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Validity and usefulness of the Line Drill test for adolescent basketball players: a Bayesian multilevel analysis

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ABSTRACT

The study examined the validity of the Line Drill test (LD) in male adolescent basketball players (10–15 years). Sensitiveness of the LD to changes in performance across a training and competition season (4 months) was also considered. Age, maturation, body size and LD were measured (n = 57). Sensitiveness of the LD was examined pre- and post-competitive season in a sub-sample (n = 44). The time at each of the four shuttle sprints of the LD (i.e. four stages) was modelled with Bayesian multilevel models. We observed very large correlation of performance at stage 4 (full LD protocol) with stage 3, but lower correlations with the early LD stages. Players' performance by somatic maturity differed substantially only when considering full LD protocol performance. Substantial improvements in all stages of the protocol were observed across the 4-month competitive season. The LD protocol should be shortened by the last full court shuttle sprint, remaining sensitive to training exposure, and independent of maturity status and body size.

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Youth; agility; athlete; maturation; allometric scaling

Introduction

Basketball is a multifaceted team sport with movement patterns that involve short, intense and repeated episodes of activity that require frequent rapid changes in direction (Ben Abdelkrim et al., 2010; Ben Abdelkrim, El Fazaa, & El Ati, 2007; McInnes, Carlson, Jones, & McKenna, 1995). Consequently, metabolic stress and muscle damage are substantial (Souglis, Bogdanis, Giannopoulou, Papadopoulos, & Apostolidis, 2015). High-intensity short-term activities (e.g. sprinting, jumping and cutting), mainly dependent on anaerobic metabolism (Ben Abdelkrim et al., 2007; Castagna et al., 2010) as well as agility (Chaouachi et al., 2009; Hoffman, Epstein, Einbinder, & Weinstein, 2000), are crucial for the success of the players in the game (Ben Abdelkrim et al., 2007).

The Line Drill test (LD) has been proposed as a viable and practical test of the maximal short-term performance of basketball players in field conditions (Semenick, 1990), potentially relevant also for agility assessment (Hoffman, Tenenbaum, Maresh, &

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Kraemer, 1996). The protocol requires progressive, high-intensity shuttle running in a regular basketball court, with typical duration between 28 and 40 s, including seven changes of direction after increasing sprint distances (5.8, 14.0, 22.2 and 28.0 m). The protocol is based on a drill commonly used by coaches in training contexts and has been noted as a reliable procedure to assess performance in adolescent players (Carvalho et al., 2011), as well as in applied research (Apostolidis, Nassis, Bolatoglou, & Geladas, 2004; Carvalho et al., 2011, 2011; Hoare, 2000; Hoffman et al., 2000, 1996; Montgomery, Pyne, Hopkins, & Minahan, 2008). Despite the practical interest in the LD and emerging evidence of its applicability to basketball-specific maximal short-term performance assessment (Carvalho et al., 2011; Castagna, Impellizzeri, Rampinini, D'Ottavio, & Manzi, 2008; Hoffman et al., 2000; Montgomery et al., 2008), little attention is given to its validity. In particular, the design of the protocol allows a reliable assessment (e.g. assessment of time to cover distance with photoelectric cells) of the performance at the starting point, and after each sprint and change of direction. Hence, determinants of changes of direction and sprinting efforts within the protocol may provide useful information to coaches and researchers. Probably more relevant is the possibility to retain sufficient information considering a shorter version of the protocol. The search for less stressful protocols, especially dealing with all-out efforts, and further analytical approaches to explore the available information, particularly when considering young athletes, should concern all interested in young athletes' performance.

The complexities of performance interpretation among young athletes often require accounting for variation from different sources and levels of observation (Carvalho et al., 2014; Drinkwater, Hopkins, McKenna, Hunt, & Pyne, 2005). The large variation between individuals in growth and complex environmental factors often misleads the accuracy and specificity of most traditional physiological tests used in talent identification in team sports (Abbott, Button, Pepping, & Collins, 2005; Pearson, Naughton, & Torode, 2006). Multilevel modelling provides a flexible approach able to consider variation at different levels, overcoming the assumptions of ordinary least squares-based estimations, such as analysis of variance (Goldstein, 2011). On the other hand, debate about small effects estimation and evaluation in sport and exercise emerged recently challenging the traditional method of making an inference based on a *p*-value derived from a hypothesis test (Batterham & Hopkins, 2006; Mengersen, Drovandi, Robert, Pyne, & Gore, 2016; Welsh & Knight, 2015). Bayesian approach treats parameters as random variables, combining both sample data and prior distribution information to estimate posterior information (McElreath, 2015). Particularly, Bayesian estimation can be undertaken for small-scale applied sport and exercise science studies, yielding comparable, but more directly interpretable and theoretically justified probabilistic outcomes (Mengersen et al., 2016).

In the present study, we hypothesized that the LD protocol can be shortened, maintaining the properties to assess basketball-specific maximal short-term performance, controlling for maturity-associated variation between adolescent players. We also hypothesized that the protocol is likely sensitive to detect changes related to basketball training exposure. Thus, in the present study we examined the construct validity of the LD in adolescent basketball players. Hence, interrelationships of age, biological maturation and body size with LD performance were examined. The study also examined the sensitiveness of the LD protocol to distinguish adolescent basketball players' changes in performance when exposed to a formal training and competition season (4 months).

Methods

Study design and participants

The study was based on a total sample of 57 male adolescent basketball players, 14 players from under-11, 24 players from the under-13 and 19 players from under-15 age categories. Players were initially tested assuming a cross-sectional design. The players were engaged in formal training and competition within a local club from the Campinas metropolitan region, Brazil, and competed in state level supervised by the *Federação Paulista* de *Basketball*. All players had at least a full season of formal training experience in basketball, and no player was suffering from injury at the time of testing or during 6 months before testing.

The measurements allowed examining the relationship of age, maturation and body size with LD performance. To examine the sensitiveness of the LD protocol to distinguish adolescent basketball players training responses, we considered a subsample (n = 44) of male adolescent players aged at baseline 13.50 ± 1.26 years. The subgroup of basketball players was evaluated in two occasions during a training and competition season: first, at the start of the season (pre-season) in August 2015; second, 4 months later in December 2015, the end period of the training and competition season (end season). The players were measured and tested within a 2-week period. On average, players participated in three to four training sessions per week (2-h duration on average per training session), totalling 57.0 (12.1) training sessions and 6243.9 (1575.4) minutes across the 4-month season. Also during the period of observation, players participated on average in 9.1 (2.8) games, playing 17.0 (7.4) minutes per game.

The study was approved by the *Research Ethics Committee of the University of Campinas* and was conducted in accordance with recognized ethical standards (Harriss & Atkinson, 2009). Participants were informed about the nature of the study, that participation was voluntary and that they could withdraw from the study at any time. Players and their parents or legal guardians provided informed written consent.

Procedures

Anthropometry

Stature and sitting height were measured with a portable stadiometer (Seca model 206, Hanover, MD, USA) to the nearest 0.1 cm. Leg (sub-ischial) length was estimated as stature minus sitting height. Body mass was measured with a calibrated portable balance (Seca model 770, Hanover, MD, USA) to the nearest 0.1 kg. Reliability estimates for the observer are published elsewhere (Carvalho et al., 2011, 2011).

Maturity status

Chronological age was calculated to the nearest 0.1 year by subtracting birth date from the date of testing. Age at peak height velocity (PHV) was estimated with the maturity offset protocol (Mirwald, Baxter-Jones, Bailey, & Beunen, 2002). The protocol predicts time before or after PHV based on chronological age, stature, body mass, sitting height and estimated leg length (stature minus sitting height). Based on maturity offset, the participants, ranging from −3.13 to +2.46 years from/to PHV, were grouped into three maturity status categories for analysis: pre-PHV (PHV <−1.00 year; n = 24), mid-PHV

(−1.00 ≤ PHV ≤ +1.00 year; n = 19) and post-PHV (PHV < +1.00; n = 13). The limitations of the method (Moore et al., 2015) were assumed in the present study, thus it should be noted that a player might have been assigned to the wrong maturity status category.

Line Drill test

In the LD protocol (Carvalho et al., 2011; Semenick, 1990), players ran 140 m as fast as possible in the form of four consecutive shuttle sprints of 5.8, 14.0, 22.2 and 28.0 m within a regulation basketball court. Players began the test 1 m behind the baseline of the basketball court, where a video recorder (recording rate of 120 fps) aligned with the baseline (Sony, Tokyo, Japan) was used as reference for the beginning and end of the test. Time was recorded by video analysis of players crossing the reference baseline with available video analysis software Kinovea – 0.8.15 (http://www.kinovea.org). Verbal encouragement for an all-out effort was given throughout the test. At each passing-by, the reference baseline time was recorded. Thus, we considered four stages within the protocol: stage 1, comprising a sprint from the reference baseline (starting point) to cross the nearest free-throw line (5.8 m) and return, thus with one change of direction and totalling a 11.6-m sprint; stage 2, comprising a sprint from the reference baseline to cross the mid-court line (14.0 m) and return added to stage 1, and totalling three changes of direction and 39.6-m sprint; stage 3, comprising a sprint from reference baseline to cross the opposite mid-court free-throw line (22.2 m) and return added to stage 2, and totalling five changes of direction and 84.0-m sprint; stage 4, completing the test, where players added to stage 3 a final sprint from the reference baseline to cross the opposite baseline and return (28.0 m) and return, and totalling seven changes of direction and 140-m sprint.

Reliability of video recording for time measurement was completed by comparison with photoelectric cells. Twenty-five time recordings at the reference baseline from a regular basketball court were made simultaneously, using a gate of photoelectric cells (Speed Test 6.0 Standard, Cefise, Nova Odessa – SP, Brazil) and a video recorder. Agreement between methods showed no systematic or proportional bias (calibration equation: $Y = 0.034 + 0.997 \cdot X$), with a technical error of measurement 0.12 s (95% confidence interval 0.10 – 0.17) and a perfect correlation between methods. Thus, video analysis for time recording in the LD was assumed to be reliable and accurate.

Statistical analysis

Descriptive statistics for chronological age, anthropometric dimensions, estimated age at PHV and LD performance at each stage were calculated. The first step of the analysis was to fit Bayesian multilevel models to describe variation between players on each stage of performance in the LD, considering the cross-sectional sample data. Also the analysis of random coefficients covariance matrix (correlation) was considered to interpret how well the rank order of the players in a stage of the LD was replicated in other stage of the test. Performance measured at each stage (level 1) was assumed nested within each player (level 2). Population-level coefficients describe the performance for the sample at each stage. Performance at each stage was allowed to vary randomly at level 2.

The second step of the analysis was to explore construct validity of the LD. We tested the influence of maturity status considering interaction terms of each stage with estimated maturity category (e.g. stage 1 × somatic maturity) to estimate posterior means and 95% credible intervals of performance for each stage of the LD by somatic category, allowing for performance to vary randomly at level 2 (group level) within each stage of the LD. Considering the age range within estimated somatic maturity category, we explored a second model including chronological age. To test the influence of body size on each stage of the LD, we explored initially simple allometric models to examine the relation between each size descriptor and stages of the LD. Thus, we modelled dependent and independent variables after performing logarithmic transformation on the variables. Proportional, multiplicative allometric modelling within a Bayesian multi-level framework was used to incorporate the influence of estimated maturity status and body size on stages of LD performance.

The sensitiveness of the LD to detect training effects as a consequence of exposure to a period training and competition stimulus (4-month season) was examined. We included time of measurement (dummy variable: beginning of the season = 0; end of the season = 1) considering both group (level 1) and population (level 2) level effects in the multilevel model describing variation between players on each stage of performance in the LD. Also, a cross-level interaction terms between time of measurement and stages of the LD were included in order to examine the response to training in each stage of the test. The magnitude of the standard deviation for individual responses and its uncertainty (95% credible intervals) at each stage of the LD was interpreted in relation to corresponding between-players standard deviation at the beginning of the season, i.e. baseline (Atkinson & Batterham, 2015).

Non-informative priors were considered (Gelman, 2004), to ensure that results reflect the knowledge available on the current data, as well as to allow model convergence. The Bayesian multilevel models were implemented using "brms" package (Burkner, in press) which call Stan (Stan Development Team, 2015), a probabilistic programming language for Bayesian inference, within R statistical language and environment (R Core Team, 2015).

Results

The descriptive statistics of adolescent basketball players for the total sample are summarized in Table 1.

Bayesian multilevel model describing variation between players on each stage of performance in the LD, based on the cross-sectional sample data, is summarized in Table 2 . Also, covariance matrix results presenting the rank order of players across the stages of sprints are shown in Table 1. Overall, the correlations ranged from 0.69 to 0.97. However, a trend of decrease in rank order of players' performance was apparent with the increase of test stages, based on stage 1 performance (stage 1 vs. stage 4 r = 0.69, 95% credible intervals 0.51–0.81). Thus, considering performance at the all stages of the

Table 1. Characteristics of the total sample of adolescent basketball players.

	Mean	Standard deviation	Range
Chronological age, years	12.99	1.53	10.28–15.51
Maturity offset, years	−0.50	1.58	−3.13 to 2.45
Predicted age at PHV, years	13.50	0.59	11.69–14.74
Stature, cm	167.3	14.3	138.9–205.0
Body mass, kg	60.0	16.8	32.4–94.7
Sitting height, cm	83.1	6.9	71.4–97.3

Table 2. Modelling of performance at each stage of performance in the Line Drill test (95% credible intervals).

	Population-level estimates, seconds		
Stage 1 (11.6 m, one change of direction)			4.10 (4.01–4.19)
Stage 2 (39.6 m, three changes of direction)			11.56 (11.37–11.78)
Stage 3 (84.0 m, five changes of direction)			22.06 (21.65–22.54)
Stage 4 (140 m, seven changes of direction)			35.03 (34.34–35.80)
	Group-level estimates, standard deviation		
Level 2			
Stage 1			0.37 (0.30–0.46)
Stage 2			0.89 (0.77–1.06)
Stage 3			1.71 (1.46–2.02)
Stage 4			2.86 (2.49–3.39)
Level 1			0.08 (0.04–0.12)
	Group-level covariance matrix, level 2 correlations		
	Stage 1	Stage 2	Stage 3
Stage 2	0.91 (0.84–0.97)		
Stage 3	0.82 (0.73–0.90)	0.97 (0.96–0.99)	
Stage 4	0.69 (0.51–0.81)	0.87 (0.77–0.91)	0.93 (0.89–0.96)

protocol may allow having further information about maximal short-term performance, particularly involving changes of direction. Based on the correlations between stages 2–4 performance, it appears that at most completing three stages of the protocol, i.e. less 58 m in the protocol distance and about 10–15 s of all-out effort, will suffice to have information about players performance in the LD. Considering the age range, we examined the influence of between players variation in chronological age in the initial model, but no substantial variation was found (data not shown).

Comparisons of performance within the stages of the LD by estimated somatic maturity category are shown in Table 3. The differences in performance between players grouped by somatic maturity were observed only at stage 4 of the LD, i.e. the total time of the test (95% credible intervals pre-PHV 35.23–37.23, mid-PHV 33.36–35.77, post-PHV 32.03–35.06). Considering the chronological age range within somatic maturity category, we explored independent effect of performance. Point estimates for body dimension exponents (95% credible intervals) from the separate allometric models at each stage of the LD are summarized in Table 3. The magnitude of point allometric exponents increased substantially with the duration of the LD for both size descriptors.

Table 3. Population-level effects based on Bayesian multilevel modelling at each stage of the Line Drill test, separately for body size and estimated maturity status, adopting allometric modelling to model body size.

	Stage 1 (11.6 m, one change of direction)	Stage 2 (39.6 m, three changes of direction)	Stage 3 (84.0 m, five changes of direction)	Stage 4 (140 m, seven changes of direction)
Posterior means (95% credible intervals)				
Pre-PHV	4.21 (4.06–4.35)	11.84 (11.51–12.16)	22.57 (21.94–23.24)	36.22 (35.23–37.23)
Mid-PHV	3.98 (3.83–4.15)	11.31 (10.92–11.72)	21.69 (20.97–22.41)	34.61 (33.36–35.77)
Post-PHV	4.05 (3.84–4.26)	11.40 (10.90–11.88)	21.65 (20.66–22.51)	33.61 (32.03–35.06)
Separate allometric models				
Stature	0.27 (0.27–0.28)	0.48 (0.47–0.48)	0.60 (0.60–0.61)	0.69 (0.69–0.70)
Body mass	0.34 (0.33–0.36)	0.60 (0.59–0.61)	0.76 (0.74–0.77)	0.87 (0.85–0.89)

The Bayesian multilevel modelling showed that the LD performance presented a likely substantial improvement in all stages of the protocol, suggesting a possible beneficial effect of basketball training and competition exposure to performance (Table 4). Considering between players baseline standard deviation, the corresponding magnitude of changes across the stages was 1.27 (95% credible interval 0.12–2.93) for stage 1, 0.65 (95% credible interval 0.24–1.18) for stage 2, 0.84 (95% credible interval 0.54–1.24) for stage 3 and 0.81 (95% credible interval 0.56–1.13). Accounting for variance of changes across the 4-month competitive season, the pattern of correlations remained consistent with cross-sectional data, but the correlations of stage 1 and 2 with stage 4 were substantial, indicating that these stages provide different information about performance. Likewise, correlation between stages 3 and 4 remained with a similar trend observed with the cross-sectional data implying that players' performance rank order was similar at the two stages, confirming that stage 4 may be redundant and removed from the protocol.

Discussion

The construct validity of the LD in adolescent basketball players was considered in the present study. Performance in the full protocol of the LD was associated with estimated maturity status, but the magnitude of associations was substantially lower, likely trivial at the early stage of the test. Also, the results showed that the LD protocol was sensible to distinguish adolescent basketball players' changes in performance when exposed to a formal training and competition season (4 months).

Allowing for variation in procedures, LD performance and variation between players considering the full protocol (140 m) in the present sample were comparable with previous data with adolescent basketball players (Apostolidis et al., 2004; Carvalho

Table 4. Modelling changes in performance at each stage of performance in the Line Drill test across a 4-month competitive period (95% credible intervals).

			Population-level estimates
Stage 1 performance at baseline, s			3.97 (3.75–4.19)
Stage 2 performance at baseline, s			11.23 (10.94–11.51)
Stage 3 performance at baseline, s			21.41 (20.99–21.83)
Stage 4 performance at baseline, s			33.87 (33.23–34.50)
Stage 1 rate of change after 4 months, s			−0.42 (−0.79 to − 0.05)
Stage 2 rate of change after 4 months, s			−0.52 (−0.78 to −0.24)
Stage 3 rate of change after 4 months, s			−1.28 (−1.55 to −1.00)
Stage 4 rate of change after 4 months, s			−1.84 (−2.11 to −1.56)
			Group-level, standard deviation
Level 2			
Stage 1			0.57 (0.43–0.75)
Stage 2			0.82 (0.65–1.02)
Stage 3			1.33 (1.08–1.64)
Stage 4			2.11 (1.71–2.61)
Rate of change after 4-months			1.04 (0.83–1.31)
Level 1			0.47 (0.43–0.52)
	Group-level covariance matrix, level 2 correlations		
	Stage 1	Stage 2	Stage 3
Stage 2	0.87 (0.71–0.96)		
Stage 3	0.67 (0.43–0.84)	0.92 (0.92–0.97)	
Stage 4	0.37 (0.07–0.62)	0.72 (0.54–0.86)	0.92 (0.86–0.96)

et al., 2011, 2011; Hoare, 2000; Montgomery et al., 2008). The LD protocol includes changes of direction after short sprints, with an important agility component, and appears to be sensitive to distinguish adolescent basketball players' performance (Carvalho et al., 2011). The results of the group-effects covariance matrix suggest different physiological determinants across the test (see Table 2). Data with adolescent basketball players showed a large association of the full protocol performance with performance in the 30-s Wingate Anaerobic test, suggesting that the duration proximity in protocols may measure in part the same anaerobic properties (Carvalho et al., 2011).

The group-effects covariance matrix results showed similar rank order between players on both stages 3 and 4 (r = 0.93, 95% credible interval 0.89–0.96), but rank order of stage 4 with stages 1 (r = 0.69, 95% credible interval 0.51–0.81) and 2 (r = 0.87, 95% credible interval 0.77–0.91) was less reliable. These trends of correlations magnitude of performance between stages were also present, although somewhat lower (see Table 4), when LD performance sensitiveness to training and competition exposure was examined. In addition, the magnitude of changes (effect sizes) point estimations and uncertainty was similar between stages 3 and 4 (stage 3: 0.84, 95% credible interval 0.54–1.24; stage 4: 0.81, 95% credible interval 0.56–1.13). Overall, these results indicate that the LD protocol should be shortened by the last full court shuttle sprint, i.e. remove 58 m and about 10–15 s of all-out effort. Considering performance up to this point in the protocol (stage 3) is sufficient to capture and rank order between players variation, and be sensitive to training exposure among adolescent basketball players.

Body dimensions variation associated with contrasting maturity status, considering chronological age alignment, among the youth basketball players in the present study was comparable with observations in basketball adolescent players (Carvalho, Silva, Eisenmann, & Malina, 2013; Carvalho et al., 2011, 2011; Torres-Unda et al., 2016) and higher than that of adolescent males in general (Malina, Bouchard, & Bar-Or, 2004). These observations are consistent with the importance placed on body size, stature in particular, to selection in youth basketball (Drinkwater, Pyne, & McKenna, 2008). Body size and maturity status (based on skeletal maturation) have been identified as predictors of LD considering the full protocol performance (Carvalho et al., 2011). Consistent with these observations, the body size allometric exponents in the present study showed a substantial relative contribution of body size to full protocol LD performance, but substantially less relevant in the early stages of the test, particularly stages 1 and 2.

Maturity-associated variation was observed when considering performance in the full LD protocol. These results are consistent with previous observations in adolescent basketball players (Carvalho et al., 2011, 2011). This trend persisted when variation in age within each maturity status category and body dimensions (no substantial influence of body dimensions, results not shown) were considered in the Bayesian multilevel models. The present study results are consistent with observations in short-term maximal performance among adolescent athletes (Buchheit et al., 2014; Carvalho et al., 2011; Montgomery et al., 2008) and adolescent males in general (Lefevre, Beunen, Steens, Claessens, & Renson, 1990) of contrasting maturity status, allowing for variation in protocols and instruments. These observations imply that pubertal growth in muscle mass and neuromuscular development and, possibly, the accumulated effects of training may contribute to the variation in results (Carvalho et al., 2011)

The Bayesian multilevel modelling results indicate a substantial improvement in the LD performance, on average, suggesting a perhaps beneficial influence of basketball-specific training and competitive exposure among adolescent athletes on anaerobic metabolism. Consistent with group-effects covariance matrix results of cross-sectional data, stage 1 and stage 2 results may provide further information about basketball-specific agility performance, as the task is similar to agility tests used in talent identification programmes in youth basketball (Hoare, 2000), composed by short sprint bouts with changes of direction. Agility performance requires displacement of the body with multidirectional nature (Sheppard & Young, 2006). Hence, coaches and researchers may consider LD performance at stages 1 and 2 to infer about enhancements in neural function, multi-joint coordination, muscle stiffness, changes in muscle architecture and increases in muscle power associated with basketball-specific training and competition exposure, as performance in the first stage of the LD was independent of maturity status and with small association with body size. Furthermore, the magnitudes of change in stage 1 and stage 2 were moderate to large, indicating that stages 1 and 2 performance in the LD is sensitive to changes across periods of exposure to training and competition. Overall, the results provide further support to the construct validity of the protocol examined in the present study for measuring basketball-specific maximal short-term performance, including agility and anaerobic mechanisms, among basketball players aged 10–15 years.

A limitation assumed in the present study is the indicator of maturity status, as the method appears to be particularly inadequate with larger distances estimated from the PHV (distances >2.0 years). Nevertheless, estimated age at PHV and its uncertainty in this study were consistent with the data where the protocol was used and reassessed (Mirwald et al., 2002; Moore et al., 2015), as well as with estimates derived from longitudinal data which modelled individual stature (Malina, Bouchard, & Beunen, 1988). Future research should consider longitudinal designs to fully capture growth patterns for body dimensions and basketball-specific maximal short-term performance of young players.

Although not new, multilevel models and Bayesian data analysis are becoming de rigueur in biological and social sciences (McElreath, 2015). In the present study, the flexibility of Bayesian multilevel modelling allowed to describe individual player's performance after each shuttle sprint, conditional on the data. We adopted a conservative approach as non-informative prior was chosen to reflect the knowledge available in the data. Non-informative priors allowed to obtain standard deviations when the estimates are near zero (Gelman, 2004) as well as attain model convergence. Also, Bayesian multilevel estimation provides viable estimates of group-level effects (random effects) when sample size is small. Coaches and researchers often attempt to select and/or predict future outcomes based on physiological performance, when there are many complex sources of variability between individuals (Abbott et al., 2005; Pearson et al., 2006). Thus, alternative analytical approaches may allow a deeper understanding of young athletes' performance.

Conclusions

In summary, the LD protocol should be shortened at least by the last full court shuttle sprint, i.e. less 58 m in the protocol distance and about 10–15 s of all-out effort, and still be able to distinguish players and be sensitive to training exposure intended in the full protocol among adolescent basketball players. Furthermore, LD up to stage 3, comprised by 84 m and five changes of direction, was independent of somatic maturation. The LD protocol was sensitive to describe performance changes in adolescent players exposed to a competitive season, moreover when considering performance at each shuttle sprint. Thus, coaches and researchers should consider a shorter version of the LD, as well as the full range of the information across the test shuttle sprints to examine maximal short-term performance in youth basketball.

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