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Initial fitness, maturity status, and total training explain small and inconsistent proportions of the variance in physical development of adolescent footballers across one season

Michael King [a,b], Derek Ball [c], Matthew Weston [d], Robert McCunn [b] and Neil Gibson [e]

[a]School of Health and Life Sciences, The University of the West of Scotland, Glasgow, UK; [b]Oriam:Scotland's Sports Performance Centre, Heriot-Watt University, Edinburgh, UK; [c]School of Medicine, Medical Sciences and Nutrition, University of Aberdeen, Aberdeen, UK; [d]School of Health and Life Sciences, Teeside University, Middlesbrough, UK; [e]City architect and transformational design, Blacktown City Council, Sydney

ABSTRACT

To investigate how initial fitness, maturity status, and training time explain changes in physical performance across one season. Eighty-eight adolescent male footballers, representing four age categories (Under 15 [n = 12], Under 14 [n = 21], Under 13 [n = 25], Under 12 [n = 30]), were tested using physical performance tests (20 m sprint, change of direction, squat jump and yo-yo intermittent recovery test level 1 [YYIRTL1]) and maturity offset at the season start (Test 1) and end (Test 2). Multiple regression determined the proportion of variance in test score changes, explained by three predictor variables: initial fitness (i.e., Test 1), maturity offset change, and training time. With combined categories, predictor variables explained 0.051 to 0.297 of the variance in physical performance score changes. Analysing age categories separately, predictor variables explained 0.047 to 0.407 (20 m sprint), 0.202 to 0.626 (change of direction), 0.336 to 0.502 (squat jump), and 0.196 to 0.777 (YYIRTL1) of variance in test score changes. Of the limited differences in relative predictor contribution, Test 1 was the strongest predictor of test score change. Initial fitness, maturity status change, and training time explain small and inconsistent proportions of variance in adolescent footballers' physical development across one season.

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Introduction

An increasing number of professional United Kingdom football clubs are establishing performance schools, whereby youth players incorporate football training into their educational curriculum. Within Scotland, the national governing body (Scottish Football Association [SFA]) established its own network of performance schools throughout the country, and one of the underlying premises for performance schools is allowing young players to accrue more hours of training. The English Premier League's Elite Player Performance Plan (EPPP) stipulates a minimum number of coaching hours that professional club academies must provide their players to achieve certain category rankings,

CONTACT Michael King Michael.King@uws.ac.uk School of Health and Life Sciences, The University of the West of Scotland, Glasgow KA8 0SX, United Kingdom.

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with training hours aligned with category ranking (Elite Player Performance Plan, 2011). However, while the notion that long-term success in sport is predicated on training time is an intuitive proposition (Ericsson et al., 1993), it has been challenged (Ericsson, 2013).

Players born earlier in the selection year can be biologically more mature than players born later in the year (Malina et al., 2007), even within one-year group. One reason posited for this overrepresentation is their ability to outperform less mature players in the physical aspects of the game (Meylan et al., 2010). More pronounced physical attributes at a young age can often be mistaken for talent in football (Helsen et al., 2000) and as a result, less physically mature (but equally skilful players) can be left out (Figueiredo et al., 2009; Matthys et al., 2012; Vandendreisessche et al., 2012). The overrepresentation of older footballers in adolescent sport has been labelled the relative age effect (RAE). The RAE occurs when a disproportionate number of players born in the earlier part of the selection year are selected when compared to the birth dates of the general population (Boucher & Mutimer, 1994; Musch & Grondin, 2001). In an effort to avoid the RAE and emphasize skill is as important as physical attributes, the SFA's new performance programme focuses on long term development.

In the context of youth football, physical maturity is another factor that should be accounted when considering longitudinal progression. Players of the same chronological age can differ significantly in their degree of physical maturity (Cumming et al., 2017). The potential discrepancy in physical maturity between players is important since it influences a number of physical attributes such as maximal sprinting speed, jump height, movement quality and repeated sprint ability – all of which are important performance components (Brownstein et al., 2018; Faude et al., 2012; McCunn et al., 2017; Ryan et al., 2018; Stølen et al., 2005).

When assessing the influence of training on any physical performance outcomes, initial values need to be considered as training adaptation is greater in those that are less fit (Weston et al., 2014). In response to the same training stimulus, those individuals with well-developed physical qualities will likely improve less than those with a relatively lower starting point. Indeed, in the context of soccer, players with higher initial levels of aerobic fitness improved less when compared to those with a lower level of initial fitness (Arcos et al., 2018). Differences in initial fitness level may be influenced by the individual's competitive level, where elite players are potentially able to outperform than their sub-elite counterparts (Milanović et al., 2017). Consequently, initial fitness is another factor that could influence the interpretation of training effectiveness within youth football. Being able to separate gains associated with training is of particular importance during adolescence as improvements in physical performance occur naturally due to growth and maturation (Lloyd et al., 2015).

The aim of the present study, therefore, was to observe the progression of physical performance test scores within youth footballers enrolled in a national association performance school programme. Specifically, we sought to investigate the extent to which initial fitness, change in physical maturity, and training time explained changes in physical performance test scores over the course of one year. We hypothesized that physical maturity would have the largest effect on physical performance.

Materials and methods

Experimental design

The present study adopted a season-long, repeated measures, observational design.

Participants

Eighty-eight male football players agreed to participate in the study (age 13.4 ± 1.2 years; stature 155.2 ± 9.6 cm; mass 43.5 ± 8.4 kg). Each player was selected into the SFA Elite Performance School programme, which integrates additional daily training into the educational curriculum. The additional training amounted to approximately 3–4 hours per week. The majority of players were also registered with a professional youth academy with which they trained and played three to four nights per week. When training within the Performance School programme, players were grouped according to chronological age categories aligned with school year cut-offs (1st March – 28th February). Four age categories were observed: Under 12 (n = 30), Under 13 (n = 25), Under 14 (n = 21), and Under 15 (n = 12). Given the age of our participants, we obtained parental assent and subject consent through institutionally approved informed consent documents that detailed the purposes and procedures of our investigation. Our study conformed to the Declaration of Helsinki, and the Heriot-Watt University research ethics committee provided ethics approval.

Procedures

Anthropometric and physical performance tests were conducted at the start of the school year (August). The initial assessment battery equated to Test 1 and represented an individual's initial fitness score. The same assessment protocol was conducted at the end of the school year (June, Test 2). Training session time was recorded, in minutes, for every session over the course of the year. Data referring to training time was entered into a player management system used by the SFA. Data was input on a daily basis, with regular data veracity checks (lead researcher generated monthly reports for coaching staff at the SFA) and the data later extracted for statistical analysis.

Anthropometric measures, including stretch stature, seated stature and body mass, were measured using a portable stadiometer and scales, respectively (SECA, Hamburg, Germany). Assessment of biological maturity in adolescents continues to be conducted using different methodologies. The gold-standard methods of estimating maturation status often involve either intimate physical examination (Tanner, 1962) and/or x-ray examination of skeletal maturation (Greulich & Pyle, 1959). Due to the invasive nature of these protocols, in many circumstances using these methods are either unacceptable, ethically questionable or impractical. Consequently, alternate measures to determine maturation have been developed. These measures use physical stature and anthropometric ratios of sitting and standing height (Khamis & Roche, 1994; Mirwald et al., 2002; Preece & Baines, 1978; Tanner et al., 1975) to determine maturity status in relation to peak height velocity. There is no consensus of which indirect method to determine biological maturity is preferable and each method is contingent upon the variables available at the time (e.g., availability of biological parents, feasibility of repeated measurements etc.). Similar concerns have been raised elsewhere (Goto et al, 2019) and justify the application of the method developed by Mirwald et al. (2002). The Mirwald et al. (2002) prediction equation was selected for calculating maturity offset since it is non-invasive, cost and time effective; therefore, the method is popular in field-based studies, similar to ours (e.g., Drenowatz et al., 2010; Gil et al., 2014; Lovell et al., 2019; Wickel & Eisenmann, 2007).

Linear speed was assessed via 20 m straight-line sprints using electronic timing gates (Brower Timing Systems, Utah, USA). Players' fastest of three attempts, each separated by a minimum 30 s rest, was recorded and used for analysis. Change of direction ability was assessed via a 15 m sprinting task incorporating a 90 degree turn at the 10 m point and the time taken was measured using electronic timing gates (Brower Timing Systems, Utah, USA). Players performed six repetitions of the change of direction test: three turning right and three turning left, each separated by 3 minutes rest. The mean of the fastest right and left repetitions for each player was retained for analysis. Each player also performed three squat jumps, with the highest jump height recorded and used for analysis. Jump height was measured using a Just Jump electronic jump mat (Probotics, Alabama, USA). Participants were instructed to place their hands on their hips and squat to approximately 90 degrees. They hold the squat position for three seconds before jumping as high as possible and landing on the same spot. Finally, each participant performed the yo-yo intermittent recovery test level 1 (YYIRTL1) as described by Krustrup et al. (2003). Each player's final distance achieved was recorded, in metres, and used for analysis.

Statistical analysis

We used Raincloud plots (Allen et al., 2019) to visualize our raw data, probability density, and boxplots of Test 1 and Test 2 data for the 20 m sprint, change of direction test, squat jump, and YYIRTL1 (Figure 1). Paired t tests were used to determine the change in physical performance test score across the training year (Test 2 versus Test 1), with uncertainty in the estimates presented as 95% confidence intervals. Using the *lme4* package, we performed a series of multiple regressions to determine the impact of our three predictor variables (Test 1, change in maturity offset and training time) on our outcome variable (change in performance [Test 2 minus Test 1]). The analysis was performed for the four physical performance tests (20 m sprint, change of direction, squat jump, and YYIRTL1) with separate models for the year groups (Under 15, Under 14, Under 13, Under 12) along with a model that combined all four age categories. For all models, regression assumptions and model metrics were checked and verified using the *broom* package, and the *relaimpo* package (Grömping, 2006) was used to calculate bootstrapped confidence intervals for contribution of each predictor (1000 replicates) and also to determine statistical differences between the relative contributions of the three predictors. A difference in the relative contribution between the three predictors on each test was declared when the 95% confidence interval for the difference did not include 0. For the overall models, p values are presented but not interpreted (Curran-Everett, 2020; Hurlbert et al., 2019). Statistical analyses were performed using R (version 3.6.1, R Foundation for Statistical Computing).

Results

Descriptive statistics (mean ± SD) for physical performance test scores (Test 1, Test 2), as well as changes in physical performance test scores and maturity offset (Test 2 minus Test 1), are presented in Table 1. At a group level, players progressed in most of the tests.

Regression diagnostics revealed no degrading collinearity between the three predictor variables. When all age categories were combined (n = 88 players), the three predictor variables (Test 1, change in maturity offset and training time) combined to explain 0.051, 0.248, 0.297, and 0.229 of the variation in the changes across the year in 20 m sprint, change of direction, squat jump, and YYIRTL1, respectively (Table 2). The only differences between the relative contributions of each predictor variable were observed for Test 1 versus training time on the change of direction test (0.168; 95% confidence interval 0.044 to 0.306), squat jump (0.209; 0.081 to 0.333) and YYIRTL1 (0.170; 0.036 to 0.294), and for the YYIRTL1, Test 1 was also a stronger predictor than maturity offset change (0.158; 0.003 to 0.291).

Table 1. Intra-season changes in physical performance test scores and maturity offset.

	Test 1	Test 2	Mean change
	Mean ± SD	Mean ± SD	(95% confidence interval)
Maturity offset (y)			
Under 15	0.84 ± 0.92	1.59 ± 1.02	0.76 (0.58 to 0.93)
Under 14	−0.51 ± 0.66	0.23 ± 0.70	0.74 (0.65 to 0.83)
Under 13	−1.36 ± 0.56	−0.56 ± 0.65	0.80 (0.72 to 0.88)
Under 12	−1.91 ± 0.49	−1.20 ± 0.96	0.71 (0.42 to 0.99)
All	−1.04 ± 1.10	0.30 ± 1.24	0.75 (0.65 to 0.85)
20 m sprint (s)			
Under 15	3.23 ± 0.14	3.20 ± 0.16	−0.04 (−0.11 to 0.03)
Under 14	3.47 ± 0.14	3.40 ± 0.14	−0.07 (−0.13 to −0.01)
Under 13	3.51 ± 0.13	3.47 ± 0.17	−0.04 (−0.09 to 0.01)
Under 12	3.57 ± 0.18	3.53 ± 0.19	−0.04 (−0.08 to −0.01)
All	3.48 ± 0.18	3.43 ± 0.20	−0.05 (−0.07 to −0.03)
Change of direction (s)			
Under 15	5.99 ± 0.22	5.87 ± 0.29	−0.12 (−0.30 to 0.05)
Under 14	6.16 ± 0.25	6.22 ± 0.28	0.06 (−0.05 to 0.17)
Under 13	6.26 ± 0.31	6.07 ± 0.22	−0.19 (−0.30 to −0.07)
Under 12	6.45 ± 0.29	6.36 ± 0.37	−0.09 (−0.21 to 0.03)
All	6.27 ± 0.32	6.18 ± 0.34	−0.09 (−0.15 to −0.02)
Squat jump (cm)			
Under 15	47.1 ± 4.6	46.4 ± 4.3	−0.66 (−2.50 to 1.17)
Under 14	40.7 ± 5.0	42.1 ± 5.6	1.50 (−0.70 to 3.56)
Under 13	38.4 ± 4.1	40.7 ± 3.4	2.40 (1.07 to 3.65)
Under 12	37.9 ± 4.4	37.7 ± 4.1	−0.20 (−1.75 to 1.35)
All	40.0 ± 5.4	40.8 ± 5.1	0.85 (0.01 to 1.70)
YYIRTL1 (m)			
Under 15	3128 ± 709	3357 ± 541	228 (3 to 454)
Under 14	2728 ± 623	2807 ± 699	79 (−225 to383)
Under 13	2086 ± 649	2495 ± 598	409 (226 to 592)
Under 12	2069 ± 653	2625 ± 721	556 (336 to 776)
All	2375 ± 758	2731 ± 705	355 (235 to 476)

SD, standard deviation; cm, centimetres; m, metres; s, seconds; y, years; YYIRTL1, yoyo intermittent recovery test level

Table 2. Multiple regression results (R^2) for variance in the change in physical performance test scores (20 m sprint, change of direction, squat jump and YYIRTL1) explained by test 1, change in maturity offset, and training time.

		20 m sprint [95% CI)	Change of direction [95% CI)	Squat jump [95% CI)	YYIRTL1 [95% CI)
Under 15 (n = 12)					
	Overall model	0.407 (p = 0.220)	0.373 (p = 0.270)	0.421 (p = 0.202)	0.777 (p = 0.005)
	Test 1	0.034 [0.008 to 0.280]	0.221 [0.014 to 0.683]	0.206 [0.030 to 0.653]	0.523 [0.351 to 0.707]
	Maturity Offset change	0.340 [0.075 to 0.753]	0.090 [0.006 to 0.421]	0.185 [0.019 to 0.512]	0.172 [0.095 to 0.344]
	Training time	0.034 [0.014 to 0.550]	0.062 [0.014 to 0.647]	0.030 [0.010 to 0.495]	0.082 [0.039 to 0.241]
Under 14 (n = 21)					
	Overall model	0.223 (p = 0.221)	0.244 (p = 0.180)	0.362 (p = 0.049)	0.196 (p = 0.283)
	Test 1	0.158 [0.021 to 0.401]	0.116 [0.013 to 0.358]	0.160 [0.016 to 0.409]	0.179 [0.028 to 0.412]
	Maturity Offset change	0.021 [0.012 to 0.344]	0.023 [0.006 to 0.176]	0.015 [0.007 to 0.267]	0.006 [0.001 to 0.104]
	Training time	0.043 [0.003 to 0.394]	0.105 [0.003 to 0.392]	0.187 [0.047 to 0.445]	0.011 [0.001 to 0.273]
Under 13 (n = 25)					
	Overall model	0.047 (p = 0.784)	0.626 (p < 0.001)	0.502 (p = 0.002)	0.396 (p = 0.013)
	Test 1	0.001 [0.001 to 0.269]	0.452 [0.241 to 0.683]	0.361 [0.104 to 0.600]	0.159 [0.010 to 0.456]
	Maturity Offset change	0.002 [0.000 to 0.174]	0.170 [0.030 to 0.386]	0.127 [0.011 to 0.372]	0.003 [0.001 to 0.126]
	Training time	0.045 [0.002 to 0.288]	0.005 [0.001 to 0.086]	0.013 [0.001 to 0.065]	0.235 [0.003 to 0.522]
Under 12 (n = 30)					
	Overall model	0.150 (p = 0.231)	0.202 (p = 0.114)	0.336 (p = 0.013)	0.394 (p = 0.004)
	Test 1	0.013 [0.001 to 0.202]	0.054 [0.003 to 0.219]	0.310 [0.086 to 0.586]	0.074 [0.003 to 0.288]
	Maturity Offset change	0.031 [0.002 to 0.198]	0.037 [0.001 to 0.299]	0.025 [0.001 to 0.196]	0.201 [0.036 to 0.462]
	Training time	0.105 [0.002 to 0.418]	0.111 [0.005 to 0.421]	0.001 [0.001 to 0.113]	0.120 [0.011 to 0.332]
All players (n = 88)					
	Overall model	0.051 (p = 0.228)	0.248 (p < 0.001)	0.297 (p < 0.001)	0.229 (p < 0.001)
	Test 1	0.020 [0.001 to 0.102]	0.176 [0.059 to 0.329]	0.215 [0.101 to 0.346]	0.186 [0.077 to 0.314]
	Maturity Offset change	0.021 [0.001 to 0.099]	0.066 [0.007 to 0.184]	0.076 [0.011 to 0.189]	0.028 [0.002 to 0.124]
	Training time	0.009 [0.001 to 0.083]	0.007 [0.002 to 0.052]	0.006 [0.001 to 0.047]	0.015 [0.003 to 0.096]

YYIRTL1, yoyo intermittent recovery test level 1; R^2, multiple regression R squared; p, p value; 95%CI, 95% confidence interval

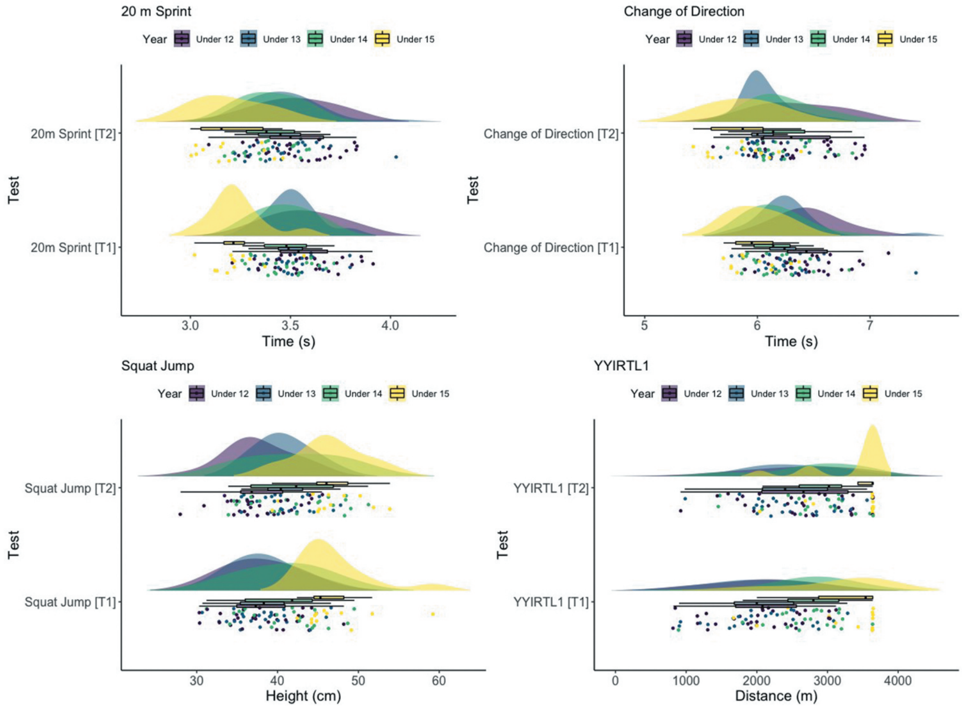

Figure 1. Raincloud plots, incorporating boxplots, showing Test 1 [T1] and Test 2 [T2] data for the 20 m sprint test, change of direction test, squat jump and YoYo Intermittent Recovery Test Level 1 (YYIRTL1).

Under 15

Predictor variables explained 0.373–0.777 of the variance in changes recorded in the four physical performance tests (Table 2). Differences in the relative contributions of each predictor were observed only for Test 1 versus training time (0.441; 0.236 to 0.646) and maturity offset change (0.351; 0.134 to 0.568) in the YYITRL1.

Under 14

Test 1, the change in maturity offset and training time combined to explain 0.196 to 0.362 of the variance for the change in physical performance tests with no statistical differences in the relative contributions of the predictors in each test.

Under 13

The three predictor variables combined to explain 0.047 to 0.626 of the variance in YYIRTL1, squat jump, and change of direction, respectively. Differences in relative contributions of each predictor were seen only for Test 1 versus training time for change of direction (0.447; 0.210 to 0.655) and squat jump (0.348; 0.073 to 0.584).

Under 12

Test 1, the change in maturity offset and training time combined to explain 0.150 to 0.394 of variance for the change in the physical performance tests. Differences in the relative contributions of each predictor were observed only for Test 1 versus training time (0.310; 0.022 to 0.563) in the squat jump test.

Discussion

The present study demonstrated that initial fitness, change in maturity offset and training time explained small, and inconsistent, proportions of the variance in physical development of adolescent footballers across one season.

Despite the prevalence of performance schools within the elite youth football landscape in the United Kingdom, a paucity of research has investigated the influence of this approach to player physical development. We therefore investigated the extent to which initial fitness, change in physical maturity, and training time explained changes in physical performance test scores over the course of one season. Despite uncertainty in our estimates the players generally improved their physical performance scores, at a group level. However, the proportion of the variance explained by the three predictor variables suggests other, non-measured factors also impacted on physical development.

When analysed as one group, initial fitness was the only predictor to show a stronger relative contribution to test score change than the other variables. When analysing change in test scores as separate groups, the proportion of the variance explained by each of the three predictor variables varied by age group and measure of physical performance, again with initial fitness being the only predictor showing a stronger relative contribution to test score change. These data show that players with superior initial fitness test scores demonstrated a smaller change in performance compared to those with poorer initial test scores. Such an observation makes sense intuitively and follows the exercise principle of individual differences (Arcos et al., 2018; Weston et al., 2014). It is important that coaches, scouts and other practitioners remain cognizant of this principle. It is also imperative that players' training history is considered for talent development programmes. Individuals that are closer to fulfiling their athletic potential may be superior to current performers on certain measures compared with those that are further away from realizing their potential; however, the latter may represent the eventual better performers (Tucker & Collins, 2012).

Physical maturity influences physical attributes relevant to football performance (Brownstein et al., 2018; Cumming et al., 2017; McCunn et al., 2017; Ryan et al., 2018). When analysed as a whole group, only 2 to 8% of the proportion of the variance was explained by change in maturity offset score. As a result, change in maturity offset over the course of one season did not appear to have a substantial impact on change in performance test scores when considering the entire cohort. Despite not being statistically stronger than initial fitness or training time, 9–34% of the variance in test score change in the Under 15 age group was explained by change in maturity offset score. While physical maturity status develops throughout adolescence, in boys it typically accelerates around the chronological age of 14 (Malina et al., 2004). Improvements in physical performance tests may be particularly apparent during this time due to increases in stature and muscle mass, although the rapid change in limb length can potentially elicit temporary impairment of sensorimotor function, colloquially referred to as "adolescent awkwardness" (Quatman-Yates et al., 2012). Therefore, coaches and practitioners should exercise caution when attempting to predict long-term success in adolescent footballing populations using anthropometric measurements, particularly in already talented groups (Craig & Swinton, 2020).

When considering all age categories analysed together (0.006 to 0.015) or as separate groups (0.001 to 0.235), training time over the season failed to account for a substantial proportion of the variation with regards to change in test status. These results therefore challenge the notion of using training time as an indicator of talent development programme quality, which is currently is suggested within the EPPP (Premier League, 2011), at least with reference to the physical preparation of youth football players.

A number of methodological limitations should be considered when interpreting the findings of the present study. While the predictor variables included in the present study were hypothesized to influence change in physical performance test scores, they do not represent an exhaustive list of potentially important factors. For example, training intensity, and a subsequent calculation of overall training load (e.g., Foster et al., 2001), along with adherence to a regular and structured strength training programme, will all influence physical development (Trecroci et al., 2020) but these were beyond the scope of this investigation. The majority of the players included in the study were also registered with professional club academies and trained/played with them several times per week. Our analysis did not incorporate this component, acknowledging the logistical issues involved in tracking training variables across multiple training groups. We acknowledge that our dependent variables provide only an insight into the physical attributes relevant to football performance. There are a number of other important variables that contribute to successful footballing performance, including psychological, technical and tactical aspects. Indeed, the effectiveness of additional training via performance schools, and other similar systematic training programmes, may better be judged via technical and tactical assessment. A further study limitation was the method used to calculate maturity offset. Despite the method being widely used in an applied setting, the calculation has greater error than other methods (Bailey et al., 2003). However, due to time, cost and access to biological parents, the Mirwald et al. (2002) equation was the only viable option for estimating biological maturity.

Nonetheless, our study holds important practical implications for those working in an applied setting within adolescent football, as well as other team sports. Following a season-long training period, adaptation to the training programme varies widely. Despite the three variables of interest explaining only small and inconsistent proportions of the variance with regards to physical development, the current findings suggest that players who perform less well during initial assessments make the greatest improvements compared to their peers. Therefore, making decisions regarding a player's potential based on the initial assessments risk excluding those that are likely to make the greatest gains from the training stimulus. Decision makers should bear this in mind when deciding which players to select, retain and release from such talent development programmes.

In conclusion, due to the small and inconsistent proportion of the variance that is explained by factors such as initial fitness, maturity status and training time, it may be the case that the effectiveness of additional training via performance schools, and other similar systematic training programmes, may better be judged via technical and tactical assessment.

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Disclosure statement

No potential conflict of interest was reported by the authors.

ORCID

Michael King http://orcid.org/0000-0003-2036-1965
Derek Ball http://orcid.org/0000-0002-4681-3889
Matthew Weston http://orcid.org/0000-0002-9531-3004

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