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Relationship of Biological Maturation with Muscle Power in Young Female Athletes

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ABSTRACT

International Journal of Exercise Science 14(6): 696-706, 2021. There is still no consensus on how biological maturation (BM) affects the muscle power of upper and lower limbs in young people. The objective was to verify associations between BM and muscle power, as well as to compare the muscle power of upper (ULP) and lower limbs (LLP) among young athletes in different stages of BM. The sample consisted of 79 female athletes (10.9 ± 1.11 years old). Regarding BM, the sample was divided into three groups: delayed BM, synchronized BM, and accelerated BM. BM was identified by subtracting chronological age from bone age (BA). BA was measured by a mathematical model based on anthropometry. The muscular power of the upper limbs was analyzed by the medicine ball launch test, and that of the lower limbs was analyzed by the countermovement jump on a force platform. BM and BA correlated with ULP (BA: r =0.74; BM: r =0.65) and LLP (BA: r = 0.50; BM: r =0.41). In the comparisons of the tests of ULP and LLP, the groups with synchronized and accelerated BM were superior to the group with delayed BM. The advance of BM is associated with the ULP and LLP, as well as the advance of the BM affects muscle power in young female athletes. This occurs due to the increase in body mass resulting from the advancement of BM, which may favor the predominance of lean body mass, assisting in the production of muscle strength.

KEY WORDS: Sport, puberty, adolescents, children’s, bone age, muscle potency

INTRODUCTION

Biological maturation (BM) is controlled by a set of genetic factors and occurs throughout the life of a human being (17). This can be affected by external influences (i.e., lifestyle, nutrition, socioeconomic class), and because of this fact, BM will not always be synchronized with chronological age (16, 17). According to Scheffler and Hermanussen (23), through the evaluation of bone age (BA) (BA is method considered gold standard), it is possible to find the exact stage of BM in relation to chronological age (CA), and through the results obtained BM can be classified into three stages: delayed, synchronized or accelerated.

Thus, the evaluation of BM in relation to CA becomes an important instrument for several areas (medicine, physical education and psychology, for example) that study growth, development and performance in physiological, psychological and neuromotor aspects (1, 5, 28). Thus, the most reliable method for the analysis of BA and, consequently, BM is the hand/wrist X-ray examination (23). However, this method has a high financial cost and emits high levels of radiation, which can be harmful to the health of young people undergoing the procedure (16). Thus, Cabral et al. (4) developed a mathematical equation that uses anthropometric data to determine the bone age of young people. The equation by Cabral et al. (4) is not invasive and has significant validation with the X-ray of the hand and wrist ($r^2 = 0.754$; $p < 0.05$), proving to be a reliable method.

In addition, in the environment of sports and health professionals, the equation for estimating BA is a tool with better applicability (4). Therefore, it is highlighted that the influence of BM on several motor skills has been associated with human performance indicators, such as strength, agility, and body speed, which are biomechanical and physiological characteristics that can favor the possibility of better neuromotor performance (3).

It is known that individuals with advanced BM offer a greater predisposition for neuromotor performance in relation to their CA than those with synchronized or delayed BM (22). It is noteworthy that among the neuromotor performance indicators, there is muscle power, which is defined as the production of strength in a short period of time (14). Within sports practice, having characteristics of motor skills related to the ability to generate muscle power can be decisive for success in several sports, such as athletics, football and fights for example (26).

In this sense, it is known that in the context of neuromotor performance, BM significantly affects the maximum isometric or static strength (i.e., peak muscle strength) in young athletes during the puberty period (2, 28). However, information on how BM can affect muscle power (i.e., maximum strength performed dynamically in a short period of time) for young athletes who experience puberty is still uncertain (7, 8, 16, 17, 22, 28).

Given the assumptions, the present study hypothesizes that BM can be associated with muscle power, as well as the advance of BM stages can affect the muscle power of young athletes. Therefore, the present study aimed to verify associations between BM and muscle power, as well as to compare the muscle power of upper and lower limbs among young athletes in different stages of BM.

METHODS

Participants

The sample consisted of 79 young female athletes (volleyball, basketball, handball, jiu-jitsu, karate, swimming). According to Matsudo, Rivet and Pereira (18), the sample is classified as level III athletes (on an increasing scale from I to VI) characterized by: (i) performing school physical education; (ii) being part of a sports program, and (iii) participate in competitions within the sports program.

The sample size was determined with observation in previous studies, considering the BM and neuromotor performance of upper and lower limbs (2, 7). Thus, an effect size of 0.80, an α <0.05, and an β = 0.80 were estimated, resulting in a sampling power of >0.80 ("T" statistic for correlations). For the analysis of sample power, open-source software was used G* Power® (Version 3.0; Berlin, Germany). The final sample was chosen intentionally in a sports club in the city of Natal – Brazil.

The participants came to the laboratory on two occasions: (i) To receive information, together with their respective legal guardians, on the objectives, risks, and benefits of the research. (ii) To sign an Informed Consent Form and to perform anthropometric measurements and neuromuscular tests, in that order (All participants and their guardians signed the consent terms accepting to participate in the present study). Volunteers were instructed to suspend vigorous activities in the 48 hours before data collection and consumption of caffeine-based substances (i.e., coffee, chocolates, soft drinks).

The following inclusion criteria were adopted: (i) Be physically active in practicing any sport. (ii) Not having muscle or bone injuries that could compromise the performance of the tests proposed by the present study. (iii) Be aged between 8 and 14 years old. We adopted as exclusion criteria: (i) Complement your diet with any exogenous substance such as creatine and branched-chain amino acids, for example. (ii) Refuse to participate in all the procedures of this study.

The research proposal was analyzed and approved by the Ethics and Research Committee - CEP of the Federal University of Rio Grande do Norte (Opinion: 1249937), according to Resolution 466/12 of the Brazilian National Health Council, on 12/12 / 2012, strictly respecting the ethical principles for research with human beings contained in the Declaration of Helsinki (29). It is worth mentioning that the study met all the international requirements and standards of the STROBE Checklist for observational studies (25). This research was carried out fully in accordance to the ethical standards of the International Journal of Exercise Science (20).

Protocol

Team of researchers: The participants were evaluated by a team of researchers previously trained and qualified in the procedures used to collect anthropometric data and power tests of the upper and lower limbs.

Anthropometric assessments: The anthropometric evaluations were performed with barefoot subjects wearing only light clothing, where their body mass was measured using a Filizola® (São Paulo, Brazil) digital scale (with a capacity up to 150 kg and a variation of 0.10 kg); for stature, the Sanny® stadiometer (São Paulo, Brazil) (0.1 mm accuracy) was used; skin fold (triceps) were measured using a Sanny® scientific adipometer (São Paulo, Brazil) (0.1 mm accuracy); the perimetry (biceps) was measured using a Sanny® anthropometric tape (São Paulo, Brazil); and a Sanny® caliper (São Paulo, Brazil) was used to measure bone diameters (Humerus and femoral). All evaluations were based on the International Society of the Advancement of Kinanthropometry (ISAK) protocol (9, 13).

Power test of upper limbs: The upper limb power (ULP) was assessed using the medicine ball test (19). The subject was seated with her back against a wall and her knees extended. At the evaluator's signal, a medicine ball (Ax Sports®, Tangará, Brazil) with a mass of 2 kg positioned at the height of the sternum, was thrown horizontally with both hands. Trunk movement was not allowed (19). The test was performed three consecutive times interspersed with a passive recovery period of three minutes (19). The best attempt was retained for analysis (19).

Lower limb power test: For the lower limb power test (LLP), the counter-movement vertical jump test (CMJ) was used (15). Before this assessment, the participants received instructions on how to execute the movement and leaped to familiarize themselves with the test, seeking to reduce errors during the execution of the proposed assessment protocol (15). Then, starting from an orthostatic position, held for 3 s, with the knees flexed at approximately 90º and hands fixed on the waist, the participants were instructed to perform a countermove to jump vertically as high as possible (15). Three attempts were made, interspersed with a passive recovery of 60 s, the best attempt was retained for analysis (15). This test was performed on a force platform (CEFISE®, São Paulo, Brazil) connected to the Jump Test Pro 2.10 software (CEFISE®, São Paulo, Brazil).

Biological Maturation analysis: BM was analyzed using BA that was verified by the equation proposed by Cabral et al.,(4) the equation is highly reliable compared to the gold standard hand and wrist X-ray method ($r = 0.868$; $r^2 = 0.754$; $p < 0.05$) and consists of:

(i) $\text{Bone age} = -11.620 + 7.004 \times (\text{Height}_{(m)}) + 1.226 \times (\text{Dsex}) + 0.749 \times (\text{Age}_{(years)}) - 0.068 \times (\text{Triceps Skinfold}_{(mm)}) + 0.214 \times (\text{Corrected Arm Circumference}_{(cm)}) - 0.588 \times (\text{Humerus Diameter}_{(cm)}) + 0.388 \times (\text{Femoral Diameter}_{(cm)})$

Dsex: For male sex = 0; for female sex = 1. (m): meters. (mm): millimeters. (cm) centimeters.

Therefore, to determine the maturation stage from the bone age result, the equation proposed by Malina and Bouchard (16) was performed:

(ii) Biological Maturation = (Chronological Age – Bone Age)
After equation (ii) the subjects can be classified into three stages: Delayed (Results ≤-1), Synchronized (Results between -1 and 1), and Accelerated (Results ≥ 1).

After acquiring the BM classification, for data analysis, seeking to make comparisons between performance in upper and lower limb power tests, the results of the participants in this research were divided into three groups: group I included girls with BM delayed, group II included girls with synchronized BM, and group III included girls with accelerated BM.

Statistical Analysis
The normality of the data was verified by the Kolmogorov-Smirnov test and asymmetry and kurtosis z-score (-1.96 to 1.96). For sample characterization, the assumption of normality of the variables: Mass (Kg), Stature (Cm), body mass index (Kg/m^2), chronological age, bone age, and Biological maturation was not denied. Thus, for the sample characterization analysis, Bonferroni's correction was applied, followed by comparisons performed by the one-way ANOVA test, followed by Tukey's post hoc. The technical error of anthropometric measurements was analyzed as follows (21): Acceptable ≤ 1.0%.

Thus, the assumptions of normality were negated for the variables: LLP (Cm) and ULP (Cm). The correlations were analyzed using the Spearman test, thus the magnitude used was that of Schober, Boer and Schwarte (24): Insignificant: r <0.10; Weak: r = 0.10-0.39; moderate: r = 0.40-0.69; Strong: r = 0.70-0.89; Very strong: r = 0.90-1.00. Bonferroni's correction was applied, and later comparisons were made. The analysis of the difference between variances of variables ULP (Cm) and LLP (Cm) between the groups (Group I = delayed maturation, Group II = normal maturation, and Group III = accelerated maturation) was performed using the Kruskal-Wallis test. Posteriorly, for comparison post hoc between groups, Mann-Whitney U test and Bonferroni's post hoc were applied. All analyzes were performed using the statistical software R (version 4.0.1; R Foundation for Statistical Computing®, Vienna, Austria), and the significance level of $\alpha<0.05$ was adopted.

RESULTS

The Bonferroni correction was successful; therefore, concerning comparative analyses among the groups, we highlight those that did not have a significant difference for chronological age, while for body mass index (BMI), total body mass, BA, and BM, group III (Accelerated BM) was superior to the other groups (p <0.05) (Table 1). All significant differences were confirmed by Tukey's post hoc test (p <0.05). It is noteworthy that the technical error of all the measures analyzed remained below 1%.

Table 2 shows the correlations between LLP and ULP with BM and BA in the total sample. For LLP, the correlation was positive for BA (p <0.0001) and for BM (p <0.0001). For ULP, the correlations were positive both for BA (p <0.0001) and for BM (p <0.0001).

Table 1. Sample Characterization

Variables	Total Sample	Group I	Group II	Group III
Sample (n %)	79 (100%)	24 (29%)	28 (36%)	27 (35%)
Mass (Kg)	43.5 ± 7.34	34.3 ± 6.00	42.7 ± 11.6	51.6 ± 10.6*
Stature (Cm)	1.48 ± 1.23	1.40 ± 0.07	1.50 ± 0.10	1.55 ± 0.06
BMI (Kg/m²)	21.3 ± 4.02	17.6 ± 0.05	18.8 ± 0.15	26.9 ± 0.08*
CA	10.9 ± 1.11	11.2 ± 1.00	11.8 ± 1.30	12.2 ± 1.50
BA	11.4 ± 1.83	10.0 ± 1.08	11.5 ± 1.89	14.0 ± 1.77*
BM	1.32 ± 0.73	- 1.67 ± 1.07	0.30 ± 1.09	2.00 ± 1.89*

Tests performed in the analysis of table 1: Bonferroni correction followed by one-way ANOVA, followed by Tukey's post hoc.*: Significant statistical difference ($F_{(2.0)}$: 2.06; $p<0.05$). n: Number. %: Percent. Group I: Delayed maturation. Group II: synchronized maturation. Group III: accelerated maturation. Cm: Centimeters. Kg: Kilograms. Kg/m²: Kilograms per square meter.BMI: body mass index. CA: chronological age. BA: bone age. BM: Biological maturation.

Table 2. Correlations of the power of upper and lower limbs with bone age with maturation.

Variables	LLP (Cm)		ULP (Cm)	
	Total Sample			
	r	r - CI 95%	r	r - CI 95%
BA	0.74**	[0.70; 0.76]	0.50**	[0.44; 0.52]
BM	0.65**	[0.63; 0.70]	0.41**	[0.39; 0.45]

Tests performed in the analysis of table 2: correlations by Spearman test. ** Significant statistical difference ($p<0.0001$). BA: bone age. BM: Biological maturation. Cm: Centimeters. r: Correlation coefficient. CI: Correlation coefficient confidence interval r. (p): Degree of significance of the correlation. ULP: Upper limb power. LLP: Lower limb power.

Bonferroni's correction was successful; therefore, concerning comparative analyses, figure 1 shows the results of the analysis of variance between groups. Groups II (synchronized BM) and III (accelerated BM) compared to the performance in the ULP (figure 1-A) and LLP (figure 1-B) tests were superior to the group I (delayed maturation). In addition, in the comparison between groups II and III, there were no significant differences between them for LLP, but there was a significant difference for ULP, in which Group III stood out concerning group II. All significant differences were confirmed by Bonferroni's post hoc and Mann-Whitney U test ($p <0.05$).

DISCUSSION

Although the relationship between BM and the peak isometric strength in young adolescent athletes is well defined in the literature (2, 28), it is still uncertain whether the relationship between BM and muscle power of upper and lower limbs in young athletes, which requires the production of new studies with this theme (7, 8, 16, 17, 22, 28). Thus, the present study evaluated the BM profile in relation to muscle power in young female athletes in different BM stages. Thus, the results showed: (i) BA and BM showed positive correlations with ULP and LLP. (ii) In the comparison of neuromotor performance between the groups for ULP, Group III (accelerated BM) stood out in relation to groups I (delayed BM) and II (synchronized BM). (iii) In the LLP test, there was a significant difference for groups II and III in relation to group I; but there was no significant difference between groups II and III.

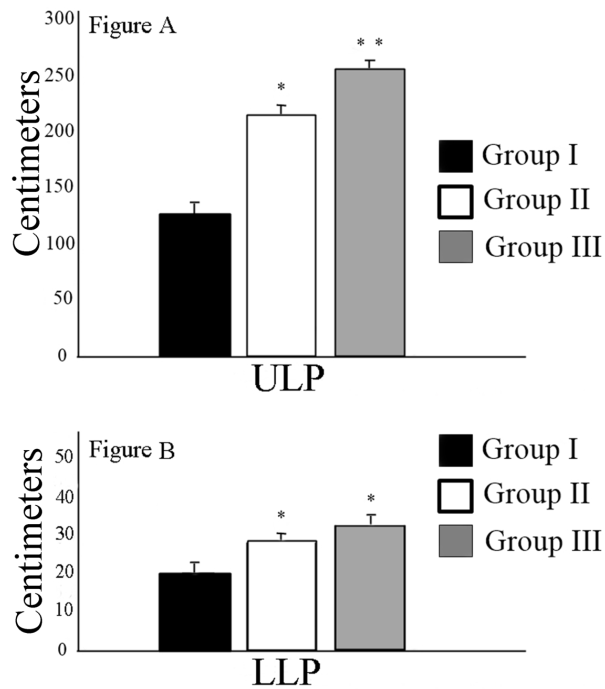

Figure 1. Comparison of the power of upper and lower limbs at different levels of biological maturation. Tests performed in the analysis of figure 1: Bonferroni's correction followed by one-way ANOVA, followed by Bonferroni's and U Mann-Whitney post hoc tests. *: Significant statistical difference in relation to group I superiority ($F_{(2.0)}$: 1.50; p<0.001). **: Significant statistical difference in relation to superiority to groups I and II ($F_{(2.0)}$: 3.15; p<0.001). Group I: Delayed maturation. Group II: Synchronized maturation. Group III: accelerated maturation. ULP: upper limbs power. LLP: lower limbs power.

The findings of the present study indicate correlations between BM and BA with the muscle power of young female athletes of sub-elite, corroborating with previous studies of our group, where Almeida-Neto et al., (2) identified in a sample of athletes elite (both sexes) that with the advance of BM, young people develop greater amounts of muscle mass and that this significantly influenced performance in relation to muscle power. This is justified because, during the period of puberty, the body improves in relation to the recruitment of fast-twitch muscle fibers (i.e., fibers: II, II-a, II-b and, II-x) responsible for generating power muscular (27).

According to De Almeida-Neto et al. (8), muscle power is influenced by BM as a function of sex hormones that increase during the advancement of puberty, and this statement may also justify the results of the present study, where the best performances in the ULP and LLP tests were observed in the advanced BM stage. Previously, Goswami et al. (11) concluded that, with the advance of BM, female subjects are exposed to higher levels of estradiol (i.e., female sex hormone), and this is due to the proximity or experience of the period of menarche (i.e., first menstrual cycle).

In the characterization data of the sample studied in the present study (Table 1), the Group III (accelerated BM) presented greater body mass and BMI (body mass of 51.6 ± 10.6 and BMI 26.9 ± 0.08), while group I (delayed BM) had low body mass and BMI (body mass of 34.6 ± 6.0 and BMI 17.6 ± 0.05), and group II (synchronized BM) of BM who had normal body mass and BMI (body mass 42.7 ± 11.6 and BMI 18.86 ± 0.15). In a study with a similar design, Costa (6) corroborated whit the findings of the present study, noting that in a sample of 210 young female schoolchildren (ages 10 to 13 years), subjects with accelerated BM pointed body weight and BMI elevated in relation to those of BM delayed and synchronized. This can also be justified by the increase in hormone levels resulting from the advancement of BM, hormones such as estradiol and progesterone (predominant in the female body) are related to increased body adipose tissue that is reflected in total body mass and body mass index (11, 16, 28).

Corroborating with the present study, Costa (6) also evaluated ULP and LLP in his sample, showing that the ULP was higher in subjects with accelerated BM, and the same occurred in our study, which in the comparison between the groups (Figure 1), the group of girls with accelerated BM outperformed the others in the ULP test. For the results of the LLP, the study by Costa (6) reported the superiority of the groups with delayed and synchronized BM in relation to those with accelerated BM. These data did not corroborate with the findings of the present study, in which groups II (synchronized BM) and III (accelerated BM) stood out in relation to group I (delayed BM) (Figure 1). We highlight that the sample used by Costa (6) was of young schoolchildren, while the sample of the present study was formed by young athletes who were already familiar with jumping techniques (used in the LLP test). This fact may influence the results obtained in both studies.

However, Júnior et al. (12) used 46 school athletes of both sexes (12.0 ± 3.0 years of age), and when analyzing ULP and LLP, they found no significant differences between the different levels of BM to LLP ($p = 0.08$); these data differed from those reported in our results, where a significant difference ($p < 0.0001$) was found in the LLP test for subjects with synchronized and accelerated BM compared to those with delayed BM. The divergence between the findings can be justified by the competitive level of the participants. In our study, the sample participated in internal competitions within the sports team, while in the study by Júnior et al. (12), the athletes participated in competitions with other sports teams (at the regional level). The training of young people competing at the regional level has a higher technical level, which causes the natural selection of the sport; thus, to remain in the main team, young athletes need to present the same technical standards as the other team members (18).

However, for ULP, Júnior et al. (12) found a significant difference ($p = 0.02$), and at this point, there is corroboration of the data from the present study, where for the ULP the individuals of synchronized and accelerated BM were superior to those of delayed BM ($p < 0.0001$). Previous findings suggest that biological maturation has a greater influence on the motor development of the upper limbs since the maturation process of the human organism occurs in the craniocaudal direction. This fact may justify the findings of the present study regarding ULP (16, 23, 28).

Previously in another study by our group, Pinto et al. (22) sought to correlate LLP and ULP with BA in children of both sexes aged between 10 and 13 years. The authors reported a significant correlation between BA and ULP ($r = 0.58$, $p < 0.001$), and found no correlation between BA and LLP ($r = 0.19$, $p = 0.2$), different from the results of the present study, where BA presented a significant correlation with LLP (r = 0.50; p <0.0001) and with ULP (r = 0.74; p <0.0001). The divergence between the findings for the LLP can be justified by the specificity of the samples; thus, in the study by Pinto et al. (22), the sample was composed of schoolchildren, whereas in the present study, the sample was composed of young athletes who, due to sports training, had constant contact with motor actions similar to those used in the LLP test.

Despite the relevance of the results of the present study, some limitations were observed: (i) The study design was of an observational type, making it impossible to establish a cause and effect relationship. (ii) Hormonal factors were not analyzed, it impossible to indicate whether endocrine characteristics typical of each stage of puberty could be associated with the results. (iii) Only young female sub-elite athletes were analyzed. Thus, when analyzing subjects with other characteristics, the results may differ from the present study. In this sense, we suggest the production of more studies that seek to analyze the relationship between BM and muscle power in young male athletes and at different competitive levels.

Considering that physical exercise and the evaluation of muscle strength is an important parameter for the pediatric population and that the literature has encouraged the production of studies on the subject (10, 30, 31), a highlights point and possible practical application of the content discussed in this article is that the analysis of the puberty stages can be used to indicate the possibility of greater capacity to generate ULP and LLP in the selection process of young talents in sport. These measures can also be useful in the development of sports training protocols based on the particularities of the puberty stages.

The present study allows us to conclude that there is a greater relationship between biological maturation and the power of the upper limbs than that of the lower limbs in young female sub-elite athletes. In addition, young people with accelerated biological maturation showed superior muscle power (upper and lower limbs) performance compared to those with delayed maturation, especially with regard to upper limb power. This occurs due to the increase in body mass resulting from the advancement of BM, which may favor the predominance of lean body mass, assisting in the production of muscle strength. Thus, the information of the present study suggests that the sports training of young athletes should consider the specificities of biological maturation stages.

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