Multilevel Development Models of Explosive Leg Power in High-Level Soccer Players

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[1]Department of Movement and Sports Science, Ghent University, Ghent, BELGIUM; [2]Faculty of Sport Science and Physical Education, University of Coimbra, Coimbra, PORTUGAL; and [3]Faculty of Physical Education and Sport, Lusofona University of Humanities and Technologies, Lisbon, PORTUGAL

ABSTRACT

DEPREZ, D., J. VALENTE-DOS-SANTOS, M. J. COELHO-E-SILVA, M. LENOIR, R. PHILIPPAERTS, and R. VAEYENS. Multilevel Development Models of Explosive Leg Power in High-Level Soccer Players. *Med. Sci. Sports Exerc.*, Vol. 47, No. 7, pp. 1408–1415, 2015. **Purpose**: The aim of the present study was to model developmental changes in explosive power based on the contribution of chronological age, anthropometrical characteristics, motor coordination parameters, and flexibility. **Methods**: Two different longitudinal, multilevel models were obtained to predict countermovement jump (CMJ) and standing broad jump (SBJ) performance in 356 high-level, youth soccer players, age 11–14 yr at baseline. Biological maturity status was estimated (age at peak height velocity [APHV]), and variation in the development of explosive power was examined based on three maturity groups (APHV; earliest < P33, P33 < average < P66, latest > P66). **Results**: The best-fitting model for the CMJ performance of the latest maturing players could be expressed as: $8.65 + 1.04 \times \text{age} + 0.17 \times \text{age}^2 + 0.15 \times$ leg length $+ 0.12 \times$ fat-free mass $+ 0.07 \times$ sit-and-reach $+ 0.01 \times$ moving sideways. The best models for average and earliest maturing players were the same as for the latest maturing players, minus 0.73 and 1.74 cm, respectively. The best-fitting model on the SBJ performance could be expressed as follows: $102.97 + 2.24 \times$ age $+ 0.55 \times$ leg length $+ 0.66 \times$ fat-free mass $+ 0.16 \times$ sit-and-reach $+ 0.13$ jumping sideways. Maturity groups had a negligible effect on SBJ performance. **Conclusions**: These findings suggest that different jumping protocols (vertical vs long jump) highlight the need for special attention in the evaluation of jump performance. Both protocols emphasized growth, muscularity, flexibility, and motor coordination as longitudinal predictors. The use of the SBJ is recommended in youth soccer identification and selection programs because biological maturity status has no effect on its development through puberty. **Key Words:** TALENT IDENTIFICATION, LONGITUDINAL ANALYSIS, COUNTERMOVEMENT JUMP, STANDING BROAD JUMP, MATURATION, AGE AT PEAK HEIGHT VELOCITY

In elite youth sport, identifying future success has proven to be problematic. Indeed talent identification processes are predominantly based on current performances (36), whereas only longitudinal designs can provide precise information about the individual development of growth and performance characteristics (14). In youth soccer, multilevel longitudinal models have been established for functional capacities and soccer-specific skills (39), repeated sprint ability (38), aerobic performance (37), and intermittent-endurance capacity (12). At present, however, no such models are presented in the literature regarding the development of explosive power in a youth soccer population. Therefore, the present study focuses on understanding the factors determining explosive power and its longitudinal development in pubertal soccer players. Explosive power refers to the ability of the neuromuscular system to produce the greatest possible impulse in a given period and has been identified as one of the factors contributing to soccer performance (31).

It is well known that strength-related motor performances are influenced by chronological age, anthropometrical characteristics, and maturational status (5,20,21,35). For example, jumping performances (such as vertical jump and standing long jump) improve linearly from 5 until 18 yr of age in normally growing boys and until 14 yr of age in girls (20). Furthermore, in young male soccer players, vertical and standing long jump performances improve with increasing body size dimensions (i.e., stature and body size) and sexual maturity (2,22). More mature players benefit from the hormonal changes occurring during puberty (e.g., increase in serum testosterone), which stimulates muscle growth and strength (17). Moreover, an experimental study implementing an 8-wk strength program showed that mid- and postpubertal athletes improved more in explosive power and maximal strength compared to their prepubertal peers (26). Consequently, pathways to develop explosive power should be selected according to young athletes' maturational status.

The effect of general motor coordination and lower extremity flexibility on several measures of physical fitness has previously

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been (1,10,16,19,27). For example, a 5-yr longitudinal study investigated differences in fitness measures and skill performance between 38 children with high and low motor coordination, age between 5 and 7 yr at baseline (16). Results revealed that the high-motor coordination group outperformed the low-motor coordination group in the standing long jump during each year of the follow-up study. Additional research has revealed a positive correlation between hip flexion range of motion and vertical jump performance in male volleyball players (20). Therefore, integrating motor coordination (12,19,41) and flexibility training programs (7,15) in the development of youth soccer players may be beneficial for improving overall physical fitness.

The present study addressed the lack of multilevel longitudinal data for explosive leg power through different jumping protocols in young, high-level soccer players contrasting in biological maturation status (earliest, average, latest maturers). Two longitudinal models were obtained: one for the development of the countermovement jump (CMJ) and one for the standing broad jump (SBJ). We hypothesized that chronological age, body size dimensions, and motor coordination would significantly contribute to the development of explosive leg power (5,20,40). To our knowledge, this is the first study to examine the contribution of hamstring flexibility to the development of jump performances in young soccer players. It has previously been reported that peak velocities for flexibility occur 1 yr after peak height velocity (29), and improved flexibility allows for higher jump performance (8). On the basis of these findings, it could be expected that flexibility significantly predicts explosive leg power during the pubertal years. Therefore, we hypothesized that the development of explosive leg power would differ between maturity groups, with early maturers performing higher jumps (13,22).

MATERIALS AND METHODS

The present longitudinal data sample consisted of 2274 data points from 356 male youth soccer players (average of 6.4 observations per player), age between 11 and 14 yr at baseline (mean age of 12.0 ± 1.3 yr). All players were sourced from two professional Flemish soccer clubs and participated in a high-level youth soccer development program consisting of three training sessions and one game per week. Players were born between 1993 and 2002 and were assessed over 1 to 7 yr between 2007 and 2014. The total measurements of each individual player varied between 3 and 16 measurements (Table 1). Subjects were divided into four age groups according to their birth year at baseline (e.g., a player born in 2000 who was assessed for the first time in 2011 was assigned to the 11-yr age group): 11 yr (n = 163), 12 yr (n = 59), 13 yr (n = 70), and 14 yr (n = 64). Within all age groups, age varied between 10.5 and 11.5 yr, between 11.5 and 12.5 yr, between 12.4 and 13.5 yr, and between 13.5 and 14.5 yr for the 11-, 12-, 13-, and 14-yr age groups, respectively. All players and their parents or legal representatives were fully informed about the experimental procedures of the study before providing written informed consent. The Ethics Committee of the University Hospital approved the study. This research was performed without financial support and the authors assure no affiliations with or involvement in any organization or entity with any financial or nonfinancial interest in the subject matter or materials discussed in this article.

Chronological age was calculated as the difference between date of birth and date on which the assessments were made, and maturity status was estimated using Equation 3 from Mirwald et al. (28). This noninvasive method predicts the time before or after peak height velocity (i.e., maturity offset in years), based on anthropometrical variables (stature, sitting height, leg length, and weight) (28).

Predicted age at peak height velocity (APHV; yr) was estimated as chronological age minus maturity offset. According to Mirwald et al. (28), this equation accurately estimates the APHV of young males within an error of ±1.14 yr in 95% of cases. These data were derived from three longitudinal studies of Canadian and Belgian youth who were 4 yr from and 3 yr after peak height velocity (i.e., 13.8 yr). Accordingly, the age range from which the equation can confidently be used is between 9.8 and 16.8 yr; which corresponds well with the age range of the present sample. For each age group at baseline, the sample was divided into three maturity groups according to percentiles (11,12): APHV < P33 (=*earliest* maturing players), P33 < APHV < P66 (=*average* maturing players), P66 < APHV (=*latest* maturing players), resulting in an equal number of players in each maturity group.

Stature (Harpenden portable stadiometer; Holtain, UK) and sitting height (Harpenden sitting table; Holtain) were assessed to the nearest 0.1 cm; body mass and fat percentage (total body composition analyzer, BC-420SMA; TANITA, Japan) were assessed to the nearest 0.1 kg and 0.1%, respectively. Leg length (0.1 cm) was calculated as the difference between stature and sitting height. Fat mass (FM, 0.1 kg) was calculated as

TABLE 1. Number of subjects and number of measurements per age group.

	No. Measurements														
Age (yr)	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Total
11	45	65	46	58	29	24	34	18	9	13	8	7	3	5	364
12	54	63	33	46	39	32	44	25	17	15	12	13	5	7	405
13	41	35	31	41	45	40	48	27	32	23	15	18	7	11	414
14	50	44	30	36	51	46	57	22	39	23	15	21	7	7	448
15	25	29	19	16	38	31	42	21	39	22	15	17	8	9	326
16	8	7	9	17	17	26	23	12	28	16	8	16	8	5	200
17	2	4	2	8	18	9	22	5	17	8	5	6	7	4	117
Total measurements	225	248	170	222	238	208	270	130	176	120	78	98	45	48	2274
No. subjects	75	62	34	37	34	26	30	13	16	10	6	7	3	3	**356**

[body mass × (body fat / 100)]; this was subtracted from body mass to obtain fat-free mass (FFM, 0.1 kg). All anthropometric measures were taken by the same investigator to ensure test accuracy and reliability. The intraclass correlation coefficient for test–retest reliability and technical error of measurement (test–retest period of 1 h) in 40 adolescents were 1.00 (P < 0.001) and 0.49 cm for height and 0.99 (P < 0.001) and 0.47 cm for sitting height, respectively.

Hamstring flexibility was assessed using the sit-and-reach test (SAR) to the nearest 0.5 cm. The SAR is part of the Eurofit test battery and was conducted according to the guidelines of the Council of Europe (9). Motor coordination was investigated using three nonspecific subtests from the "Körperkoordinations Test für Kinder" (KTK), namely, moving sideways (MS), backward balancing (BB), and jumping sideways (JS), conducted according to the methods of Kiphard and Shilling (18). This testing battery has been demonstrated as reliable and valid in the age-range of the present population (41). Hopping for height, the fourth subtest of the KTK, was not included in the present study for the following reasons: the discriminating ability is relatively low in a homogeneous group of high-level players; the injury risk is increased with the high jumping ability of soccer players (mainly due to stature and leg length rather than motor coordination); and the test is very time consuming within the present test battery.

To evaluate jumping performance, SBJ and CMJ were executed. These two strength tests are commonly used to evaluate explosive leg power. The SBJ is part of the Eurofit test battery and was conducted according to the guidelines of the Council of Europe (9). CMJ was recorded using an OptoJump system (MicroGate, Italy) and conducted according to the methods described by Bosco et al. (6), with the arms kept in the akimbo position to minimize their contribution. The highest of three jumps was used for further analysis (0.1 cm).

Means (±95% confidence intervals [CI]) were calculated for each age group at baseline for age, APHV, anthropometrical characteristics, flexibility, motor coordination, and jumping performance. Earliest, average, and latest maturing players at baseline were compared for APHV, body size and composition, flexibility, motor coordination parameters, and jumping performance using ANCOVA with age as covariate.

For the longitudinal analyses, two multilevel regression analyses (CMJ and SBJ) were performed using MLwiN 2.16 software (30). The repeated measurements were assessed within (level 1) and between individuals (level 2). The following additive polynomial random-effects multilevel regression model was adopted to describe the developmental changes in explosive leg power (30):

$$y_{ij} = \alpha + \beta_j x_{ij} + k_1 Z_{ij} + \cdots + k_n Z_{ij} + \mu_j + \varepsilon_{ij}$$

where y is the jumping performance parameter on measurement occasion i in the jth individual; α is a constant; $\beta_j x_{ij}$ is the slope of the jumping performance parameter with age for the jth individual; and k_1 to k_n are the coefficients of various explanatory variables at assessment occasion i in the jth individual. Both μ_j and ε_{ij} are random quantities, whose means are equal to zero; they form the random parameters in the model. They are assumed to be uncorrelated and follow a normal distribution; μ_j is the level 2 and ε_{ij} the level 1 residual for the ith assessment of jumping performance in the jth individual. The model was built in a stepwise procedure; predictor variables (k fixed effects) were added one at a time, and likelihood ratio statistics were used to judge the effects of including further variables (4). If the retention criteria were not met (mean coefficient > 1.96, the SE of the estimate at an alpha level of 0.05), the predictor variable was discarded. The final model included only variables that were significant independent predictors.

Age, as an explanatory random variable, was centered on its mean value (i.e., 13.44 yr). To allow for the nonlinearity of the explosive leg power development, age power function (i.e., age centered^2) was introduced into the linear model (3). It has been demonstrated that maximal gains in explosive leg power occur in the later stages of the pubertal years (i.e., after the timing of peak height velocity) (20,29). Furthermore, at an older age, the improvement per year is expected to be smaller (29), which also allows for the use of age squared in the multilevel model. Finally, maturity groups (latest vs average vs earliest maturers) were incorporated into a subsequent analysis by introducing it as a fixed dummy-coded variable with latest maturers as the reference category.

Finally, multicollinearity was examined for each longitudinal model (CMJ = model A, SBJ = model B) using correlation matrix and diagnostic statistics (32). Variables with a variance inflation factor (VIF) > 10 and with small tolerance (1/VIF ≤ 0.10; corresponding to an R^2 of 0.90) were considered indicative of harmful multicollinearity (33).

RESULTS

Age, APHV, anthropometry, flexibility, motor coordination parameters, and explosive leg power with the 95% CI, by age group at baseline, are presented in Table 2. Generally, players improved with age on all parameters, except for backward balancing, which remained relatively stable (score around 57–58). Overall, significant differences between latest, average, and earliest maturing players at baseline were found for anthropometrical characteristics, SAR and SBJ, with the following gradient: earliest > average > latest maturers. Motor coordination parameters and CMJ did not differ between maturity groups (Table 3).

Both predicted jump performances (CMJ = model A; SBJ = model B) from the multilevel model are presented in Table 4. It can be seen in model A (deviance from the intercept only model = 5758.811) that, after each explanatory variable was adjusted for covariables, age (P < 0.01), age^2 (P < 0.01), leg length (P < 0.01, FFM (P < 0.01), SAR (P < 0.01), MS (P < 0.01), and maturity status (P < 0.01) had significant effects on CMJ. Equations for the three maturity groups were also derived. The best-fitting model for CMJ performance in the latest maturing players could be expressed as: 8.65 + 1.04 × age + 0.17 × age^2 + 0.15 × leg length + 0.12 × fat-free mass + 0.07 ×

TABLE 2. Mean scores ± SD for age, APHV, anthropometrical characteristics, flexibility, motor coordination, and jumping performance at baseline.

	Units	*n*	11 yr	*n*	12 yr	*n*	13 yr	*n*	14 yr
Chronological age	yr	163	10.8 ± 0.3	59	12.1 ± 0.3	70	13.0 ± 0.3	64	14.0 ± 0.3
APHV	yr	163	13.4 ± 0.3	59	13.9 ± 0.3	70	13.9 ± 0.5	64	13.8 ± 0.7
Earliest (<P33)	*n*		53		20		24		21
Average (P33 < *x* < P66)	*n*		55		19		22		21
Latest (P66<)	*n*		55		20		22		22
Stature	cm	163	144.4 ± 5.4	59	149.8 ± 5.8	70	158.4 ± 7.9	64	165.9 ± 8.9
Sitting height	cm	163	75.8 ± 2.7	59	77.6 ± 3.2	70	81.8 ± 4.2	64	85.9 ± 5.2
Leg length	cm	163	68.6 ± 3.4	59	72.3 ± 3.7	70	76.7 ± 4.3	64	80.0 ± 4.6
Body mass	kg	163	34.9 ± 4.1	59	38.6 ± 5.4	70	46.4 ± 7.7	64	53.6 ± 10.1
Body fat	%	163	14.0 ± 3.1	59	13.0 ± 3.8	70	11.9 ± 3.0	64	11.7 ± 3.4
FM	kg	163	5.0 ± 1.5	59	5.2 ± 2.2	70	5.6 ± 1.9	64	6.5 ± 3.0
FFM	kg	163	29.9 ± 3.1	59	33.4 ± 3.8	70	40.8 ± 6.4	64	47.1 ± 7.8
SAR	cm	163	20.2 ± 5.1	59	19.0 ± 5.9	70	21.6 ± 6.4	64	22.0 ± 6.3
Backward balancing	*n*	123	58 ± 9	31	57 ± 12	36	58 ± 11	40	57 ± 8
Moving sideways	*n*	123	59 ± 7	31	58 ± 8	36	62 ± 6	40	62 ± 8
Jumping sideways	*n*	123	91 ± 9	31	92 ± 10	36	95 ± 9	40	98 ± 8
CMJ	cm	163	23.7 ± 3.4	59	24.8 ± 3.1	70	27.6 ± 3.5	64	30.2 ± 4.6
SBJ	cm	163	169 ± 12	59	177 ± 15	70	190 ± 13	64	202 ± 19

APHV, age at peak height velocity; CMJ, countermovement jump; FFM, fat-free mass; FM, fat mass; SAR, sit-and-reach; SBJ, standing broad jump.

sit-and-reach+ 0.01 × moving sideways. The best models for average and earliest maturing players were the same as for the latest maturing players, minus 0.73 and 1.74 cm, respectively.

The significant parameters predicting SBJ performance in the multilevel model B (deviance from the intercept only model = 7031.520) were age ($P < 0.01$), leg length ($P < 0.01$), FFM ($P < 0.01$), SAR ($P < 0.01$), and JS ($P < 0.01$). Maturity groups had a negligible effect on SBJ performance (−45.32 ± 66.28, $P > 0.05$). The best-fitting model on SBJ performance could be expressed as follows: 102.97 + 2.24 × age + 0.55 × leg length + 0.66 × fat-free mass + 0.16 × sit-and-reach + 0.13 jumping sideways.

The random-effects coefficients describe the two levels of variance (within individuals = level 1, between individuals = level 2). The significant variances for both models (A and B) at level 1 indicate that all players significantly improved jumping performance at each measurement occasion within individuals (estimate > 1.96 × SE; $P < 0.05$). The between-individual variance matrix (level 2) indicated that players had significant explosive power growth curves in terms of curve intercepts (constant/constant, $P < 0.05$) and slopes (age/age, $P < 0.05$). The positive covariance between intercepts and slopes (model A = 1.02 ± 0.22, $P < 0.05$; model B = 8.75 ± 2.78, $P < 0.05$) suggests that, at the end of the pubertal years, the rate of improvement for both CMJ and SBJ continues to increase.

The measured and predicted curves for CMJ and SBJ performance were plotted by age in Figure 1. Predicted CMJ performance (*solid line* in Fig. 1) almost perfectly followed the measured CMJ performance (*dashed line* in Fig. 1). The predicted SBJ performance fluctuated below (11–13 yr) and above (13–17 yr) the measured SBJ performance. Notably, from the age of 15 yr, the discrepancy between predicted and measured SBJ performance increased with age.

DISCUSSION

The present study aimed to model the development of explosive power, assessed by CMJ and SBJ in 356 Flemish, high-level youth soccer players during the pubertal years. Two longitudinal multilevel models (for CMJ and SBJ) were obtained from 2274 measurements. Generally, results

TABLE 3. ANCOVA between maturity groups for APHV, anthropometry, flexibility, motor coordination, and jumping performance, controlling for age.

Variable	*n*	Latest maturers	*n*	Average maturers	*n*	Earliest maturers	*F*	*Post hoc*
APHV	118	14.1 ± 0.4	117	13.6 ± 0.3	121	13.2 ± 0.3	341.4*	1 > 2 > 3
Stature	118	146.5 ± 7.6	117	151.6 ± 9.8	121	157.9 ± 11.3	222.3*	1 < 2 < 3
Sitting height	118	75.7 ± 3.4	117	78.9 ± 4.3	121	82.7 ± 5.5	393.1*	1 < 2 < 3
Leg length	118	70.8 ± 4.6	117	72.7 ± 6.0	121	75.1 ± 6.2	59.7*	1 < 2 < 3
Body mass	118	35.8 ± 5.5	117	41.1 ± 8.9	121	46.6 ± 10.9	190.1*	1 < 2 < 3
Body fat	118	11.8 ± 3.0	117	13.0 ± 3.0	121	14.3 ± 3.7	19.0*	1 < 2 < 3
FM	118	4.2 ± 1.3	117	5.3 ± 1.6	121	6.7 ± 2.5	60.3*	1 < 2 < 3
FFM	118	31.6 ± 5.0	117	35.8 ± 8.0	121	39.9 ± 9.4	195.9*	1 < 2 < 3
SAR	118	19.1 ± 5.7	117	21.1 ± 5.4	121	21.6 ± 6.0	6.7 **	1 < 2 = 3
BB	80	58 ± 10	75	59 ± 9	75	57 ± 10	0.4	NS
MS	80	59 ± 7	75	60 ± 7	75	60 ± 8	1.0	NS
JS	80	92 ± 9	75	94 ± 10	75	93 ± 9	1.6	NS
CMJ	118	25.6 ± 3.7	117	26.0 ± 4.1	121	25.9 ± 5.2	0.6	NS
SBJ	118	177 ± 14	117	183 ± 19	121	181 ± 23	8.3*	1 < 2 = 3

Data are expressed as means ± SD.
Post hoc: 1 = latest maturers, 2 = average maturers, 3 = earliest maturers.
APHV, age at peak height velocity; BB, backward balancing; CMJ, countermovement jump; FFM, fat-free mass; FM, fat mass; JS, jumping sideways; MS, moving sideways; NS, not significant; SAR, sit-and-reach; SBJ, standing broad jump.
*Significant at the 0.001 level.
**Significant at the 0.01 level.

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TABLE 4. Multilevel regression models for counter movement jump and standing broad jump (2274 measurements).

Variance–Covariance Matrix of Random Variables	Countermovement Jump (Model A) Constant	Countermovement Jump (Model A) Chronological Age		Standing Broad Jump (Model B) Constant	Standing Broad Jump (Model B) Chronological Age
Level 1 (within individuals)					
Constant	3.557 (0.140)		*Level 1*	57.586 (2.244)	
Level 2 (between individuals)					
Constant	8.645 (0.816)	1.019 (0.219)	*Level 2*	125.138 (11.702)	8.752 (2.788)
Chronological age	1.019 (0.219)	0.734 (0.116)		8.752 (2.788)	6.841 (1.381)

Step	Fixed Explanatory Variables	*P*	*VIF*	*1/VIF*	Value at Final Step *k*	Value at Final Step SE	Step	*P*	*VIF*	*1/VIF*	Value at Final Step *k*	Value at Final Step SE
1	Intercept (constant)				8.652	2.787	1				102.974	9.899
2	Chronological age	<0.01	1.27	0.79	1.043	0.142	2	<0.01	1.22	0.82	2.235	0.491
3	Chronological age^2	<0.01	1.07	0.94	0.171	0.025	3	NS				
4	Leg length	<0.01	1.06	0.95	0.154	0.041	4	<0.01	1.05	0.95	0.552	0.139
5	Fat-free mass	<0.01	1.21	0.83	0.118	0.027	5	<0.01	1.17	0.86	0.659	0.097
6	Fat mass	NS		6	NS							
7	Sit-and-reach	<0.01	1.01	0.99	0.071	0.018	7	<0.01	1.01	0.99	0.164	0.070
8	Backward balancing	NS					8	NS				
9	Moving sideways	<0.01	1.03	0.97	0.027	0.009	9	NS				
10	Jumping sideways	NS					10	<0.01	1.02	0.98	0.131	0.029
11	Average vs latest maturers	<0.01	1.04	0.96	−0.728	0.427	11	NS				
	Earliest vs latest maturers				−1.741	0.459						
IGLS deviance from the null model					5758.811						7031.520	
–2 × log likelihood					8549.929						13,575.770	

Latest maturers were used as baseline measure, and other maturity groups were compared with it.
Random-effects values are estimated mean variance ± SE; fixed-effect values (explanatory variables) are estimated mean coefficients ± SE; chronological age was adjusted about the origin using mean age ± 13.5 yr.
Multicollinearity statistics: VIF (variance inflation factors); 1/VIF (tolerance).
k, mean coefficients of various explanatory variables; NS, not significant; IGLS, iterative generalized least squares.

revealed that chronological age and its squared value, body size (given by leg length), body composition (FFM derived from a two-component model), flexibility (SAR) and motor coordination (one item from a three-component test battery) are predictors of explosive power. To our knowledge, this is the first study to report the importance of hamstring flexibility in the development of explosive power. Remarkably, the variability in maturity status seems to benefit later maturing soccer players when assessing the CMJ but not the SBJ. These findings suggest that different jumping protocols (vertical vs long jump) highlight the need for special attention in evaluating jump performances. Both protocols emphasized growth, muscularity, flexibility, and motor coordination as longitudinal predictors. The use of the SBJ is recommended in youth soccer identification and selection programs because biological maturity status has no effect in SBJ development through puberty.

It was initially hypothesized that the predicted longitudinal models for explosive power would differ between players contrasting in maturity status. Therefore, an estimate of biological maturation was considered as a dummy variable (later vs average vs earlier maturing players based on tertiles) and as a candidate variable in the analyses. Introducing maturity groups into the model predicting CMJ substantially differed from the model that included six predictor variables. Notably, compared to the latest maturing players, the average and earliest maturing players jumped significantly lower (−0.73 and −1.74 cm, respectively; Table 4). In contrast, introducing maturity groups into the model predicting SBJ was not significantly different from the model that included five predictor variables. We do, however, acknowledge the limitation of the present method of categorizing players into maturity groups based on tertiles (11,12), which does not correspond to previously described methods (28). Indeed,

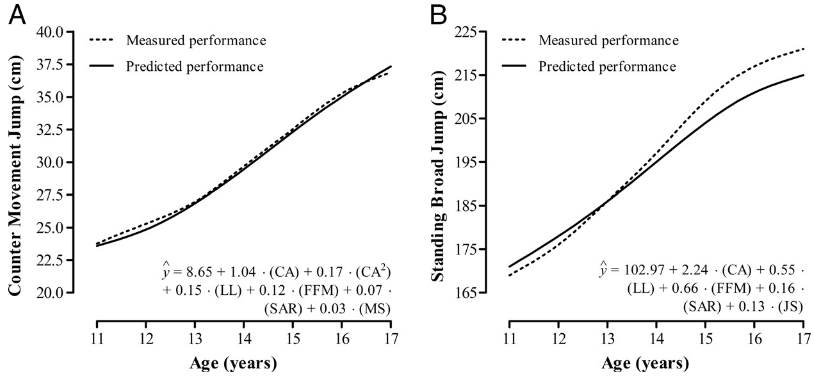

FIGURE 1—Measured and predicted performance for countermovement jump (A) and standing broad jump (B) aligned by chronological age.

Mirwald et al. defined pubertal players as follows: early = preceding the average APHV by >1 yr, average = ±1 yr from APHV, and late = >1 yr after APHV. Moreover, it has been stated that the sport of soccer systematically excludes late(r) maturing boys and tends to favor more early and average maturing players as chronological age and sport specialization increase (13,23).

A recent study attempted to validate the estimated timing of peak height velocity against actual APHV obtained using Preece–Baines Model 1 in an 11-yr longitudinal study of 193 Polish school boys (24); actual APHV was underestimated at younger ages and overestimated at older ages. Moreover, mean differences between actual and predicted APHV were reasonably stable between 13 and 15 yr. It was concluded that predicted APHV has applicability among average maturing boys, age 12 to 16 yr. The mean age of the current sample at baseline was 12.0 ± 1.3 yr, and therefore, the application of the maturity offset protocol to estimate APHV should be recognized as a limitation.

To our knowledge, this is the first study to report higher values for explosive power (CMJ) in later maturing soccer players during the pubertal years. This contrasts with previous findings in Portuguese soccer players (varying in maturity status between 11 and 15 yr) (13,22), where players advanced in maturity status outperformed their less mature counterparts on vertical jump tests. With this in mind, as soccer players grow older, late maturing players are systematically excluded (13,23). Indeed, the proportion of late maturing male soccer players in a Portuguese sample (classified on the basis of differences between skeletal and chronological ages) decreased from 19.5% to 5.6% between the ages of 11 and 12 yr and 13 and 14 yr, respectively (13). Therefore, it is possible that the present high-level youth soccer sample might also exclude these late maturing players and that the selection process favors a homogeneous group of early to average maturing soccer players. Nevertheless, baseline values for CMJ revealed similar performances for all maturity groups (Table 3). Further research should focus on the inclusion of other maturity indicators such as skeletal age or Tanner stage of pubic hair development (13,21,25).

In contrast to CMJ, no differences between maturity groups were found for SBJ performance, despite the smaller performance for the latest maturers at baseline compared with the average and earliest maturers (Table 3). Arm swing and countermovement before jumping have been identified as important factors for SBJ performance (1). Indeed, the standing long jump performed with arm swing increased the take-off velocity of the center of gravity by 15% compared with arms restricted, resulting in a possible benefit of 40 cm (1). Interlimb coordination seems to heavily influence SBJ performance, evidenced by the significant role for certain subtests of the KTK (i.e., moving sideways for the CMJ and jumping sideways for the SBJ) in the prediction of explosive power. Therefore, less explosive players can counter their more explosive peers by a proper jumping technique, which may lead to further benefits in the later stages of puberty when muscle mass is increased (20). Therefore, the inclusion of specific programs focusing on general motor coordination is recommended within the pubertal years because it is beneficial for improving the explosive power of all players. In addition, motor coordination tasks are independent of maturational status (40) and provide more insight into the future potential of young athletes (40).

In agreement with our hypothesis, chronological age and body size dimensions significantly contribute to the development of explosive power. A cross-sectional study in French schoolchildren explored the relationship between anthropometrical characteristics and three different jumping tasks (34). The authors found similar and increasing jumping performances in boys and girls until the age of 14 yr. From then on, boys significantly outperformed girls. This is likely explained by the increase in leg length and leg muscle volume. Indeed, the present findings revealed that, on average, an increase of 1 cm in leg length would improve CMJ and SBJ performance by 0.15 and 0.55 cm, respectively. In addition, during the pubertal years, the role of FFM, which correlates with the "muscularity" of the player, seems significant in predicting explosive power. Moreover, the growth curve for muscular strength is almost identical to that of body size during childhood and adolescence (20). However, in elite soccer players, after the age of 13–14 yr, estimated velocities for vertical jump and standing long jump performances remained constant, which might reflect the growth in muscle mass and the influence of systematic sports training (29). Therefore, monitoring increases in anthropometrical characteristics (i.e., stature, leg length and FFM) on a regular basis would allow youth coaches to better understand the players' individual development of explosive power.

No information is currently available in the literature regarding the influence of flexibility on different jumping tasks in an athletic population, without implementing different stretching protocols. Several studies have focused on the acute effects of different stretching protocols on fitness performances in soccer players (7,15). However, many of their outcomes are confusing and contain contrasting conclusions. Moreover, relationships between improved hamstring flexibility and fitness performances remain unclear. To date, the influence of hamstring flexibility on the development of explosive power in young soccer players has not been investigated. This study revealed that SAR performance significantly contributed to CMJ and SBJ performances during the pubertal years. An inverse relationship between the development of growth in stature and flexibility for a short period around peak height velocity has been reported (29). The estimated velocity curve for flexibility peaks 1 yr after peak height velocity, suggesting that more flexible hamstrings enhance jump performances from 13 to 14 yr of age.

From the age of 13 to 14 yr (i.e., around peak height velocity), the slope of the developmental curves for CMJ and SBJ (Fig. 1) becomes steeper, suggesting a substantial increase in muscle mass (20,29). Therefore, we strongly recommend the implementation of additional strength programs from the age of 13 to 14 yr in regular soccer training, with respect to individual growth and maturation. Furthermore, the positive covariance between intercepts and slopes for both jumping models (Table 4) suggests that explosive power is still increasing even after the age of 17 yr, which explains why the developmental curves do not plateau (Fig. 1).

This study showed that the longitudinal development of explosive power in young soccer players is related to growth, muscle mass, flexibility, and general motor coordination. Maturity-related variation in the development of CMJ seems to benefit the more late maturing players. However, we acknowledge that the use of the maturity offset protocol is a limitation and future studies need to include skeletal age as a classification index. Finally, this study provides a rationale for youth coaches to approach the development of explosive power on an individual basis, with scientifically based identification and evaluation processes. Further studies should consider specific training parameters such as annual minutes of training and playing time and an estimate of training intensity.

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APPLIED SCIENCES

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