Locomotor Performance in Highly-Trained Young Soccer Players: Does Body Size Always Matter?

DOI 10.1055/s-0033-1353140
Int J Sports Med

Publisher and Copyright
© 2013 by
Georg Thieme Verlag KG
Rüdigerstraße 14
70469 Stuttgart
ISSN 0172-4622

Locomotor Performance in Highly-Trained Young Soccer Players: Does Body Size Always Matter?

Authors
M. Buchheit[1,2], A. Mendez-Villanueva[1], N. Mayer[2,3], H. Jullien[2,4], A. Marles[2], L. Bosquet[2,3], P. Maille[2], J.-B. Morin[2,5], G. Cazorla[2], P. Lambert[2]

Affiliations
Affiliation addresses are listed at the end of the article

Key words
- association football
- allometric scaling field tests
- maturation

Abstract

To examine the effects of body size on locomotor performance, 807 15-year-old French and 64 Qatari soccer players participated in the present study. They performed a 40-m sprint and an incremental running test to assess maximal sprinting (MSS) and aerobic speeds, respectively. French players were advanced in maturity, taller, heavier, faster and fitter than their Qatari counterparts (e.g., Cohen's d = +1.3 and +0.5 for body mass and MSS). However, when adjusted for body mass (BM), Qatari players had possibly greater MSS than French players (d = +0.2). A relative age effect was observed within both countries, with the players born in the first quarter of the year being taller, heavier and faster that those born during the fourth quarter (e.g., d = +0.2 for MSS in French players). When directly adjusted for BM, these MSS differences remained (d = +0.2). Finally, in both countries, players selected in National teams were taller, heavier, faster and fitter than their non-selected counterparts (e.g., d = +0.6 for MSS in French players), even after adjustments for body size (d = +0.5). Differences in locomotor performances between players with different phenotypes are likely mediated by differences in body size. However, when considering more homogeneous player groups, body dimensions are unlikely to substantially explain the superior locomotor performances of older and/or international players.

Introduction

Among the numerous factors that contribute to success in soccer, tactical and technical skills are probably the most important ones. As such, successful teams and players are not necessarily fitter and faster than the less successful ones [7, 8, 15, 17, 39, 42]. Nevertheless, well-developed physical capacities are still believed to be important aspects to reach success in soccer [52]. For example, speed capabilities may be crucial at decisive moments in the game to win the ball or overrun an opponent [18]. Additionally, well-developed physical capacities may allow for a decreased relative exercise intensity during games [43], which might delay both acute and accumulated fatigue. For these reasons, physical capacities represent an important component of young players testing batteries, both from a selection or talent identification perspective.

While a myriad of physical qualities such as acceleration, maximal sprinting speed, agility, coordination or maximal aerobic power have been suggested to be important in young soccer players [52], an overall performance picture can be gained with the assessment of a player's locomotor profile, i.e., determined by the maximal running speeds supported by both the aerobic (maximal aerobic speed, MAS) and anaerobic (maximal sprinting speed, MSS) systems [10, 43]. These 2 key locomotor speeds have received growing attention in the scientific literature and coaching community in the past years, especially because of their ability to predict high-intensity exercise performance [3, 6, 10, 44, 56]. Additionally, these 2 locomotor speeds can be easily identified and assessed by means of low-cost field tests [9, 41]. With respect to actual on-field running performance during games, the value of these 2 running speeds is straightforward both in adult [51] and adolescent [7] players: positive, moderate-to-large relationships have actually been reported between match running performance and these 2 key running speeds (at least for some playing positions) [7, 51]. However, from a selection and/or player development perspective in adolescent players, the informative nature of locomotor performance may be more problem-

accepted after revision
July 03, 2013

Bibliography
DOI http://dx.doi.org/10.1055/s-0033-1353140
Published online: 2013
Int J Sports Med
© Georg Thieme Verlag KG Stuttgart · New York
ISSN 0172-4622

Correspondence
Dr. Martin Buchheit
Football Performance and Science Department
ASPIRE
Academy for Sports Excellence
PO Box 22287
Doha
Qatar, N/a
Tel.: +974/4413/6103
Fax: +974/4413/6060
mb@martin-buchheit.net

atic. For instance, it is during the early phase of adolescence (i.e., 11–15 years) that between-player differences in growth, maturation and, hence, body dimensions within a similar age group are the greatest [36]. Experimental studies have shown that body dimensions, and especially muscle mass, explains a large fraction of the between-subject differences in muscle power output during non weight-bearing physical performance measures, both in adults [47] and adolescents [16] (with the larger the muscle mass, the greater the power). This is related to the generally reported proportional relationship between muscle physiological cross-sectional area and muscle force production capacity [27]. This relationship might however not always be true: it was recently shown in young soccer players that regular soccer training increases knee extensors strength relative to muscle cross-sectional area [30]. The beneficial effect of body dimensions, including muscle and body mass, on locomotor (weight-bearing) performance is however, likely related to the nature of the performance test. Since the mean force applied during the ground contact phase is the greatest determinant of sprint running performance, and since these forces are very-largely related to a runner's body mass [57], body mass has generally a beneficial effect on sprint running performance (at least when considering homogeneous populations presenting with similar training background and body composition). This relationship was demonstrated with field-based measures both in adult athletes [50,57] and adolescent soccer players [19,41]. In contrast, when considering aerobic-related performances, results are less straightforward. While the relationship between blood vessels cross-sectional area and maximal aerobic power [2] suggests a beneficial effect of muscle mass on the absolute maximal oxygen uptake, it is worth noting that during weight-bearing activities such as running, athletes have also to overcome their own body mass. It appears that the longer the event, the greater the detrimental effect of excessive body dimensions [31,54,57]. While positive relationships were reported between MAS and body mass [41], body mass was shown to be detrimental for Yo-Yo test performance [19]. Therefore, the observed variations in maturation and body dimensions [20,36] may prevent an accurate estimation of adolescent players' "true" locomotor profile. In support of this hypothesis, the players preferentially selected in soccer academies [21], first youth teams [22,25] or National teams [24] are consistently more advanced in age (players born earlier in the year) and/or in maturation. They also present greater body size and generally outperform their smaller and lighter counterparts by up to 5–20% [20–23,25]. In youth soccer elite teams and academies, this phenomenon leads to a systematic exclusion of the youngest and less mature players, whose physical (and soccer) potential might only be revealed later after puberty [37].

To partial out the potential effect of maturation and/or body size on physical performances and better reveal adolescent players' "true" potential, several approaches have been used so far. These include, for example, group means statistical adjustments on chronological age [11,12,36], estimates of pubertal status [40,53], body dimensions [11,36,40], or the use of allometric scaling [13,32,41]. While group-mean adjustments render possible the understanding of the independent effect of age, maturation and/or body dimensions on physical performances [40], they do not allow, like allometric scaling, adjustments at the individual level [32] (which is likely crucial from a selection/identification perspective to avoid exclusion of the less mature/shorter and smaller players). The disadvantages of allometric scaling are, in contrast, that it cannot be used to compare different populations (since the exponent to control for body size is likely population-dependent [32]), and it also changes the units of measure (e.g., s to s.kg^{-exp}). Such changes may be problematic to practitioners who are used to traditional performance values. These 2 methods have however, not been compared directly; it is unknown whether both adjustment methods lead to similar conclusions. It is also worth noting that while chronological age and body dimensions are easy-to-get measures associated with low error of measurements [5], the use of estimates of maturity status as independent variables is questionable for several reasons. Bone age-based methods are expensive and time consuming, dependent of the bone analysed and the methods of assessment (e.g., Greulich-Pyle, Tanner-Whitehouse, Gilsanz-Ratib or Fels). Non-invasive methods based on anthropometric measures [45] are more practical, but the effect of ethnicity on the validity of biological maturity estimates is unclear [34]. Additionally, the interrelationships among the different methods is poor [35]. In this latter study in young Portuguese soccer players [35], the classification of their maturation status was actually dependent on the method used (i.e., the use of skeletal age, stage of pubic hair, predicted age at peak height velocity or percentage of predicted adult height suggested different maturation status in some players). It is also unclear whether body dimensions have a consistent impact on physical performances, since differences in body size can result from the well-known variations in age and/or maturation [20,36], but also from differences in genotypic backgrounds (e.g., nationality and/or ethnicity) [48,55]. Since more mature/older players [20,36] or those selected for National teams generally present both greater body dimensions and physical performances [21,23,25], the selective impact of body size on physical capacities is also difficult to decipher. The first aim of the present study was to (re)examine the specific impact of body dimensions on locomotor profile in highly-trained soccer players. We first compared different player groups known to differ in body size, as it is the case for players with different phenotypes (i.e., French vs. Qatari players) [48,55] or players varying in chronological age and/or maturation levels [20,36]. In a second time, we also investigated how body size affects the expected differences in physical performances between players of different playing standards (i.e., players selected in National teams vs. those non-selected [21,23,25]). Given the strong influence of body dimensions on locomotor performance [19,41], all between-group differences in locomotor performances were expected to be abolished, or at least largely reduced, after statistical adjustments for body dimensions. The second aim was to compare the effectiveness of different statistical approaches to partial out the effect of body size on locomotor performance (i.e., group-mean adjustments and allometric scaling).

Methods

Participants

Data from 807 Under 15 (U15) French and 64 Qatari soccer players were included in the present study (**Table 1**). The best 14 outfield players of each of the 30 French regions for 2 consecutive years formed the French players group. Outfield Qatari players were representatives of the Aspire Academy, which can be compared to an elite regional/national center in European countries. Within each country, players were divided into one of 4

Table 1 Physical characteristics and performance of highly-trained French and Qatari U15 players.

	French (U15 Regional team selection)	Qatari (Aspire)	Standardized differences for Qatari vs. French players	Chances for smaller/similar/greater value for Qatari vs. French players	Qualitative outcome
n	807	64			
age (y)	15.0 ± 0.3	15.0 ± 0.3	− 0.04 (− 0.26; 0.17)	11/85/3	likely trivial difference
month of birth	4.6 ± 3.1	5.6 ± 3.1	+ 0.35 (0.15; 0.56)	0/11/89	Qatari likely born later in the year
age at PHV (y)	13.9 ± 0.5	14.4 ± 0.6	0.73 (0.51; 0.96)	0/1/97	Qatari very likely mature later
APHV (y)	1.1 ± 0.6	0.6 ± 0.7	− 0.47 (− 0.71; − 0.23)	97/3/0	Qatari very likely less mature when tested
height (cm)	172.5 ± 6.8	165.7 ± 6.8	− 1.02 (− 1.24; − 0.79)	100/0/0	Qatari almost certainly shorter
body mass (kg)	62.3 ± 7.0	52.5 ± 7.7	− 1.30 (− 1.54; − 1.06)	100/0/0	Qatari almost certainly lighter
10 m (s)	1.81 ± 0.08	1.81 ± 0.07	+ 0.03 (− 0.19;0.24)	4/86/9	likely trivial difference
10 m adjusted for BM (s)	1.81 ± 0.08	1.77 ± 0.07	− 0.54 (− 0.85; − 0.24)	97/3/0	Qatari very likely faster
10 m adjusted for height (s)	1.81 ± 0.08	1.79 ± 0.07	− 0.33 (− 0.59; − 0.07)	80/20/0	Qatari very likely faster
MSS (km/h)	29.82 ± 1.71	28.94 ± 1.52	− 0.51 (− 0.72; − 0.31)	99/1/0	Qatari very likely slower
MSS adjusted for BM (km/h)	29.75 ± 1.66	29.97 ± 1.25	+ 0.18 (− 0.11; 0.46)	2/54/44	Qatari possibly faster
MSS adjusted for height (km/h)	29.78 ± 1.71	29.66 ± 1.32	− 0.05 (− 0.31; 0.20)	17/77/5	unclear
$V_{Vam\text{-}Eval}$ (km/h)	16.8 ± 0.9	16.5 ± 0.9	− 0.29 (− 0.52; − 0.05)	72/28/0	Qatari possibly slower
$V_{Vam\text{-}Eval}$ adjusted for BM (km/h)	16.7 ± 0.9	16.5 ± 0.9	− 0.20 (− 0.56; 0.17)	50/47/4	Qatari possibly slower
$V_{Vam\text{-}Eval}$ adjusted for height (km/h)	16.8 ± 0.9	16.6 ± 0.9	− 0.19 (− 0.52; 0.13)	49/49/2	Qatari possibly slower

Values are mean ± SD for age, month of birth, age at peak height velocity (PHV), age from/to peak height velocity (APHV), height, body mass (BM), 10-m sprint time (10 m), maximal sprinting speed (MSS) and peak incremental test running speed ($V_{Vam\text{-}Eval}$), with performance values adjusted for individual body mass (BM), height, or without adjustment

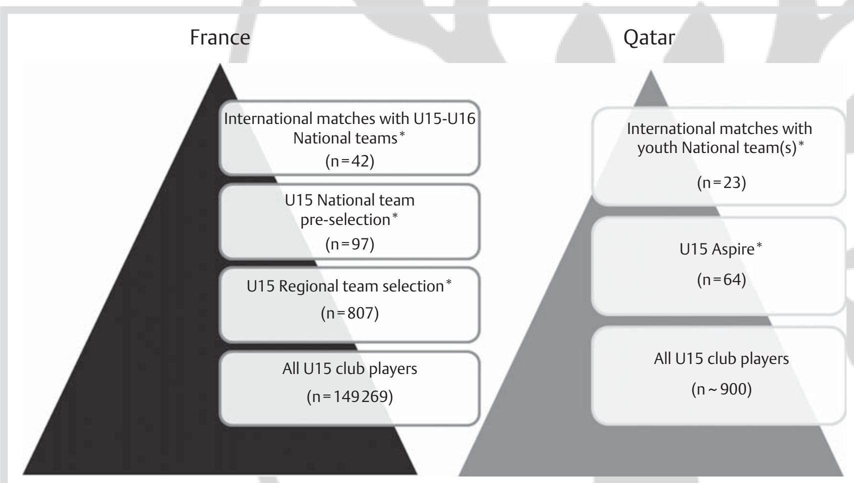

Fig. 1 Flow chart showing players group allocation as a function of playing level. *: Only players with complete testing data sets were included.

groups (based on the quarters of the year) according to their date of birth in the selection year. Finally, players were also divided into sub-groups based on whether they were pre-selected and/or played for their National teams (Under 15 and Under 16 year-old teams, French and Under 15 to under 19 year-old teams, Qatari players) (▶ **Fig. 1**). The age at peak height velocity (PHV) was used as a relative indicator of somatic maturity representing the time of maximum growth in stature during adolescence as described by Mirwald et al. [45]. The age at PHV is the most commonly used indicator of maturity in longitudinal studies of adolescence [34]. The ethnicity of French players was mixed and included Whites, Blacks, and North African Arabs. Due to both ethical considerations and the fact that there is no possible ethnical description for players with mixed ancestries, French players were considered as a unique ethnic group. Ethnicity of Qatari players was Middle Eastern Arab (considered as White on the Census forms, as were the Canadian adolescents who served to determine the initial regressions to estimate age at PHV [45]). The effect of ethnicity on the validity of biological maturity estimates using the procedures described above is presently unknown; the equation was therefore assumed to be valid for both populations. In the present study, the average estimate of age at PHV (▶ **Table 1**) was close to the range previously described for European boys (13.8–14.2 years, [34]). French players participated on average in ~8 h of combined soccer-specific training and competitive play per week (4–5 soccer training sessions and 1 domestic game per week). Qatari players participated on average in ~12 h of combined soccer-specific training and competitive play per week (6–8 soccer training sessions, 1 strength training session, 1–2 conditioning sessions, 1 domestic game per week and 2 international club games every 3 weeks). All players had a minimum of 3 years prior soccer-specific training. While approval for the study was obtained from the French Football Federation (French players) and Aspire Academy (Qatari players), these data arose as a condition of selection in which player performance is routinely measured over the course of the competitive season [58]. Therefore, usual appropriate ethics committee clearance was not required; however, the study conformed to the ethical standards of the International Journal of Sports Medicine [26]. Finally, to ensure team and player confidentiality, all physical performance data were anonymized before analysis.

Study overview

All measurements were taken in April (over 2 [2011–2012] and 6 [2007–2012] successive years for French and Qatari players, respectively). Testing was conducted on a synthetic track which allowed the maintenance of standardized environmental conditions (roof covered field [~20 ± 2 °C, ~50 % relative humidity] and indoor [22 ± 0.5 °C, 55 % relative humidity] for French and Qatari players, respectively). Training contents and load during the 3–5 days preceding the testing sessions were reduced and well standardized. All players were familiar with the physical tests, which included a maximal continuous and incremental running test (Vam-Eval) to approach MAS and a 40-m sprint with 10-m splits to assess acceleration and MSS [10]. For the French players, both tests were performed during the same morning testing session (10:00–12:00 AM), with the 40-m sprint performed before the Vam-Eval. For Qatari players, the Vam-Eval test was performed during a morning training session (8:00 AM), while the speed tests during an afternoon session (4:00 PM). Testing sessions were at least 24 h apart.

Incremental field running test

A modified version of the University of Montreal Track Test (UM-TT, [34]) (i.e., Vam-Eval) was used to approach MAS [7]. The test began with an initial running speed of 8.5 km.h^{-1} with consecutive speed increases of 0.5 km.h^{-1} each minute until exhaustion. The players adjusted their running speed according to auditory signals timed to match 20-m intervals delineated by marker cones around a 200-m long track. The test ended when the players failed on 2 consecutive occasions to reach the next cone in the required time. Throughout the test, players were given verbal encouragement by the testers and coaches. The average velocity of the last completed stage was recorded as the players' $V_{Vam\text{-}Eval}$ (km.h^{-1}). If the last stage was not fully completed, the $V_{Vam\text{-}Eval}$ was calculated as follows:

$$V_{Vam\text{-}Eval} = S + (t/60 \times 0.5) \qquad \text{Eq. 1.}$$

where S is the speed of the last completed stage (in km.h^{-1}) and t is the time in seconds of the uncompleted stage. The reliability of $V_{Vam\text{-}Eval}$ was assessed prior to the present study in a group of 65 players of our soccer academy. The typical error, expressed as a CV, was 3.5 % (90 % confidence interval: 3.0; 4.1) [5].

Speed tests

All players performed 2 maximal 40-m sprints during which 10-m split times were recorded using dual-beam electronic timing gates (Swift Performance Equipment, Lismore, Australia). Ten-meter sprint time (10 m) was used as a measure of acceleration. Maximal sprinting speed (MSS) was defined as the fastest 10-m split time measured during a maximal 40-m sprint [10]. Split times were measured to the nearest 0.01 s. Players commenced each sprint from a standing start with their front foot 0.5 m behind the first timing gate and were instructed to sprint as fast as possible over the full 40 m. The players started when ready, thus eliminating reaction time. Each trial was separated by at least 60 s of recovery with the best performances used as the final result. As for $V_{vam\text{-}eval}$, the reliability of 10 m and MSS was assessed prior to the present study in a group of 65 players. The typical error, expressed as a CV, was 2.2 % (1.9; 2.5) and 1.4 % (1.2; 1.6) for 10 m and MSS, respectively [5].

Statistical analyses

Data in the text and figures are presented as means (SD). All data were first log-transformed to reduce bias arising from non-uniformity error. Data were then analyzed for practical significance using magnitude-based inferences [29]. We used this qualitative approach because traditional statistical approaches often do not indicate the magnitude of an effect, which is typically more relevant to athletic performance than any statistically significant effect. Between-age group standardized differences or Cohen Effect Sizes (d) (90 % confidence limits, CL) in the selected performance variables were calculated using pooled standard deviations. Threshold values for d statistics were > 0.2 (small), > 0.6 (moderate), and > 1.2 (large). Probabilities were also calculated to establish whether the true (unknown) differences were lower, similar or higher than the smallest worthwhile difference or change (0.2 multiplied by the pooled between-subject standard deviation, based on Cohen's Effect Size principle). Quantitative chances of higher or lower differences were evaluated qualitatively as follows: < 1 %, almost certainly not; 1 − 5 %, very unlikely; 5 − 25 %, unlikely; 25 − 75 %, possible; 75 − 95 %, likely; 95 − 99 %, very likely; > 99 %, almost certain. If the chance of both higher and lower values was > 5 %, the true difference was assessed as unclear [29]. Otherwise, we interpreted that change as the observed chance.

To examine the specific effect of body size on group-average performance measures, all between-group comparisons were performed with or without adjustments for body mass or height [40]. Finally, to partial out the effect of body size on individual performances measures, we used a linear regression allometric scaling model [32]. Since more complex modelling (e.g., multiple regression analyses [31], proportional allometric scaling [13]) did not improve the gain of variance for the fit between dependent and independent variables, a zero-order linear regression model was retained for simplicity. Since the effect of body size on physical performance is likely physical test-specific [32], specific allometric exponents were calculated for each performance variable. Ten-meter sprint time, MSS and $V_{Vam\text{-}Eval}$ were used as the dependent variables. Body mass (kg) and height (cm) served as independent variables to construct 6 different regression models and to identify the scaling exponents for each player group. Scaling exponents were not calculated for age and APHV since the magnitude of their relationship with performance were either unclear or lower than the relationships between performance and body dimensions. The following steps outline the procedures used to construct the model [41,59]. First, normality of the dependent variables was assessed in the entire cohort. Second, a log-linear regression analysis was performed on the independent and dependent variables. The slope of the regression line (90 % CL) was used as the allometric scaling exponent [32,41,59]. Third, distribution of residuals and the assumption of homoscedasticity were tested by the Anderson-Darling normality test and visual inspection of the residuals. The residual errors should demonstrate a constant variance (homoscedasticity) and a normal distribution, indicating that the model fits all individuals across the entire range [49]. Fourth and last, independence of the power ratio (i.e., allometrically-scaled 10 m, MSS and MAS) and independent variable (i.e., body mass, height and leg length) was assessed. For an allometric model to be deemed appropriate there should be no significant correlation between the allometrically-scaled performance measures and the independent variable [41,59].

Finally, Pearson's correlation coefficients were also calculated to establish the respective relationships between performance

Table 2 Relationships between physical performance and body size in highly-trained French and Qatari U15 players.

		Height	Body mass	Chronological age	APHV
French (U15 regional team selection)	10 m	k = −0.24 (−0.34; −0.13)	k = −0.08 (−0.11; −0.04)		
		r = −0.18 (−0.24; −0.13)	r = −0.19 (−0.24; −0.13)	r = −0.10 (−0.16; −0.04)	r = −0.14 (−0.19; −0.08)
	MSS	k = 0.35 (0.26; 0.44)	k = 0.17 (0.14; 0.20)		
		r = 0.22 (0.16; 0.27)	r = 0.32 (0.27; 0.37)	r = 0.07 (0.02; 0.13)	r = 0.24 (0.18; 0.29)
	$V_{Vam\text{-}Eval}$	k = 0.11 (0.02; 0.20)	k = −0.01 (−0.04; 0.02)		
		r = 0.07 (0.02; 0.13)	r = −0.02 (0.08; −0.04)	r = 0.06 (0.00; 0.12)	r = 0.10 (0.04; 0.16)
Qatari (Aspire)	10 m	k = −0.40 (−0.59; −0.21)	k = −0.13 (−0.18; −0.08)		
		r = −0.41 (−0.57; −0.22)	r = −0.47 (−0.62; −0.29)	r = −0.11 (−0.31;0.10)	r = −0.47 (−0.62; −0.29)
	MSS	k = 0.66 (0.43; 0.89)	k = 0.20 (0.14; 0.26)		
		r = 0.52 (0.35; 0.65)	r = 0.58 (0.42; 0.70)	r = 0.14 (−0.07; 0.34)	r = 0.55 (0.39; 0.68)
	$V_{Vam\text{-}Eval}$	k = 0.12 (−0.18; 0.41)	k = 0.02 (−0.08; 0.08)		
		r = 0.09 (−0.12; 0.29)	r = 0.05 (−0.16; 0.25)	r = 0.15 (−0.06; 0.34)	r = 0.08 (−0.13; 0.28)

Allometric exponent (k) and correlation coefficient (r (90 % Confidence limits)) derived from zero-order correlations between measures of body size (height and body mass), age, age from/to peak height velocity (APHV) and 10-m sprint time (10 m), maximal sprinting speed (MSS) and peak incremental test running speed ($V_{Vam\text{-}Eval}$) in French and Qatari young soccer players

Table 3 Characteristics of highly-trained French and Qatari U15 soccer players as a function of birth dates.

		1st quarter	2nd quarter	3rd quarter	4th quarter	Between-group differences
French (U15 regional team selection)	n (%)	354 (44)	246 (30)	132 (16)	74 (9)	X^2_3 = 229.9 (<0.001)
	age (y)	15.2 ± 0.1	15.0 ± 0.1	14.7 ± 0.1	14.4 ± 0.1	1 = 2 > 3 > 4
	month of birth	1.8 ± 0.8	4.9 ± 0.8	8.0 ± 0.8	11.0 ± 0.8	1 > 2 > 3 > 4
	APHV (y)	+ 1.2 ± 0.6	+ 1.2 ± 0.6	+ 0.8 ± 0.5	+ 0.6 ± 0.6	1 = 2 > 3 > 4
	height (cm)	172.5 ± 6.3	173.4 ± 5.7	171.3 ± 7.2	171.0 ± 7.8	1 = 2 > 3 = 4
	body mass (kg)	62.5 ± 6.8	63.2 ± 6.5	61.4 ± 7.9	60.4 ± 7.8	1 = 2 > 3 = 4
Qatari (Aspire)	n (%)	18 (28)	22 (34)	15 (25)	8 (13)	X^2_3 = 6.7 (0.08)
	age (y)	15.3 ± 0.1	15.0 ± 0.1	14.8 ± 0.1	14.5 ± 0.1	1 > 2 > 3 > 4
	month of birth	2.0 ± 0.8	4.9 ± 0.9	7.9 ± 0.8	11.0 ± 0.9	1 > 2 > 3 > 4
	APHV (y)	+ 1.0 ± 0.6	+ 0.6 ± 0.6	+ 0.5 ± 0.7	+ 0.4 ± 0.4	1 > 2 = 3 > 4
	height (cm)	165.7 ± 7.3	165.4 ± 6.0	165.9 ± 8.6	165.8 ± 4.6	1 = 2 = 3 = 4
	body mass (kg)	54.1 ± 7.3	52.1 ± 8.1	51.8 ± 9.1	51.5 ± 5.2	1 > 2 = 3 = 4

Values are mean ± SD for age, month of birth, age from/to peak height velocity (APHV), height and body mass. Between-group differences are quantified based on a clear decision (i.e., at least possible difference) together with a standardized difference ≥0.2. All between-group differences were small in magnitude, with the exception of Q1 vs. Q3, Q1 vs. Q4 and Q2 vs. Q4 for age, Q1 vs. Q4, Q1 vs. Q3 for APHV, and Q2 vs. Q3 and Q2 vs. Q4 for APHV, which were of moderate magnitude. X^2_3: Chi-Square statistics (P-value)

measures and both chronological age and APHV. The magnitude of the correlations (*r* (90 % confidence limits)) between test measures were assessed with the following thresholds: ≤0.1, trivial; >0.1–0.3, small; >0.3–0.5, moderate; >0.5–0.7, large; >0.7–0.9, very large; and >0.9–1.0, almost perfect. If the 90 % confidence intervals overlapped small positive and negative values, the magnitude was deemed unclear; otherwise the magnitude was deemed to be the observed magnitude [29]. Finally, differences between the observed and expected birth-date distributions were tested with the Chi-Square statistic. Expected birth-date distributions were estimated to be 25 % for each quarter of the year.

Results

French vs. Qatari players

Anthropometric and performance measures of both player groups are presented in **Table 1**. Compared with French players, Qatari players were at least likely born later in the year, less mature, shorter, lighter, slower and less fit. However, when adjusted for body size, Qatari players were possibly to likely faster. In contrast, their $V_{Vam\text{-}Eval}$ remained lower than French players after adjustments.

Allometric models and relationship between variables

The relationships between players' physical characteristics and performance measures are presented in **Table 2**. The use of the 2 independent variables (i.e., body mass and height) as scaling variables was successful in meeting all of the statistical criteria. Physical performance measures were not clearly ($V_{Vam\text{-}Eval}$ in both groups), slightly (10 m for French players) and moderately (MSS for French players, 10 m and MSS for Qatari players) correlated with body size measures (**Table 2**). Body mass tended to yield larger correlations with performance variables than height. Moreover, given the high level of interrelatedness between the 2 anthropometric variables and body mass being the most commonly used allometric scaling variable, only data scaled for body mass are reported. Correlations with chronological age were all trivial and/or unclear for all performance measures in both groups. Correlations with APHV were only small for MSS in French players, and moderate for both 10 m and MSS in Qatari players.

Relative age effect

Physical characteristics and physical performances of players divided into groups based on their birth dates are presented in **Table 3**. In both groups, players born early in the selection year were highly represented, with a decreasing number of play-

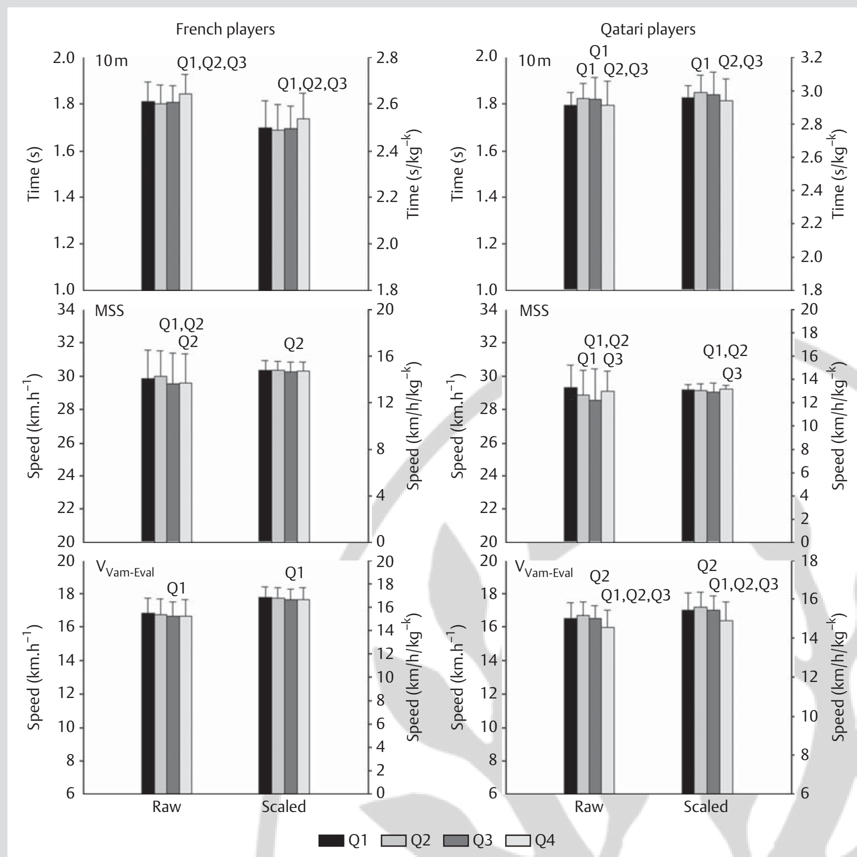

Fig. 2 Raw or allometrically-scaled (body mass) physical performance measures of highly-trained French and Qatari U15 soccer players as a function of birth dates: 10-m sprint time (10 m), maximal sprinting speed (MSS) and peak incremental test running speed ($V_{Vam-Eval}$). Between-group differences (with Q1, Q2, Q3 and Q4 standing for difference vs. the first, second, third and fourth year quarter, respectively) are quantified based on a clear decision (i.e., at least possible difference) together with a standardized difference ≥0.2. All between-group differences were small in magnitude. See ▶ **Table 3** for samples size.

ers born in the subsequent quarters. Similarly in both groups also, there was a trend for the older players to be more mature, taller and heavier than their younger counterparts (▶ **Table 3**), while they also tended to be faster and fitter (▶ **Fig. 2**, left panels). These relative age effect-related differences in physical performance persisted after adjustments for body mass (scaled performance, ▶ **Fig. 2**, right panels).

Selected vs. non-selected players comparison

Physical characteristics and physical performances of players divided into groups based on their participation to international games with national teams are presented in ▶ **Table 4** (French) and **5** (Qatari). While international Qatari players tended to be more mature at the time of the physical performance tests than their non-selected counterparts, there was no substantial difference in maturity status between the 3 French players groups. For both countries, international players were taller, heavier, faster and fitter than their pre-selected (French) and non-selected counterparts (French and Qatari). Results from these between-group comparisons remained very similar when accounting for differences in body size.

Adjustment methods

For all adjustments for body mass, the effect was similar when using either (group means adjustments or allometrically-scaled values, i.e., between-group differences remained the same and presented similar magnitudes. For example, in French players (▶ **Table 4**), the standardized differences in MSS between players selected in National teams and the others was small, considering either group-mean values adjusted for body mass (d = 0.42) or allometrically scaled values (d = 0.51). Similarly, the between player group standardized differences in $V_{Vam-Eval}$ were similar: d = 0.58 vs. 0.44 for group-mean values adjusted for body mass vs. allometrically scaled values, respectively. Finally, in Qatari players, the magnitude of the between-group differences was also similar for group-mean values adjusted for body mass vs. allometrically scaled values (▶ **Table 5**).

Discussion

The aim of the present study was to (re)examine the impact of body dimensions on locomotor performance in highly-trained young soccer players, and to directly compare different adjustment methods. The main findings were as follow: 1) French players were advanced in maturity, taller, heavier, faster and fitter than their Qatari counterparts. These physical performance differences were, at least partly, body size-related since Qatari players were possibly faster than French players when adjusted for body size; 2) a relative age effect was observed within both countries, with the players born in the first quarter being taller, heavier and faster than those born during the fourth quarter of the year. In this case however, body size difference was unlikely a mediator of the observed locomotor performance differences, since the MSS differences remained when adjusted for body dimensions (using both group means comparisons or allometric scaling); 3) similarly, in comparison with their non-selected counterparts, the greater body dimensions of international players were unlikely to explain their superior locomotor performances, since these differences remained after adjustments for body size; and finally, 4) both adjustment methods used to partial out the effect of body size, i.e., either group-mean adjustments or allometric scaling, led to similar conclusions.

Table 4 Physical characteristics and physical performance for highly-trained U15 French soccer players with respect to youth national team selections.

	U15 Regional team selection	U15 National team Pre-Selection	Matches with the U15 National team	Between-group difference
N	710	55	42	
age (y)	15.0 ± 0.3	15.0 ± 0.2	15.0 ± 0.3	Reg = Pre-Sel = Match
month of birth	4.6 ± 3.1	4.4 ± 2.8	4.8 ± 3.5	Reg = Pre-Sel = Match
APHV (y)	1.0 ± 0.6	1.1 ± 0.6	1.1 ± 0.5	Reg = Pre-Sel = Match
height (cm)	172.3 ± 6.4	172.7 ± 6.2	175.3 ± 5.3	Reg = Pre-Sel < Match
body mass (kg)	62.0 ± 7.0	63.9 ± 7.3	65.2 ± 6.8	Reg < Pre-Sel < Match
10 m (s)	1.81 ± 0.08	1.78 ± 0.06	1.76 ± 0.06	Reg < Pre-Sel < Match
10 m adjusted for height (s)	1.81 ± 0.11	1.79 ± 0.13	1.77 ± 0.12	Reg < Pre-Sel = Match
10 m adjusted for BM (s)	1.81 ± 0.11	1.79 ± 0.13	1.77 ± 0.12	Reg < Pre-Sel = Match
10 m (s/kg^{-k})	2.50 ± 0.11	2.47 ± 0.07	2.45 ± 0.12	Reg < Pre-Sel = Match
MSS (km/h)	29.75 ± 1.64	30.21 ± 2.05	30.67 ± 1.95	Reg < Pre-Sel < Match
MSS adjusted for height (km/h)	29.76 ± 1.60	30.20 ± 1.67	30.51 ± 1.68	Reg < Pre-Sel < Match
MSS adjusted for BM (km/h)	29.77 ± 1.60	30.10 ± 1.60	30.46 ± 1.61	Reg < Pre-Sel < Match
MSS ($km/h/kg^{-k}$)	14.74 ± 0.77	14.90 ± 0.96	15.06 ± 0.93	Reg < Pre-Sel < Match
$V_{Vam\text{-}Eval}$ (km/h)	16.7 ± 0.9	16.9 ± 0.8	17.1 ± 0.7	Reg < Pre-Sel < Match
$V_{Vam\text{-}Eval}$ adjusted for height (km/h)	16.7 ± 0.8	16.9 ± 0.9	17.1 ± 0.9	Reg < Pre-Sel < Match
$V_{Vam\text{-}Eval}$ adjusted for BM (km/h)	16.7 ± 0.8	16.9 ± 0.9	17.2 ± 0.9	Reg < Pre-Sel < Match
$V_{Vam\text{-}Eval}$ ($km/h/kg^{-k}$)	17.4 ± 1.0	17.7 ± 0.8	17.9 ± 0.8	Reg < Pre-Sel = Match

Values are mean ± SD for age, month of birth, age from/to peak height velocity (APHV), height, body mass (BM), 10-m sprint time (10 m), maximal sprinting speed (MSS) and peak incremental test running speed ($V_{Vam\text{-}Eval}$), with performance values adjusted for either individual height or body mass (BM) or not, or allometrically scaled based on BM, in players classified as best regional players (Reg), pre-selected in U15 National team (Pre-Sel) or participating in official international matches with the U15 National team (Match). Between-group differences are quantified based on a clear decision (i. e., at least possible difference) together with a standardized difference ≥ 0.2. The only difference with a moderate magnitude was observed for Match vs. Reg 10-m sprint time

Table 5 Physical characteristics and physical performance for highly-trained U15 Qatari soccer players with respect to youth national team selections.

	U15 Aspire	International matches with National team(s)	Standardized differences for International vs. Aspire players	Chances for smaller/similar/greater value for International vs. Aspire players	Qualitative outcome
n	41	23			
age (y)	15.0 ± 0.2	14.9 ± 0.3	−0.1 (−0.6; 0.3)	39/49/11	unclear
month of birth	5.5 ± 2.8	5.9 ± 3.5	−0.1 (−0.5; 0.4)	29/53/17	unclear
APHV (y)	0.5 ± 0.7	0.8 ± 0.6	+0.4 (−0.1; 0.9)	1/21/78	international likely more mature
height (cm)	164.6 ± 6.9	167.6 ± 6.4	+0.44 (0.01; 0.86)	1/17/82	international likely taller
body mass (kg)	51.7 ± 7.9	54.0 ± 7.3	+0.31 (−0.12; 0.73)	2/31/67	international possibly heavier
10 m (s)	1.83 ± 0.08	1.78 ± 0.06	−0.65 (−1.06; −0.23)	96/4/0	international very likely faster
10 m adjusted for height (s)	1.82 ± 0.07	1.79 ± 0.06	−0.56 (−0.99; −0.12)	92/8/0	international very likely faster
10 m adjusted for BM (s)	1.82 ± 0.07	1.79 ± 0.06	−0.58 (−1.00; −0.15)	93/7/0	international very likely faster
10 m (s/kg^{-k})	2.99 ± 0.11	2.93 ± 0.09	−0.55 (−0.97; −0.12)	91/9/0	international very likely faster
MSS (km/h)	28.66 ± 1.56	29.45 ± 1.32	+0.54 (0.12; 0.96)	0/9/91	international likely faster
MSS adjusted for height (km/h)	28.79 ± 1.56	29.34 ± 1.32	+0.41 (−0.03; 0.85)	1/20/79	international likely faster
MSS adjusted for BM (km/h)	28.76 ± 1.23	29.34 ± 1.24	+0.46 (0.03; 0.90)	1/15/84	international likely faster
MSS ($km/h/kg^{-k}$)	13.21 ± 0.55	12.99 ± 0.57	+0.59 (0.17; 1.01)	0/6/94	international likely faster
$V_{Vam\text{-}Eval}$ (km/h)	16.3 ± 0.9	16.7 ± 0.9	+0.47 (0.00; 0.95)	1/16/83	international likely faster
$V_{Vam\text{-}Eval}$ adjusted for height (km/h)	16.3 ± 0.9	16.7 ± 0.9	+0.42 (−0.07; 0.91)	2/20/78	international likely faster
$V_{Vam\text{-}Eval}$ adjusted for BM (km/h)	16.3 ± 0.9	16.7 ± 0.9	+0.45 (−0.03; 0.94)	1/18/81	international likely faster
$V_{Vam\text{-}Eval}$ ($km/h/kg^{-k}$)	15.2 ± 0.8	15.6 ± 0.9	+0.43 (−0.04; 0.91)	1/19/79	International likely faster

Values are mean ± SD for age, month of birth, age from/to peak height velocity (APHV), height, body mass (BM), 10-m sprint time (10 m), maximal sprinting speed (MSS) and peak incremental test running speed ($V_{Vam\text{-}Eval}$), with performance values adjusted for either individual height or body mass (BM) or not, or allometrically scaled based on BM

French vs. Qatari players

Present results showed initially that French players were at least likely advanced in maturity, taller, heavier, faster and fitter than their Qatari counterparts (▸ **Table 1**). This is, to our knowledge, the first time that anthropometric and performance measures of French and Qatari young players have been compared. Despite the mixed ethnicity of French players, players in both groups had clearly different ancestries (e.g., White, Black and North African Arabs vs. Middle East Arabs), and were therefore representative of clearly different phenotypes. Our results confirmed previous observations with the general population, highlighting very large (d = 1.3) inter-ethnicity differences in body dimensions [48, 55], which may directly affect locomotor performance [19, 41]. However, when adjusted for either BM or height, Qatari players appeared possibly-to-very likely faster than French players; $V_{Vam\text{-}Eval}$ values remained lower for this latter group (▸ **Table 1**). These data suggest that the smaller body size of Qatari players is likely responsible for their slower sprinting performance. It should however be acknowledged that anthropometric measures were restricted to BM in the present study; data on body composition (e.g., lean BM and % body fat [40]) would provide more detailed interpretations of the present results. Percentage of body fat was nevertheless comparable for both groups, or even likely lower in Qatari players: values around ~12.5 and ~9.5% were previously reported in highly comparable French [11] and Qatari [40] players, respectively. Of note, BM as a whole measure still remains the more practical variable to collect and is therefore the variable that has the greater interest for practitioners. Finally, the negligible impact of body dimensions on $V_{Vam\text{-}Eval}$ compared with that on speed-related capacities (Table 1) is consistent with previous findings [19,41] and likely related to the fact that BM and associated muscle power factors are more determinant for speed-related measures than distance running performance [57]. Excessive body dimensions can even be detrimental for prolonged running performance [54,57]. To conclude, present results confirm that the beneficial effect of body size on speed-related locomotor performance can overpower differences in phenotypic traits and/or training background. Since faster players may receive more attention from coaches and are generally selected in better teams [21–23,25], our results highlight the importance of controlling for potential differences in body size when evaluating speed-related measures in different player populations. This may help to reduce the exclusion of the youngest and slowest players, whose physical potential might only be revealed after puberty [37].

Allometric models and relationship between variables

While adjusting locomotor performances for body mass is of little interest with respect to actual on-field performance during games (coaches likely simply want the faster athletes regardless of body size), failure to consider the positive effect of increased body dimensions on maximal sprinting and aerobic speeds could rule out late-maturing high potential players [37]. One of the most promising methods to do so is allometric scaling [32] (Table 2). There are however some important points that need to be considered for accurate interpretation of the present results. Factors such as age, sex, body composition, level of physical activity, and skill can confound the relationship between human movement abilities and body size [32]. We nevertheless believe that the potential influence of these factors was minimal in the present study, since the players tested were representative of a very homogeneous group in term of training background and body composition (i.e., low percentage of body fat). Within-country analyses showed in both populations that BM tended to have the greatest impact on locomotor performance when compared to height, chronological age or APHV, especially for speed-related measures (Table 2). This might be explained by the fact that BM is a more functional body dimension than height (i.e., via muscle mass and associated force production capacity during the ground contact phase) [57]. The greater associations between body mass and MSS (exponents of 0.17–0.20, Table 2) compared with those for body mass vs. MAS (exponents of −0.01–0.02) are consistent with the idea that during weight-bearing activities such as running, the beneficial effect of muscle mass on muscle force production capacity that may help to reach a faster MSS or MAS has to be balanced with the need to carry body weight. For sprinting performance, within homogeneous group of athletes, body mass is generally beneficial [57]. However, when considering players differing in body shapes, locomotor abilities (e.g., coordination, running technique), and/or training background, the relationship between muscle cross-sectional area and muscle strength might be dissociated [28]. The relationship between aerobic-related performance and BM is more equivocal. While BM was shown not to affect performance during short events such as 800 and 1500-m runs [31], it was consistently shown to be detrimental to prolonged running performance (e.g., 5 km to marathon [54,57]). In fact, there may exist a body size optima for any type of running event which maximizes the ratio between mass-specific aerobic power and the musculoskeletal structure required to race at the required running speed during the event [57]. The influence of body dimensions on aerobic performance in young football players is therefore also likely to be test specific [19,41]. In the present study, BM had no clear link with MAS (Table 2, exponent −0.01–0.02), while it had a small and positive effect on this variable in a previous study (exponent: 0.22 [41]). The greater effect of body dimensions in this latter study [41] might be related to the larger range of player age (12–18 years old, and hence, MAS and body dimensions), which might have increased the magnitude of the association between performance and body size. In contrast, BM was shown to be detrimental for Yo-Yo test performance in a group of 13–14-year-old players [19]. These results were actually expected, since the Yo-Yo test tends to last longer than the incremental test used to assess MAS, and more importantly, it includes changes of direction. Large body dimensions have been shown to impair the energetic cost of running during changes of direction runs in adults [4].

The relatively smaller effect of chronological age on locomotor performances compared with the literature [19] is likely related to the limited range of age/pubertal variations in the present groups, since all players were born within the same calendar year. In contrasts, in Figueiredo's study [19], experimental groups included players born over 2 calendar years. It is also worth noting that the relationship between locomotor performance and APHV was much larger for Qatari vs. French players ($r=0.47$–0.55 vs. -0.14–0.24), which could be related to the mixed ethnicity origins of the French group. Indeed, the mixed origins of the French players could have induced variations in the accuracy of PHV timing estimation [34], which further dissociated the relationship between maturity and locomotor performances. Interestingly also, the exponents were population-dependent, irrespective of the locomotor performance (Table 2). These exponents (Table 2) were also clearly different from those previously reported in a similar Qatari population of young soccer players (but including a wider range of player ages; 0.33 and 0.22 for MSS and $V_{Vam\text{-}Eval}$, respectively [41]). Taken together, these results confirm the need to generate population-specific exponents for appropriate adjustments [32]. Further studies comparing maturity timing between different populations would help understand better the present results [34].

Relative age effect

In both populations, a relative age effect was observed, with more players born in the early months of the year (Table 3). This uneven birth month distribution is not a new finding in young soccer players [12,22,38], and has been reported in many, if not all, sports [46]. In a recent study on ice hockey players, it was clearly shown that the selections biases related to maturity/body dimensions and physical performance are actually causal mechanisms for this relative age effect [14]. The fact that players born in the first quarter of the year were also taller and heavier that those born during the 2 last quarters (Table 3, Fig. 2) is also in agreement with previous results in young soccer players [12,22,38]. One interesting finding of the present study is however that the older (and bigger) players had also slightly but substantially faster locomotor performances than their younger counterparts (◉ **Fig. 2**). In previous studies [12,38], such differences in physical capacities were also apparent (e.g., d = 0.5 for 40-m sprint time [12]), but were partly ignored because the differences did not reach statistical significance. The differences observed both in the present and previous studies are in fact substantial and can potentially impact on field physical performance [7,42]. Additionally, when adjusted for body size (both with group-means comparisons or when using allometric scaling), the majority of the differences in locomotor performance remained and the magnitude of the between-group differences was almost unaffected (◉ **Fig. 2**). This confirms that the physical advantages of the older players might not be (only) mediated by their greater body dimensions [16,40]. For example, neural activation, which can affect muscle strength independently of muscle cross-sectional area [30], could explain the greater scaled performance of the older players. Maturation-related differences in neuromuscular function and/or metabolism [1], as well as enhanced training and coaching opportunities [38] could possibly explain these findings. Practically, present results lend support to previous recommendations [38], i.e., the need to provide greater opportunities to smaller/later maturing talented boys to avoid exaggerated rate of drop out. Finally, present results suggest that in homogeneous groups of highly-trained young players, the influence of body dimensions on locomotor performances are, although substantial, likely overpowered by other components (e.g., training opportunities/history mediated by differences in age).

Playing standard

In the present study, both French and Qatari players selected in National teams were taller, heavier, faster and fitter than their non-selected counterparts (◉ **Table 4, 5**). While these data compare well to the usual differences observed between selected and non-selected players with respect to youth teams selection [22,25] or soccer academies entries [11], data on young international players is limited [23]. More specifically, the physical differences between players pre-selected in National teams, and those who actually played during international games (◉ **Table 4**), have never been investigated. Interestingly, despite the lack of difference in either age or maturity status, the international players competing for France were shown to be taller, heavier, faster and fitter than the 2 other groups. It is difficult to decipher whether the greater locomotor performance of the international players is the cause or the consequence of their higher playing standard. Both the similar maturity status and the likely identical training schedules (except time spent with the National teams) between the different player groups could suggest that the superior performance of international players is more related to individual physical predispositions (e.g., genetic factors explaining both greater body dimensions and physical performances). However, a greater training 'quality' during training sessions in the more skilled players, and hence, a better motivation and training stimuli for improvement cannot be ruled out. In fact, a greater progression in physical capacities has been observed within a year in first compared with reserve teams (e.g., d = −1.2 vs. −0.1 for 30-m sprint time in first and reserve team, respectively) [25]. Importantly, the superior locomotor performances of the best players remained substantial after adjustments for body size (no change in the magnitude of the between-group differences, irrespective of the method considered), suggesting, as discussed above, that the impact of body dimensions on physical performance can be overpowered by other factors such as genetic make up and training [30]. Taken together, these findings also highlight the importance of examining training history/opportunities when assessing a young soccer player's physical potential [24].

Adjustment methods

Finally, the fact that both body size adjustment methods lead to similar conclusions (◉ **Table 4, 5**) shows that either method could be used successfully, with the final decision left to the practitioners. This is, to our knowledge, the first time that such a comparison has been examined. The calculation behind these 2 adjustment methods differs partially, but they are both based on the direct relationship (linear in the present case) between the dependent (locomotor performance) and independent (body dimensions) variables. The mean body size-adjusted locomotor performance corresponds to the locomotor performance value that is predicted for the average body size of the population, using the linear regression equation derived from the relationship between the 2 variables. When using allometric scaling, the dependent variable is adjusted for each player individually (with the slope of the relationship between the 2 variables used as the scaling exponent, see Methods section for more details). Practically, the first advantage of allometric scaling is that with this method, players can be ranked individually and compared independently of their body dimensions (i.e., normalized individual performance [32]). This has likely direct implications from a selection/identification perspective, to avoid exclusion of the less mature/shorter and smaller players. While case study examples have limitations, the comparison between 2 French players of similar chronological age serves to illustrate the interest of allometric scaling. While player A (182 cm, 74.8 kg, +1.7 years from PHV, MSS = 30.1 km/h) is substantially faster than player B (168 cm, 50.4 kg, −0.2 years to PHV, MSS = 28.9 km/h) with respect to their actual performance on the field, player B might be seen as possibly slightly faster when looking at their normalized performances (14.4 vs. 14.8 $km/k/kg^{0.32}$ for player A and B, respectively). Importantly also, player B might have 'more room' for body size changes and concurrent performance improvements than player A, which is probably even more important than their actual normalized performances. Predicting future locomotor performance in young soccer players is challenging [5], and the consideration of several factors may be needed for an appropriate assessment of a player's 'true' potential: the player's relative age and maturation status at the time of testing, the percentage of predicted adult height already reached, the baseline level and trainability of the quality of interest, and the training program that can be practically implemented. In practice, to facilitate the scaling of locomotor performance for practitioners, the use of specifically designed spreadsheets is recommended. The disadvantages of allometric scaling are, however, that it cannot be used to compare different populations (since the exponent to control for body size is likely population- and sample size dependent [32]), and it also changes the units of measure (e.g., s to $s.kg^{-exp}$).

To conclude, the present results confirm that body size explains a large fraction of the variation in locomotor performances in players with different phenotypes and training volume, with body size having a much larger impact on speed-related capacities than on peak incremental test speed. However, when considering more homogeneous player groups, body dimensions were unlikely to substantially explain the superior locomotor performances of older and/or international players. Results also show that BM remains the more powerful and practical measure to control for body size differences in young soccer players. Taken together, present findings confirm the importance of taking body dimensions into account when assessing the locomotor profile of young players (and more especially, speed-related capacities), as large variation in maturation status are often observed during puberty. Present findings showed also that both adjustment methods (i.e., group-mean adjustments and allometric scaling) lead to similar conclusions. From a selection/identification perspective within a homogeneous player group, we therefore recommend the use of the allometric method since it allows adjustments at the individual level, which is crucial when interpreting a young player's physical test results. Group-mean adjustments remain however the only available option when comparing different populations. Further research is required to improve our understanding of the effect of ethnicity on the relationship between age, maturation, body size, and locomotor performance.

Acknowledgements
▼
The authors thank the technical staff of the French Football Federation, as well as Ben Simpson from Aspire Academy for their precious help in data collection.

Disclosures: Nothing to disclose.

Affiliations
[1] Physiology Unit, Football Performance and Science Department, ASPIRE Academy for Sports Excellence, Doha, Qatar
[2] Research Unit, French Football Federation, Clairefontaine, France
[3] Laboratory MOVE (EA6314), Faculty of Sport Sciences, University of Poitiers, Poitiers, France
[4] Laboratory of Exercise Physiology (EA4338) and Rehabilitation (EA3300), Faculty of Sport Sciences, University of Picardie, Amiens, France
[5] Laboratory of Exercise Physiology, University of Lyon, Saint-Etienne, France

References

1 *Armstrong N, Welsman JR, Chia MY.* Short term power output in relation to growth and maturation. Br J Sports Med 2001; 35: 118–124
2 *Astrand PO, Rodhal K.* Textbook of work physiology: physiological bases of exercise. Human Kinetics, MacGraw-Hill Series in Health Education, Physical Education, and Recreation, 649, 2003
3 *Buchheit M.* Repeated-sprint performance in team sport players: associations with measures of aerobic fitness, metabolic control and locomotor function. Int J Sports Med 2012; 33: 230–239
4 *Buchheit M, Haydar B, Hader K, Ufland P, Ahmaidi S.* Assessing running economy during field running with changes of direction: application to 20-m shuttle-runs. Int J Sports Physiol Perform 2011; 6: 380–395
5 *Buchheit M, Mendez-Villanueva A.* Reliability and stability of anthropometric and performance measures in highly-trained young soccer players: effect of age and maturation. J Sports Sci 2013 In press
6 *Buchheit M, Mendez-Villanueva A.* Supramaximal intermittent running performance in relation to age and locomotor profile in highly-trained young soccer players. J Sports Sci 2013 In press
7 *Buchheit M, Mendez-Villanueva A, Simpson BM, Bourdon PC.* Match running performance and fitness in youth soccer. Int J Sports Med 2010; 31: 818–825
8 *Buchheit M, Simpson BM, Mendez-Villaneuva A.* Repeated high-speed activities during youth soccer games in relation to changes in maximal sprinting and aerobic speeds. Int J Sports Med 2012; 34: 40–48
9 *Buchheit M, Simpson BM, Peltola E, Mendez-Villanueva A.* Assessing Maximal Sprinting Speed in Highly Trained Young Soccer Players. Int J Sports Physiol Perform 2012; 7: 76–78
10 *Bundle MW, Hoyt RW, Weyand PG.* High-speed running performance: a new approach to assessment and prediction. J Appl Physiol 2003; 95: 1955–1962
11 *Carling C, Le Gall F, Malina RM.* Body size, skeletal maturity, and functional characteristics of elite academy soccer players on entry between 1992 and 2003. J Sports Sci 2012; 30: 1683–1693
12 *Carling C, le Gall F, Reilly T, Williams AM.* Do anthropometric and fitness characteristics vary according to birth date distribution in elite youth academy soccer players? Scand J Med Sci Sports 2009; 19: 3–9
13 *Carvalho HM, Coelho-e-Silva MJ, Goncalves CE, Philippaerts RM, Castagna C, Malina RM.* Age-related variation of anaerobic power after controlling for size and maturation in adolescent basketball players. Ann Hum Biol 2011; 38: 721–727
14 *Deaner RO, Lowen A, Cobley S.* Born at the wrong time: selection bias in the NHL draft. PLoS One 2013; 8: e57753
15 *Di Salvo V, Pigozzi F, Gonzalez-Haro C, Laughlin MS, De Witt JK.* Match performance comparison in top English soccer leagues. Int J Sports Med 2013; 34: 526–532
16 *Dore E, Diallo O, Franca NM, Bedu M, Van Praagh E.* Dimensional changes cannot account for all differences in short-term cycling power during growth. Int J Sports Med 2000; 21: 360–365
17 *Dupont G, Nedelec M, McCall A, McCormack D, Berthoin S, Wisloff U.* Effect of 2 soccer matches in a week on physical performance and injury rate. Am J Sports Med 2010; 38: 1752–1758
18 *Faude O, Koch T, Meyer T.* Straight sprinting is the most frequent action in goal situations in professional football. J Sports Sci 2012 In press
19 *Figueiredo AJ, Coelho e Silva MJ, Malina RM.* Predictors of functional capacity and skill in youth soccer players. Scand J Med Sci Sports 2011; 21: 446–454
20 *Figueiredo AJ, Coelho ESMJ, Cumming SP, Malina RM.* Size and maturity mismatch in youth soccer players 11- to 14-years-old. Pediatr Exerc Sci 2010; 22: 596–612
21 *Figueiredo AJ, Goncalves CE, Coelho ESMJ, Malina RM.* Characteristics of youth soccer players who drop out, persist or move up. J Sports Sci 2009; 27: 883–891
22 *Gil S, Ruiz F, Irazusta A, Gil J, Irazusta J.* Selection of young soccer players in terms of anthropometric and physiological factors. J Sports Med Phys Fitness 2007; 47: 25–32
23 *Gissis I, Papadopoulos C, Kalapotharakos VI, Sotiropoulos A, Komsis G, Manolopoulos E.* Strength and speed characteristics of elite, subelite, and recreational young soccer players. Res Sports Med 2006; 14: 205–214
24 *Goncalves CE, Rama LM, Figueiredo AB.* Talent identification and specialization in sport: an overview of some unanswered questions. Int J Sports Physiol Perform 2012; 7: 390–393
25 *Gravina L, Gil SM, Ruiz F, Zubero J, Gil J, Irazusta J.* Anthropometric and physiological differences between first team and reserve soccer players aged 10–14 years at the beginning and end of the season. J Strength Cond Res 2008; 22: 1308–1314
26 *Harriss DJ, Atkinson G.* Update – Ethical standards in sport and exercise science research. Int J Sports Med 2011; 32: 819–821
27 *Hill AV.* The dimensions of animals and their muscular dynamics. Sci Prog 1950; 38: 209
28 *Hochachka PW, Darveau CA, Andrews RD, Suarez RK.* Allometric cascade: a model for resolving body mass effects on metabolism. Comp Biochem Physiol A Mol Integr Physiol 2003; 134: 675–691
29 *Hopkins WG, Marshall SW, Batterham AM, Hanin J.* Progressive statistics for studies in sports medicine and exercise science. Med Sci Sports Exerc 2009; 41: 3–13
30 *Hoshikawa Y, Iida T, Muramatsu M, Ii N, Nakajima Y, Chumank K, Kanehisa H.* Thigh muscularity and strength in teenage soccer players. Int J Sports Med 2013; 34: 415–423
31 *Ingham SA, Whyte GP, Pedlar C, Bailey DM, Dunman N, Nevill AM.* Determinants of 800-m and 1500-m running performance using allometric models. Med Sci Sports Exerc 2008; 40: 345–350
32 *Jaric S, Mirkov D, Markovic G.* Normalizing physical performance tests for body size: a proposal for standardization. J Strength Cond Res 2005; 19: 467–474
33 *Leger LA, Boucher R.* An indirect continuous running multistage field test: the Universite de Montreal track test. Can J Appl Sport Sci 1980; 5: 77–84
34 *Malina RM, Bouchard C, Bar-Or O.* Growth, maturation and physical activity. Second Edition ed. Champaing, IL: Human Kinetics, 2004
35 *Malina RM, Coelho ESMJ, Figueiredo AJ, Carling C, Beunen GP.* Interrelationships among invasive and non-invasive indicators of biological maturation in adolescent male soccer players. J Sports Sci 2012; 30: 1705–1717

36 *Malina RM*, *Cumming SP*, *Kontos AP*, *Eisenmann JC*, *Ribeiro B*, *Aroso J*. Maturity-associated variation in sport-specific skills of youth soccer players aged 13–15 years. J Sports Sci 2005; 23: 515–522
37 *Malina RM*, *Pena Reyes ME*, *Eisenmann JC*, *Horta L*, *Rodrigues J*, *Miller R*. Height, mass and skeletal maturity of elite Portuguese soccer players aged 11–16 years. J Sports Sci 2000; 18: 685–693
38 *Malina RM*, *Ribeiro B*, *Aroso J*, *Cumming SP*. Characteristics of youth soccer players aged 13–15 years classified by skill level. Br J Sports Med 2007; 41: 290–295 discussion 295
39 *Mendez-Villanueva A*, *Buchheit M*. Physical capacity-match physical performance relationships in soccer: simply, more complex. Eur J Appl Physiol 2011; 111: 2387–2389
40 *Mendez-Villanueva A*, *Buchheit M*, *Kuitunen S*, *Douglas A*, *Peltola E*, *Bourdon P*. Age-related differences in acceleration, maximum running speed, and repeated-sprint performance in young soccer players. J Sports Sci 2011; 29: 477–484
41 *Mendez-Villanueva A*, *Buchheit M*, *Kuitunen S*, *Poon TK*, *Simpson B*, *Peltola E*. Is the relationship between sprinting and maximal aerobic speeds in young soccer players affected by maturation? Ped Exerc Sci 2010; 4: 497–510
42 *Mendez-Villanueva A*, *Buchheit M*, *Simpson B*, *Peltola E*, *Bourdon P*. Does on-field sprinting performance in young soccer players depend on how fast they can run or how fast they do run? J Strength Cond Res 2011; 25: 2634–2638
43 *Mendez-Villanueva A*, *Buchheit M*, *Simpson BM*, *Bourdon PC*. Match play intensity distribution in youth soccer. Int J Sports Med 2013; 34: 101–110
44 *Mendez-Villanueva A*, *Hamer P*, *Bishop D*. Fatigue in repeated-sprint exercise is related to muscle power factors and reduced neuromuscular activity. Eur J Appl Physiol 2008; 103: 411–419
45 *Mirwald RL*, *Baxter-Jones AD*, *Bailey DA*, *Beunen GP*. An assessment of maturity from anthropometric measurements. Med Sci Sports Exerc 2002; 34: 689–694
46 *Musch J*, *Grondin S*. Unequal competition as an impediment to personal development: a review of the relative age effect in sport. Dev Rev 2001; 21: 147–167
47 *Nedeljkovic A*, *Mirkov DM*, *Bozic P*, *Jaric S*. Tests of muscle power output: the role of body size. Int J Sports Med 2009; 30: 100–106
48 *Nelson DA*, *Barondess DA*. Whole body bone, fat and lean mass in children: comparison of three ethnic groups. Am J Phys Anthropol 1997; 103: 157–162
49 *Nevill AM*, *Holder RL*. Scaling, normalizing, and per ratio standards: an allometric modeling approach. J Appl Physiol 1995; 79: 1027–1031
50 *Perez-Gomez J*, *Rodriguez GV*, *Ara I*, *Olmedillas H*, *Chavarren J*, *Gonzalez-Henriquez JJ*, *Dorado C*, *Calbet JA*. Role of muscle mass on sprint performance: gender differences? Eur J Appl Physiol 2008; 102: 685–694
51 *Rampinini E*, *Bishop D*, *Marcora SM*, *Ferrari Bravo D*, *Sassi R*, *Impellizzeri FM*. Validity of simple field tests as indicators of match-related physical performance in top-level professional soccer players. Int J Sports Med 2007; 28: 228–235
52 *Reilly T*, *Bangsbo J*, *Franks A*. Anthropometric and physiological predispositions for elite soccer. J Sports Sci 2000; 18: 669–683
53 *Vaeyens R*, *Malina RM*, *Janssens M*, *Van Renterghem B*, *Bourgois J*, *Vrijens J*, *Philippaerts RM*. A multidisciplinary selection model for youth soccer: the Ghent Youth Soccer Project. Br J Sports Med 2006; 40: 928–934 discussion 934
54 *Vanderburgh PM*. Occupational relevance and body mass bias in military physical fitness tests. Med Sci Sports Exerc 2008; 40: 1538–1545
55 *Wagner DR*, *Heyward VH*. Measures of body composition in blacks and whites: a comparative review. Am J Clin Nutr 2000; 71: 1392–1402
56 *Weyand PG*, *Bundle MW*. Energetics of high-speed running: integrating classical theory and contemporary observations. Am J Physiol 2005; 288: R956–R965
57 *Weyand PG*, *Davis JA*. Running performance has a structural basis. Exp Biol 2005; 208: 2625–2631
58 *Winter EM*, *Maughan RJ*. Requirements for ethics approvals. J Sports Sci 2009; 27: 985
59 *Zoeller RF*, *Ryan ED*, *Gordish-Dressman H*, *Price TB*, *Seip RL*, *Angelopoulos TJ*, *Moyna NM*, *Gordon PM*, *Thompson PD*, *Hoffman EP*. Allometric scaling of biceps strength before and after resistance training in men. Med Sci Sports Exerc 2007; 39: 1013–1019