ORIGINAL RESEARCH

Relationship between skeletal age, hormonal markers and physical capacity in adolescents

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Abstract

Introduction: Physical capabilities are an important parameter of the functional development of adolescents, not only by chronological age but also by their maturational state, as individuals with the same chronological age can have different performance to their less mature counterparts.

Objective: To compare and relate the physical capabilities and hormonal markers according to sex and maturity of adolescents.

Methods: The sample consisted of adolescents of both sexes, aged 10 to 14 years. We evaluated the maturity achieved by a predictive equation of skeletal age, physical capabilities (explosive power of upper and lower limbs, velocity of upper limbs and agility) and hormonal markers (testosterone and oestradiol) via chemiluminescence.

Results: Females showed more advanced maturational status, higher weight, body height and oestradiol levels; males performed better in the explosive force of upper and lower limbs, upper limb speed, agility and testosterone levels. In the normal maturational state males showed greater skeletal age, body weight, body height, explosive strength of upper and lower limbs, and testosterone levels; the females in the normal maturational state had higher skeletal age, body weight, body height, explosive upper limb strength and oestradiol levels. In the male correlation analysis, skeletal age was related to the explosive strength of upper and lower limbs and testosterone; while skeletal age in females was related to explosive upper limb strength and oestradiol.

Conclusion: It is concluded that maturation, testosterone and oestradiol levels play an important role in the physical aspects and performance of motor skills of adolescents, especially in upper limb force which was more related to the maturation obtained by skeletal age of males and females.

Keywords: testosterone, oestradiol, muscle strength, physical aptitude.

INTRODUCTION

Puberty is a period of transience between childhood and adulthood marked by successive and fast anatomical and physiological changes that cause transformations in the size and shape composition of the body[1]. According to Cole et al.[2], it is commonly accepted that the development process in adolescence is guided by a range of hormones, which affect earlier maturational pace of females and are mostly initiated by an increase of sex hormones. Accordingly, puberty is the process of sexual and bone maturation[3], during which the development of sexual characteristics is an important indicator of pubertal status.

The modulation in the maturational process is influenced by several changes in the endocrine system, mainly activation of the hypothalamic-pituitary-gonadal axis, which induces a progressive release of androgens such as testosterone[4] and activation of the hypothalamic-pituitary-ovarian axis, which results in the production of oestrogen by the ovaries[5]. Goswani et al.[1] report that changes in the secretion of these two types of hormones play an important role in both physical profile changes, as well as concomitant motor ability at pubertal stage.

Within this context, it is possible to identify differences in physical and motor aspects in youth according to gender and similar age because of their maturational

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stage, emphasising the need for evaluation[6]. With regard to studies investigating motor performance in adolescents, sexual and bone maturation are considered the evaluation methods most commonly used to check the maturational stage of individuals[7]. Moreover, it is noteworthy that bone maturation through the radiography of hands is the method of evaluation most appropriate to determine the level of biological maturation, by monitoring the ossification process[8].

Although it is considered the gold standard, Malina et al.[9] illustrates the major limitations to the use of this method for the evaluation of biological maturation based on the use of expensive equipment, radiation exposure and lack of extensive knowledge about the method. Given these limitations, Cabral et al.[10] found a need to develop a non-invasive protocol of easy accessibility and interpretation based on a predictive model of bone age using anthropometric variables.

In this sense, the literature indicates the relationship between ageing and hormonal markers with physical ability, and this issue has mainly been addressed in athletes entering into different sports in order to obtain valuable information on the orientation and detection of talent[9]. Despite its extensive relationship with the sporting arena, the need to investigate this issue in a broader context is important, considering that the analysis of motor performance can also provide information regarding suitable functional development, as an appropriate standard of fitness for young people appears to be associated with the requirements of different daily tasks, as well as the individual's participation in physical activity programmes[11].

In view of this, the ratio of maturation obtained by skeletal age with the motor performance becomes a target of interest in the areas of physical activity and sports sciences[7] by virtue of their influence on motor and physical parameters, as recently emphasised in the study of Malina et al.[9] In this light, the objective of this study is to compare physical profile, physical abilities and hormonal markers according to sex and maturational state and relate the skeletal age and hormonal markers with the physical abilities of adolescents. The hypothesis of the study is that subjects with a higher maturational state show a greater body size and motor performance and that skeletal age and hormonal markers show a relationship with the physical abilities of males and females.

METHODS

Experimental design

This study uses a descriptive cross-sectional design. The participants received an explanation about the scope and objective of the study, the procedures for data collection, followed by the Consent and Informed Terms which required the signature of the responsible adult and Consent Statement for the participants, which were delivered the next day. Following receipt of the duly completed terms, on the first day the volunteers had a blood test followed by an anthropometric evaluation, which was held on three consecutive days. The evaluation of physical capacity was carried out over two days, in which each volunteer completed an upper and lower limbs test (Day 1 = explosive strength of upper limb + agility; Day 2 = explosive power of lower limb + upper limb speed). The blood test and anthropometric evaluation were done at the school, in a room reserved for such procedures, while tests of physical abilities were conducted in the sports field.

Participants

The selection was a convenience sample and not probabilistic, consisting of 89 individuals of both genders aged between 10 and 13 years, students from public schools in the city of Natal, Rio Grande do Norte, Brazil. We excluded from the sample composition those subjects who presented with any psychomotor restriction and were on hormone treatment.

The study was approved by the Ethics and Research of Health of the local institution (CAEE: 1249937/2015), following the guidelines for the collection of data in humans, according to the resolution 466/12 of the National Health Council on 12/12/2012.

Study variables

Physical abilities

The evaluated motor abilities were the explosive strength of the upper limbs (ESUL) by throwing a medicine ball (2 kg)[12]; the explosive strength of the lower limbs (ESLL) employing the jump test with counter-movement without the use of the arms on a Cefise® contact platform connected to the Jump Test Pro 2.10 software[13]. Agility was tested using the 30 metres test[14] and upper limb speed (ULS) by using a strike plate inserted into the test battery EUROFIT[15]. For analysis purposes the best performances in each test were analysed after two attempts spaced over a period of one minute.

Anthropometric measurements

For the purpose of this study, the body mass and stature were measured using an electronic scale (Filizola® 110, with a capacity of 150 kg and divisions of 1/10 kg and accuracy of 100 grams) and a stadiometer (Sanny ES2020®, with scale of 0.5 cm) respectively. The fixed perimeter of the arm, the triceps skinfold (adipometer Harpenden® (John Bull Indicators Ltd)) and the biepicondylar distance of the humerus and femur were measured. The reliability of the measurements was tested by the technical error of measurement (< 5%) and test-retest reliability coefficient (> 0.97). All procedures were performed by a single evaluator and strictly followed the guidelines of the International Society for Advancement in Kinanthropometry (ISAK)[16].

Skeletal age and maturity

Skeletal age was obtained using the equation proposed by Cabral et al.[10] which is determined from the anthropometric variables according to the equation:

Skeletal age = −11.620 + 7.004 (height) + 1.226. Dgender + 0.749 (age) – 0.068 (Tr) + 0.214 (Pab) – 0.588 (Hd) + 0.388 (Fd).

where: tr = triceps skinfold thickness, pab = perimeter of the arm bone, hd = humeral diameter, fd = femoral bone diameter and dgender = 0 for males and dgender = 1 for females.

To determine the maturity required the subtraction of skeletal age from the chronological age in years (sum of months divided by 12). for this study the maturation was stratified according to the following cut-off points; late (results above 12 months negative in relation to chronological age), normal (up to 12 positive or negative months in relation to chronological age) or accelerated (above 12 positive months in relation to chronological age)[17].

Hormonal evaluation

The venepuncture was conducted in the antecubital region removing approximately 10 ml of peripheral blood (circulating blood in the veins). the analysis and hormonal collection storage were carried out by a laboratory and specialised professionals. Using this sample, chemiluminescence was utilised to determine the hormone levels; testosterone and oestrogen of oestradiol type.

Statistical analysis

To check the normality of the data the kolmogorov-smirnov test was used, in which the data showed a non-parametric distribution. The description of the data was reported as means and standard deviations. Comparison of physical skills and hormonal markers between the genders and the maturational status was performed using the mann-whitney test. The spearman correlation test was used to analyse the relationship between skeletal age, hormonal markers and physical abilities. data analysis was performed using the statistical package for social sciences software (spss version 20.0). the significance level was set at $p < 0.05$.

RESULTS

It`s noteworthy that individuals classified as being in an accelerated maturational state were not identified in this study. table 1 shows the description of the sample means and standard deviations and compares the features of maturity, physical abilities and hormone levels according to gender. it can be seen that females had more advanced maturation (32.11%) than males, were heavier (13.40%) and taller (2.76%). in comparison, males showed higher performance for physical capacities, esul (18.95%), esll (9.80%), agility (5.02%), uls (12.20%); and their sex hormones also showed significant differences (males (120.13%) > testosterone, females (200.68%) > oestradiol) (Table 1).

Table 1: Description and comparison of features, maturity, physical fitness and hormone levels of males and females.

	Total (n = 89) Median (±)	Males (n = 45) Median (±)	Females (n = 44) Median (±)	P
Skeletal Age	10.64 ± 1.55	10.50 ± 1.34	10.71 ± 1.68	**0.53**
Chronological Age	11.54 ± 1.23	11.60 ± 1.06	11.45 ± 1.39	**0.56**
Maturation	−0.89 ± 0.77	−1.09 ± 0.61	−0.74 ± 0.83	0.024
Weight (kg)	39.85 ± 10.78	36.95 ± 9.14	41.90 ± 10.19	0.023
Height (m)	1.47 ± 0.09	1.45 ± 0.07	1.49 ± 0.09	0.018
ESUL (m)	1.69 ± 0.51	1.82 ± 0.44	1.53 ± 0.49	0.005
ESLL (cm)	21.93 ± 3.65	22.96 ± 3.62	20.91 ± 3.68	0.011
Agility (s)	8.37 ± 0.76	8.16 ± 0.63	8.57 ± 0.82	0.018
ULS (s)	13.20 ± 2.9	12.46 ± 3.58	13.98 ± 1.72	0.014
Testosterone (ng/ml)	60.34 ± 77.78	83.21 ± 103.70	37.80 ± 20.45	0.005
Oestradiol (ng/ml)	34.65 ± 54.42	17.59 ± 42.26	52.89 ± 60.24	0.002

ESUL = explosive strength of upper limbs; ESLL = explosive strength of lower limbs; ULS = upper limbs speed.

Table 2 illustrates the results of the comparison of the components of maturity, physical abilities and hormone levels of males and females according to maturational state. On the components of maturity, it was observed that males in the normal maturational state showed greater skeletal age (12.46%), weight (32.83%) and height (7.09%), as well as capacity ESUL of (26.51%), ESLL (13.84%) and testosterone (107,54%). Similar results were observed for females, in which those classified in the normal maturational state had higher skeletal age (21.66%), weight (36.50%) and height (9.29%), as well as higher performance in ESUL (50%) and oestradiol levels (146.76%) (Table 2).

Table 2: Comparison of components of maturity, physical abilities and hormonal markers, according to the maturational stratum of males and females

	Maturation (Males n= 45)		
	Late n= 28 Median (±)	Normal n= 17 Median (±)	p
Chronological Age	11.50 ± 0.86	11.77 ± 0.86	0.251
Skeletal Age	10.03 ± 1.29	11.28 ± 1.05	**0.002**
Weight (kg)	32.87 ± 7.43	43.66 ± 7.73	**0.001**
Height (m)	1.41 ± 0.05	1.51 ± 0.06	**0.001**
ESUL (m)	1.66 ± 0.35	2.10 ± 0.45	**0.002**
ESLL (cm)	21.81 ± 24.84	24.84 ± 4.38	**0.010**
USL (s)	13.21 ± 3.07	11.23 ± 4.08	0.147
Agility (s)	8.25 ± 0.72	8.02 ± 0.43	0.392
Testosterone (ng/ml)	59.17 ± 83.87	122.80 ± 122.58	**0.016**
Oestradiol (ng/ml)	22.01 ± 52.45	10.31 ± 13.35	0.374

	Maturation (Females n= 44)		
	Late n = 16 Median (±)	Normal n = 28 Median (±)	p
Chronological Age	10.99 ± 0.94	11.76 ± 1.52	0.136
Skeletal Age	9.37 ± 1.07	11.40 ± 1.56	**0.001**
Weight (kg)	33.64 ± 7.29	45.92 ± 8.86	**0.001**
Height (m)	1.40 ± 0.05	1.53 ± 0.06	**0.001**
ESUL (m)	1.16 ± 0.26	1.74 ± 0.49	**0.001**
ESLL (cm)	20.01 ± 3.10	21.46 ± 3.99	0.207
ULS (s)	14.10 ± 1.43	13.88 ± 1.89	0.557
Agility (s)	8.68 ± 0.57	8.42 ± 0.80	0.146
Testosterone (ng/ml)	35.75 ± 27.46	38.98 ± 17.27	0.296
Oestradiol (ng/ml)	27.61 ± 20.38	68.13 ± 70.06	**0.011**

ESUL = explosive strength of upper limbs; ESLL = explosive strength of lower limbs; ULS = upper limbs speed.

The correlation between skeletal age and hormonal markers with the physical abilities of males and females is illustrated in Table 3. It was found that the skeletal age of males was related to the ESUL, ESLL and testosterone levels. For females, both skeletal age and oestradiol showed a relationship between themselves and with ESUL (Table 3).

Table 3: Correlation of skeletal age and hormonal markers with the physical capability of males and females

Variables	Males (n = 45)			
	Skeletal Age		Testosterone	
	r	p	r	p
Skeletal Age	-	-	0.296	0.048
ESUL (m)	0.660	**0.001**	0.260	0.085
ESLL (cm)	0.430	**0.001**	0.200	0.188
Agility	−0.012	0.937	0.068	0.655
ULS	−0.419	0.004	−0.136	0.373
Testosterone	0.296	0.048	-	-
Variables	**Females (n = 44)**			
	Skeletal Age		**Oestradiol**	
	r	**p**	**r**	**p**
Skeletal Age	-	-	0.514	**0.001**
ESUL (m)	0.586	**0.001**	0.377	0.013
ESLL (cm)	0.191	0.219	0.158	0.312
Agility	−0.212	0.173	−0.220	0.156
ULS	−0.110	0.487	0.035	0.827
Oestradiol	0.514	**0.001**	-	-

ESUL = explosive strength of upper limbs; ESLL = explosive strength of lower limbs; ULS: Upper Limb Speed.

DISCUSSION

The main findings of this study support the initial hypothesis that subjects with more advanced maturational state show differences in body shape, physical capacity performance, hormonal levels and skeletal age, and that hormonal markers have a relationship with physical capacity, although a relationship with testosterone in males was not observed. This idea is supported by the literature which illustrates the influence of maturation and hormonal markers on the physical capacity performance of adolescents[1,9].

Concerning gender comparisons, females were more advanced in maturational state concurrently with weight and stature when compared to males. In fact, these findings are consistent with the literature and the study of Silva et al.[18] in which it was found that females were heavier and taller than males. These same authors attribute these differences to hormonal influences, in which females are affected earlier than males, and even add that oestrogen is responsible for the enlargement of the pelvis, breast development and an increase in fat stores, resulting in a higher body weight. Concerning motor skills, the present findings also agree with the literature. Studies report that greater muscle strength for males can be partly explained by the possible increase in muscle mass associated with testosterone, which probably results in greater force production[1]. The best performance of ULS and agility for males can be attributed to the influence of maturation of females in these tests. Some studies found a negative relationship with the maturational state on tests of motor coordination, attributing this decline to increased body growth[7,19]. Therefore, it would appear that physical profile and physical capabilities are affected by gender, in parallel with other factors such as ageing and hormonal concentration.

Concerning the comparison of the physical profile and physical capability of males and females according to maturational state, similar results were found for both genders. The greater weight and height of males and females in normal maturational status can be attributed to the influence of testosterone on muscle mass in males and bone formation, and in females because of the action of oestrogen[18]. In the last decade, some studies have identified a relationship between higher body weight and height of subjects with a more advanced maturational state. A positive relationship between being overweight and obesity with early maturation was observed for both males and females, as demonstrated in the study by Ribeiro et al.[20] Recently, a study by Zhai et al.[21] reported that obesity in females was related more to maturational stage, as well as a higher concentration of oestradiol and concluded that obesity is a contributing factor to a faster level of maturation. Therefore, early identification of these variables can contribute to interventions for the prevention of obesity. In addition to differences in the physical profile, differences were also observed in the performance of ESUL and ESLL for males, while females only showed differences in ESUL. According to Goswami et al.[1] muscle strength is a component of physical fitness affected by altering secretion of sex hormones which may contribute to the better performance by subjects of a more advanced maturational state, which had, in parallel, an increased concentration of the labelled hormone. In this sense, Volver et al.[22] also attribute anabolic androgen actions in the pubertal stimulation of the development of fast-twitch muscle fibres, which are responsible for generating explosive power. These data can be taken as parameters for a better adult life in regard to daily demands, since muscle strength is considered an important indicator of physical fitness and health. Furthermore, maturation should be taken into consideration for the requirements of physical activity, given that the most mature young have a power output greater than their less mature counterparts, which can be a limiting factor for the performance of certain activities.

Regarding correlation analysis, it was observed that the ESUL was the physical fitness variable more closely related to skeletal age. A study by Cabral et al.[23] had similar findings to those of the present study. In addition to the factors already elucidated regarding increasing the capacity to generate force, based on the literature, it can be speculated that body weight can reflect this relationship. Marta et al.[24] found an association between body weight and the ESUL test reporting that obese children and adolescents performed better in the test, followed by the overweight. Furthermore, Casajús et al.[25] also found that obese and overweight children and adolescents had better static strength test results (handgrip) when compared to normal weight children and adolescents. Although the literature reports the ratio of testosterone to fitness, our findings diverged from this, as the age range may have been a contributing factor to these findings, on the premise that the testosterone surge occurs around 13 years in boys, while in females hormonal action occurs around 11 years of age[18]. Based on our findings, it is reasonable to assume that skeletal age relates more to ESUL than testosterone in the age group investigated, although other factors must be taken into account for the performance of this capacity.

In general, this study presents a significant contribution to the relationship between maturation and hormonal markers on the performance of physical capabilities, highlighting the importance of investigating parameters that may interfere in an interrelated manner with other variables that could affect the development of adolescents, which might influence athletic performance and consequently the formation processes, guidance or detection of future athletes. For this, longitudinal studies are also recommended in order to understand the behaviour of these variables during the youth development process.

CONCLUSION

It was concluded that the physical profile and physiological performance differ according to sex and maturational stage of adolescents, even in a similar age group. In addition, it was observed that skeletal age was related to motor performance in both males and females, especially upper limb strength, which showed a higher correlation with skeletal age. Regarding the hormonal relationship, it is possible to suggest that it correlates differently between the sexes, since only oestradiol was associated with the physiological performance of the females.

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Resumo

Introdução: A capacidade física é um importante parâmetro do desenvolvimento funcional a ser investigado em crianças e adolescentes, não apenas pela idade cronológica e sim pelo seu estado maturacional, já que sujeitos com mesma idade cronológica podem apresentar desempenho diferente ao seu par menos maturado.

Objetivo: Comparar e relacionar as capacidades físicas e marcadores hormonais de acordo com o sexo e maturação de crianças e adolescentes.

Método: A amostra foi composta por 89 crianças e adolescentes de ambos os sexos de 10 a 13 anos. Foram avaliados a maturação obtida através de uma equação preditora da idade óssea, capacidades físicas (força explosiva de membros superiores e inferiores, velocidade de membros superiores e agilidade) e marcadores hormonais (testosterona e estradiol) através do método de quimioluminescência.

Resultados: Na comparação entre os sexos as meninas obtiveram estado maturacional mais avançado, maior peso, estatura corporal e níveis de estradiol; já os meninos apresentaram melhor desempenho na força explosiva de membros superior e inferior, velocidade de membro superior, agilidade e níveis de testosterona. Relativo à maturação, os meninos em estado maturacional normal apresentaram maior idade óssea, peso e estatura corporal, força explosiva de membros superior e inferior, e níveis de testosterona; já as meninas no estado maturacional normal obtiveram maior idade óssea, peso, estatura corporal, força explosiva de membro superior e níveis de estradiol. Na análise de correlação dos meninos a idade óssea se relacionou com a força explosiva de membros superior e inferior e testosterona; já a idade óssea das meninas se relacionou com a força explosiva de membro superior e estradiol.

Conclusão: Desta forma, se conclui que maturação e os níveis de testosterona e estradiol exercem um importante papel nos aspectos físicos e no desempenho das habilidades motoras das crianças e dos adolescentes, principalmente na força de membro superior a qual se mostrou mais relacionada com a maturação obtida pela idade óssea de meninos e meninas.

Palavras-chave: testosterona, estradiol, força muscular, aptidão física.