05$	0.37
$300° \cdot s^{-1}$	0.34	0.71	–	–	–
H/Q – Fig. **4**	F ratio	p	D1 vs D2	D1 vs AM	D2 vs AM
FLEX 120	8.09	$p < 0.001$	0.25	$p < 0.01$	$p < 0.001$
FLEX 60	5.41	$p < 0.01$	0.54	$p < 0.01$	$p < 0.05$
EXT 60	14.28	$p < 0.001$	0.35	$p < 0.001$	$p < 0.001$
EXT 120	16.62	$p < 0.001$	0.17	$p < 0.001$	$p < 0.001$

angular velocity in favour of professional players, for both knee flexion and extension ($p < 0.05$).

Anaerobic power

Elite and subelite players ran faster over 10 m than the amateurs ($p < 0.05$), but no significant difference was observed between D1 and D2 soccer players. There was no statistically significant difference in the 30 m sprint time and in the maximum ball speed during shooting among the 3 groups of players
(Table **3**). Elite players jumped higher than D2 players in SJ ($p < 0.01$). Surprisingly the results of SJ and CMJ were also higher in amateur soccer players than in D2 players ($p < 0.01$) (Table **3**). No significant difference was observed between D1 and AM groups.

No correlations were found between torque values, H/Q ratios, and anaerobic power performances in the three groups of subjects.

Discussion

This study points out important differences between the three groups of players. (i) The strength of the knee flexor differs between elite, subelite, and amateur players, with professional players having stronger hamstrings than amateurs. (ii) A soccer player's sprint performance over 10 m is more indicative of this level of play than a 30 m sprint. (iii) The ball striking performances do not vary with the player's level.

In soccer practice it is normally considered that the quadriceps muscle group plays an important role in jumping and ball kicking while the hamstring controls the running activities and stabilizes the knee during turns or tackles [14]. Moreover, it seems that knee flexor contribution to joint stability becomes increasingly important with increasing limb velocity [18]. In our study elite players were significantly stronger in their knee flexor muscles than the amateurs at all angular velocities measured, and these differences were greater during eccentric actions. One direct application to soccer practice is ball striking. The knee flexor muscles act mainly to brake the leg by ec-

Table 3 Times over 10 m and 30 m, maximum ball speed and height jump in SJ and CMJ for the three groups. One-way analysis of variance, F ratios and p values for main effect (group) are also shown as well as post hoc comparisons

	Mean values (SD)			ANOVA main effect		Newman-Keuls post hoc comparisons		
	D1	D2	AM	F ratio	p	D1 vs D2	D1 vs AM	D2 vs AM
10 m	1.804	1.818	1.859					
(s)	(0.063)	(0.058)	(0.075)	5.20	$p < 0.01$	0.41	$p < 0.01$	$p < 0.05$
30 m	4.223	4.249	4.294					
(s)	(0.192)	(0.147)	(0.141)	1.30	0.28	–	–	–
Ball speed	106.37	106.94	107.77					
($km \cdot h^{-1}$)	(12.89)	(7.52)	(5.71)	0.19	0.83	–	–	–
SJ	38.48	33.86	39.83					
(cm)	(3.80)	(7.47)	(5.15)	9.71	$p < 0.001$	$p < 0.01$	0.35	$p < 0.001$
CMJ	41.56	39.71	43.93					
(cm)	(4.18)	(5.17)	(5.65)	5.59	$p < 0.01$	0.15	0.07	$p < 0.01$

centric contraction during this movement, hence limiting the forward motion of the leg after the foot has struck the ball, as shown by electromyography [17]. They act similarly in decelerating when running. Aagaard et al. [3] observed significant changes in the H/Q ratio after a 12 week heavy resistance strength training. They concluded that the potential capacity of the hamstring muscles to provide stability of the knee joint was increased as a consequence of the increase in eccentric hamstring strength. In the present study the H/Q ratios were significantly higher in elite players as a result of the highest eccentric hamstring torque. This observation can be applied to training. Indeed, it seems that eccentric strength of the hamstrings is easily trainable. De Proft et al. [12] obtained a 77% increase in maximum torque of the knee flexors by adding two strength training sessions per week to the annual program of a Belgian soccer team, possibly an indication that the hamstrings are not routinely stimulated during traditional soccer practice. Based on these observations and on our own results, it appears that knee flexor strength is extremely important in soccer players for joint stabilization during various tasks, notably in eccentric action, and systematic strength training is therefore required.

The D1 and D2 players ran faster over 10 m than the amateur players, confirming the findings of Bangsbo et al. [4]. These authors showed that high speed and moderate speed sprints were more frequent among Danish first division players than in lower divisions. These players averaged 76 high intensity runs over a soccer game on mean distances of about 12 to 15 m. Reilly and Thomas [24] measured 62 sprints per game with a mean length of 15.7 m in the English First Division. Thus measuring speed over 10–15 m is relevant to activity on the pitch. On this basis, short-sprinting performance might be an important determinant of match-winning actions. On the other hand, speed over 30 m showed no significant difference among the three groups, contrary to data reported for English players [13]. This is perhaps too long a sprinting distance and does not mirror actual game situations. Further analysis of sprinting should take into consideration different distances (e.g. 5, 15, and 20 m) or introduce a skill component (e.g. sprinting with the ball).

Practice level was not a determining factor for ball striking speed. Our results were consistent with those reported by Aagaard et al. [1], Huang et al. [19], and Robertson and Mosher [25]. De Proft et al. [12] found that specific strength training improved moderately (about 4%) kicking performance over a season. It should be noted that this improvement was not fully determined by the improvement in muscle strength suggesting that skill is also a crucial factor. Aagaard et al. [3] showed that low resistance, high resistance, or loaded kicking movements training over 12 weeks produced no significant increase in ball speed during shooting. It was concluded that task-specific transfer is difficult to achieve. Indeed, technical skill is a predominant factor in the soccer kick since the kick incorporates a complex series of synergistic muscle movements, involving the antagonist muscle as well. As an explanation for our findings, elite players most likely have other, more relevant features, such as shooting accuracy and execution technique.

In our study jumping ability did not differ between D1 and AM groups, and the amateur players performed even better than the subelite professionals. In spite of this, both SJ and CMJ values for the D1 players were consistent with those found in Italian elite teams [7]. As a player jumps an average of only 15.5 times during a game [24], it appears that this capacity cannot be developed in match situations. It would be interesting to quantify the jumps performed during training for soccer at various levels in order to better understand the influence on the maximal jumping height over a season. Thomas and Reilly [28] showed that vertical jump performance of professional soccer players was relatively stable at various stages of the competitive season. Therefore this could be supposed that soccer practice may represent an inadequate training stimulus to develop jumping ability, and systematic plyometric programs should therefore be implemented.

We did not find a correlation between maximal strength and anaerobic power performances. This would imply that isokinetic tests do not reflect the movement of the limbs involved during sprinting, kicking a ball, or jumping. Wisloff et al. [29] suggested that tests employing free weights will reflect the functional strength of the soccer player more accurately.

Nevertheless a major use of isokinetic dynamometry lies in the determination of eccentric strength, muscles imbalances (i.e. H/Q ratios), and torque values at different preset angular velocities (i.e. torque/angular velocity relationship) compared to free weights testing. Much research needs to be performed in this field to determine which evaluation protocols are relevant for soccer players. In any case, knee flexor strength and short-distance sprint assessment appear more interesting than jumping or kicking evaluation for soccer.

Our study was a cross sectional survey of adult players. Therefore an inevitable selection bias was present, as it was not possible to determine whether the differences found in the various performance characteristic studies depend on adaptation to training or on selection. However, long-term longitudinal cohort studies taking into account the various physical characteristics of soccer may prove impossible to perform, given the large number of young athletes who approach the sport, the small number of them who reach elite status, the length of time necessary for this progression, and the costs that such research program would require. In the present study no attempt was made to relate strength and power results to the players field position. Indeed, it has been shown that higher endurance demands are necessary for the more active midfield players [11,29] while defense and forward players display a higher level of vertical jump [29] or sprinting performance [11]. As a matter of fact, the percentage of defense, midfield and attack players was comparable between the three groups considered in the present study.

In conclusion, while soccer performance is not determined solely by physical factors, this investigation has revealed that professional players differ from amateurs in terms of knee flexor muscle strength and short-distance sprinting speed. According to Wisloff et al. [29] a higher level of both strength and power variables would be preferable in soccer and would reduce the risk for injuries and allow for more powerful jumps kicks, tackles, and sprints among other factors. Greater emphasis on these aspects could help the coach to effectively develop training programs and thus further improve the level of play in soccer.

Finally, this study allowed some normative data for French soccer players to be established and provided a more complete isokinetic strength picture than in earlier studies.

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