

Change of direction speed in youth male soccer players: The predictive value of anthropometrics and biological maturity

Running title: Allometric model and change of direction speed.

Abstract

This study aimed to develop the optimal allometric body size/ shape and biological maturity model that predicted the change of direction (CoD) mean speed performance in youth male soccer players. One-hundred-fifteen youth soccer players (age: 12.4 ± 1.3 years) participated in this study. The 505 test was used to assess CoD mean speed performance ($\text{m}\cdot\text{s}^{-1}$). Anthropometric measurements comprised body-height (cm), sitting-height (cm), body-mass (kg), fat-mass (kg), lower-limb-length (cm), thigh-length (cm), leg-length (cm), foot-length (cm), thigh-girth (cm), and calf-girth (cm). The maturity status of participants was determined based on the maturity offset (MO) method. To identify size/shape, and maturity characteristics associated with CoD speed performance, we computed a multiplicative allometric log-linear regression model, which was refined using backward elimination. The multiplicative allometric model exploring the association between 505 CoD mean speed performance and the different anthropometric characteristics in youth soccer players estimated that fat-mass ($p < 0.001$), sitting-height ($p = 0.02$), and MO ($p = 0.004$) are the key predictors. More specifically, youths who are more mature and have a lower fat mass and a short sitting height, are likely to achieve a better CoD mean speed performance. These findings highlight the relevance of considering anthropometric and maturity characteristics in youth male soccer players to support talent identification.

Key Words: Youth athletes, team sports, physical fitness, somatic characteristics, maturity level

INTRODUCTION

Physical fitness tests (i.e., change of direction [CoD]) are typically used to either identify the level of physical fitness of an athlete compared with his teammates and/or normative values or as a tool to set new training goals (17, 19). A key and known consideration when trying to understand the development of physical fitness (i.e., CoD) in youth is growth and maturation. Timing and tempo of growth and maturation are characterized by large inter-individual variation and so is physical and athletic development (19). This is because chronological age and biological maturity seldomly progress at the same rate (19).

Change of direction (CoD) speed is a key physical fitness component in team sports such as soccer, handball, and basketball, amongst others (3,4,9). In soccer, CoD speed performance is associated with success in high-performance scenarios (31) with analyses of matches showing that fast movements occur frequently (every 2–3 s) and repeatedly ($> 1000/\text{game}$) (31) throughout the play. Additionally, many studies conducted in youth (20,29) reported that CoD speed discriminates elite from sub-elite soccer players and could thus be considered a practically relevant parameter for talent identification and selection (13).

The relationship between human physical characteristics and sports performance has been a source of unceasing interest among scientists (8, 9, 16). Notably, the association between anthropometric characteristics and sports performance constitutes a worthwhile marker for talent identification to engage children in a long-term athlete development process. A recent review by Morais et al (16) suggested that anthropometric characteristics are among the critical factors used as a precursor for early recognition of talented athletes.

Generally, individual differences in physical fitness are affected by genetic factors (18, 19, 22). More specifically, it is well established that anthropometric characteristics such as body length (e.g., body height, limb length) are more genetically determined (level of inheritance of 70%) compared with physical fitness attributes (12,28). Therefore, anthropometric characteristics should be considered important for the early recognition/detection of talented athletes (16). Earlier studies demonstrated that differences in general anthropometric characteristics (e.g., body-mass, whole body-height, body-fat) may confound measures of physical fitness (e.g., muscle strength, muscle power, cardiorespiratory endurance, CoD speed) in team (e.g., soccer, handball) and individual (e.g., swimming) sports alike (6,17,24). For instance, Negra et al. (17) reported large-to-very large associations between the Illinois CoD speed test, and body-mass, height, and leg-length ($r = -0.58, -0.75, \text{ and } -0.75$, respectively) in youth male soccer players

aged 12 years. Likewise, Chaouachi et al. (8) found that increased fat-mass is associated with decreased CoD speed performance (i.e., 180° CoD test) in elite male soccer players aged 19 years.

In addition, other studies pointed to the importance of considering more detailed anthropometric characteristics (e.g., limb segment length, segment girth) to better predict athletic performance in trained populations in comparison with more general characteristics (e.g., whole-body height) (5,18,22). For instance, Sammoud et al. (24), highlighted the importance of assessing detailed anthropometric characteristics in young front-crawl swimmers for talent identification. The same authors indicated that length ratio (i.e., height/leg length), foot length and ankle girth, biacromial breadth, and the percentage of body fat were associated with 100-m front-crawl mean swimming speed performance. To the best of the authors' knowledge, no previous studies have taken into account the association between detailed anthropometric, and maturity characteristics (e.g., foot length, calf girth, thigh girth/length) and CoD speed performance in youth male soccer players.

As stated in previous studies (18, 24), the ratio of limb segment lengths better predicts athletic performance in both athletic and sedentary populations compared with whole limb lengths, e.g. BMI or the Reciprocal Ponderal Index. These same studies have also noted that the ratio of two limb segment lengths will of course provide a dimensionless ratio. The allometric modelling is currently considered an appropriate analytical procedure to explore the association between anthropometric characteristics and measures of athletic performance given its sound theoretical basis as well as its biologically driven and versatile statistical underpinning (18,22,23). Specifically, the allometric approach provides a dimensionless expression of data in the form of ratios (e.g., crural index, upper-arm-to-lower-arm ratio, and reciprocal ponderal index [stature-to-body-mass 0.333 ratio]). Furthermore, its modeling techniques address the effects of age on growth and biological maturation in motor performance interpretation. However, to the best of the authors' knowledge, no studies have examined the association between anthropometric characteristics and CoD speed performance in youth male soccer players using the allometric approach.

Based on the considerations described above, there is still a need to carry out further research about the impact of anthropometric and maturity characteristics on CoD speed performance in youth male soccer players. We believe that our allometric modelling approach used to identify the key anthropometric dimensions and their ratios in youth male soccer players is a novel

contribution to the literature, especially for talent identification. Therefore, the aim of this study was to adopt allometric models to explore and assess/estimate the optimal body size/ shape, associated with CoD mean speed performance in youth male soccer players. Additionally, biological maturity was considered in the model to assess its impact on CoD mean speed performance. Based on previous findings (18,19), we hypothesized that CoD mean speed performance is more dependent on limb segment length rather than the whole body size in youth male soccer players. We additionally hypothesized that the level of maturity status is associated with CoD mean speed performance.

METHODS

Participants

In total, 115 elite youth male soccer players from three clubs (age: 12.40 ± 1.31 years) participated in the study. All participants were regularly involved in four-to-five training sessions per week (7 ± 1 hour per week) over the past 4 years. Written informed parental consent and participant assent were obtained before the start of the study. All youth athletes and their parents / legal representatives were informed about the experimental protocol and its potential risks and benefits before the start of the research project. The study was conducted in accordance with the latest Declaration of Helsinki, and the protocol was approved by the Ethics Committee of the *****blind to review (*****).

Experimental approach to the problem

To estimate the optimal body size/ shape, biological maturity associated with CoD mean speed performance in youth male soccer players several body measurements were taken including body-mass, height, sitting-height, skinfold thicknesses, limb lengths, and girths. (25).

Performance time and average change of direction speed ($m \cdot s^{-1}$)

The 505 CoD times and/or speeds (speed based on the race time) expressed in seconds and meters per second ($m \cdot s^{-1}$), respectively, were adopted as our measures of change of direction ability according to the established methods by Draper and Lancaster (9). Performance was recorded during the first half of the competitive season in an artificial turf pitch. After a warm-up, each participant performed three trials with a 3-min rest between each before proceeding with the rest of the training session. The best trial was used for further analysis. The ICC for test-retest trials was 0.93. The 505 CoD average speed was calculated as the ratio between the total distance (10-m) and the total time recorded in this distance ($m \cdot s^{-1}$). Performance (s) was measured with a high technology electronic timing (Microgate, Bolzano, Italy) during the first

phase of the season (October). All assessment sessions were scheduled at least 48 hours after the last training session or match.

Anthropometric characteristics

All anthropometric measures were conducted with reference to the standardized procedures of the international society for the advancement of kinanthropometry (ISAK) by reference to Stewart et al. (27) (Table 1). Testing was carried out in a standardized order after proper calibration of the measuring instruments. Each participant's height (cm) and body-mass (kg) were assessed to the nearest 0.1 cm and 0.1 kg, using a SECA stadiometer and a SECA weighing scale (SECA Instruments Ltd, Hamburg, Germany), respectively. Skinfolds measurements (in millimeters) were taken on the right-hand side of the body at two sites (the triceps and the subscapular) using Harpenden skinfold calipers (Harpenden Instruments, Cambridge, UK). Skinfold data, alongside the skinfold equation of Slaughter et al.(23), were used to estimate the body-fat mass (kg) and fat-free mass (kg). The following limb-lengths, and girths were assessed using a large sliding caliper and a non-stretchable tape measure via direct measures using landmarks techniques: lower-limb length (cm), thigh length (cm), leg length (cm), foot length (cm), thigh girth (cm), and calf girth (cm).

Lower limb length was determined by subtracting sitting height from standing height.

Thigh-length (cm) was determined as the distance between the marked trochanterion and tibiale lateral landmarks. Leg-length (cm) was measured as the distance from the height of the tibiale lateral to the top of the box (or the floor). Foot length (cm) was determined as the distance from the Akropodion (i.e., the tip of the longest toe which may be the first or second phalanx) to the Pternion (i.e., most posterior point on the calcaneus of the foot).

Thigh-girth (cm) measure was taken at the marked mid-trochanterion-tibiale-lateral site. Calf girth was defined as the maximum girth of the calf taken at the marked medial calf skinfold site. The Intraclass correlation coefficients (ICCs) for test-retest reliability for all anthropometric and skinfolds measures ranged from 0.97 to 0.99, and all typical errors of measurement were <5%.

The percentage of body fat (%BF) of children with triceps and subscapular skinfolds <35 mm was calculated as follow: Boys= $1.21 (\text{sum of 2 skinfolds}) - 0.008 (\text{sum of 2 skinfolds}^2) - 1.7$. The %BF for children with triceps and subscapular skinfolds >35 mm was calculated as follow: Boys= $0.783 (\text{sum of 2 skinfolds}) - 1.7 (23)$. Fat-mass was calculated as follow: fat-mass = (body mass * % BF)/100; fat-free mass (kg) = body mass - fat mass (25).

Biological maturity

The maturity status of participants was determined based on the offset method. Maturity offset was estimated using the predictive equation established by Mirwald et al. (15) as follows: in boys, maturity offset = $- 9.236 + 0.0002708 \cdot \text{leg length and sitting height interaction} - 0.001663 \cdot \text{age and leg length interaction} + 0.007216 \cdot \text{age and sitting height interaction} + 0.02292 \cdot \text{weight by height ratio} \cdot 100$.

****Table 1 near here****

Statistical analyses

Descriptive statistics were computed and expressed as means and standard deviations. To identify the most suitable anthropometric measurements [i.e., body-mass (M), height (H), percentage body fat (BF%), body-size lengths, and girths (BS)] that are associated with 505-CoD speed performance, we adopted the proportional multiplicative model with allometric body size components similar to that used to predict swimming speed (18).

$$505\text{-CoD speed} = (M)^{k_1} \cdot (H)^{k_2} \cdot (BF\%)^{k_3} \cdot \prod (BS_i)^{k_i} \cdot \exp(a + b \cdot MO) \cdot \varepsilon. \quad (1)$$

where 'a' is a constant allowed to vary for each age group and $\prod (BS_i)^{k_i}$ ($i=4, 5, \dots$) represents the product of body-size length and girth measurements raised to the power k_i ; with $i=4$ being the sitting height, 5 =thigh length, etc (see Table 1). This model has the advantages of having proportional body size components and the flexibility of a maturity offset (MO) term within an exponential function that will ensure that the 505-CoD speeds will always remain non-negative irrespective of the child or adolescent's maturity status. Note that the multiplicative error ratio 'ε' assumes the error will increase in proportion to the players' 505-CoD performance, see Figure 1A, and 1B

****Figure 1A near here****

****Figure 1B near here****

The model (Eq. 1) can be linearized with a log transformation. A linear regression on $\ln(505 \text{ CoD speed})$ (\ln =natural logarithms) can then be used to estimate the unknown parameters of the log-transformed model:

$$\ln(505 \text{ CoD speed}) = k_1 \cdot \ln(M) + k_2 \cdot \ln(H) + k_3 \cdot \ln(BF\%) + \sum k_i \cdot \ln(BS_i) + a + b \cdot MO + \ln(\varepsilon). \quad (2)$$

Having fitted the saturated model (all available body size variables), an appropriate 'parsimonious' model can be obtained using 'backward elimination' (18,22) in which at each

step the least important (non-significant) body-size variable is dropped from the current model. Note that MO and the log-transformed body-size variables are all entered as continuous covariates in the regression model. The significance level was set at $p < 0.05$.

RESULTS

Table 1 shows the anthropometric characteristics and CoD performance data of participants. Our data showed a large standard deviation of the body mass and height of our participants (i.e., body-mass = 42.5 ± 9.0 , and height = 154.52 ± 12.4). In addition, our descriptive statistics showed that our participants' MO ranged between -2.7 and -0.7 years (mean \pm SD = -1.8 ± 1.1 years).

Table 2 indicates the parsimonious solution to the backward elimination regression analysis of $\ln(505 \text{ CoD average speed } [m.s^{-1}])$.

****Table 2 near here****

The multiplicative allometric model exploring the association between 505 CoD mean speed performance ($m.s^{-1}$) and the different anthropometric characteristics estimated that fat-mass (as a whole body size dimension), sitting-height and the MO are the main significant predictors of log-transformed 505 CoD mean speed performance.

The adjusted coefficient of determination (R^2) was 58.7% with the log-transformed error ratio being 0.0519 or 5.3%, having taken antilogs.

The constant 'a' varied significantly by age group, see Figure 2.

****Figure 2 near here****

DISCUSSION

This study adopted allometric models to estimate the optimal body size/shape, limb segment length, and girth ratios associated with CoD mean speed performance and to examine the impact of biological maturity on the same performance in youth male soccer players. The main results of this study showed that the percentage of fat-mass (as a whole body size dimension), sitting-height, and the MO are the significant predictors of 505 CoD mean speed performance in youth male soccer players. In this sense, body height and mass did not significantly contribute to the model.

The negative impact of the percentage of fat-mass on CoD mean speed performance concurs with previous findings (7,8). Particularly, Chaouachi et al. (8) found that the percentage of fat-mass is negatively associated with 180° CoD test performance in elite male soccer players aged 19 years. In another study, a very large and positive association between CoD performance (s) (i.e., T-test) and the percentage of fat-mass ($r=0.80$) was reported in adolescent basketball male players aged 23 years (7). Peterson et al. (21) found that CoD performance relies on the greater acceleration of body mass and therefore a lower percentage of fat mass, along with great relative strength are desirable. The mechanical forces, expressed via Newton's laws of motion can explain this. Newton's first law of motion states that an object (athlete) remains at a constant velocity unless acted upon by a force. This means an athlete must apply force to the ground to shift in speed. The necessary force required for a CoD is dependent on the athlete's body mass, velocity when approaching the CoD step, and the angle of direction change (4).

Another key result from the allometric model displayed in Table 2 is the disadvantage of having a long sitting-height. This result suggests that low centre of mass (COM) may be an advantage when conducting CoD speed tasks in youth male soccer players. It would appear that players with lower COM could be conceivably able to apply horizontal forces more effectively than taller players, with a shorter time required to lower the centre of gravity to perform quick CoD speed tasks (4,8). Additionally, when changing momentum in a CoD task, the athlete is required to rapidly lower the COM for appropriate force production, which is an advantage for shorter athletes, since they commonly possess lower COM than taller athletes (4). Thereby, they outperform their taller counterparts with significantly less completion time in CoD tasks (11). To sum, a long sitting height appears to be disadvantageous for CoD mean speed performance in youth male soccer players.

Results from earlier studies indicated that CoD performance increases throughout childhood, and adolescence, albeit in a nonlinear fashion (16,18,19) with a peak rate of development occurring around PHV (30). Our findings indicated that MO made a positive contribution to the 505 CoD average speed performance suggesting that youth who are more mature have a better CoD mean speed performance. These results are in agreement with previous studies (2,19,22). For example, in their recent study, Nevill and co-workers, (19) identified how important MO is at predicting the boys' and girls' physical performance (i.e., Illinois change of direction speed test; handgrip strength test) tests during childhood and adolescence, having also controlled for differences body size, shape, sex, and chronological age. The same authors found that boys who

go through peak height velocity (PHV) at an earlier/younger age (with a more positive MO score) will perform better CoD speed performance than boys who go through peak height velocity at a later/older age (who have negative MO scores), assuming the same body size/shape and chronological age. The concept of bio-banding was introduced in recent years to account for inter-individual differences due to maturation (14). It consists of grouping players according to their maturity status but not chronological age (14). Of note, bio-banding seems to be an adequate approach to control for differences in CoD speed performance due to maturation level in youth. Based on this result, coaches and strength and conditioning trainers should consider the MO in addition to the chronological age as a key factor in determining CoD mean speed performance.

The current study presents some limitations that need to be acknowledged. First, our allometric model did not include variables related to functional fitness (e.g., muscular strength or flexibility). Second, biomechanical testing methods should be implemented in future studies to obtain in-depth knowledge regarding the allometric associations between biomechanical, shape, and CoD mean speed performance. Third, the 505 CoD speed test may not be representative of all CoD speed tests. Fourth, although more accessible and easier to conduct, non-invasive methods of maturity assessments have limitations when applied to young athletes and need to be considered with caution (7). More specifically, the predicted age at PHV is associated with an error of approximately ± 6 months in males and females alike (15). Additionally, the predicted age at PHV tends to overestimate early-maturing and underestimate late-maturing young (15). Finally, there is evidence that in the context of linear regression, at least two subjects per variable are required to guarantee a good statistical power (1), nevertheless, it would have been preferable conducting an a priori power analysis to provide a clear estimation of the required size of the sample. As such, future studies may have to consider replicating and comparing our approach by using other CoD speed tests.

Conclusions

The main findings of the present study indicated that the MO, sitting-height, and the percentage of body-fat could be used as predictors for 505 CoD mean speed performance in youth male soccer players. Therefore, these results highlight the importance of considering anthropometric characteristics alongside the maturity status of youth male soccer players for talent identification.

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Disclosure statement

No potential conflict of interest was reported by the authors.

Table 1: Descriptive statistics for participants' anthropometric characteristics and 505 change of direction performance. (Data are presented as mean ± SD)

| Variables | Players (n=115) |
|--|-----------------|
| Age (years) | 12.4 ± 1.3 |
| Maturity Offset (years) | -1.8 ± 1.1 |
| Body-Mass (kg) | 42.5 ± 9.0 |
| Height (cm) | 154.2 ± 12.4 |
| Sitting-Height (cm) | 76.1 ± 6.2 |
| Body-Fat % | 14.2 ± 4.3 |
| Fat-Mass (kg) | 6.1 ± 2.6 |
| Fat-Free-Mass (kg) | 36.4 ± 7.7 |
| Body-Mass Index (kg.m ⁻²) | 17.7 ± 2.4 |
| Thigh-Length (cm) | 41.5 ± 4.4 |
| Leg-Length (cm) | 39.0 ± 3.5 |
| Foot-Length (cm) | 24.0 ± 2.2 |
| Thigh-Girth (cm) | 42.7 ± 4.0 |
| Calf-Girth (cm) | 29.3 ± 3.5 |
| 505 CoD performance (s) | 2.6 ± 0.2 |
| 505 CoD average speed (m.s ⁻¹) | 3.9 ± 0.3 |

CoD: change of
standard deviation

direction; SD:

TABLE 2. Estimated body size and limb segment parameter (B) obtained from regression analysis predicting log-transformed 505 CoD average speed performance.

| Variables in the Model | B | Std. Error | p | 95% Confidence Interval for B |
|-------------------------------|----------|-------------------|----------|--------------------------------------|
| Constant | 5.192 | 1.492 | 0.001 | 2.2324 to 8.150 |
| lnFat | -0.078 | 0.019 | <0.001 | -0.116 to -0.040 |
| lnsittingheight | -0.794 | 0.339 | 0.02 | -1.466 to -0.123 |
| MO | 0.107 | 0.036 | 0.004 | 0.035 to 0.178 |

Ln: Natural Log; Std: Standard