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Blind Title:

Physical determinants of sprint and long jump performance in male youth track and field athletes with differing maturity statuses

Abstract

Purpose: This study examined the physical determinants of 60m sprint and long jump (LJ) performance and differences between maturity groups in physical characteristics in young male track and field athletes. Methods: Competition results, countermovement jump (CMJ), isometric leg press (ILP), 10-5 repeated jump test and 50m sprint were collected over 3 seasons for 54 male athletes (age 13±1 years; stature 160.0±8.9 cm; body mass, 48.0±9.8 kg; predicted adult height 92.2±5.5%) grouped by maturity status: approaching- (n = 16), circa- (n = 19) and post-Peak Height Velocity (PHV) (n = 19). Results: There were significant between-group differences in 60m, LJ, and all physical testing variables ($P<0.001$, $g= 0.88\text{-}5.44$) when comparing the approaching- and circa-PHV groups with the post-PHV group. Significant differences were identified between the approaching- and circa-PHV groups in 40m ($P=0.033$, $g=0.89$), 50m ($P=0.024$, $g=1.64$) and 60m ($P<0.001$, $g=0.89$) sprint times. Valid multivariate models were established for 60m and LJ, using the whole sample, with several CMJ, ILP and 50m sprint variables important for projecting performance. Conclusion: Large differences in performance across maturity groups highlight the importance of understanding athletes' maturity status to accurately interpret performance. Several physical performance variables were important for projecting competition 60m and LJ performance.

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Keywords:

Athletics, growth, maturation, speed, power

INTRODUCTION

Track and field events consist of running, jumping, and throwing, with performance outcomes largely affected by genetic factors and physical characteristics (6). Success in track and field is dependent on high levels of strength, speed, endurance, and power(3,18,44,53), with the exact contribution of these qualities varying depending on the event. These physical qualities are affected by training, age, growth, and maturity(32,36,46,50); therefore, at the youth level, results are likely to be influenced by growth. Within a single chronological age group, large variations exist in the status, timing, and rate of maturation, especially between 12-15 years of age(33). Earlier maturing athletes have advantages in terms of size, strength, power, and speed compared to their on-time or later developing peers(13). However, there is limited research examining the impact of growth and maturation on performance in youth track and field.

Existing research on track and field at the youth level has focused on the relative age effect(4,9), injuries(35) and progression from junior to senior rankings(5,26). The impact of maturity on performance has not been adequately examined in track and field. Improving our understanding of how maturity affects performance will enable practitioners to evaluate young athletes more accurately, resulting in more informed decision-making around selection, deselection, and progression within talent pathways. Previous research has indicated that, in national track and field rankings, only a small percentage of highly ranked youth progress to the senior level(5,6,26). This may be a result of early maturing athletes dominating the sport at younger ages before declining, as maturity differences are less apparent, and the later developing athletes catch up.

The physical determinants of elite performance have been examined previously in short sprint and long jump senior athletes(18,21,40,44,53). High-level performers in these events generate greater levels of force and power relative to body weight in short periods (3,18,44,53), given the short ground contact times in sprinting (34,54) and during long jump take-off(18,19). Research has shown world class elite sprinters to have significantly higher jump height, propulsive and braking forces in the CMJ, compared to sub-elite counter parts

(3). Peak isometric force, rate of force development, CMJ height and drop jump height have been shown to be strongly associated with sprint, bound, and jump test performance in elite horizontal jumpers. Tests including a stretch-shortening cycle component were noted as demonstrated stronger relationships than purely concentric tests (18). However, the underlying physical determinants of sprint and jump performance in youth track and field athletes at differing maturity statuses, using a similar battery of tests, remains unexplored.

A growing body of research has shown improvements in strength, power(14,38,49,50,52), sprinting speed(15,36,41,52), and stretch-shortening cycle function (2,27,45) with advancing age, growth, and maturation. These findings can be attributed to changes in muscle size, fiber-type, architecture, activation, mechanical tendon properties, and neuromuscular function (45,46). In youth athletes, research measuring sprint performance, strength, and power indices has identified a performance improvement with advancing maturity status(15,39,41). Meylan et al. (39)showed that a 10% increase in strength and power results in a 1.6 to 2.4% improvement in sprint performance within a maturity group. Edwards et al. (15) reported differences in maximum speed and mechanical sprint variables between the post-PHV, pre-, and mid-PHV groups. However, there were no differences between the two least mature groups over short distances (5m and 10m). Meaningful reductions in sprint split times emerged only beyond 15m in the post-PHV group. The running technique (increased stride length and reduced stride frequency) and anthropometric changes from pre- to post-PHV are contributing factors to improved maximal speed with maturation(36,37). Improvements in stretch-shortening cycle function owing to increases in strength and muscle pre-activation (27,46) may also contribute to improvements over longer distances at maximum speed, where the ability to produce high forces in short ground contact times is important.

Cumulatively, these findings suggest that advanced maturity leads to improved performance in sprint and jump events. Given that all previous studies utilized untrained school children (36, 37) or team sport athletes (15, 41, 46, 52), there is a need to investigate the effects on performance within a cohort of high-level youth track and field athletes. In addition, the physical performance determinants are not well established in these cohorts. Sprint performance was also only assessed over shorter distances than event distances (<40m). Given that changes in performance outcomes may be more apparent as sprint distance increases(15), it would appear to indicate that maturity divergences over specific track and field distances and the key physical determinants of these performances should be examined.

Therefore, the aims of this study were to 1) examine between-group differences as defined by maturity status in the 60m sprint, long jump, and a physical testing battery; 2) identify key physical determinants of sprint and long jump performance; 3) determine whether different test variables are more useful for projecting performance at different stages of maturity; 4) provide maturity status benchmarks for the 60m and LJ, based on a group of highly trained, young male athletes of differing maturity status specifically selected for a national track and field development program. 60m and LJ were selected because the format of these events was consistent across the age groups within the study. Other events, such as the hurdles and throwing events, utilize different hurdle heights and spacing, and implement weights, respectively across the age categories limiting our ability to provide meaningful performance comparisons.

METHODS

Study Design

This cross-sectional study examined data collected within a national sports academy over three seasons (2019-22) during the first physical testing and competition period at the end of the 8-week general preparatory phase in November, or during the second testing and competition period in February. The weekly schedule included two athletics sessions, two strength and conditioning sessions, and one of each of the following: swimming, gymnastics, and a multi-sport session, where athletes would typically participate in invasion games (e.g., basketball, handball). To be included in the study, a complete profile of competition results (60m sprint and long jump [LJ]) had to be collected within a 31-day period of physical testing (50m sprint, countermovement jump [CMJ], 10-5 repeated jump test [10-5 RJT], Isometric Leg Press [ILP], and anthropometric and maturity assessments). Due to scheduling restrictions within the academy, physical testing was completed during two separate sessions. The maturity assessments, 10-5 RJT, CMJ were completed in the first session and ILP during the second session. Each participant was only sampled once for the present study, on the first occasion where both the competition and physical testing had both been completed in the required timeframe. A standardized warm up was completed by all athletes prior to testing.

Participants

Fifty-four male youths (age 13±1 years; stature 160.0±8.9 cm; body mass, 48.0±9.8 kg; percentage of predicted adult height 92.2±5.5%) of different maturity statuses (approaching-PHV n=16; circa-PHV n=19, post-PHV n=19) were recruited from an elite development academy for Track and Field (Athletics) into the academy is permitted following the national talent ID selection process. See table 1 for detailed participant characteristics for each maturity group. All the subjects were part of the athletics national talent development programme and participated in competitions at a local, regional, and national level. Athletes are exposed to 16 hours a week of structured technical training including formalized strength and conditioning. Participants were required to have been a member of the academy for a minimum of three months and a maximum of three years. Ethical approval, parental consent, and participant assent were obtained from the Institutional Review Board prior to commencement of the study.

Procedures

Anthropometry

Athletes' stature, sitting height, and body mass were recorded on a calibrated measurement platform (Harpenden Stadiometer, Holtain Limited, Crosswell, UK) and weighing scale (M304601, ADE Hamburg, Germany), respectively.

Adult Predicted Height (Bone Xpert)

Hand-wrist radiographs, standing height, and body mass measurements were used to determine the skeletal age, and subsequently, the calculation of predicted adult height. Skeletal age was assessed using standard radiographs (Digital Diagnost; Philips, USA) of the radius, ulna, carpals, metacarpals, and phalanges(31). Roentgenograms were evaluated by automated processing of digital images using the computerized BoneXpert ® determination method (51) according to the manufacturer's recommendations (version 3.1.4, Visiana, Holte, Denmark), and skeletal age and predicted adult height were determined according to the TW-II protocol. The specific details of these methods have been previously published(29).

Maturity status

Maturation status was calculated using the final predicted adult height from the BoneXpert software. Stature measurements were then used to calculate each participant's current Percentage of Predicted Adult Height (%PAH) and were classified using the following thresholds: pre-PHV (<85% PAH), approaching-PHV (≥85–<90% PAH), circa-PHV (≥90–<95%PAH), and post-PHV (≥95% PAH)(13).

Collection and analysis of saliva samples

Salivary testosterone was collected as an additional marker of maturation status, as part of routine athlete monitoring processes within the development programme for athletics. Athletes arrived at the test venue before 10 am to avoid diurnal variations in salivary testosterone levels(22). According to the manufacturer's recommendations (Salimetrics, PA, USA), participants were instructed to refrain from eating or brushing their teeth within 60 min of sample collection. They were then asked to rinse their mouth with water, sit quietly for

10 min, and place the SalivaBio Oral Swab (SOS) under the tongue for 2 min to collect saliva. The swabs were then transferred into collection kits and stored at -20°C until data collection was completed.

On the day of analysis, the samples were thawed and spun for 15 min at 1500 g. The enzyme-linked immunosorbent assay (ELISA) method was used to determine the salivary free testosterone concentrations (Salimetrics, PA, USA). Absorbance was measured using an automated plate reader (Tecan Infinite 200Pro, CH). The inter-assay coefficient of variation (CV) ranged from 5.6% to 14.1%, and the intra-assay variability was <6.0% in all measurements (10,20).

Competition Data (60m and Long Jump)

The results were collected during official indoor athletic competitions hosted by the academy, for which the lead investigator was present at all the events. Indoor competition was chosen because it provided a consistent environment without wind. The sixty-meter (60m) and long jump (LJ) events took place on an indoor athletics track that met the IAAF standards for international competition. The 60m event was electronically timed using the FinishLynx photo-finish technology timing system (Haverhill, MA, USA), the athletes started from blocks and participated in a heat and a final, if they qualified. In the LJ event, athletes had three jumps and started their approach from a distance determined with their coach, typically between 20-30m. Jump distance was measured with a metal measuring tape from the take-off board to the athletes nearest imprint in the sand. Spikes were worn by all athletes during both events. The competition results were uploaded into an internal database and retrieved later for the study. The best performance in each event was used in the analysis, regardless of where it occurred in the competition.

10-5 Repeated Jump Test

The 10-5 RJT was completed using a contact jump mat (Smartspeed, Vald Performance, Brisbane, Australia). The test was initiated with a countermovement jump, followed by 10 consecutive reactive maximal jumps, keeping their hands on their hips throughout. Participants were instructed to jump ‘as high as possible and minimize the time spent on the ground’. The five jumps with the highest flight time (FT) and ground contact time (GCT) < 250 $m \cdot s^{-1}$` were used for the analysis. The reactive strength index (RSI) was calculated as the FT divided by the GCT (both in milliseconds). The mean RSI, FT, GCT, and jump height (JH) were calculated for the five selected jumps. Athletes completed two trials with 3 minutes rest. The trial with the highest mean RSI was used in the analysis. Further details of the methods, validity, and reliability of the 10-5 RJT protocol have been previously published(2).

Countermovement Jump

Participants performed three maximal countermovement jumps on a dual-force platform system (ForceDecks FD4000, Vald Performance, Brisbane, Australia) sampling at 1000 Hz, with their hands placed on their hips(7). They were instructed to stand perfectly still prior to being given the command to ‘jump as high as possible’, resetting their foot position between trials. All 3 jumps were performed within 60 seconds. The variables used in the analysis were CMJ jump height (CMJ JH), relative power (RP), mean peak eccentric power, mean peak concentric power, and mean total force.

The onset of movement was defined as the point when the total vertical force deviated -20 N from the body weight determined during the quiet standing phase, and the take-off was set to the point when the total vertical force dropped below 10 N. Jump height was calculated from the total vertical force (summation of left and right forces), and its first derivative was used to determine vertical velocity. The eccentric phase was defined as the point from the movement onset to the instant at which the vertical velocity was zero (the maximum downward displacement of the center of mass). The concentric phase was then characterized as the point from zero center of mass velocity to take off. Power was calculated as the product of the total vertical force and vertical velocity.

50m sprint

Three maximal 50m sprints were performed whilst being tracked using a laser speed gun sampling at 100 Hz (Laveg LDM 300C, Jenoptik, Jena), positioned approximately 3m behind the zero line. The subjects performed the sprints individually, starting each run in an upright position 0.5m behind the zero line. Subjects were instructed to "run as fast as possible through the 50m marker before slowing down".

Data were exported into a bespoke Excel analysis spreadsheet to determine 10m split times and instantaneous velocity and smoothed using 5- and 51-point moving averages, respectively(18). The variables extracted for analysis included: (0-50m), (0-40m), (0-30m), (0-20m), (0-10m), (0-5m), as well as the maximum instantaneous velocity and the distance at maximum velocity.

Isometric Leg Press

A 45-degree leg press (Plated Loaded Linear Leg Press, Hammer Strength, Des Plaines, IL, USA) was adapted with a mounted 60 × 40 cm single force plate (Kistler, model 9281E, Winterthur, Switzerland) to assess isometric leg extension peak and relative force. The knee angle was set to 110 ° using a manual goniometer. Athletes worked through a progressive warm up at a self-determined 50, 70 and 90% of maximum effort for 5 s, with at least 1 min rest between each. The athletes were instructed to start with a small push to remove any slack from the machine, and then to 'push as hard as possible' for 5 s. Athletes were verbally encouraged to maintain their effort for the duration of each trial. Two trials were completed, with 3 minutes rest between each. Data were collected using Kistler BioWare software and processed to calculate the resultant force of each trial. The trial with the highest peak force was used for analysis.

STATISTICAL ANALYSIS

Maturational Differences

Descriptive statistics (mean [SD]) for anthropometric data, competition results, and physical tests were calculated for each maturity group. Normality was tested using the Shapiro-Wilk test. The following variables were not normally distributed ($P<0.05$): age, PPAH, 30m time, 40m time, ILP peak force and relative force, CMJ RP, mean peak concentric power, mean total force, and salivary testosterone. All other variables were normally distributed. Athletes were grouped according to their current PPAH: pre-PHV (<85%), approaching-PHV (≥85-<90%), circa-PHV (≥90-<95%) and post-PHV (≥95%)(13). Kruskal-Wallis one-way analysis of variance was performed to examine any between group differences for all variables, with the alpha level set at $P<0.05$. Dwass-Steel-Critchlow-Fligner pairwise comparisons were performed to identify differences between the groups. Hedges' g effect sizes (ES) were also calculated to interpret the magnitude of between group differences using the following classification: standardized mean difference of 0.2 (small), 0.5 (moderate), 0.8 (large) and 1.1 (very large)(23). Benchmarks were calculated for the 60m and LJ using the mean and standard deviation for each maturity group and the following Z-score thresholds: excellent (>1.5), good (0.5 to 1.5), average (-0.5 to 0.5), below average (-0.5 to -1.5) and poor (<-1.5).

Multivariate data analysis

Analyses were conducted using SIMCA 16.0 (MKS AB, Umeå, Sweden). Multivariate data analysis (MVDA) methods were used to examine whether competition 60 m sprint and long jump performance could be projected using a combination of laboratory and field-tested strength and power indices. Principal component analysis (PCA) was used to analyze the relationships between the strength and power indices, and to assess any hidden structures and patterns via the reduction of data dimensions. Orthogonal projections to latent structures (OPLS) were employed to identify linear relationships between two groups of variables: (1) sprint and long jump performance and (2) speed, strength, and power indices. The specific details of these methods have been published previously(16,25).

Sprint and long jump performances (Y variables) were projected from speed, strength, and power metrics (X variables), and R^2VY is the cumulative percentage of the variation of the response explained by the model after the last component. The R^2 is a measure of how well the model fits the data. R^2VYAdj is the cumulative percentage of the variation in the response, adjusted for degrees of freedom, explained by the model after the last component. Q^2VY is the cumulative percentage of the variation in the response predicted by the model after the last component, according to cross-validation. Q^2 indicates how well the model projects new data, and permutations (one less cycle than the number of X variables) of the models were deemed valid if the intercept was < 0, or if all permuted Q^2 values were below the original model value. R^2 and Q^2 should be > 0.8 and > 0.5, for well-modelled data (extracted from the SIMCA-P + Handbook).

To evaluate the importance of specific strength and power metrics for projecting sprint and long jump performance, variable influence on projection (VIP) analyses were conducted. In the OPLS model, VIP summarizes the importance of the X variables for both the X and Y models. VIP is normalized and the average squared VIP value is 1; thus, a VIP > 1 indicates that the variable is important for projection, and a value < 0.5 indicates that the variable is not important for the projection(16). Block-wise multiple linear regression (MLR) analyses were run for equivalent models to confirm that the inferences generated by OPLS were reflective of the underlying data. The Root Mean Square Error (RMSE) was calculated for all OPLS and MLR models to determine which models had the best predictive ability.

Models were constructed for 60 m sprint and long jump performance for all athletes combined and then by maturation status: approaching, circa, and post-PHV. Specific variables such as speed, strength, and power metrics (*X* variables) were included in the models for the 60m Sprint. 20m sprint time was included as a measure of acceleration because it has a strong relationship with maximum speed(1). The ILP peak and relative force were selected based on the high forces required to overcome inertia in the block start of a sprint, and previous research has indicated that relative force-producing capabilities differentiate faster and slower athletes(44,53). The ability to rapidly produce large forces relative to body mass is required to accelerate quickly. Beattie et al. (6) found a difference in CMJ jump height and relative power between elite (0.57m ±0.03; 75.0 W·kg^{-1}±2.6) and sub-elite male sprinters (0.44m ±0.01; 68.2 W·kg^{-1}±3.2). Therefore, we included several metrics from the CMJ test: jump height, relative power, mean peak eccentric and concentric powers, and mean total force. Throughout a race, flight times increase and contact times decrease as the maximal velocity is achieved. Contact times at the top speed in elite sprinters are typically 80-100ms (34,54) making the ability to produce high forces in minimal times a key ability for sprinters. Hence, we included the RSI, jump height, flight time, and contact time from the 10-5 RJT.

For the long jump, 30m time was selected as the young athletes in this cohort typically use this distance for their approach to the take-off board. Senior athletes used up to 40m, so this distance was also included. The ILP peak and relative force were used because of the requirement to produce extremely high forces at take-off(18). Power variables (CMJ jump height, relative power, mean total force, and mean eccentric and concentric peak power) were selected, given the need to produce force quickly in a stretch-shortening cycle action in the take-off at the board and during the approach run. RSI, CT, and FT from 10-5 RJT were included as the ability to respond to a high impact and reverse an eccentric action to a concentric action in a minimal time frame necessary at take-off.

RESULTS

Maturational Differences

Table 1 shows the age, maturity, anthropometry, competition performance, and physical testing results of all athletes in the study according to their maturity status:

<TABLE 1 HERE>

Significant between groups differences ($P<0.001$) with a large ES were present for age ($g=1.25$ to 3.07). Pairwise comparisons indicated differences between the approaching- and post-PHV and circa- and post-PHV groups ($P<0.001$). Stature increased significantly between the maturity groups with large ES ($g=1.02$ to 2.66). There were also large differences in body mass between approaching- and circa-PHV ($P=0.020$, $g=1.26$), approaching- and post-PHV ($P<0.001$, $g=2.77$), and circa- to post-PHV ($P<0.001$, $g=0.83$). PPAH was significantly different corresponding to large ES between all 3 maturity groups ($g=2.91$ to 5.83). Saliva testosterone levels were significantly different between the approaching- and post-PHV ($P<0.001$, $g=1.31$) and circa- and post-PHV groups ($P=0.001$, $g=1.09$), but not between the approaching and circa-PHV ($P=0.083$, $g=0.33$) groups.

The 60m sprint and long-jump competition and physical testing results for each maturation group are shown in table 1. 60m sprint time decreased significantly with advancing maturity ($P<0.001$) with a large ES when comparing the approaching- to circa-PHV ($P<0.001$, $g=0.89$) and circa- to post- PHV ($P<0.001$, $g=1.67$) groups. A very large ES was observed between approaching- and post-PHV groups ($g=3.14$). The long jump distance also increased across maturity groups. However, significant differences were only present between the circa- and post-PHV ($P=0.023$, $g=0.94$) and approaching- and post-PHV ($P=0.002$, $g=1.52$) group comparisons, with large and very large ES, respectively.

In the CMJ, no significant differences were found between the approaching and circa-PHV groups for any of the variables. Comparisons between the approaching- and post-PHV groups revealed significant differences and very large ES for all variables: JH ($P<0.001$, $g=1.96$), relative power ($P<0.001$, $g=1.44$), mean peak eccentric power ($P=0.005$, $g=1.34$), mean peak concentric power ($P<0.001$, $g=1.95$), and mean total force ($P=0.004$, $g=1.22$). Similarly, the differences between circa- and post-PHV were all statistically significant with large to very large ES: JH ($P<0.001$, $g=1.54$), relative power ($P<0.001$, $g=1.25$), mean peak eccentric power (*P*=0.012, g=1.05), mean peak concentric power (*P*=0.001, *g*=1.61), and mean total force (*P*=0.006, *g*=1.03).

In the 10-5 RJT, significant differences in RSI, FT, and JH were observed. RSI increased significantly between the approaching and post-PHV groups (*P*=0.015), displaying a large ES (*g*=0.88). There were no significant differences between those who were approaching- to circa-PHV (*P*=0.265, *g*=0.49) or circa- and post-PHV (*P*=0.176, *g*=0.46). FT increased significantly with a large ES between approaching- and post-PHV (*P*=0.027, *g*=0.87) and circa- to post-PHV (*P*=0.011, *g*=0.95), but not between the approaching- and circa-PHV groups (*P*=0.942, *g*=0.02). There were no significant differences in the mean CT across the groups.

Isometric leg press results revealed significant increases in peak force with maturity status, but no significant difference was observed in relative force. There were no statistically significant differences in the peak force between the two least mature groups (*P*=0.822, *g*=0.15). Peak force increased when comparing the approaching and post-PHV groups (*P*=0.003, *g*=1.15), as well as those who were circa- and post-PHV (*P*=0.001, *g*=1.18), corresponding to a very large ES.

Significant differences were observed for all measured variables in the 50m sprint between maturity groups (see table 1). Pairwise comparisons revealed no significant differences for the 5m, 10m, 20m, and 30m time between the approaching-PHV and circa-PHV groups (*P*>0.05, *g*=0.66-0.83). However, significant reductions with large to very large ES were observed for the 40m (*P*=0.033, *g*=0.89) and 50m (*P*=0.024, *g*=1.64) split times. The maximum velocity also increased (*P*=0.001, *g*=1.04) between the two groups. Significant differences were present in all the split times and maximum velocities when comparing the approaching- and post-PHV groups with very large ES that increased with each subsequent split time (*g*=1.79 5.44). Circa and post-PHV group differences were also significant with large to very large ES (*g*=0.98 to 2.78), again increasing with sprint distance. For the distance at maximum velocity, a significant between-group difference existed between the approaching and post-PHV groups only (*P*=0.021, *g*=0.81).

Multivariate data analysis

The details of the OPLS models for long jump and sprint performance (Y variables) are presented in table 2. In all cases, the MLR models exhibited a greater RMSE than that of the OPLS models. When analyzing the whole sample, valid projective models were identified for the 60m and LJ with several speed, strength and power indices from the 50m, ILP and CMJ important for projecting performance. No variables from the 10-5 RJT were able to project performance in either event. The specific variables and their relative importance to performance are shown in figure 1, plots a) and d) for the whole sample. When analyzing within the maturity groups, valid models could not be established for all three maturity groups in either event. The valid models were in the approaching- and circa-PHV models for the LJ, and in the circa- and post-PHV for the 60m. Fewer variables, only from the CMJ and 50m sprint, were able to project performance in the maturity group models. The specific variables and their relative importance for projecting performance in are shown in figure 1, in plots b) and c) for the 60m and plots e) and f) for the LJ.

<TABLE 2 HERE>

< FIGURE 1 HERE>

Figure 1. Multivariate models for the 60m and long jump

<TABLE 3 & 4 HERE>

Tables 3 and 4 provide the maturity group benchmarks for the 60m sprint and long-jump events using Z-scores.

DISCUSSION

The current study aimed to examine the between-group differences between athletes of different maturity status in 60m and long jump performance and a physical testing battery including speed, strength and power indices commonly used in athlete monitoring and talent identification processes. An additional aim was to establish whether variables from the physical tests were able to project performance in the 60m and LJ within this sample of elite male youth track and field athletes of different maturity statuses. Significant differences with moderate to very large effect sizes ($P<0.001$, $g= 0.88$-5.44) were found in performance in the competition events and physical tests between the maturity groups. Valid multivariate models were established for the 60m and LJ in the whole sample and some of the maturity groups with several speed, strength and power indices important for projecting performance.

The first aim of our study was to examine between-group differences in competitive events and physical tests across maturity groups. Significant reductions in sprint time with large to very large ES (g=0.89-3.14) in the 60m sprint time were present in all three maturity groups. This is consistent with previous research that has examined speed in youth over shorter distances (15,36,48,52), highlighting the potential advantage for early maturing athletes within their chronological age group category. This reinforces the importance of understanding the maturity status of athletes to understand the true context of performance in the youth track and field.

In the long jump, performance increased with advancing maturity; however, there were no significant differences between approaching-PHV and circa-PHV athletes. The smaller ES compared to the 60m sprint may be due to the greater skill component in the long jump. Athletes must convert their horizontal velocity into a vertical velocity at take-off on the board. Relatively younger and less mature athletes (approaching- and circa-PHV) are still developing these skills. We have observed they do not generate as much speed during the approach and are not strong enough to maximize the conversion of horizontal speed to vertical force production for take-off. This has connotations for coaches when considering the training age during maturation. In this case, the athlete might have the speed capacity to be a good jumper in the future but may not have the technical ability and strength to use the speed, or vice versa.

This study is the first to examine anthropometry, maturity, event performance speed, strength, and power metrics concurrently in a youth track and field cohort involved in a development training program. Significant differences were observed between the maturity groups in all the physical tests. The largest differences and ES were typically from approaching- to post-PHV and circa-PHV to post-PHV, whereas the effect sizes were moderate between approaching- and circa-PHV. The 50m sprint test, with split times at 5- and 10m intervals assesses how the athletes perform in acceleration and maximal velocity phases when sprinting compared to the sole outcome measure in the 60m sprint. In the acceleration phase (represented by the 5-30m times), there were no significant differences between the approaching- and circa-PHV groups. This is consistent with other research in youth populations, where differences between the least mature groups over similar distances were not clear(15,36). In the present study, significant differences with large to very large effect sizes appeared in the 40m, 50m split times and maximum velocity. This emphasizes the need to examine a more comprehensive speed profile and utilize specific distances when testing to fully understand how speed develops in young athletes.

The lack of differences in the acceleration phase (0-30m) between the approaching- and circa-PHVs may be explained by several factors. First, body mass significantly increased in relation to changes in stature and potentially peak weight velocity (PWV). Therefore, inertia would have been greater at the start for the more mature group. Second, there were no significant increases in any strength or power variables that would have helped them overcome their higher mass, which is possibly related to testosterone levels remaining similar between the groups. Without changes in hormone levels, muscle mass, and muscle characteristics, increases in force production are unlikely. Third, rapid changes in stature and leg length may also result in some degree of disruption in technique and motor coordination in the form of adolescent awkwardness(43). Significant differences emerged between the approaching- and circa-PHV groups in the split times at 40m and 50m, and the maximum velocity may be explained by the increase in leg length, and thus stride length, between the two groups (37). Speed being the product of stride length and stride frequency, the greater stride length of circa-PHV athletes likely enabled them to achieve higher speeds once they had overcome inertia and any coordination or technical challenges at the start. In contrast, the post-PHV athletes were significantly faster at all split times and maximum velocities compared to the other groups, consistent with previous research(15,36,48). This is likely a result of the increase in strength and power observed in the physical tests combined with further increases in stride length (related to further increases in leg length). Meaningful differences in RSI were found only between approaching- and post-PHV athletes, which is consistent with previous research, where significant increases in RSI were indicated between the least and most mature athletes only (2). The large increases in strength and power in the post-PHV group are likely a reflection of the increased levels of testosterone compared with the two least mature groups. While all athletes completed two strength & conditioning sessions per week in the academy, higher testosterone availability in the post-PHV group may have led to greater improvements in strength and power(12).

The second aim of this study was to analyze whether speed, strength and power indices from the physical testing battery were able to project competition performance in the 60m and long jump events. Valid multivariate models were established using OPLS and PCA methods for 60m and LJ, with several variables considered important for projection, when all athletes were grouped together. In both the 60m and long jump, speed, power, and strength variables from the 50m, CMJ, and ILP, respectively, were important for projecting performance in the whole sample. The data indicates that sprinting speed, the ability to produce high isometric peak force, CMJ jump heights and power relative to body weight are important for projection of long jump and 60m sprint performance in youth athletes. These findings are consistent with research in senior athletes, where similar qualities were correlated with performance in high-level sprinters and horizontal jumpers(3,18,44,53,54). In the present study, the CMJ was the most important variable for projecting performance in the long jump, whereas approach speed was identified as the most important factor in senior athletes in previous research(18). The magnitude of the correlation between vertical jumping and sprinting variables has been well defined in various populations; (8,11) however, recent observations suggest that this relationship decreases as the level of performance of the athlete increases (24). These findings may also reflect that sprinting ability is still developing in younger athletes, and comparatively, a CMJ is a relatively simpler task to express their abilities.

The third aim was to determine whether different test variables are more useful for projecting performance at different stages of maturity. When the models were constructed separately for the three maturity groups. The multivariate models couldn't be established for all groups. Valid models were only established in the approaching- and circa-PHV groups in the LJ, and circa- and post-PHV groups in the 60m. Within the models for these groups, only variables from the CMJ and 50m sprint were able to project performance in both events (see figure 1). Smaller sample sizes may have affected within group comparisons, due to greater variability. In addition, less mature athletes (i.e. approaching-PHV) have previously been shown to have greater variability in jumping task performance (17,28), and similar jump metrics were unable to differentiate between elite youth footballers and a non-elite control group at a similar stage of maturity (pre-PHV)(41). Within the post-PHV group, there was a wide range of chronological ages (13.3–15.8 years), reflecting the variance in the timing of maturation. Relatively younger post-PHV athletes may have accumulated less training and therefore may not have performed as well in the competition events or physical tests, creating greater variability. Finally, changing PPAH, a continuous variable, into a categorical variable by grouping according to the percentage thresholds, although simple and convenient, can cause a significant loss of statistical power and residual confounding(47).

No metrics from the 10-5 RJT were able to project performance in either of the competitive events. These findings might reflect the fact that stretch-shortening cycle (SSC) abilities are still developing during maturation. Athletes experiencing rapid increases in stature and body mass might display a higher level of disruption to their performance levels in this test (2,43). The emergence of CMJ eccentric power as an important variable for projection in the post-PHV group, which is related to SSC function, may indicate that these variables will begin to differentiate performance levels once maturity-related adaptations to muscles and tendons occurred, contributing to the development of SSC function(45). Whilst the 10-5 RJT did not project performance in our study, we propose that it would still be a useful test to track SSC development longitudinally, given that reactive strength has shown to be reliable, and valid with young athletes(2), and correlated with performance in senior track and field athletes(18).

The fourth aim was to provide maturity group benchmarks for the 60m and LJ to enhance coaches' ability to interpret performance (see tables 3 and 4). Based on the significant differences identified in performance between the maturity groups in both events (and physical testing measures) this approach would appear to be valuable for the athlete and key stakeholders. It can be used to provide the coach, athlete and parents with an alternative perspective on current performance levels in age group track and field competitions, where large inter-individual differences in maturity exist but are not currently accounted for. Future research should aim to establish similar benchmarks for more track and field events.

When interpreting the findings of this study, some limitations should be acknowledged. First, the sample size was relatively small, particularly when grouped by maturity status. Second, limitations in the PPAH grouping should be considered when interpreting the results or applying the approach used in the current study. A reduction in statistical power was associated with changing a continuous variable (PPAH) to a categorical variable (47) when grouping was applied according to percentage thresholds (13). Future research should explore alternative methods to evaluate competition and test performance against age and maturity to avoid compromising the statistical power. In addition, there is conflicting evidence regarding the efficacy of the PPAH method in correctly assigning athletes to maturity groups(30,42). Despite these potential limitations, using PPAH offers a practical, time-efficient solution to determine the maturity status repeatedly, overcoming medical restrictions on the number of X-rays and the time-consuming nature of the measurement and analysis procedures.

In conclusion, the significant differences and large effect sizes found between maturity groups in both competition and physical tests have highlighted the potential inequality of the youth track and field when differences in maturity status are present. Therefore, determining the maturation status appears to be very important for coaches, athletes, and parents when interpreting current performance in youth track and field athletes. Valid models for the projection of 60m sprint and long jump performances were established across several metrics from the CMJ, ILP and 50m sprint test, validating the selection of these tests. The validity of the models in the whole sample suggests that coaches and sports scientists can confidently utilize the CMJ, ILP and 50m Sprint to assess strength, power, and speed qualities in male youth track and field athletes (aged 12-16) to project performance.

PRACTICAL APPLICATIONS

Using tables 3 and 4, coaches can evaluate performance in the 60 m and long jump events by considering an athlete's individual maturity status in addition to any age group evaluations. The reader can create similar benchmarks for the physical tests using the means and standard deviations from table 1 and the Z-score grading bands highlighted above. Using these benchmarks may assist in talent identification processes in young athletes, where maturity differences exist. This potentially allows less mature athletes' talent to be recognized when their potential is hidden when compared to age-based standards.

The CMJ and 50 m sprint tests may be the most useful and practical for practitioners looking to differentiate 60 m and long jump performance levels in young track and field athletes. The authors recommend monitoring growth and maturation when working with male adolescent athletes in the sport. Establishing maturity status will enable practitioners to make more informed decisions about athletes' training and more accurately evaluate current performance using the maturity-based benchmarks provided. Bio-banding is a process that has been utilized in team sports, such as soccer, where athletes are grouped according to maturity status rather than chronological age to create a more balanced competition(13). It is not currently applied in youth track and field, but it could provide an alternative competition format to ensure that all athletes are appropriately challenged against athletes of a similar maturity status.

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