# Skeletal Maturation, Body Size, and Motor Coordination in Youth 11–14 Years

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*[1]Department of Physical Education and Sport, University of Madeira, Funchal, PORTUGAL; [2]Department of Mathematical Sciences, University of Essex, Colchester, England, UNITED KINGDOM; [3]CIFI²D, Faculty of Sport, University of Porto, Porto, PORTUGAL; [4]Department of Kinesiology, Faculty of Kinesiology and Rehabilitation Sciences, KU Leuven, Leuven, BELGIUM; and [5]Department of Kinesiology and Health Education, University of Texas, Austin, TX*

## ABSTRACT

FREITAS, D. L., B. LAUSEN, J. A. R. MAIA, E. R. GOUVEIA, M. THOMIS, J. LEFEVRE, R. D. SILVA, and R. M. MALINA. Skeletal Maturation, Body Size, and Motor Coordination in Youth 11–14 Years. *Med. Sci. Sports Exerc.*, Vol. 48, No. 6, pp. 1129–1135, 2016. **Purpose**: The objective of this study is to estimate the relative contribution of biological maturation to variance in the motor coordination (MC) among youth and to explore gender differences in the associations. **Methods**: Skeletal maturation (Tanner-Whitehouse 3), stature, body mass, and MC (*Körperkoordinationstest für Kinder*) were assessed in 613 youths, 284 boys and 329 girls 11–14 yr of age. Standardized residuals of skeletal age on chronological age were used as the estimate of skeletal maturity status independent of chronological age. Hierarchical multiple regression analyses were used to analyse associations between skeletal maturity status and MC. **Results**: Skeletal maturity status by itself, i.e., standardized residuals of skeletal age on chronological age (step 3) explained a maximum of 8.1% of the variance in MC in boys ($\Delta R_3^2$ in the range of 0.0%–8.1%) and 2.8% of the variance in girls ($\Delta R_3^2$ in the range of 0.0%–2.8%), after controlling for stature, body mass and interactions of the standardized residuals of skeletal age on chronological age with stature and body mass. Corresponding percentages for the interactions of the standardized residuals of skeletal age and stature and body mass, after adjusting for stature and body mass (step 2) were 8.7% in boys ($\Delta R_2^2$ in the range of 0.3%–8.7%) and 7.1% in girls ($\Delta R_2^2$ in the range of 0.1%–7.1%). Chow tests suggested structural changes in $\beta$-coefficients in the four MC tests among boys and girls, 12–13 yr. **Conclusion**: The percentage of variance in the four MC tests explained by skeletal maturation was relatively small, but the relationships differed between boys and girls. By inference, other factors, e.g., neuromuscular maturation, specific instruction and practice, sport participation, and others may influence MC at these ages. **Key Words:** GROWTH, MATURATION, MOTOR DEVELOPMENT, YOUTH

Motor coordination (MC) plays an important role in the day to day activities of youth. In general, well-coordinated youths show higher levels of physical activity (14) and physical fitness (11,16) than less-coordinated peers, whereas poorer levels of MC are associated with obesity in youth (2,10). MC is also central to speed, jumping and agility, and associated skills, which are central to participation in games and sports (23). More recently, MC has been associated with emotional function and academic achievement/skills among youth (15,20).

Several motor performances are influenced by individual differences in maturity status, although the influence is more marked during adolescence than in childhood (3,4). Earlier studies were correlational, whereas more recent approaches have addressed potential interactions between maturity status and body size as factors affecting performance. In two earlier studies, skeletal age, alone or interacting with chronological age, stature, or body mass, accounted for a maximum of 17% of variance in motor fitness in boys (3) and was not a predictor of the Flamingo balance, plate tapping, and vertical jump in girls (4). Another approach used standardized residuals of the regression of skeletal age on chronological age as the indicator of maturity status to account for the relationship between skeletal and chronological ages (18). The interaction terms of the standardized residuals of skeletal age on chronological age with stature and body mass explained between 2% and 9% of variance in the standing long jump, dash, and ball throw for distance in children 7–12 yr of age.

The literature addressing the influence of maturity status on MC is less extensive. Using a specific MC battery (*Körperkoordinationstest für Kinder* (KTK) [19]) with children 7–10 yr of age, standardized residuals of skeletal

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age on chronological age alone accounted for a maximum of 9.0% of variance in MC tasks over that attributed to body size *per se* and to the interactions between standardized residuals of skeletal age on chronological age and body size.

The present article extends the preceding analysis to youth 11–14 yr of age. Changes in size, proportions, body composition, and strength associated with the transition into puberty and with puberty *per se* may influence specific measures of MC. To this end, the purpose of this study was to evaluate the relationships among skeletal maturity status, body size, and MC in single-year age groups of boys and girls 11 to 14 yr of age and to explore gender differences within each age group. It was hypothesized that skeletal maturation *per se* or interacting with body size has a negligible influence on the explained variance in MC, over and beyond body size, and that this relationship is different among boys and girls.

## METHODS

**Participants.** Data were from the "Healthy Growth of Madeira Study," a cross-sectional study with 12 birth cohorts, assessed/measured in 2005/2006. The sample and sampling procedures, study design, organizational aspects, and protocols have been previously described (12). Briefly, all participants ($n$ = 1637, 801 boys and 836 girls, age 3 to 15 yr) attended 40 public and/or private schools from the 11 districts of Madeira and Porto Santo Islands, Portugal. A proportional stratified sampling procedure was carried out by a member of Statistics Portugal. The number of participants enrolled in each school was proportional to the number of children living in this district. In each district, at least one kindergarten, one primary school, and one high school participated in the study. Children of specific ages and sex were randomly selected within each school. The current analysis was limited to 613 healthy youths, 284 boys and 329 girls, 11 to 14 yr of age (Table 1). Procedures were explained to each participant, and written informed consent was granted from parents or legal guardians before testing. The Scientific Board of the University of Madeira and the Regional Ethics Committee for Health approved the study.

**Field team.** Six teachers of physical education were trained by members of the research team and collected the data. The field team completed a 3-month training program, 2 h·d$^{-1}$, at the University of Madeira. The program included theoretical and practical sessions. First, instructions and demonstrations for anthropometry and MC testing were given to the field team. Second, the field team members practiced on each other. Third, protocols were tested in 10 children (six boys and four girls, 8 to 12 yr). And fourth, the field team participated in a pilot study of anthropometry in 46 primary school children, 3–10 yr of age, and of MC in 30 children, 6–10 yr. The children were assessed twice with an interval of 1 wk.

**Anthropometry.** Measurements were taken in the gymnasium or an unused classroom. Stature and body mass were measured using a standardized protocol (7). Stature was measured with a portable stadiometer (Siber-Hegner, GPM) to the nearest 0.1 cm, and body mass was measured on a balance-beam scale accurate to 0.1 kg (Seca Optima 760, Germany). Children wore a swimming costume (two-piece for females) without shoes and with jewelry removed. In the pilot study, the absolute and relative intraobserver technical errors of measurement were 0.31 cm

TABLE 1. Descriptive statistics of study variables.

| | Age Intervals (yr) | | | |
|---|---|---|---|---|
| | 11 | 12 | 13 | 14 |
| **Variables** | $\bar{x}$ ± SD | $\bar{x}$ ± SD | $\bar{x}$ ± SD | $\bar{x}$ ± SD |
| Boys | ($n$ = 84) | ($n$ = 75) | ($n$ = 67) | ($n$ = 58) |
| Chronological age (yr) | 11.5 ± 0.30[a] | 12.5 ± 0.30 | 13.5 ± 0.27 | 14.5 ± 0.27 |
| Skeletal age (yr) | 11.3 ± 1.09 | 12.6 ± 1.08 | 13.5 ± 1.03 | 14.8 ± 1.03 |
| Anthropometry | | | | |
| Stature (cm) | 147.2 ± 7.5 | 154.2 ± 8.1 | 160.3 ± 8.7 | 166.6 ± 7.3 |
| Body mass (kg) | 42.5 ± 9.9 | 48.9 ± 12.1 | 52.4 ± 11.8 | 56.6 ± 11.0 |
| MC[b] | | | | |
| Balancing backward | 53.8 ± 12.1 | 57.5 ± 10.7 | 56.8 ± 10.2 | 60.2 ± 8.5 |
| Hopping on one leg | 47.1 ± 14.2 | 54.7 ± 13.1 | 58.9 ± 15.7 | 66.9 ± 8.3 |
| Jumping side to side | 53.9 ± 12.3 | 60.0 ± 13.2 | 64.8 ± 14.1 | 68.8 ± 11.9 |
| Shifting platforms | 43.7 ± 6.1 | 46.5 ± 5.9 | 48.7 ± 6.2 | 52.2 ± 6.8 |
| Girls | ($n$ = 97) | ($n$ = 89) | ($n$ = 73) | ($n$ = 70) |
| Chronological age (yr) | 11.5 ± 0.31 | 12.4 ± 0.31 | 13.5 ± 0.29 | 14.4 ± 0.29 |
| Skeletal age (yr) | 11.8 ± 0.94 | 12.4 ± 0.79 | 13.3 ± 0.88 | 14.2 ± 0.57 |
| Anthropometry | | | | |
| Stature (cm) | 149.3 ± 7.2 | 154.0 ± 6.6 | 156.0 ± 10.1 | 160.4 ± 6.5 |
| Body mass (kg) | 43.9 ± 9.8 | 46.4 ± 10.2 | 51.8 ± 10.4 | 54.4 ± 8.8 |
| MC[b] | | | | |
| Balancing backward | 55.1 ± 12.3 | 55.9 ± 10.5 | 57.6 ± 10.1 | 56.0 ± 10.7 |
| Hopping on one leg | 44.1 ± 14.1 | 47.8 ± 14.1 | 52.6 ± 12.9 | 57.5 ± 11.6 |
| Jumping side to side | 55.6 ± 10.8 | 60.2 ± 12.0 | 62.6 ± 10.9 | 66.0 ± 11.1 |
| Shifting platforms | 42.4 ± 5.2 | 45.4 ± 5.8 | 45.5 ± 6.9 | 49.1 ± 6.2 |

Units for each motor test: balancing backward—number of successful steps; hopping on one leg over an obstacle—sum of successful attempts at each height (3 points for the first, 2 points for the second, and 1 point for the third attempt); jumping side to side—number of correct jumps in 15 s; shifting platforms—number of successful transfers (2 points per transfer) in 20 s.

[a] Data are presented as means and SD.

[b] Raw scores.

and 0.26% for stature, and 0.66 kg and 2.56% for body mass, respectively. Test–retest reliability via ANOVA-based intraclass correlations ranged from 0.98 to 0.99 for stature and body mass.

**MC.** The four tests of the KTK MC test battery (19) were administered to all youth:

1. Balancing backward. The child walked backward on three balance beams of 3 m in length and 5 cm in height, but of different widths: 6.0, 4.5, and 3.0 cm. Three trials were administered and scored for each beam, for a total of nine trials. The assessor awarded the first point when the second foot left the starting board placed in front of the beam (25 cm × 25 cm × 5.7 cm) and touched the first beam. One point was given for each successful step; a maximum of 8 points could be achieved per trial on each beam. The maximum score was 3 × 3 × 8 = 72.
2. Hopping on one leg. The test required the child to jump over one or more superposed foam-based panels (60 cm × 20 cm × 5 cm, each). The starting height depended on the child's age and on the outcome of the practice trials (one or two per leg). For children over 6 yr, the test had a minimum height of 5 cm (one foam panel) for each leg. If the child failed this jump, then he or she would start the first scored attempt at a height of 0 cm; if the child succeeded, then he or she would begin the first scored attempt with the recommended starting height for age. When hopping over the foam panels, the assessor ensured that the child started to hop at an adequate distance from the foam panels (about 1.50 m). After hopping over the foam panels, the child continued to hop on the same foot for at least two more hops. During the trial, the other foot may not touch the ground. The child had three attempts at each height, which were scored in the following manner: valid first attempt = 3 points; valid second attempt = 2 points; valid third attempt = 1 point. For a starting height of 5 cm or higher, if the first attempt was successful, the assessor awarded 3 points for all the underlying heights. If, at any given height, the child failed all three attempts, the next height was conducted only if the sum of the two lower heights was at least 5 points. With 12 foam panels (a total height of 60 cm) plus the 0-cm height (with no foam panel), a maximum of 39 points could be achieved per leg for a total of 78 points.
3. Jumping side to side. The child was required to jump laterally with both feet over a wooden platform (100 cm × 60 cm × 2 cm) as many times as possible in 15 s. A wooden slat (60 cm × 4 cm × 2 cm) was attached in the middle of the platform. The child was instructed to jump laterally over the wooden slat with both feet simultaneously; both feet had to leave and land on the floor at the same time. A total of two attempts were given, and the number of correct jumps was summed.
4. Shifting platforms. The child was required to move sideways on wooden boxes (25 cm × 25 cm × 2 cm with four supports of 3.7-cm height attached to each corner), placed side to side on the floor, as many times as possible in 20 s. A free space of 3 or 4 m in the direction to which the transposition would take place was required. The boxes should not be placed too far away or too near, and the child should not spend too much time trying to align the boxes. The assessor stood facing the child (at a maximum distance of 2 m) and moved along with the child as he or she transposed the boxes. Each successful transfer from one platform to the other was given 2 points, one for shifting the platform and one for transfer of the body; the number of points in 20 s was recorded. Two attempts of 20 s each were performed with a break of minimally 10 s. The score of the two attempts was recorded and summed.

Raw scores for each MC test were used in the analysis. Intraclass correlation coefficients in the pilot study indicated good test–retest reliability. Correlations ranged from 0.64 (hopping on one leg; 95% confidence interval, 0.25–0.83) to 0.90 (balancing backward; 95% confidence interval, 0.80–0.95).

**Skeletal age.** Radiographs of the left hand wrist were taken for each child with a portable unit (Model TOP 25 (140 kVp, 25 mA); For You Company, Belgium). A local hospital technician, with the assistance of a field team member, completed this task at the school. Radiographs were assessed using the Tanner–Whitehouse 3 method (25). The radius, ulna, and metacarpals and phalanges of the first, third, and fifth rays and seven carpals (excluding the pisiform) were compared with the written criteria, and a stage and associated maturity score was assigned to each bone. The summed maturity scores were converted to radius–ulna–short bone (RUS) and carpal skeletal ages. All readings were made by the first author who was trained by an experienced assessor (Gaston Beunen). There was a high agreement between independent ratings of the same observer (91.8%) and between his ratings and those of Gaston Beunen (85.3%) (1).

RUS skeletal ages were used in the present analysis because the carpal bones were near maturity and/or already mature during puberty and the growth spurt, whereas changes in the long bones leading to the epiphyseal union were the dominant activities in skeletal maturation at these ages (21). Nevertheless, 25 youths (4 boys, 14 yr; 2 girls, 13 yr; and 19 girls, 14 yr of age) were excluded from the analysis because they were already skeletally mature, i.e., a maturity score of 1000 in RUS. A skeletal age is not assigned to skeletally mature individuals. Consequently, the total sample ($n$ = 613) included youth with full data and who had not reached skeletal maturity as assigned by the Tanner–Whitehouse 3 RUS method.

**Statistics.** Statistic analyses were performed using STATA, version 13 (24), and SPSS 22.0 (17). Means and SD were calculated by sex within each age group for chronological age, skeletal age, height, body mass, and each MC test. A two-way ANOVA was used to test for the effect of chronological age (four levels: 11, 12, 13, and 14) and sex (two levels: boys and girls) on each MC test and to explore interaction effects. Effect size is given by the partial eta squared ($\eta_p^2$). Multiple comparisons were performed by means of Tukey honest significant difference tests.

Skeletal age regressed on chronological age, and the standardized residuals of skeletal age on chronological age (SAsr) were retained for analysis. The residuals represented the effects of skeletal age, independent of chronological age (18). The associations between each MC test (dependent variables) and the SAsr alone or interacting with stature and/or body mass (independent variables (IV)) were analyzed with sex-specific hierarchical multiple regressions within each age group. To reduce collinearity, stature and body mass (log transformed) were *z*-standardized within each age and sex, and first- and second-order interactions were computed from the standardized values before being modelled. SAsr–stature and SAsr–stature–body mass interactions were excluded in some models because of collinearity ($r > 0.76$) (9). Correlations between each MC test and SAsr ranged from −0.31 and 0.19. Variance inflation factors ranged from 1.398 to 3.919. Assumptions of linearity and homoscedasticity were also met.

Stature, body mass, and stature × body mass were entered as covariates in the first block. The second block included SAsr × stature, SAsr × body mass, and SAsr × stature × body mass. SAsr was entered alone in the third block. Changes in the explained variance ($R^2$ change) across blocks were estimated using *F*-tests. The effect size was defined as $f^2 = (R_{AB}^2 - R_A^2)/(1 - R_{AB}^2)$, where $R_A^2$ is the variance accounted for a block of IV *A* and $R_{AB}^2$ is the combined variance accounted for the block of IV *A* and another block of IV *B* (8). Structural change tests (Chow test [6]) were used to test the equality between sets of coefficients (intercept and/or slopes) in boys and girls, i.e., whether relationships between biological maturation and MC were the same among boys and girls. This was conducted only at 12 and 13 yr of age, steps 2 and 3, where the regression models presented the same number of parameters. The residual sums of squares obtained in each of the three ANOVA (boys, girls, and sexes pooled) were used in the computations. The level of significance was set at $P < 0.05$, unless otherwise stated.

## RESULTS

Sample sizes and means and SD for all variables are summarized in Table 1 by the sex and age group. Several comparisons are significant. The interaction between chronological age and sex is significant for stature ($F_{3,605} = 8.83$, $P < 0.001$, $\eta_p^2 = 0.04$). Older children are heavier ($F_{3,605} = 39.59$, $P < 0.001$, $\eta_p^2 = 0.16$) and perform better on three tests: balancing backward ($F_{3,605} = 3.18$, $P = 0.024$, $\eta_p^2 = 0.02$), hopping on one leg ($F_{3,605} = 41.65$, $P < 0.001$, $\eta_p^2 = 0.17$), jumping side to side ($F_{3,605} = 30.89$, $P < 0.001$, $\eta_p^2 = 0.13$), and shifting platforms ($F_{3,605} = 40.10$, $P < 0.001$, $\eta_p^2 = 0.17$). Boys perform better than girls in hopping on one leg ($F_{3,605} = 33.87$, $P < 0.001$, $\eta_p^2 = 0.05$) and shifting platforms ($F_{3,605} = 19.08$, $P < 0.001$, $\eta_p^2 = 0.03$). Other main and interaction effects for MC tests are not significant.

Estimated percentages of variance in each MC test explained by SAsr alone or interacting with body size derived from the hierarchical regression analyses are summarized by the sex and age group in Table 2. Details of the regression analyses, specifically step 3 of the models, are presented in the Supplemental Digital Content (Tables S1–S4, http://links.lww.com/MSS/A636, http://links.lww.com/MSS/A637, http://links.lww.com/MSS/A638, http://links.lww.com/MSS/A639), whereas the complete tables will be provided upon request.

For balancing backward, step 2 of the model, entering the SAsr–stature, SAsr–body mass, and SAsr–stature–body mass interactions explains 1.0%–3.7% and 0.3%–7.1% of variance in boys and girls, respectively, over and above the stature, body mass, and stature–body mass interactions. The addition of SAsr in step 3 of the model accounts for extra 0.0%–1.5% (boys) and 0.0%–2.5% (girls) of the variance in balance scores. Changes in $R^2$ from step 1 to step 2 and from step 2 to step 3 are not statistically significant in all age groups and for boys and girls (see Table S1, Supplemental Digital Content 1, results of the hierarchical multiple regression analyses of size and skeletal maturation on balancing backward, http://links.lww.com/MSS/A636).

For hopping on one leg, the addition of the SAsr–stature, SAsr–body mass, and SAsr–stature–body mass interactions in the second model explains 0.3%–7.5% and 0.1%–3.6% of variance in boys and girls, respectively, after accounting for the variance in hopping on one leg explained by step 1 (see Table S2, Supplemental Digital Content 2, results of the hierarchical multiple regression analyses of size and skeletal maturation on hopping on one leg, http://links.lww.com/MSS/A637). Step 2 adds significantly to the explained variance in boys at 14 yr ($\Delta R_2^2 = 0.08$, $F$ change$_{1,53} = 5.07$, $P = 0.029$, $f^2 = 0.10$). In the third model (step 3), the percentage of variance

TABLE 2. Summary table of the percentages of variance explained by standardized residuals of skeletal age on chronological age (SAsr) interacting with body size ($\Delta R_2^2$) and SAsr alone ($\Delta R_3^2$) for each MC test by the sex and age group 11 to 14 yr.

| | Balancing Backward | | | | Hopping on One Leg | | | | Jumping Side to Side | | | | Shifting Platforms | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Variable[a] | 11 | 12 | 13 | 14 | 11 | 12 | 13 | 14 | 11 | 12 | 13 | 14 | 11 | 12 | 13 | 14 |
| Boys | | | | | | | | | | | | | | | | |
| $\Delta R_2^2$ | 3.7[b] | 1.7 | 1.0 | 2.7 | 2.0 | 1.5 | 0.3 | 7.5 | 0.5 | 2.4 | 7.5 | 0.3 | 0.5 | 5.1 | 8.7 | 4.3 |
| $\Delta R_3^2$ | 0.0 | 0.6 | 1.5 | 0.4 | 0.0 | 4.5 | 4.0 | 5.0 | 0.4 | 0.8 | 1.0 | 3.6 | 0.0 | 0.1 | 2.4 | 8.1 |
| Girls | | | | | | | | | | | | | | | | |
| $\Delta R_2^2$ | 0.3 | 3.9 | 4.8 | 7.1 | 0.1 | 0.7 | 3.6 | 1.9 | 2.4 | 3.3 | 5.3 | 4.7 | 2.5 | 0.3 | 1.2 | 0.4 |
| $\Delta R_3^2$ | 2.5 | 2.3 | 2.3 | 0.0 | 0.1 | 1.6 | 2.8 | 2.4 | 0.2 | 0.3 | 1.3 | 0.0 | 0.8 | 0.7 | 0.4 | 2.0 |

$\Delta R_2^2$, changes in $R^2$ from step 1 to step 2; $\Delta R_3^2$, changes in $R^2$ from step 2 to step 3.

[a] Block 1: stature, body mass, and stature × body mass; block 2: SAsr × stature, SAsr × body mass, and SAsr × stature × body mass; block 3: SAsr.

[b] Percentage.

explained by SAsr beyond that explained by steps 1 and 2 is 0.0%–5.0% in boys and 0.1%–2.8% in girls. The third model adds significantly to the explained variance in boys at 12 yr ($\Delta R_3^2 = 0.05$, $F$ change$_{1,67}$ = 4.03, $P = 0.049$, $f^2 = 0.06$).

The second step of hierarchical multiple regression analysis for jumping side to side (see Table S3, Supplemental Digital Content 3, results of the hierarchical multiple regression analyses of size and skeletal maturation on jumping side to side, http://links.lww.com/MSS/A638), in which the interactions of SAsr and body size are entered, accounts for 0.3%–7.5% (boys) and 2.4%–5.3% (girls) of the variance over and above the variance explained by the stature, body mass, and stature × body mass. In the third step of the model, stature, body mass, and stature × body mass (block 1) were entered followed by SAsr × stature, SAsr × body mass, and SAsr × stature × body mass (block 2). The variance explained in jumping side to side increased 0.4%–3.6% in boys and 0.0%–1.3% in girls. In steps 2 and 3, however, the addition of the variables did not significantly increase $R^2$.

Results of the corresponding analysis for shifting platforms (see Table S4, Supplemental Digital Content 4, results of the hierarchical multiple regression analyses of size and skeletal maturation on shifting platforms, http://links.lww.com/MSS/A639) indicate that over and above the variance accounted for by stature, body mass, and stature × body mass, the variance explained by block 2 variables, i.e., interactions of SAsr with the stature, body mass, and stature and body mass, ranged from 0.5% to 8.7% in boys and from 0.3% to 2.5% in girls. Corresponding estimates for step 3, over and beyond the variance accounted for blocks 1 and 2, were 0.0%–8.1% in boys and 0.4%–2.0% in girls. The $F$ change in $R^2$ ($\Delta R_3^2$) was significant in boys at 14 yr ($\Delta R_3^2 = 0.08$, $F$ change$_{1,52}$ = 5.09, $P = 0.028$, $f^2 = 0.10$).

Results of the chow tests are summarized in Table 3. With the exception of balancing backward at 13 yr, results of all other $F$ tests are higher than the critical value indicating structural differences in the regression coefficients for all MC test performances of boys and girls. For balancing backward, step 2 at 13 yr indicates no structural differences between boys and girls (chow test $F = 0.98 < F_{7,126} = 2.08$, $\alpha = 0.05$); i.e., the relationship between balancing backward and IV is the same in boys and girls.

TABLE 3. Structural changes among boys and girls.

| | Regression Models | | | |
|---|---|---|---|---|
| | Step 2 | | Step 3 | |
| MC | Chow Test ($F$) | Structural Change | Chow Test ($F$) | Structural Change |
| Balancing backward | | | | |
| 12 yr | 4.60*** | Yes | 5.93*** | Yes |
| 13 yr | 0.98 | No | 2.25* | Yes |
| Hopping on one leg | | | | |
| 12 yr | 10.16*** | Yes | 10.26*** | Yes |
| 13 yr | 4.13*** | Yes | 2.79** | Yes |
| Jumping side to side | | | | |
| 12 yr | 2.14* | Yes | 2.07* | Yes |
| 13 yr | 5.49*** | Yes | 6.26*** | Yes |
| Shifting platforms | | | | |
| 12 yr | 5.11*** | Yes | 5.00*** | Yes |
| 13 yr | 7.41*** | Yes | 8.11*** | Yes |

*$P < 0.05$.
**$P < 0.01$.
***$P < 0.001$.

## DISCUSSION

The estimated contribution of skeletal maturation expressed at the standardized residual of skeletal age on chronological age (SAsr) to performances on four MC tests was considered in a sample of largely adolescent youth 11–14 yr. The amount of variance in each of the four MC tests explained by SAsr or by SAsr interacting with body size was small and overlapped considerably between boys and girls. In addition, age-related trends in the percentage of variance explained in each of the four MC tests were largely inconsistent with perhaps three exceptions: the variance explained by skeletal age alone increased with age in boys from 11 to 14 yr for jumping side to side and shifting platforms, whereas the variance explained by skeletal age interacting with body size increased with age in girls for balancing backward.

A previous analysis of relationships among skeletal maturation, body size, and MC in Portuguese children 7–10 yr showed that SAsr alone explained a maximum of 9.0% of variance in MC in boys but only 1.0% in girls (13). This was generally consistent with the variance explained in the current study among youth 11–14 yr. The specific percentages of variance explained in MC tests in boys 7–10 yr (13) and 11–14 yr (this study) were as follows: balancing backward, 1.5% and 1.0%; hopping on one leg, 5.0% and 9.0%; jumping side to side, 3.6% and 2.0%; and shifting platforms, 8.1% and 1.0%. Corresponding percentages of variance in girls 7–10 and 11–14 yr, respectively, were as follows: balancing backward, 2.5% and 0.0%; hopping on one leg, 2.8% and 1.0%; jumping side to side, 1.3% and 0.0%; and shifting platforms, 2.0% and 1.0%. Although the percentages of explained variance were not high, the results suggested a tendency for SAsr by itself to account for a higher share of the variance in MC tests in boys compared with girls. By inference, the possibility that the influence of skeletal maturation on MC may be sex specific at these ages merits further study.

Interestingly, none of the interaction terms of SAsr and body size reached statistical significance in youth 11–14 yr (see Tables S1–S4, Supplemental Digital Content 1–4, http://links.lww.com/MSS/A636, http://links.lww.com/MSS/A637, http://links.lww.com/MSS/A638, http://links.lww.com/MSS/A639). By inference, relationships between SAsr and MC tests did not differ as a function of stature and/or body mass in youth 11–14 yr. However, it may be worth noting that step 2, interactions between SAsr and body size, added relatively little to the explained variance in jumping side to side (7.5%) and shifting platforms (8.7%) at 13 yr and in hopping on one leg (7.5%) at 14 yr of age in boys (Table 2). And, in step 3, variance explained by SAsr alone added a relatively large amount to the explained variance in shifting platform (8.1%) at 14 yr in boys. These ages (13–14 yr) approximate the timing of peak height velocity in European boys (21). Among girls, it was only at 14 yr when there was an increase in the explained variance in balancing backward (7.1%) by SAsr interacting with body size. This age is about 2 yr later than the mean age at peak height velocity in European girls (21). However, effect sizes of increments from step 1 to step 2 or from step 2 to step 3 were small ($f^2 = 0.06$ to 0.10). Among Portuguese children 7–10 yr, SAsr influenced balancing backward and hopping on one leg through its interaction with stature (13). Nevertheless, the results of both studies highlight the small increments in the total explained variance in specific MC tests.

Although the KTK test battery was described as a measure of MC on the basis of a factor analysis in which the four tests loaded on a single factor (19), it is possible that other functional capacities are involved. For example, hopping on one leg and jumping side to side are both items that require projection of the body through space. As such, performance of the tests likely requires a combination of agility, speed, and strength in addition to balance and coordination. On the other hand, balancing backward and shifting platforms do not require projection of the body through space, and as such are perhaps largely dependent on balance and coordination *per se*.

The study of Portuguese children 7–10 yr also considered fundamental movement skills in addition to MC (13). For locomotor skills (running, galloping, hopping, leaping, horizontal jumping, and sliding), SAsr alone contributed 0.0%–2.0% to the total variance over and above the body size, and interactions of SAsr with body size in boys and girls. For object control skills (striking a stationary ball, stationary dribbling, catching, kicking, overhand throwing, and underhand rolling), the contributions of SAsr alone were from 1.0% to 7.0% in boys and 2.0% to 3.0% in girls. Although earlier studies addressing the contribution of skeletal maturation to variation in motor performance have used different motor tasks and analytical strategies, the results were generally consistent with the hierarchical regression analyses; i.e., skeletal age alone or interacting with body size explained relatively small percentages of the variance in motor performances. With standardized residuals of skeletal age on chronological age as the indicator of maturity status, interrelationships among skeletal maturity, body size, and three motor performance tasks were addressed in American children 7–12 yr (18). Results of the stepwise regression analyses showed that standardized residuals of skeletal age on chronological age were the best predictor of the 35-yard dash, standing long jump, and softball throw for distance. The variance explained by the standardized residuals (partial $R^2$) was 7%–14% in boys and 4% in girls, whereas the interaction terms (SAsr × stature, SAsr × body mass, and SAsr × stature × body mass) explained 3%–7% of the variance in boys and 2%–9% in girls. Overall, the variance in the three motor performance tasks attributed to skeletal maturation overlapped the variance observed in MC in the present study.

Also using a regression approach, the contribution of skeletal age alone or in combination with chronological age and body size to variance in a variety of fitness tests was considered in Belgian girls 6–16 yr (4) and boys 12–19 yr (3). Among girls, skeletal age alone or in combination with chronological age and body size did not explain any of the variance in balance (Flamingo stand), speed of limb movement (plate tapping), vertical and standing long jumps, and shuttle run (speed and agility). Among boys, skeletal age alone or in combination with chronological age and body size did not explain any of the variance in the stick balance task, but it explained variable amounts of the variance in the vertical jump (0%–17%), shuttle run (0%–10%), and plate tapping (0%–13%). The highest estimation of the explained variance occurred during the interval of the adolescent spurt in boys, 10% in the shuttle run at 14 yr, 13% in plate tapping at 14 yr, and 12%–17% in the jump at 14–16 yr. It should be noted that estimated peak gains in the shuttle run and plate tapping occurred before the age at peak height velocity, whereas estimated peak gain in the vertical jump occurred after the age at peak height velocity in the longitudinal series of the Belgian boys (5). Although the MC tasks considered and the analytical strategy used in this study were different, the maximum amounts of variance explained by skeletal age alone or in combination with body size (Table 2) occurred around the interval of the growth spurt in Portuguese boys, jumping side to side (7.5%, 13 yr), hopping on one foot (7.5%, 14 yr), and shifting platforms (8.7%, 13 yr; 8.1%, 14 yr). In contrast, there did not appear to be an association between explained variance and the interval of the growth spurt in Portuguese girls; the maximum amount of variance explained in balancing backward (7.1%) was noted at 14 yr, which is about 2 yr after the average age at peak height velocity in European girls (21).

This study of the relationships among skeletal maturation, body size, and MC assessed with the KTK test battery in youth 11–14 yr is somewhat novel. Hierarchical analysis, which permits the estimation of unique and incremental contributions of IV, is an advantage compared with other regression approaches. The large sample size, the representativeness of the sample, and the reliability of the data also provide confidence in generalizing the results to other samples. However, given the cross-sectional design, variation in potential associations over time during adolescence cannot be ascertained. This would require a longitudinal research to capture temporal changes and permit control of interindividual variation in rates of growth and maturation and also rates of development of MC.

Skeletal maturation was assessed with the most recent version of the Tanner–Whitehouse RUS method (25). A number of 14-yr-old boys and 13- and 14-yr-old girls were already skeletally mature and were excluded from the analysis. Nevertheless, performances on the four MC tests did not statistically differ between the small samples of skeletally mature and larger samples of nonskeletally mature boys and girls 14 yr of age (table available upon request). The small sample of skeletally mature boys was taller and heavier than nonmature boys (though not significant), whereas the skeletally mature girls were significantly heavier though not taller. It should also be noted that the criterion for the final stages of the radius and ulna is simply that epiphyseal fusion has begun. The interval from the beginning of epiphyseal fusion to the complete union is thus not considered. As such, it is likely that many of the mature boys and girls may not have been skeletally mature if another assessment protocol was used.

Despite the above limitations, skeletal maturation *per se* or interacting with body size had a limited role in explaining variation in MC in Portuguese youth 11–14 yr of age. By inference, other factors are involved including interactions among neuromuscular maturation, differential rates of growth in body segments during the transition into adolescence, habits of outdoor play and physical activity, and perhaps specific instruction and practice as in physical education and sport, among others (13,22).

In summary, standardized residuals of skeletal age on chronological age, alone or interacting with body size, explained a maximum of 8.7% of total variance in four MC tests, over and above the body size in Portuguese youth 11–14 yr of age. The estimated variances accounted for by skeletal age alone or in interactions with body size overlapped considerably between boys and girls and did not vary consistent among age groups 11–14 yr.

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