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UNIVERSIDADE Đ COIMBRA

Bruno Barbosa Giudicelli

THE YOUNG JUDO ATHLETE

BIOLOGICAL ISSUES UNDERPINNING SELECTION AND PERFORMANCE

PhD Thesis of the Doctorate Program in Sport Sciences, Branch of Sport Training, supervised by Professors António José Barata Figueiredo, Alain Guy Marie Massart, and Arnaldo Tenório da Cunha Júnior, and submitted to the Faculty of Sport Sciences and Physical Education of the University of Coimbra.

November 2022

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To those who do science, who in times of a pandemic overcame denial and saved millions of lives.

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Out of the night that covers me,
Black as the pit from pole to pole,
I thank whatever gods may be
For my unconquerable soul.
In the fell clutch of circumstance
I have not winced nor cried aloud.
Under the bludgeoning of chance
My head is bloody, but unbowed.
Beyond this place of wrath and tears
Looms but the horror of the shade,
And yet the menace of the years
Finds and shall find me unafraid.
It matters not how strait the gate,
How charged with punishments the scroll,
I am the master of my fate:
I am the captain of my soul.

Invictus (William Ernest Henley)

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ABSTRACT

The great inter-individual variability in growth and maturation processes has consequences for physical and sports performance of children and adolescents, as individuals of the same age and sex may have incompatible functional capabilities and skills. A considerable number of studies show the existing biological variability in children and youth sports practitioners, and in most competitive sports, less mature athletes may be in disadvantage in terms of physical fitness. Therefore, the complex process of growth and maturation must be considered for children and adolescents in sport to ensure suitable training and competition routines. Nonetheless, in combat sports less research attention has been given to the effect of maturation over performance. There is evidence of maturational discrepancies within weight categories in young combat sports, raising questions about the suitability of chronological age and body mass as criteria to guarantee equal conditions among young combat sports athletes. In judo and other combat sports, using body mass as a criterion for distribution of youth athletes into competitive categories is a common bio-banding strategy and could attenuate the maturational effect. Nevertheless, doubts may be raised about the suitability of body mass-based classification to guarantee fair play in combat sports due to evidence of maturation effect within weight categories in young combat sports, and due to rapid weight loss practice as competitive strategy. This doctoral thesis aimed to explore the relationship between chronological age, growth, and biological maturation to explain the physical performance of young Portuguese judo athletes, as well as to investigate the contribution of body mass and other anthropometric variables to the control of possible biological maturation effects on the performance of young judokas. Three specific cross-sectional studies, using the same data collection, were developed, with independent but related objectives, methods, and analysis. Sixty-seven Portuguese young male judokas aged 11.0-14.7 years were included in the sample. Anthropometric assessment and physical fitness tests were performed. Data were analyzed using descriptive statistics, analysis of variance, correlations, multiple linear regressions, and mediation analysis. From the analyzes and discussions underwent in the three studies that composed the thesis, it was evidenced that: (a) biological maturation significantly influenced growth and performance of the young judokas participating in the study regardless of age, in a clear trend that more mature athletes are taller, have greater body mass and greater muscle mass, and perform better than their less mature colleagues in all applied physical tests, predominantly in aerobic performance, general upper body strength and handgrip strength; (b) hierarchical linear regression models confirmed the effect of maturation on the performance of the evaluated judokas, attenuating the effect of age.

However, when included in the model as predictors, the variables associated with growth better explained performance and attenuated the maturation effect on the physical capacity tests performed, indicating that the anticipated development of more biologically mature young athletes can translate into performance gains depending on the task. In this perspective, may be necessary to adopt criteria in addition to chronological age to banding young judokas and, by extension, young athletes from other combat sports; (c) when chronological age and body mass were controlled, the maturation effect on aerobic performance and handgrip strength remained, creating disparity of conditions between athletes with different maturity status. This situation is aggravated by the prospect of manipulating body mass as a competitive strategy, as in the case of the rapid weight loss, widely used in adult athletes, but also in young athletes, with yet not cleared consequences for the health and development of adolescents. In this perspective, the adoption of bio-banding in judo and other combat sports could potentially guarantee more adequate conditions for selection, training, and progression of these athletes; (d) considering the analyzes with age and body mass control, the evidenced effects of biological maturation on aerobic and handgrip tests best performances seem to be mediated by growth variables. There were mediating effects of fat mass and fat-free mass in the aerobic performance test, and mediating effects of fat mass, fat-free mass, stature, arm span, and lower limbs length in the handgrip strength test. These growth-associated variables have the potential to be used as bio-banding criteria. In conclusion, bio-banding strategies could be adopted in judo and other combat sports to control the maturational variability of young athletes regardless of chronological age and body mass, as well as due to the need to eradicate rapid weight loss strategies. The percentage of predicted mature stature reached at the time of competition, and other growth indicators, have potential as criterion for bio-banding, requiring further investigations and implementation of more intervention proposals focused on bio-banding to understand its potential and limitations.

Keywords: young athlete; combat sports; somatic maturation; judokas; bio-banding; predicted mature stature; rapid weight loss; anthropometry; physical fitness.

RESUMO

A grande variabilidade interindividual nos processos de crescimento e maturação traz consequências para o desempenho físico e esportivo de crianças e adolescentes, pois indivíduos da mesma idade e sexo podem apresentar capacidades e habilidades funcionais incompatíveis. Um número considerável de estudos mostra a variabilidade biológica existente em crianças e jovens praticantes de esportes, e na maioria dos esportes competitivos atletas menos maduros podem estar em desvantagem em termos de aptidão física. Portanto, o complexo processo de crescimento e maturação deve ser considerado para crianças e adolescentes no esporte para garantir rotinas adequadas de treinamento e competição. No entanto, nos esportes de combate, poucos estudos têm dado atenção ao efeito da maturação sobre o desempenho. Há evidências de discrepâncias maturacionais dentro das categorias de peso em jovens esportes de combate, levantando questões sobre a adequação da idade cronológica e massa corporal como critérios para garantir igualdade de condições entre jovens atletas de esportes de combate. No judô e em outros esportes de combate, utilizar a massa corporal como critério para distribuição de atletas juvenis em categorias competitivas é uma estratégia comum de bio-banding e pode atenuar o efeito maturacional. No entanto, dúvidas podem ser levantadas sobre a adequação da classificação baseada na massa corporal para garantir o fair play em esportes de combate devido à evidência de efeito da maturação dentro das categorias de peso em esportes de combate de jovens, e devido à prática de perda rápida de peso como estratégia competitiva. Esta tese de doutorado teve como objetivo explorar a relação entre idade cronológica, crescimento e maturação biológica para explicar o desempenho físico de jovens judocas portugueses, bem como investigar a contribuição da massa corporal e outras variáveis antropométricas para o controle de possíveis efeitos da maturação biológica sobre o desempenho de jovens judocas. Três estudos transversais específicos, utilizando a mesma coleta de dados, foram desenvolvidos, com objetivos, métodos e análises independentes, mas relacionados. Sessenta e sete jovens judocas portugueses do sexo masculino com idades compreendidas entre os 11,0 e os 14,7 anos foram incluídos na amostra. Foi realizada avaliação antropométrica e testes de aptidão física. Os dados foram analisados por meio de estatística descritiva, análise de variância, correlações, regressões lineares múltiplas e análise de mediação. A partir das análises e discussões realizadas nos três estudos que compuseram a tese, evidenciou-se que: (a) a maturação biológica influenciou significativamente o crescimento e desempenho dos jovens judocas participantes do estudo independentemente da idade, em uma clara tendência de que atletas mais maduros são mais altos, têm maior massa corporal e maior massa muscular e

apresentam melhor desempenho do que seus colegas menos maduros em todos os testes físicos aplicados, predominantemente no desempenho aeróbico, força geral de membros superiores e força de preensão manual; (b) modelos de regressão linear hierárquica confirmaram o efeito da maturação sobre o desempenho dos judocas avaliados, atenuando o efeito da idade. No entanto, quando incluídas no modelo como preditores, as variáveis associadas ao crescimento explicaram melhor o desempenho e atenuaram o efeito da maturação nos testes de capacidade física realizados, indicando que o desenvolvimento antecipado de jovens atletas mais maduros biologicamente pode se traduzir em ganhos de desempenho dependendo da tarefa. Nessa perspectiva, pode ser necessário adotar critérios além da idade cronológica para categorizar jovens judocas e, por extensão, jovens atletas de outras modalidades de combate; (c) quando a idade cronológica e a massa corporal foram controladas, o efeito da maturação sobre o desempenho aeróbico e força de preensão manual permaneceu, criando disparidade de condições entre atletas com diferentes estados de maturidade. Essa situação é agravada pela perspectiva de manipulação da massa corporal como estratégia competitiva, como é o caso da estratégia de perda rápida de peso, amplamente utilizado em atletas adultos, mas também em atletas jovens, com consequências ainda não esclarecidas para a saúde e desenvolvimento dos adolescentes. Nessa perspectiva, a adoção do bio-banding no judô e em outros esportes de combate poderia garantir condições mais adequadas para seleção, treinamento e progressão desses atletas; (d) considerando as análises com controle de idade e massa corporal, os efeitos evidenciados da maturação biológica nos melhores desempenhos aeróbicos e de preensão manual parecem ser mediados por variáveis de crescimento. Houve efeitos mediadores de massa gorda e massa magra no teste de desempenho aeróbio, e efeitos mediadores de massa gorda, massa magra, estatura, envergadura e comprimento de membros inferiores no teste de força de preensão manual. Essas variáveis associadas ao crescimento têm potencial para serem usadas como critérios de bio-banding. Em conclusão, estratégias de bio-banding podem ser adotadas no judô e em outros esportes de combate para controlar a variabilidade maturacional de jovens atletas independentemente da idade cronológica e da massa corporal, bem como pela necessidade de erradicar estratégias de perda de peso rápida. A porcentagem de estatura madura prevista alcançada no momento da competição, e outros indicadores de crescimento, têm potencial como critério de bio-banding, necessitando de maiores investigações e implementação de mais propostas de intervenção focadas em bio-banding para entender seu potencial e limitações.

Palavas-chave: jovem atleta; desporto de combate; maturação somática; judocas; bio-banding; estatura madura prevista; perda de peso rápida; antropometria; aptidão física.

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LIST OF ABBREVIATIONS

%PMS	Percentage of predicted mature stature
95%CI	95% confidence interval
AC	Arm circumference
AMS	Abdominal muscle strength
ANCOVA	Univariate analysis of covariance
ANOVA	Univariate analysis of variance
APAS	Attained predicted adult stature
AS	Arm span
BFFM	Body fat-free mass
BFM	Body fat mass
BM	Body mass
CA	Chronological age
CC	Calf circumference
CDC	Control Disease Center
CE/FCDEF-UC	Ethics Committee of the Faculty of Sports Sciences and Physical Education of the University of Coimbra
EUROFIT	European test of physical fitness
FL	Foot length
HgS	Handgrip strength
HL	Hand length
IML	Inferior members length
LBS	Lower body muscle strength
MANCOVA	Multivariate analysis of covariance
MANOVA	Multivariate analysis of variance
PAS	Predicted adult stature
PHV	Peak of height velocity
PMS	Predicted mature stature
RAE	Relative age effect
RWL	Rapid weight loss
SD	Standard deviation
SH	Sitting height
SJFT	Special Judo Fitness Test
U12	Under 15 years old
U13	Under 13 years old
U15	Under 15 years old
UBS	Upper body muscle strength
η^2_p	Partial *eta* square

CHAPTER 1

General Introduction

1.1. Growth and biological maturation

Growth and biological maturation are distinct, but extremely interconnected processes that starts during gestation and can be observed during the first two decades of life. After this period, growth remains throughout life, while the maturation process ceases when the individual reaches its mature or adult stage (Figueiredo et al., 2009).

Growth regards to the increasing in body size as a whole or its parts and tissues (Malina, Bouchard, & Bar-Or, 2004), and not only entails changes in weight and stature, but also morphological and physiological changes, with different parts of the body growing at different times and rates, with a strong variation in the final stature reached. The inter-individual variability in the growth process has important impacts on the general behavior, engagement in physical activities and performance of young people. (Eveleth & Tanner, 1990; Figueiredo *et al.*, 2009).

On the order hand, the maturation process is distinguished from growth by all subjects reaching the same end state, the adult or mature state (Figueiredo *et al.*, 2009), but like growth, it also presents huge inter-individual variability, even among young people of the same age, who differ in maturational status in relation to the moment (timing) that a maturational event occurs and the duration (tempo) of events (Malina et al, 2004).

Due to growth and maturation during childhood and adolescence, young people experience increments in size of body segments and stature; in body composition, with increasing fat and lean mass; in functional capacity, with increasing aerobic, anaerobic and strength capacities; and in motor dexterity, with the development of neuromuscular capabilities (Bar-Or & Rowland, 2004; Malina et al., 2004).

Growth and maturation reach their peak in adolescence due to puberty, which is characterized by a tremendous increase in growth and maturation rates, second only to the period of early childhood, with important morphological and physiological changes that involve almost all organs and body structures, and marks the development of secondary sexual characteristics and the passage to adulthood (Malina et al., 2004). The main manifestations of puberty are: a) pubertal growth spurt - a growth acceleration following by a decelerating in most skeletal dimensions and in many of the internal organs; b) the development of the gonads;

c) the development of secondary sexual characteristics; d) changes in body composition - the amount and distribution of fat and skeletal and muscular development; e) development of the circulatory and respiratory systems, which leads, particularly in boys, to an increase in strength and endurance (Malina et al., 2004).

The great inter-individual variability in growth and maturation processes has consequences for physical and sports performance of children and adolescents, as individuals of the same age and sex may have incompatible functional capabilities and skills (Cumming et al., 2017). Due to the increase of muscle mass and the development of neuromuscular, cardiopulmonary and endocrine systems, young people, especially young athletes in training, have substantial gains in strength, aerobic and anaerobic performance, speed, agility and motor control (Beunen & Malina, 1996), but at different rates between individuals, requiring adaptations in education and training processes, as well as special attention in the distribution of athletes in competitive categories, with age-based categorization being the most used (Figueiredo et al., 2009; Malina, Eugenia Peña Reyes, et al., 2010).

1.2. Combat sports and biological maturation

A considerable number of studies show the existing biological variability in children and youth sports practitioners (Baxter-Jones et al., 2005; Beunen, 1989; Coelho E Silva et al., 2010; Detanico et al., 2020; Malina, 1994). These biological variability among young athletes derive from growth, biological maturity, and cognitive development (Delorme *et al.*, 2011; Musch & Grondin, 2001), and in most competitive sports, less mature athletes may be in disadvantage in terms of physical fitness (Malina *et al.*, 2004), a fact that influences the sport selection and exclusion, although differently in each modality.

Therefore, the complex process of growth and maturation must be considered for children and adolescents in sport to ensure suitable training and competition routines, since individual variability may increase the risk of injury (Wik et al., 2020) and impair motivation due to the performance discrepancy (Carvalho et al., 2018), influencing whether the young athlete will continue in long-term sports practice (Figueiredo et al., 2009b). In sports where strength, power, and speed are paramount, and in those where physical contact is inevitable, mature individuals tend to have a physical advantage over their less mature peers (Till et al., 2014).

For children and adolescents competing in sport, chronological age has been used as a criterion for aggregating young athletes into competitive age groups, to provide adequate physical and technical training routines and facilitate fairness in competition (Lloyd et al., 2014). However, this approach has a limitation, since at any given age there can be large maturity-associated variations in size and functional capacities among children (Bailey et al., 2003; Figueiredo et al., 2010; Malina et al., 2004; Sherar et al., 2007). Therefore, alternative strategies to chronological age for the categorization of young athletes were sought, namely those based on the use of body size and/or maturational status (Abbott et al., 2019; Baxter-Jones et al., 2020; Malina et al., 2005).

Nonetheless, in combat sports less research attention has been given to the effect of maturation over performance (Nabofa, 2012; Zubitashvili, 2011). In these modalities, grouping young combat athletes based on physical attributes is common, where athletes are grouped based on chronological age and body mass, competing in weight classes to promote fair competition and reduce potential injuries (Langan-Evans et al., 2011). Nevertheless, although studies on the topic are still scarce (Detanico et al., 2020), there is evidence of maturational discrepancies within weight categories in young combat sports (Branco et al., 2019), raising questions about the suitability of chronological age and body mass as criteria to guarantee equal conditions among young combat sports athletes, justifying research on the topic.

1.3. Biological maturation and Judo

Judo is one of the most popular combat sports in the world. Transformed into Olympic sport at the Tokyo Olympic Games in 1964, it now has more than 20 million practitioners worldwide[1]. According to the Portuguese Judo Federation[2], the number of judo practitioners in Portugal is more than 12,000. The popularity of Judo and the raising level of demand of sports training over the long term bring the necessity to respond to problems related to identification of young talent, to prognosis of sport performance, to alignment of training content to growth, maturity, and development characteristics of young athletes, to concerns with the motivational and others

[1] International Judo Federation - https://www.ijf.org/
[2] http://www.fpj.pt

psychological conditions, to the monitoring of incidence of sports injuries and their omen variables, among other issues.

In judo and other combat sports, the use of body weight as a criterion for distribution of athletes in competitive categories, along with chronological age, could reduce the biological maturation variation within categories (Krstulović *et al.*, 2005). However, the findings in investigations on the subject are inconsistent. In a sample of 34 judokas with a mean age of 15.6 years (± 0.3), all participants of the Croatian National Championship, distributed in 8 weight categories, Krstulović *et al.* (2005) did not evidence correlation between anthropometric and success in the competition, with the exception of absolute weight category. The authors suggest as a possible explanation the low anthropometric variability within each category due to the grouping of athletes by weight.

In contrast, Beunen & Malina (2007) argue that the weight categories in sports such as judo and wrestling are often quite broad so that high variation in biological maturation are still possible. Zubitashvili (2011), showed in a sample of 2000 judokas from Georgia, aged between 8 and 20 years and distributed in 8 weight categories, that even within the same category older athletes have more handgrip strength and greater lung capacity than younger, most notably between the age of 13 and 15 years, which would represent a competitive advantage since aerobic capacity and handgrip strength have been pointed as important characteristics to be developed by judo players (Bonitch-Góngora *et al.*, 2013; Franchini *et al.*, 2009; Thomas *et al.*, 1989).

1.4. Bio-banding and judo

Due to the inadequacy of chronological age as a criterion for dividing youth athletes into competitive categories, alternative strategies which use physical attributes as criteria have been examined for their effectiveness and applicability. Among these strategies, there are those called bio-banding that use biological maturation, instead chronological age, as the criterion for the distribution of young athletes in competitive categories, but not neglecting other factors which should be considered when it comes to the distribution of youth athletes in competitive categories such as body size, skill level and psychological profile (Cumming et al., 2017).

In judo and other combat sports, using body mass as a criterion for distribution of youth athletes into competitive categories is a common bio-banding strategy. This approach could reduce the maturity effect and contribute to the adequacy of training routines and competitions, protecting the development and well-being of youth athletes, facilitating the maintenance of a long-term career in sport. However, few studies have investigated the effectiveness of body mass, or other criteria, as a bio-banding strategy in young combat sports (De la Fuente, 2018; Dubnov-raz et al., 2015).

Nevertheless, doubts may be raised about the suitability of body mass-based classification to guarantee fair play in combat sports due to evidence of maturation effect within weight categories in young combat sports (Branco et al., 2019). In addition, various research investigated the use of anthropometric variables for detection and prediction of success in young athletes (Sánchez-Muñoz et al., 2012), which can potentially also be used as bio-banding alternatives instead of body mass for categorizing young athletes in various sports, including combat sports.

Furthermore, the use of body mass to categorize combat sports athletes raises another issue with important impacts on athletes' performance and health: the rapid weight loss (RWL) strategy, widely adopted by athletes seeking competitive advantage (Barley et al., 2019; Oppliger & Tipton, 1988), in which to qualify in a lighter weight division, in an attempt to gain an advantage against lighter, smaller, and weaker opponents (references), combat sport athletes use a combination of several potentially harmful weight loss methods such as severe restriction of food and fluid intake, exercising in rubber or plastic suits, using saunas, taking diet pills, and even vomiting (Alderman *et al.*, 2004; Artioli, Gualano, *et al.*, 2010; Artioli, Scagliusi, *et al.*, 2010; Degoutte *et al.*, 2006; Oppliger *et al.*, 2003; Steen & Brownell, 1990).

Not an issue restricted to adult or professional sports, children and adolescents combat sports athletes also use the RWL for competitive advantage. In a sample constituted of Brazilian and international judo athletes, Artioli, Gualano, *et al.*, (2010) found that about 60% of judo athletes started such rapid weight reduction at the ages of 12–15 years, while 18% of Iranian wrestlers started before 14 years old (Kordi *et al.*, 2011). Brazilian karate and taekwondo athletes reported beginning these procedures at the ages of 13.6 (±1.4) and 14.2 (±2.1) years, respectively (Brito et al., 2012), whereas jujitsu athletes started reducing weight later, at the age of 21.1 (±5.2) years (Franchini et al., 2012). In a sample of 75 competitive adolescent taekwondo athletes, the youngest age of the first RWL attempt was 10 years (Constantini *et al.*, 2011). Among Iranian wrestlers there were cases of RWL in athletes under 10 years old (Kordi et al., 2011). Therefore, it was proposed that the sports community should frame RWL as doping and ban it from combat sports because of its detrimental health effects and for causing unfair competition (Artioli et al., 2016). In youth combat sports, while there is a need to verify the efficacy of body mass-based categorization to control the maturity effect providing fair competitions, reducing the injury risk, and promoting engagement in sports for the long-term, it is imperative to find alternatives to body mass as a bio-banding strategy because of the RWL consequences.

1.5. Thesis objectives

In the light of the foregoing, this doctoral thesis aimed to explore the relationship between chronological age, growth, and biological maturation to explain the physical performance of young Portuguese judo athletes, as well as to investigate the contribution of body mass and other anthropometric variables to the control of possible biological maturation effects on the performance of young judokas. To this end, the following specific objectives were considered, developed in three separate but complementary cross-sectional studies:

- To assess the independent and combined effect of chronological age and biological maturation on the anthropometric profile and physical performance of young judo athletes **(Study 1)**.

- To analyze the association between chronological age, biological maturation, and anthropometric characteristics to explain the physical performance of young judo athletes **(Study 2)**.

- To investigate whether there is an effect of biological maturation on the performance of young judo athletes after controlling chronological age and body mass and, in case the maturational effect remains, to examine anthropometric variables that can mediate this effect **(Study 3)**.

1.6. Thesis organization

The thesis is organized into four chapters, namely:

Chapter 1: General introduction

Chapter 2: General methodological considerations

Chapter 3: Cross-sectional Study 1

Chapter 4: Cross-sectional Study 2

Chapter 5: Cross-sectional Study 3

Chapter 6: General discussion and thesis conclusions

The first chapter aims to contextualize the research problem, presenting the general and specific objectives that guided the development of the three independent cross-sectional studies, which will be presented in subsequent chapters.

In the second chapter, general methodological considerations are presented on the data collection carried out in Portuguese judo clubs, as well as on the data analysis performed.

From the third to the fifth chapters, the three cross-sectional studies carried out to meet the specific objectives proposed in the thesis and described in item 1.5 are presented. Study 1, presented in chapter 3 was published in the Journal of Human Kinetics. Study 2 presented in chapter 4 and Study 3 presented in chapter 5 were both published in the International Journal of Environmental Research and Public Health.

The sixth chapter brings the general discussion of the thesis and the conclusions.

1.7. References

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CHAPTER 2

General Methodological Considerations

2.1. Study Design

The data analyzed in the three studies that constitute this doctoral thesis, and which are presented in chapters 3, 4 and 5, were obtained in a single data collection, performed at a single point in time, representing a momentary understanding of the characteristics of the participating subjects. Thus, the three studies are characterized as cross-sectional studies. Are they:

- Chapter 3: Age and maturity effects on morphological and physical performance measures of adolescent judo athletes **(Study 1)**.

- Chapter 4: Chronological age, somatic maturation, and anthropometric measures: Association with physical performance of young male judo athletes **(Study 2)**.

- Chapter 5: Bio-banding in judo: The mediation role of anthropometric variables on the maturation effect.

2.2. Sample and Ethical Aspects

The sample included 67 young male judokas aged 11.0-14.7 years from eight clubs in the midlands of Portugal and did not pretend to represent the judo athletes' population of this country. The choice of this age group was due to the fact that it is during this period that the processes of growth and maturation have strong quantitative and qualitative increments relating to the pubertal growth spurt, with intensifications in growth rate, in maturation of different systems and substantial gains in physical fitness components (Malina *et al.*, 2004). To be included in the study, the participants needed to be between 11.0 and 14.9 years old, have at least one year of judo training, and have no physical or psychological contraindications to participation.

Parents or guardians of all participants provided written informed consent to participate. In this document, objectives, duration, and procedures to be performed were presented, as well as were clarified the possible risks and the possibility of withdrawing of participation at any time. Verbal consent was also obtained from participants before the start of data collection. All data were collected between April and May 2014, in a single visit to anthropometric and physical fitness evaluation. The study was conducted in accordance with the Declaration of Helsinki for Human Studies of the World Medical Association and approved by the Ethics Committee of the Faculty of Sports Sciences and Physical Education of the University of Coimbra [CE/FCDEF-UC/00452019].

The Portuguese Judo Federation utilizes a combination of age and body mass to distribute young judokas in competitive categories. However, body mass is only considered as a criterion to create weight categories from the under 15 years old group (U15). Therefore, due to the presence of young athletes from age classifications below the U15, we chose to consider for the purposes of analysis in our studies only the age categories, namely under 12 years old (U12), under 13 years old (U13) and U15. Subsequently, the participants were also divided into maturational categories.

2.3. Variables

Anthropometry

Anthropometry presupposes the use of standardized references and requiring the usage of appropriate and in good condition tools, as well as the collaboration of the observed. Since there are no universal batteries to apply to all studies, it is the purposes of each research that should dictate the external morphology measures to integrate the battery. The anthropometric procedures described by Lohman *et al.* (1988) was mainly adopted in the present study.

The simple anthropometric measurements used were body mass, stature, sitting height, arm span, biacromial diameter, hand length, foot length, arm circumference, calf circumference, and skin folds (triceps, subscapular, suprailiac, and calf). At the time, the athletes wore light clothes and were barefoot, with their upper limbs relaxed and loose laterally. From the simple measurements, the following composite anthropometric measurements were determined: fat mass and fat-free mass, superior and inferior members length. The instruments and procedures applied in the measurement of simple anthropometric measurements and in the calculation of composite anthropometric measurements are described in the three independent studies.

Decimal age

Decimal age was calculated using the athletes' date of birth and data collection date.

Somatic maturation

The most used indicators to determine biological maturation are skeletal age determination, usually performed through wrist radiography; sexual maturation, through the observation of secondary sexual characteristics for both sexes and menarche for girls; and somatic maturation, using anthropometric measurements. Among the methods of somatic maturation, those that express the maturational state of a young person from the percentage of mature stature reached at a given moment have application in cross-sectional studies (Baxter-Jones et al., 2005).

Several equations for predicting stature in adulthood have been proposed, the most classic being those developed by Bayley and Pinneau (1952), Roche et al. (1975), and Tanner et al. (1983). However, they have in common the need to determine skeletal age before calculating the predicted mature stature, making their use limited. More recently, mature stature prediction equations have been developed, abdicating the use of skeletal age and, therefore, making this indicator of somatic maturation more suitable for cross-sectional studies (Khamis and Roche, 1994).

In the three studies developed in this doctoral thesis, the predicted mature stature (PMS) method proposed by Khamis and Roche (1994) was used to assess the maturational status of young athletes and to distribute them between two maturational categories, called early maturing and late maturing. Considered a non-invasive method, the protocol uses decimal age, stature, body mass and the average stature of the biological parents, and it has been used in investigations about the biological maturation effect on physical fitness of young people in general (Coelho-E-Silva et al., 2013; Cumming et al., 2012; Luz et al., 2016), in research focusing on youth performance in sport (Howard et al., 2016; Myburgh et al., 2019), and as a criterion for bio-banding in experimental training and tournaments (Abbott et al., 2019; Cumming et al., 2018; Reeves et al., 2018), due to the advantages it presents compared to more valid but invasive indicators (Beunen et al., 1997; Coelho et al., 2004; Malina et al., 2012).

Once the measurements are taken on the necessary variables, the calculation of the PMS is done through the multiplication of these variables by ponderal coefficients associated with stature, weight and average parental stature, obtained from linear regressions used in the construction and validation of a previous method for predicting adult stature, the Roche, Wainer and Thissen method (RWT) (Khamis and Roche, 1994), through the following formula:

PMS = intercept + stature x (stature coefficient) + weight x (weight coefficient) + parental medium stature x (parental medium stature coefficient)

The coefficients of Khamis-Roche method are shown in inches and pounds, requiring their conversion to the metric system (centimeters and kilograms). The maturational indicator is given by the percentage of predicted mature status (%PMS) reached at the time of measurement, using the following equation:

%PMS = (actual stature / predicted mature stature) x 100

It is assumed that among children of the same chronological age, individuals closer to the PMS are more advanced in biological maturation compared with individuals who are farther (Malina et al., 2004). From the %PMS, z-score was calculated on the mean and standard deviation from the sample itself to classify the evaluated judokas by maturity status. Two groups contrasting in somatic maturation were derived from z-scores of attained %PMS: early/more mature ($P > 50\%$) and late/less mature ($P \leq 50\%$).

Physical performance

The evaluation of the physical performance of young judokas was accomplished through the combination of some physical testing protocols, selected to cover components of physical fitness important for performance in judo, but considering the circumstances resulting from the conduction of data collection in several judo clubs.

To evaluate aerobic performance, 20m shuttle-run test was applied (Léger et al., 1988), with the number of completed laps being used as performance indicator. Agility, lower body muscle strength, and hand-grip strength were evaluated using the EUROFIT protocol (EUROFIT, 1996), utilizing the 10 × 5m shuttle-run test, standing long jump test, and dynamometry, respectively. To complete physical performance assessment, anaerobic performance was evaluated through the line-drill test (Carvalho et al., 2011); abdominal strength through 60s sit-up test (Cesario et al., 2018); and upper body muscle strength using 2-kg medicine ball throw (Vossen et al., 2000).

A brief description of the tests is provided below:

20m shuttle-run test: it consists of making the subjects pass throughout a corridor of 20 meters in length, in a back-and-forth system, for as long as possible. The speed is imposed by beep signals produced by a stereo and the arrival of the performers at both ends of the corridor should match the beep. If the performer reaches the end of the course before the beep, he should wait for it before resuming. The time available to perform the route decreases every minute. There are no recovery periods between each track of 20 meters. The test ends when the performers drop out or fail twice in a row to finish the route in the beep time.

10 × 5m shuttle-run test: where the assessed run ten times the same route of 5 meters in a back-and-forth system and in the shortest time possible.

standing long jump test: where the evaluated, with feet in parallel in the starting point marked on the ground, must jump horizontally to the maximum possible distance with impulsion in both lower limbs; movements of the torso and upper limbs were allowed. Two attempts were carried out and the best mark in meters recorded.

Dynamometry: measured using a dynamometer, through two attempts using the dominant hand. The best of two attempts in kilograms were recorded.

Line-drill test: it consists of a race in a total distance of 140 meters, carried out as quickly as possible through four consecutive sprints, in the form of back-and-forth, through courses of 5.8, 14.0, 22.2 and 28.0 meters.

60s sit-ups: where the participant was positioned lying on his back, with his knees bent at 90, upper limbs crossed and hands on the opposite shoulder. The legs were slightly apart and were held on the ground by an assistant. It was recorded the number of complete cycles (lifting and lowering the trunk) performed in 60 seconds.

2kg medicine ball throw: where the performer throws a 2kg medicine ball with both hands over his head, from a demarcation line without moving his feet before the release, however, being allowed to fall beyond the line afterwards. Two attempts were made, and the best mark in meters was recorded.

2.4. Procedures

All data were collected by the same trained team, in a single visit for each judo club, where the anthropometric measurements were carried out initially, followed by the physical performance assessments. Participants completed a warm-up, under the guidance of a trainee researcher, before each station was completed in circuit form, in the following order: (1) pacer; (2) 2 kg standing medicine ball throw; (3) stand broad jump test; (4) 10 × 5 m shuttle-run test; (5) sit-ups; (6) handgrip strength; and (7) line-drill test.

2.5. Variable format:

The use of a given statistical test depends, among other conditions, on the format adopted to register the variable. Thus, to enable a quick reading of both the variables in the present study and its formats, the Table 2.1 below was prepared, which also includes the number of significant digits.

2.1. Format of the variables used in studies 1, 2 and 3.

Variables	Units of measurement	Significant digits
Decimal age	years	00.00
Anthropometry		
Body mass	kg	00.0
Body Fat mass	kg	00.0
Body Fat-free mass	kg	00.0
Stature	cm	000.0
Sitting height	cm	00.0
Inferior members length	cm	00.0
Foot length	Cm	00.0
Superior members length	cm	00.0
Arm span	cm	000.0
Hand length	cm	00.0
Arm circumference	cm	00.0
Calf circumference	cm	00.0
Biological maturation		
%PMS	%	00.0
Physical fitness		
20m shuttle-run	m	0000
Line-drill test	s	00.00
10x5 shuttle run	s	00.00

60s sit-ups	-	00
Standing long jump	m	0.00
2kg medicine ball throw	m	0.00
Handgrip strength	kgf	00.0

2.6. Statistical analysis

According to the specific objectives of each of the studies, different statistical analyzes were performed, listed in Table 2.2. In all studies, the descriptive statistics of the analyzed data were determined, and the normality of the distributions was tested with the Kolmogorov-Smirnov test. The variables that did not meet the assumptions of normal distribution underwent logarithmic transformation (Field, 2013) to perform the inferential analyses; however, it was decided to present the original values in the result tables in the three studies. Data were analyzed using IBM SPSS 22.0 software (SPSS, Inc., Chicago, IL). The level of significance was set at 0.05 for the analyzes performed.

Table 2.2. Statistical analyses of the studies 1, 2 and 3.

Analyses	Studies		
	1	2	3
Descriptive statistics	X	X	X
Kolmogorov-Smirnov test	X	X	X
Multivariate analysis of variance (MANOVA)	X		
Multivariate analysis of covariance (MANCOVA)	X		
Univariate analysis of variance (ANOVA)	X		
Univariate analysis of covariance (ANCOVA)	X		
Effect size	X		
Pearson's bivariate correlation		X	
Hierarchical multiple linear regression		X	
Pearson's partial correlation			X
Mediation analysis			X

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CHAPTER 3

Study 1

(Published version available in Annex 1)

Age and Maturity Effects on Morphological and Physical Performance Measures of Adolescent Judo Athletes

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ABSTRACT

Studies assessing age and maturation effects on morphological and physical performance measures of young judokas are scarce. This study aimed to assess the independent and combined effects of chronological age and biological maturation on anthropometry and physical performance of 67 judokas aged 11-14. Participants' anthropometric profiles were assessed, and physical performance tests were completed. Multivariate analyses of variance revealed an independent effect of age (anthropometry: $F = 1.871$; $p < 0.05$; Pillai's trace = 0.545; $\eta 2p$ = 0.272; physical performance: $F = 2.876$; $p < 0.01$; Pillai's trace = 0.509; $\eta 2p = 0.254$) and maturity (anthropometry: $F = 10.085$; $p < 0.01$; Pillai's trace = 0.669; $\eta 2p = 0.669$; physical performance: $F = 11.700$; $p < 0.01$; Pillai's trace = 0.581; $\eta 2p = 0.581$). There was no significant combined effect of age and maturity. The maturation effect remained significant when controlled for age (anthropometry: $F = 4.097$; $p < 0.01$; Pillai's trace = 0.481; $\eta 2p$ = 0.481; physical performance: $F = 3.859$; $p < 0.01$; Pillai's trace = 0.0.318; $\eta 2p = 0.318$). In young judokas, the maturation effect on growth and physical performance seems to be more relevant than the age effect, leading to the need to control this effect in training routines and competitive events. As in studies with youth soccer players and other youth athletes, bio-banding can be a strategy for controlling maturation.

Keywords: anthropometry, aerobic performance, anaerobic performance, agility, muscle strength, biological maturation.

Reference: Giudicelli, Bruno Barbosa, Luz, L. G. de O., Santos, D. H. B., Sarmento, H., Massart, A. G. M., Júnior, A. T. da C., Field, A., & Figueiredo, A. J. B. (2021). Age and Maturity Effects on Morphological and Physical Performance Measures of Adolescent Judo Athletes. *Journal of Human Kinetics*, *80*(October), 131–143.
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3.1. Introduction

For children and adolescents competing in sport, chronological age has been used as a criterion for aggregating young athletes into competitive age groups, to provide adequate physical and technical training routines and facilitate fairness in competition. Previous research suggests that there are many growth and maturity-associated effects to movement mechanics (Towlson et al., 2020), potentially resulting in impairment of motor coordination and physical performance of youth athletes (Cumming et al., 2017). In competitive sports, athletes who are younger tend to be less developed physically and psychologically, which may place them at a performance disadvantage (Malina et al., 2004). Furthermore, biologically mature youth athletes tend to be taller and heavier than their age-matched peers, which has advantages, in particular for contact sports (Till et al., 2014). While several studies have been conducted on the influence of growth and maturation on sporting performance of youth athletes, relatively few have focused their attention on the impact of these variables on youth athletes competing in combat sports such as judo (Nabofa, 2012; Zubitashvili, 2011).

Due to the inadequacy of chronological age as a criterion for dividing youth athletes into competitive categories, alternative strategies which use physical attributes as criteria have been examined for their effectiveness and applicability (Cumming et al., 2017). In general, these strategies are based on the use of body size and/or maturational status together with chronological age. A strategy called bio-banding does not neglect other factors which should be considered when it comes to the distribution of youth athletes in competitive categories, such as their skill level and psychological profile (Branco et al., 2019; Cumming et al., 2017).

In judo and other combat sports, using body weight as a criterion for distribution of youth athletes into competitive categories is a common bio-banding strategy. This approach could reduce the maturity effect and contribute to the adequacy of training routines and competitions. This could help protect the development and well-being of youth athletes facilitating the maintenance of a long-term career in sport. Furthermore, few studies have examined the independent effect of age and maturation on the morphology and physical performance of young judokas. Such research appears warranted to develop an understanding of the impact of age and maturation on the anthropometric profile and performance of young judokas, and the efficacy of using body mass as a bio-banding strategy. For this reason, the objective of this study was to assess the independent and combined effect of chronological age and biological maturation on the anthropometric profile and physical performance of young judo athletes. The hypothesis was that biological maturation would improve performance of young judokas, regardless of chronological age.

3.2. Methods

Participants

The sample included 67 youth male judokas aged 11.0-14.7 years from eight different judo clubs in Portugal (2 dropouts). To be included in the study, the judoka needed to be between 11 and 14 years old, have at least one year of judo training experience and have no contraindications to exercise. Judokas were divided into three age groups: U12 (11.0 and 11.9 years), U13 (12.0 and 12.9 years) and U15 (13.0 and 14.9 years). The study was conducted in accordance with the Declaration of Helsinki for human studies of the World Medical Association and was approved by the Ethics Committee of the Faculty of Sports Sciences and Physical Education of the University of Coimbra [CE/FCDEFUC/ 00452019]. Prior to data collection, parents or legal guardians signed informed consent. In addition, verbal assent was obtained from participants after the presentation of the aim and procedures of the study.

Anthropometric Measures

The anthropometric procedures described by Lohman et al. (1988) were adopted in the present study. Stature and sitting height were measured using a portable stadiometer (Seca Bodymeter 206, Seca GmBH & Co Kg, Hamburg, Germany) and a segmometer (Rosscraft Innovations, Spokane, Washington), respectively. The lower limb length was determined as stature minus sitting height. The arm span was measured assessing the distance between right and left dactylion points with both arms abducted 90 degrees. Hand length was determined by measuring the distance between the stylion and dactylion, while foot length was measured by the distance between the acropodion and pterion points. The arm and calf circumferences were measured with an anthropometric tape. All length measures were made to the nearest 0.1 cm. Body mass was evaluated to the nearest 0.1 kg using a portable digital scale (Seca Bella 840, Seca GmBH & Co Kg, Hamburg, Germany). Skinfold thickness was assessed to the nearest 0.1 mm using Rosscraft skinfold calipers (Rosscraft Innovations Inc, Vancouver, Canada). Assessments were conducted in the following order: triceps, subscapular, suprailiac and calf.

Thereafter, fat and fat-free masses were calculated based on sex specific equations derived from the sum of the triceps and subscapular skinfolds (Slaughter et al., 1988).

Biological Maturation

The Khamis-Roche method was used to predict the mature stature (PMS) (Khamis and Roche, 1994). The protocol requires decimal age, stature, and body mass of the participant and average parental stature. The stature of parents was collected through a questionnaire sent via email to the parents or legal guardians. The current stature was expressed as a percentage of PMS (%PMS). It is assumed that among children of the same chronological age, individuals closer to the PMS are more advanced in biological maturation (Malina et al., 2004). To classify the evaluated judokas by maturity status, the %PMS was expressed as the z-score of the mean and standard deviation from the sample itself. Two groups contrasting in somatic maturation were derived from z-scores of attained %PMS: early maturing (P > 50%) and late maturing (P < 50%).

Physical Performance

Aerobic performance and agility of the judokas were evaluated through the application of the multi-stage fitness test, with the number of completed laps being used as a performance indicator, and the 10 x 5 m shuttle-run test, recording the total time in seconds to cover 10 laps on a 5 m course (EUROFIT, 1996). The line-drill test was used to evaluate anaerobic performance, with the time for course completion recorded in seconds (Carvalho et al., 2011). Muscle strength was evaluated by abdominal muscle strength (AMS; 60-s sit-ups test) (Cesario et al., 2018), upper body muscle strength (UBS; 2-kg medicine ball throw) (Vossen et al., 2000), lower body muscle strength (LBS; standing long jump test) (EUROFIT, 1996) and handgrip strength (HgS; dynamometer Lafayette model 78-10), through two attempts using the dominant hand (EUROFIT, 1996). The best of the two attempts in kilograms was recorded for further analysis.

Procedures

All data were collected between April and May by the same trained team, during a single visit. Anthropometric measurements were carried out initially, followed by the physical performance tests. Data collection was organized in the form of a circuit. When passing through all anthropometric stations, judokas performed warm-up exercises under the guidance of a trainee researcher before undertaking stations in the following order: (1) multi-stage fitness test; (2) 2 kg standing medicine ball throw; (3) standing broad jump; (4) 10 x 5 m shuttle-run; (5) sit-ups; (6) handgrip strength with a dynamometer; and (7) a line-drill test.

Statistical Analysis

Descriptive statistics (ranges, means, standard deviations and 95% confidence intervals) were used for delineating the anthropometric profiles, physical fitness, and maturational status of judokas. Means, 95% confidence intervals and standard deviations were used to characterize the age groups, while means and standard deviations were calculated within the maturity groups. The Kolmogorov-Smirnov test was used to test normality of the total sample and appropriate log transformations (log 10) were adopted to normalize distributions.

The independent effects of chronological age and maturity on the anthropometric and physical performance variables were tested using multivariate analyses of variance (MANOVA), with analyses of variance (one-way ANOVA) performed when significance was detected. To determine the effect of age, a Bonferroni *post hoc* test was used to verify which age groups differed significantly. Age and maturity combined effects were assessed using a two-way MANOVA. A multivariate analysis of covariance (MANCOVA) was used to verify the independent effects of chronological age and maturity status on the dependent variables when controlling for maturity and age, respectively. Data were analyzed using IBM SPSS 22.0 (SPSS, Inc., Chicago, IL). The level of significance was set at $p \leq 0.05$.

3.3. Results

The descriptive statistics for the total sample and the results of the normality tests are presented in Table 3.1.

The descriptive statistics of the age groups are presented in Table 3.2. In absolute values, older judokas reached a higher percentage of their PMS, performed better than their younger peers, and had higher absolute measurements in most anthropometric measures.

Table 3.1. Descriptive statistics for the total sample and test of normality (n=67).

Variables	Range		Mean		Standard deviation	Kolmogorov-Smirnov	
	Minimum	Maximum	Value	95%CI		Value	p
Chronological age (years)	11.01	14,70	12.54	12.30 to 12,78	0.99	-	-
Predicted mature stature (cm)	161.9	198.3	182.6	180.2 to 184.3	7.2	-	-
Attained PMS (%)	77.0	94.0	84.4	83.2 to 85.5	4.7	-	-
Training experience (years)	1	9	3.33	2.74 to 3.91	2.40	-	-
Body mass (kg)	27.6	79.6	47.6	44.7 to 50.5	11.2	0.102	0.081
Fat mass (kg)	2.1	34.4	9.6	8.0 to 11.1	6.3	0.150	<0.01
Fat free mass (kg)	25.5	65.1	38.0	36.1 to 39.9	7.8	0.099	0.173
Stature (cm)	134.8	176.5	154.0	151.6 to 156.4	9.9	0.075	0.200
Sitting height (cm)	71.5	93.2	80.0	78.8 to 81.2	5.1	0.078	0.200
Arm span (cm)	133.0	180.0	154.1	151.5 to 156.7	10.8	0.060	0.200
Superior members length (cm)	36.2	70.8q	60.2	58.9 to 61.5	5.4	0.086	0.200
Hand length (cm)	14.1	21.3	16.9	16.5 to 17.2	1.5	0.074	0.200
Inferior members length (cm)	60.3	85.5	74.0	72.7 to 75.4	5.5	0.057	0.200
Foot length (cm)	20.1	29.0	24.4	24.0 to 24.9	2.0	0.098	0.185
Arm circumference (cm)	19.0	36.0	25.3	24.5 to 26.1	3.3	0.068	0.200
Calf circumference (cm)	27.0	40.1	32.6	31.8 to 33.4	3.3	0.071	0.200
Pacer test (m)	140	1740	757	680 to 835	318	0.094	0.200
Line-drill test (sec)	30.09	46.60	36.14	35.36 to 36.92	3.20	0.074	0.200
Agility 10x5 shuttle run (sec)	15.88	26.25	19.44	18.93 to 19.96	2.12	0.139	<0.01
60-s sit-ups (count)	15	61	41	39 to 44	10	0.089	0.200
2-kg ball throw (m)	3.19	8.79	5.22	4.93 to 5.52	1.22	0.077	0.200
Standing long jump (m)	1.12	5.65	1.69	1.55 to 1.83	0.57	0.179	<0.01
Hand grip strength (kgf)	14.0	40.0	24.80	23.38 to 26.23	5.85	0.158	<0.01

95% CI (confidence interval); Attained PMS (predicted mature status).

Table 3.2. Descriptive statistics for the total sample contrasting for age groups (n = 67).

Variables	U12 (n=23)			U13 (n=22)			U15 (n=22)		
	Mean	95%CI	SD	Mean	95%CI	SD	Mean	95%CI	SD
Chronological age (years)	11.43	11.28 to 11.59	0.35	12.59	12.45 to 12.73	0.32	13.7	13.5 to 13.9	0.5
Predicted mature stature (cm)	183.8	180.8 to 186.8	6.9	184.6	182.2 to 187.0	5.4	179.3	175.5 to 183.0	8.3
Attained PMS (%)	79.5	78.7 to 80.3	1.8	85.0	83.9 to 86.1	2.4	88.9	87.3 to 90.5	3.6
Training experience (yrs)	3	2 to 4	2	4	2 to 5	3	3	2 to 4	2
Body mass (kg)	39.3	35.8 to 42.8	8.1	51.7	47.4 to 56.0	9.7	52.2	46.5 to 57.8	12.7
Fat mass (kg)	7.5	5.0 to 10.0	5.8	11.5	8.9 to 14.1	5.9	10.0	6.9 to 13.0	7.0
Fat free mass (kg)	31.8	30.4 to 33.3	3.4	40.2	37.4 to 43.0	6.4	42.2	38.4 to 46.0	8.6
Stature (cm)	146.1	143.7 to 148.5	5.6	156.9	153.8 to 160.1	7.1	159.5	154.7 to 164.2	10.7
Sitting height (cm)	76.3	75.1 to 77.5	2.8	81.4	79.5 to 83.3	4.3	82.5	80.1 to 84.9	5.5
Arm span (cm)	146.3	143.2 to 149.4	7.2	156.2	152.0 to 160.4	9.4	160.1	155.5 to 164.8	10.5
Superior members length (cm)	57.3	55.9 to 58.8	3.2	61.7	59.8 to 63.6	4.2	61.7	58.6 to 64.8	7.0
Hand length (cm)	15.9	15.3 to 16.5	1.4	17.2	16.5 to 17.9	1.5	17.6	17.1 to 18.1	1.1
Inferior members length (cm)	69.8	68.3 to 71.2	3.4	75.5	73.9 to 77.2	3.8	77.0	74.3 to 79.6	6.0
Foot length (cm)	23.3	22.5 to 24.1	1.9	24.9	24.1 to 25.7	1.8	25.1	24.3 to 25.9	1.8
Arm circumference (cm)	23.3	22.0 to 24.5	2.9	26.3	25.0 to 27.6	2.9	26.4	24.9 to 27.9	3.3
Calf circumference	30.6	29.4 to 31.7	2.7	33.9	32.7 to 35.2	2.8	33.5	32.0 to 34.9	3.3
Pacer test (m)	617	511 to 722	243	731	606 to 856	282	931	776 to 1085	349
Line-drill test (sec)	37.68	36.22 to 39.14	3.38	36.26	35.18 to 37.34	2.44	34.41	33.12 to 35.70	2.91
Agility 10x5 shuttle run (sec)	20.04	18.93 to 21.15	2.57	19.42	18.67 to 20.16	1.69	18.84	18.00 to 19.67	1.88
60-s sit-ups (count)	39	35 to 43	9	42	38 to 47	11	42	38 to 46	9
2-kg ball throw (m)	4.27	3.88 to 4.65	0.89	5.43	5.03 to 5.83	0.90	6.01	5.50 to 6.53	1.16
Standing long jump	1.46	1.36 to 1.56	0.23	1.86	1.46 to 2.25	0.89	1.76	1.64 to 1.88	0.27
Hand grip strength (kgf)	21.6	20.0 to 23.2	3.7	25.0	22.6 to 27.3	5.2	28.1	25.1 to 31.0	6.6

95%CI (95% confidence interval); Attained PMS (attained predicted mature status).

Table 3.3 shows the effect of chronological age on anthropometry and physical performance. Significant effects were found in the two sets of variables (anthropometry: F = 1.871; $p < 0.05$; Pillai's trace = 0.545; $\eta 2p$ = 0.272; physical performance: F = 2.876; $p < 0.01$; Pillai's trace = 0.509; $\eta 2p$ = 0.254). The *post hoc* comparison (Bonferroni) indicated a tendency in the anthropometry measurements where U12 had significantly smaller measurements than U13 and U15 in almost all the anthropometric variables. The exception was body fat mass as the U12 group was significantly thinner than U13 (F = 3.854; $p < 0.05$; $\eta 2p$ = 0.107). Upper and lower body strength in the U12 group was significantly lower than in U13 and U15 (UBS - F = 18.220; $p < 0.01$; $\eta 2p$ = 0.363; LBS - F = 5.817; $p < 0.01$; $\eta 2p$ = 0.154). Considering aerobic and anaerobic performance and handgrip strength, U15 judokas performed significantly better than U12 (aerobic - F = 6.568; $p < 0.01$; $\eta 2p$ = 0.170; anaerobic - F = 7.005; $p < 0.01$; $\eta 2p$ = 0.180; HgS - F = 7.977; $p < 0.01$; $\eta 2p$ = 0.200).

Maturation, anthropometry, and physical performance data are presented in Table 3.4. More mature judokas presented greater anthropometric measurements in all variables and better performance in all physical performance tests. Maturation had a significant effect on anthropometry (F = 10.085; p < 0< 0.01; Pillai's trace = 0.669; $\eta 2p$ = 0.669) and physical performance (F = 11.700; $p < 0.01$; Pillai's trace = 0.581; $\eta 2p$ = 0.581). Subsequent ANOVA showed a significant maturity effect on all anthropometric variables except for body fat mass, and on all physical tests except for agility and abdominal strength.

The combined effects of chronological age and maturation on anthropometric and physical performance variables are presented in Table 3.5. No significant effect of interaction between age and maturational status was observed. However, even after controlling for chronological age, the maturity effect on anthropometric (F = 4.097; $p < 0.01$; Pillai's trace = 0.481; $\eta 2p$ = 0.481) and physical performances variables (F = 3.859; $p < 0.01$; Pillai's trace = 0.0.318; $\eta 2p$ = 0.318) was observed. A reduction in the maturation effect was noted with age control, but it remained significant in aerobic performance (F = 4.928; $p < 0.05$; $\eta 2p$ = 0.071), upper body strength (F = 5.894; $p < 0.05$; $\eta 2p$ = 0.084) and handgrip strength (F = 6.522; $p < 0.05$; $\eta 2p$ = 0.092).

Table 3.3. Results of multivariate analyses of variance (MANOVA) and univariate analyses of variance (ANOVA) to examine the effects of chronological age on anthropometrics and physical performances variables (n = 67).

Dependent variables	Analyses of variance					Post-hoc comparisons
	Test	Pillai's trace	*F*	*p*	η^2_p	
Anthropometry	MANOVA	0.545	1.871	<0.05	0.272	
Body mass	ANOVA		11.311	<0.01	0.261	U12 < U13 & U15
Body Fat mass*	ANOVA		3.854	<0.05	0.107	U12 < U13
Body Fat free mass	ANOVA		16.435	<0.01	0.339	U12 < U13 & U15
Stature	ANOVA		17.717	<0.01	0.356	U12 < U13 & U15
Sitting height	ANOVA		13.251	<0.01	0.239	U12 < U13 & U15
Arm span	ANOVA		13.800	<0.01	0.301	U12 < U13 & U15
Superior members length	ANOVA		5.719	<0.01	0.152	U12 < U13 & U15
Hand length	ANOVA		10.093	<0.01	0.240	U12 < U13 & U15
Inferior members length	ANOVA		15.980	<0.01	0.333	U12 < U13 & U15
Foot length	ANOVA		6.524	<0.01	0.169	U12 < U13 & U15
Arm circumference	ANOVA		7.704	<0.01	0.194	U12 < U13 & U15
Calf circumference	ANOVA		8.847	<0.01	0.217	U12 < U13 & U15
Physical fitness	MANOVA	0.509	2.876	<0.01	0.254	
Pacer test	ANOVA		6.568	<0.01	0.170	U12 < U15
Line-drill test	ANOVA		7.005	<0.01	0.180	U12 > U15
Agility 10x5 shuttle run*	ANOVA		1.824	0.170	0.054	
60-s sit-ups	ANOVA		0.739	0.482	0.023	
2-kg ball throw	ANOVA		18.220	<0.01	0.363	U12 < U13 & U15
Standing long jump*	ANOVA		5.817	<0.01	0.154	U12 < U13 & U15
Hand grip strength*	ANOVA		7.977	<0.01	0.200	U12 < U15

η^2_p (partial eta square); * test was performed on log-transformed variable.

Table 3.4. Descriptive statistics (mean and standard deviation), results of multivariate analyses of variance (MANOVA) and univariate analyses of variance (ANOVA) to examine the effects of maturity status on anthropometry and physical fitness variables (n = 67).

Dependent variables	Contrasting Maturity Group				Analyses of variance				
	Latest Maturing (n=35)		Earliest Maturing (n=32)						
	Mean	SD	Mean	SD	Test	Pillai's trace	*F*	*P*	η^2_p
Anthropometry					MANOVA	0.669	10.085	< 0.01	0.669
Body mass (kg)	41.3	8.5	54.4	11.2	ANOVA		29.027	< 0.01	0.309
Body Fat mass (kg)*	8.5	5.6	10.8	6.9	ANOVA		2.931	0.092	0.043
Body Fat free mass (kg)	32.9	4.1	43.6	7.1	ANOVA		58.426	< 0.01	0.473
Stature (cm)	147.1	6.0	161.6	7.4	ANOVA		76.719	< 0.01	0.541
Sitting height (cm)	76.7	2.7	83.7	4.5	ANOVA		62.067	< 0.01	0.488
Arm span (cm)	147.7	7.8	161.1	9.0	ANOVA		42.323	< 0.01	0.394
Superior members length (cm)	58.0	3.5	62.6	6.1	ANOVA		15.082	< 0.01	0.188
Hand length (cm)	15.9	1.2	17.9	1.1	ANOVA		45.298	< 0.01	0.411
Inferior members length (cm)	70.5	4.2	77.9	3.9	ANOVA		56.441	< 0.01	0.465
Foot length (cm)	23.5	1.9	25.4	1.6	ANOVA		18.646	< 0.01	0.223
Arm circumference (cm)	23.8	2.7	26.9	3.2	ANOVA		18.399	< 0.01	0.221
Calf circumference (cm)	31.1	2.6	34.2	3.1	ANOVA		19.170	< 0.01	0.228
Physical fitness					MANOVA	0.581	11.700	< 0.01	0.581
Pacer test (m)	615	217	913	340	ANOVA		18.684	< 0.01	0.223
Line-drill test (sec)	37.24	3.04	34.94	2.96	ANOVA		9.750	< 0.01	0.130
Agility 10x5 shuttle run (sec)*	19.61	2.27	19.26	1.95	ANOVA		0.421	0.519	0.006
60-s sit-ups (count)	40	9	43	10	ANOVA		1.086	0.301	0.016
2-kg ball throw (m)	4.49	0.85	6.03	1.05	ANOVA		43.757	< 0.01	0.402
Standing long jump (m)*	1.53	0.27	1.86	0.74	ANOVA		9.101	< 0.01	0.123
Hand grip strength (kgf)*	21.71	3.85	28.19	5.84	ANOVA		29.203	< 0.01	0.310

SD (standard deviation); η^2_p (partial eta square); * test was performed on log-transformed variable.

Table 3.5. Results of Two-Way MANOVA to examine the interaction effect (chronological age × maturity status) and results of MANCOVA to assess the age effect when controlling by maturity and the maturity effect when controlling by age on anthropometry and physical performance variables (n = 67).

Dependent variables	Test	Analyses of variance											
		Interaction effect Age x Maturity				Age effect (controlling for maturity)				Maturity effect (controlling for age)			
		Pillai's trace	*F*	*p*	η^2_p	Pillai's trace	*F*	*p*	η^2_p	Pillai's trace	*F*	*p*	η^2_p
Anthropometry	MANOVA*	0.281	1.843	0.070	0.281								
Physical fitness	MANOVA*	0.110	0.991	0.447	0.110								
Anthropometry	MANCOVA					0.280	0.798	0.722	0.140	0.481	4.097	<0.01	0.481
Body mass	ANCOVA										9.278	<0.05	0.127
Body Fat mass**	ANCOVA										1.226	0.272	0.019
Body Fat free mass	ANCOVA										14.677	<0.01	0.187
Stature	ANCOVA										23.046	<0.01	0.265
Sitting height	ANCOVA										20.055	<0.01	0.239
Arm span	ANCOVA										11.538	<0.01	0.153
Superior members length	ANCOVA										3.513	0.065	0.052
Hand length	ANCOVA										16.402	<0.01	0.204
Inferior members length	ANCOVA										15.715	<0.01	0.197
Foot length	ANCOVA										5.043	<0.05	0.073
Arm circumference	ANCOVA										4.685	<0.05	0.068
Calf circumference	ANCOVA										7.613	<0.01	0.106
Physical fitness	MANCOVA					0.200	0.919	0.541	0.100	0.318	3.859	<0.01	0.318
Pacer test	ANCOVA										4.928	<0.05	0.071
Line-drill test	ANCOVA										0.031	0.861	0.000
Agility 10x5 shuttle run**	ANCOVA										2.320	0.133	0.035
60-s sit-ups	ANCOVA										0.018	0.894	0.000
2-kg ball throw	ANCOVA										5.894	<0.05	0.084
Standing long jump**	ANCOVA										0.378	0.541	0.006
Hand grip strength**	ANCOVA										6.522	<0.05	0.092

η^2_p (partial eta square); * Two-Way MANOVA; ** test was performed on log-transformed variable.

3.4. Discussion

The present study evaluated the independent and combined effect of chronological age and biological maturation on anthropometric and physical performance variables in a sample of young Portuguese judokas. Significant independent effects of chronological age and maturity status on all anthropometric variables were evidenced, with older and more maturing judokas reaching higher anthropometric measurements. There were also significant differences between age groups and maturational groups in most of the physical performance variables. Older and more mature judokas demonstrated better performance in all variables, except for agility and abdominal strength tests, supporting the hypothesis that older and more mature individuals are physically superior (Malina et al., 2015). When maturation was controlled, the effect of age was no longer noticeable. On the contrary, after controlling for the effect of age, the impact of maturation on anthropometric and physical performance variables remained significant, which may indicate that in performance of youth judo athletes' maturation has a greater impact than age.

The current data suggest that maturation has a greater impact on the judokas' morphology and physical performance than chronological age. Studies which verified the effect of age and maturation on anthropometric variables and physical performance also suggest a greater impact of biological maturation in youth athletes than chronological age. In a sample of 58 basketball players aged 9.5 to 15.5 years, Carvalho et al. (2018) found a significant variation in body size and functional capacities due to maturity status. Meylan et al. (2014) studying 74 youth athletes aged 11 to 15 years from different sports found a significant influence of maturity status on strength and power performance. Towlson et al. (2018) evaluated 969 soccer players aged 8 to 18 years to identify moments of greater and lesser influence of chronological age and biological maturation on the anthropometry and physical performance of these athletes. They concluded that biological maturation reached higher impact rates at different times for different anthropometric and physical performance variables. Therefore, the distribution of youth athletes in competitive categories requires to consider the impact of biological maturation. Nevertheless, a recent study with 146 young soccer players found a significant prevalence of athletes presenting normal maturity status, emphasizing the need for further studies on the impact of biological maturation on youth athletes' performance (Altimari et al., 2021).

Similar studies with youth judokas and other youth martial arts athletes are scarce. Torres-Luque et al. (2015) studied 146 judo athletes aged 14-17 years and noticed an age effect, with older judokas presenting higher handgrip strength than younger judokas, which are results comparable to those of the present study. Branco et al. (2019) in the search for alternatives of classification of youth karate athletes which would consider biological maturation (bio-banding), evidenced maturational differences within weight categories in a sample of 20 females (11.76 ± 2.49 yrs) and 34 males (11.74 ± 2.49 yrs). Fukuda et al. (2018) in a study which investigated the influence of somatic maturation on indicators of muscular morphology, biomechanical variables, and bilateral asymmetry, evidenced that somatic maturity had the greatest relationship with handgrip performance and lower-body plyometric ability. However, research examining individual and combined contribution of chronological, biological, and training age to performance in judo is limited. The present study intended to contribute to fill this gap. The apparently greater effect of biological maturation on the anthropometry and physical performance of youth judokas, in comparison with the age effect, corroborates the literature and points to the need to maturation control in training and competition of youth judo athletes.

Training experience is another variable that deserves consideration in studies assessing the impact of maturation on youth judo and combat sports athletes. In a recent study investigating a sample of youth judokas with a similar age range, but with greater training experience than in the present study, it was found that growth and maturation predicted performance in generic neuromuscular tests, except for the standing long jump, while growth, maturation and training experience explained the variation in a judo-specific test (Detanico et al., 2020). Courel-Ibnez et al. (2018) indicated that the accumulated training experience improved the ability to perform the required judo technique. In the present study, which used generic tests to assess physical performance of youth judokas, where the application of a specific technique is not required, training experience was considered only for the inclusion of participants in the sample. This is a limitation that should be addressed in future studies, with the inclusion of accumulated judo training experience as a relevant variable.

Although the age-independent effect was evidenced, analyses performed allow us to understand that the maturational effect had a greater impact on the morphology and physical performance of youth judokas evaluated, since this effect remained after controlling for age. The opposite did not occur with the effect of age disappearing upon maturation control.

Furthermore, no significant effect of the interaction between chronological age and maturation was evidenced, which could have been caused by the small sample size due to the difficulty of recruiting more youth judo athletes. The maturation effect on physical performance evidenced in the present study converges with the cited investigations, most notable on upper body and handgrip strength and aerobic and anaerobic performance, characteristics which are among the foremost to be developed in judokas (Bonitch-Góngora et al., 2013; Franchini et al., 2009; Thomas et al., 1989), and on which the maturation effect remained even after controlling for age, notably in the aerobic performance tests and in the upper limb and handgrip strength tests.

A major limitation of this study refers to predicting/estimating biological maturation as opposed to direct measurements. PMS has been used in several studies as a non-invasive indicator of biological maturation and was reported with a reasonable validity when compared with gold standard methods (Coelho et al., 2004). However, this method requires the stature of the biological parents to predict the adult stature of the evaluated individual. In this study, this information was obtained through self-report, which might cause bias.

It has been suggested that within combat sports, such as judo, chronological age, weight categories and skill levels could minimize the maturity effect over the youth judokas performance (Fukuda, 2015; Krstulović et al., 2005). However, due to the little number of investigations on the subject it cannot be refuted nor proved whether this was the case. In addition, there are studies that outline the possibility of maturation effect and relative age effect on performance of youth judokas despite the division into weight categories.

Moreover, investigators and sports organizations are critical to the use of body mass as a criterion for youth combat sports athletes as a consequence of the increasing use of rapid weight loss in the pre-competitive period as a strategy to gain competitive advantage, with possible health and performance implications (Dubnov-Raz et al., 2015). Future investigations should consider the effectiveness of categorization by chronological age and body mass in the control of the maturational effect, as well as the search for classification criteria which could substitute the use of weight.

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CHAPTER 4

Study 2

(Published version available in Annex 2)

Chronological Age, Somatic Maturation and Anthropometric Measures: Association with Physical Performance of Young Male Judo Athletes

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ABSTRACT

Sport for children and adolescents must consider growth and maturation to ensure suitable training and competition, and anthropometric variables could be used as bio-banding strategies in youth sport. This investigation aimed to analyze the association between chronological age, biologic maturation, and anthropometric characteristics to explain physical performance of young judo athletes. Sixty-seven judokas (11.0–14.7 years) were assessed for anthropometric and physical performance. Predicted adult stature was used as a somatic maturation indicator. A Pearson's bivariate correlation was performed to define which anthropometric variables were associated with each physical test. A multiple linear hierarchical regression was conducted to verify the effects of age, maturity, and anthropometry on physical performance. The regression models were built with age, predicted adult stature, and the three most significantly correlated anthropometric variables for each physical test. Older judokas performed better in most of the physical tests. However, maturation attenuated the age effect in most variables and significantly affected upper body and handgrip strength. Anthropometric variables attenuated age and maturity and those associated with body composition significantly affected the performance in most tests, suggesting a potential as bio-banding strategies. Future studies should investigate the role of anthropometric variables on the maturity effect in young judokas.

Keywords: adolescent athlete; combat sports; body composition; bio-banding.

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4.1. Introduction

The complex process of growth and maturation must be considered for children and adolescents in sport to ensure suitable training and competition routines. Chronological age is the traditional strategy to categorize young athletes appropriately for their level of development (Lloyd et al., 2014). While growth is the process of increasing body size in whole or in parts, biological maturation refers to physiological and cognitive development towards adulthood. Although maturational events have an established order in which they happen, the moment when they occur and their duration have immense variability between individuals, even at the same age, which affect the physical, technical, and psychological performance of young athletes. This happens more prominently in boys between 13 and 16 years old (Malina et al., 2004), which may increase the risk of injury (Wik et al., 2020) and impair motivation due to the performance discrepancy (Carvalho et al., 2017), influencing whether the young athlete will continue in sports practice long-term (Figueiredo et al., 2009). In sports where strength, power, and speed are paramount, and in those where physical contact is inevitable, mature individuals tend to have a physical advantage over their less mature peers, since young people that mature and develop early tend to be taller and heavier (Till et al., 2014).

Several investigations have been carried out to examine the effect of growth and maturation on young athletes' performance and to seek alternative strategies to chronological age for the categorization of young athletes, namely those that are based on the use of body size and/or maturational status (Abbott et al., 2019; Baxter-Jones et al., 2020; Malina et al., 2005). These strategies are called bio-banding and do not disregard other aspects that must be considered regarding the allocation of young athletes in competitive categories, such as skill level and psychological profile ((Cumming et al., 2017). However, most of these investigations focus on team sports, mainly in soccer, some with support from official sporting entities, and have already resulted in the first experiences of unofficial tournaments using bio-banding to distribute young athletes in competitive categories, with positive results (Cumming et al., 2018). In combat sports, less research attention has been given to the plausible effect of maturation over performance ((Nabofa, 2012; Zubitashvili, 2011), and to the applicability of bio-banding to different modalities. Nonetheless, grouping young combat athletes based on physical attributes is common (e.g., boxing, judo, taekwondo, wrestling). In these modalities, athletes are grouped based on chronological age and body mass, and compete in weight classes to promote fair competition and reduce potential injuries (Langan-Evans et al., 2011). Although studies on the topic are still scarce (Zubitashvili, 2011), there is evidence of maturation effect within weight categories in young combat sports (Branco et al., 2019), raising questions about the suitability of body mass as criteria to guarantee equal conditions among athletes, justifying research on the topic.

In addition, various research investigated the use of anthropometric variables for detection and prediction of success in young athletes (Sánchez-Muñoz et al., 2012), which can potentially also be used as bio-banding alternatives instead of body mass for categorizing young athletes in various sports, including combat sports. Based on the above-mentioned factors, the aim of the present investigation was to analyze the association between chronological age, biological maturation, and anthropometric characteristics to explain the physical performance of young judo athletes. Assuming that anthropometric characteristics may mitigate the effect of chronological age and biological maturation on the performance of young judo athletes, bio-banding strategies in judo and other combat sports could be developed using anthropometric variables, aiming to promote training and competition routines best suited to the development stages of young combat sport athletes.

4.2 Methods

Participants

This is a cross-sectional study with a convenience sample, consisting of 67 young male judokas aged 11.0–14.7 years old selected from eight clubs in Portugal. To be included in the study, the participants needed to be between 11.0 and 14.9 years old, have at least one year of judo training, and have no physical or psychological contraindications to participation. Parents or legal guardians provided signed informed consent prior to data collection. Verbal consent was also obtained from participants. Two participants from different clubs dropped out of the study once data collection had commenced. The study was conducted in accordance with the Declaration of Helsinki for Human Studies of the World Medical Association and approved by the Ethics Committee of the Faculty of Sports Sciences and Physical Education of the University of Coimbra [CE/FCDEF-UC/00452019].

Anthropometric Measures

Common anthropometric procedures (Gordon et al., 1988) were adopted. Stature and sitting height (SH) were measured using a portable stadiometer (Seca Bodymeter 206; Seca Deutschland, Hamburg, Germany) and a segmometer (Rosscraft, T.E. and B. Ross, Perth, Australia), respectively. The inferior members' length (IML) was estimated as stature minus SH. Arm span (AS) was measured using a metallic anthropometric tape by assessing the distance between right and left dactylion points, with both arms abducted 90 degrees. The hand length (HL) was measured as the distance between the stylion and dactylion, while the foot length (FL) was measured as a straight distance between the acropodion and pterion points using an anthropometer. Arm circumference (AC) and calf circumference (CC) were measured with a metallic anthropometric tape. All measures were taken to the nearest 0.1 cm. Body mass (BM) was measured to the nearest 0.1 kg using a portable digital scale (Seca Bella 840; Seca Deutschland, Hamburg, Germany). Skinfold thickness was assessed to the nearest 0.1 mm using a Rosscraft skinfold calipers in the following references: triceps, subscapular, suprailiac, and calf. Estimates of fat mass percentage were obtained from the sex-specific equation derived from the sum of the triceps and subscapular skinfolds (Slaughter et al., 1988). Thereafter, estimated body fat mass (BFM) and body fat-free mass (BFFM) were calculated.

Biological Maturation

Predicted adult stature (PAS) was used as a maturational indicator (Khamis and Roche, 1994). It has been adopted in investigations on the biological maturation effect on physical fitness of children in general (Coelho-E-Silva et al., 2013) and in research focusing on youth performance in sport (Howard et al., 2016), due to the feasibility compared with more valid but invasive indicators (Malina et al., 2012). Predicted adult stature has been used instead of peak of height velocity (PHV) in studies on bio-banding, since both have correspondence with pubertal status given by stage of pubic hair (Cumming et al., 2017), but the latter seems to have limited application depending on chronological age and actual age at the peak of height velocity (Malina and Kozieł, 2014). The PAS protocol requires the participants' decimal age, stature, and body mass, as well as the average parental stature. The stature of the parents was collected through a questionnaire attached to the informed consent form. The PAS variable was also expressed as the percentage of predicted adult stature attained (APAS). It is assumed that among children of the same chronological age, individuals with higher APAS are more advanced in somatic maturation compared with individuals with lower APAS (Malina et al., 2004).

Physical Performance

The pacer test was used to evaluate aerobic performance, with the number of completed laps being used as performance indicator. Agility was measured using a 10 x 5 m shuttle-run test, with the time to complete all laps recorded in seconds (EUROFIT, 1996). The line-drill test was used to evaluate anaerobic performance, with the time taken to complete the course expressed in seconds (Carvalho et al., 2011). Strength was assessed using the following indicators: abdominal muscle strength (AMS), 60-s sit-up test (Cesario et al., 2018); upper body muscle strength (UBS), 2-kg medicine ball throw (Vossen et al., 2000) ; lower body muscle strength (LBS), standing long jump test (EUROFIT, 1996); and dominant-hand grip strength (HgS), measured by a dynamometer (Lafayette) (EUROFIT, 1996). The best of two attempts was recorded in kilograms for HgS.

Procedures

All data were collected by the same trained team, in a single visit for each judo club, where the anthropometric measurements were carried out initially, followed by the physical performance assessments. Participants completed a warm-up, under the guidance of a trainee researcher, before each station was completed in circuit form, in the following order: (1) pacer; (2) 2 kg standing medicine ball throw; (3) stand broad jump test; (4) 10 _ 5 m shuttle-run test; (5) sit-ups; (6) handgrip strength; and (7) line-drill test.

Statistical Analysis

Descriptive statistics (ranges, means, standard deviations, and 95% confidence intervals) were used for chronological age (CA), APAS, anthropometric characteristics, and physical test performance. The Kolmogorov–Smirnov test was used to test normality: body fat mass, agility, lower body strength, and handgrip strength were significant. A Pearson's bivariate correlation, with 95% bias corrected and accelerated confidence limits based on 1000 bootstrap samples, to correct data normality (Field, 2013), was performed to assess the level of association between all variables. Multiple linear regression, which does not assume the assumption of data normality (Field, 2013), was conducted to verify the influence of the maturity indicators and anthropometric variables on physical performance. CA and APAS were previously selected for the first and second regression models, respectively, based on their impact on the performance of young athletes described in the literature (Malina et al., 2004). For each performance test, the three anthropometric variables with the highest correlation coefficient were selected for the third model. Independent variables were inserted into the regression models hierarchically: Model 1 was constituted by CA; Model 2 by CA and APAS; and Model 3 by CA, APAS, and the three anthropometric variables with the highest correlation coefficients for each physical performance test. Most models met all assumptions for the multiple linear regression (Field, 2013): error independence (Durbin-Watson values between 1–3), non-multicollinearity (Tolerance values >0.1; VIF values <10), homoscedasticity (standardized residual values between -3 and 3) and non-influential cases (Cook's distance values <1). The exception was LBS, which failed on the assumption of non-influential cases. Significance of $p < 0.05$ was adopted in the analyses. IBM SPSS 26.0 software (SPSS, Inc., Chicago, IL, USA) was used in the study.

4.3 Results

Table 4.1 presents the descriptive statistics for the total sample, showing ranges, means, standard deviations, and 95% confidence intervals for CA, APAS, anthropometric characteristics, and physical test performance.

Table 4.1. Descriptive statistics for the total sample (*n* = 67).

Variables	Range		Mean		*sd*
	Minimum	Maximum	Value	95%CI	
Chronological age (years)	11.01	14.70	12.54	12.30 to 12.78	0.99
APAS (%)	77.0	94.0	84.4	83.2 to 85.5	4.7
Body mass (kg)	27.6	79.6	47.6	44.7 to 50.5	11.2
Body fat mass (kg)	2.1	34.4	9.6	8.0 to 11.1	6.3
Body fat-free mass (kg)	25.5	65.1	38.0	36.1 to 39.9	7.8
Stature (cm)	134.8	176.5	154.0	151.6 to 156.4	9.9
Sitting height (cm)	71.5	93.2	80.0	78.8 to 81.2	5.1
Arm span (cm)	133.0	180.0	154.1	151.5 to 156.7	10.8
Superior members length (cm)	36.2	70.8	60.2	58.9 to 61.5	5.4
Hand length (cm)	14.1	21.3	16.9	16.5 to 17.2	1.5
Inferior members length (cm)	60.3	85.5	74.0	72.7 to 75.4	5.5
Foot length (cm)	20.1	29.0	24.4	24.0 to 24.9	2.0
Arm circumference (cm)	19.0	36.0	25.3	24.5 to 26.1	3.3
Calf circumference (cm)	27.0	40.1	32.6	31.8 to 33.4	3.3
Pacer test (m)	140	1740	757	680 to 835	318
Line-drill test (sec) *	30.09	46.60	36.14	35.36 to 36.92	3.20
Agility 10 × 5 shuttle run (sec) *	15.88	26.25	19.44	18.93 to 19.96	2.12
60-s sit-ups (count)	15	61	41	39 to 44	10
2-kg ball throw (m)	3.19	8.79	5.22	4.93 to 5.52	1.22
Standing long jump (m)	1.12	5.65	1.69	1.55 to 1.83	0.57
Hand grip strength (kgf)	14.0	40.0	24.8	23.4 to 26.2	5.8

95%CI, confidence interval; *sd*, standard deviation; APAS, attained predicted mature stature; * Runtime tests—lower value represents better performance.

Table 4.2 summarizes the Pearson's bivariate correlation coefficient between maturational indicators and anthropometric variables, and the physical performance. Significant moderate to high correlations were found for CA and APAS with the performance variables, except for agility, in which only CA was significant, and except for abdominal strength. Among the measured anthropometric variables, body fat mass correlated with all physical tests associated with running, and with abdominal strength. Body fat-free mass correlated with the neuromuscular strength performance, except for abdominal strength. Body mass, arm circumference, and calf circumference were not selected for any regression model, as no significant correlations were found.

Table 4.3 showed the multiple linear regression models for the aerobic, anaerobic and agility physical test performances. Model 1 significantly explained 16.8% of the aerobic performance, 19.9% of the anaerobic performance, and 6.2% of the agility performance. The effect of age on these tests was mitigated with the inclusion of the somatic maturation indicator. Model 2 was not significantly associated with the agility test since there was no significant correlation between agility and APAS. Model 3 explained the performance relative to aerobic (44.6%), anaerobic (47.6%), and agility (24.3%) tests significantly better than the other models. The inclusion of the anthropometric variables attenuated the effects of CA and APAS. Body fat mass ($\beta = -0.507$, $p < 0.001$) and hand length ($\beta = 0.262$, $p = 0.046$) explained aerobic performance better than the other variables. For anaerobic performance, only body fat mass ($\beta = 0.536$, $p < 0.001$) was highlighted with a significantly effect. For agility test performance, body fat mass ($\beta = 0.360$, $p = 0.003$), and superior members length ($\beta = -0.290$, $p = 0.034$) emerged as being significantly associated.

Table 4.2. Pearson bivariate correlation coefficients between maturational indicators and anthropometric variables, and physical tests performance variables, with 95% bias corrected and accelerated confidence limits based on 1000 bootstrap samples (n = 67).

Independent Variables	Dependent Variables (Physical Tests Performance)						
	Pacer Test (m)	**Line-Drill test (s)** $^{+}$	**Agility 10 × 5 Shuttle Run (s)** $^{+}$	**60-s Sit-Ups (*n*)**	**2-kg Ball Throw (m)**	**Stand Long Jump (m)**	**Handgrip Strength (kg)**
Maturational indicator							
Age	0.41 ** (0.21; 0.59)	−0.45 *** (−0.61; −0.24)	−0.25 * (−0.48; 0.02)	0.15 (−0.07; 0.37)	0.63 *** (0.42; 0.80)	0.47 *** (0.25; 0.67)	0.52 *** (0.29; 0.68)
APAS (%)	0.39 ** (0.18; 0.57)	−0.41 ** (−0.58; −0.21)	−0.19 (−0.43; 0.12)	0.06 (−0.20; 0.30)	0.68 *** (0.47; 0.83)	0.47 *** (0.24; 0.68)	0.65 *** (0.49; 0.77)
Anthropometry							
Body mass (kg)	−0.07 (−0.29; 0.19)	0.02 (−0.22; 0.21)	−0.10 (−0.14; 0.33)	−0.09 (−0.32; 0.17)	0.66 *** (0.48; 0.79)	0.10 (−0.14; 0.34)	0.66 *** (0.49; 0.78)
Body fat mass (kg)	−0.41 ** (−0.56; −0.19)	0.40 ** (0.16; 0.57)	0.32 ** (0.05; 0.53)	−0.27 * (−0.50; 0.03)	0.22 (0.01; 0.42)	−0.31 * (−0.50; −0.10)	0.26 * (0.01; 0.46)
Body fat-free mass (kg)	0.23 (0.04; 0.42)	−0.29 * (−0.46; −0.14)	−0.11 (−0.34; 0.10)	0.08 (−0.16; 0.32)	0.82 *** (0.71; 0.89)	0.40 ** (0.15; 0.61)	0.78 *** (0.66; 0.86)
Stature (cm)	0.25 * (0.06; 0.43)	−0.34 ** (−0.48; −0.17)	−0.19 (−0.40; 0.04)	0.05 (−0.22; 0.31)	0.71 *** (0.55; 0.82)	0.37 ** (0.16; 0.57)	0.73 *** (0.61; 0.82)
Sitting height (cm)	0.20 (−0.02; 0.40)	−0.25 * (−0.40; −0;07)	−0.14 (−0.31; 0.06)	0.05 (−0.20; 0.30)	0.69 *** (0.51; 0.82)	0.33 ** (0.13; 0.52)	0.71 *** (0.54; 0.82)
Arm span (cm)	0.16 (−0.02; 0.37)	−0.34 ** (−0.50; −0.18)	−0.21 (−0.43; 0.01)	0.11 (−0.16; 0.34)	0.73 *** (0.60; 0.82)	0.52 ** (0.13; 0.55)	0.70 *** (0.56; 0.81
Superior members length (cm)	0.13 (−0.08; 0.38)	−0.30 * (−0.54; −0.08)	−0.26 * (−0.45; −0.10)	−0.01 (−0.23; 0.24)	0.58 *** (0.38; 0.78)	0.40 ** (0.19; 0.59)	0.56 *** (0.35; 0.79)
Hand length (cm)	0.38 ** (0.20; 0.55)	−0.31 * (−0.45; −0.16)	−0.15 (−0.35; 0.07)	0.31 * (0.10; 0.55)	0.55 *** (0.29; 0.74)	0.28 * (0.02; 0.53)	0.53 *** (0.29; 0.72)
Inferior members length (cm)	0.27 * (0.09; 0.44)	−0.38 ** (−0.53; −0.20)	−0.21 (−0.43; 0.04)	0.04 (−0.21; 0.29)	0.64 *** (0.48; 0.75)	0.36 ** (0.14; 0.55)	0.66 *** (0.55; 0.77)
Foot length (cm)	0.26 * (0.08; 0.46)	−0.22 (−0.40; −0.04)	−0.15 (−0.36; 0.09)	0.28 * (0.05; 0.51)	0.49 *** (0.26; 0.70)	0.21 (−0.01; 0.44)	0.50 *** (0.29; 0.69)
Arm circumference (cm)	−0.09 (−0.30; 0.13)	0.03 (−0.20; 0.24)	0.12 (−0.14; 0.36)	−0.05 (−0.28; 0.19)	0.66 *** (0.48; 0.78)	0.12 (−0.15; 0.35)	0.57 *** (0.37; 0.71)
Calf circumference (cm)	−0.15 (−0.37; 0.09)	0.06 (−0.18; 0.25)	0.16 (−0.09; 0.39)	−0.16 (−0.38; 0.12)	0.57 *** (0.38; 0.72)	0.01 (−0,22; 0.25)	0.53 *** (0.35; 0.68)

APAS attainted predicted adult stature; * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$; $^{+}$ Runtime tests—lower value represents better performance; BCa, bootstrap 95% CLs reported in brackets; Bold records represent the anthropometric variables chosen to the multilinear regression models.

Table 4.3. Hierarchical multiple linear regression models for physical performance tests (aerobic, anaerobic, and agility) in youth male judokas.

Physical Test	Multilinear Regression Models					
	Model	**R^2**	***p***	**Independent Variables**	**β**	***p***
Pacer Test (m)	Model 1	0.168	0.001	Age	0.410	0.001 *
	Model 2	0.171	0.637	Age	0.307	0.215
				APAS	0.116	0.637
	Model 3	0.446	<0.001	Age	0.127	0.553
				APAS	0.254	0.330
				Body fat mass	−0.507	<0.001 *
				Hand length	0.262	0.046*
				Inferior members length	−0.037	0.816
Line-drill test (s) +	Model 1	0.199	<0.001	Age	−0.446	<0.001 *
	Model 2	0.200	0.753	Age	−0.379	0.120
				APAS	−0.076	0.753
	Model 3	0.476	<0.001	Age	−0.326	0.124
				APAS	0.040	0.876
				Body fat mass	0.536	<0.001 *
				Arm span	−0.267	0.152
				Inferior members length	−0.118	0.533
Agility 10 × 5 shuttle run (s) +	Model 1	0.062	0.042	Age	−0.250	0.042 *
	Model 2 #	-	-	Age	-	-
				APAS	-	-
	Model 3	0.243	0.002	Age	−0.365	0.145
				APAS	0.213	0.436
				Body fat mass	0.360	0.003 *
				Superior members length	−0.290	0.034 *

* $p < 0.05$; APAS attainted predicted adult stature; + Runtime tests—lower value represents better performance; # The models were not adequate to explain the variable.

The regression models for neuromuscular strength were presented in Table 4.4. Model 1, containing only CA, explained lower body strength better than other models. Model 2 was better suited for UBS (46.3%) and HgS (44.4%) to explain performance than Model 1. With its inclusion in Model 2, APAS attenuated the CA effect, while remaining significant (β = 0.544, p = 0.008 for UBS; β = 0.897, p < 0.001 for HgS). Model 3 explained performance better in the majority of the neuromuscular strength tests, except for LBS. The addition of the anthropometric variables attenuated age and maturity effects and significantly explained 23.9% of AbS, 71.6% of the UBS, and 79% of the HgS. Body fat mass better explained AbS (β = -0.295, p < 0.05), while age (β = 0.402, p < 0.011) and body fat-free mass (β = 0.747, p < 0.001) better explained UBS. Only body fat-free mass was significantly related to HgS (β = 0.626, p < 0.01). Superior members length was the only variable significantly related to LBS (β = 0.318, p < 0.05).

Table 4.4. Hierarchical multiple linear regression models for physical performance tests (neuromuscular strength) in youth male judokas.

Physical Test	Multilinear Regression Models					
	Model	**R^2**	***p***	**Independent Variables**	**β**	***p***
60-s sit-ups (count)	Model 1 #			Age		
	Model 2 #			Age		
				APAS		
	Model 3	0.239	0.003	Age	0.359	0.147
				APAS	−0.442	0.102
				Hand length	0.296	0.236
				Foot length	0.157	0.493
				Body fat mass	−0.295	0.016 *
2-kg ball throw (m)	Model 1	0.399	<0.001	Age	0.632	<0.001 *
	Model 2	0.463	0.008	Age	0.150	0.450
				APAS	0.544	0.008 *
	Model 3	0.716	<0.001	Age	0.402	0.011 *
				APAS	−0.239	0.235
				Body fat-free mass	0.747	<0.001 *
				Arm span	0.250	0.130
				Stature	−0.238	0.210
Stand long jump (m)	Model 1	0.286	<0.001	Age	0.535	<0.001*
	Model 2	0.317	0.093	Age	0.199	0.374
				APAS	0.379	0.093
	Model 3	0.375	0.143	Age	0.274	0.233
				APAS	0.208	0.464
				Arm span	−0.213	0.336
				Body fat-free mass	0.114	0.615
				Superior members length	0.318	0.034 *
Handgrip Strength (kg)	Model 1	0.270	<0.001	Age	0.520	<0.001 *
	Model 2	0.444	<0.001	Age	−0.275	0.175
				APAS	0.897	<0.001 *
	Model 3	0.790	<0.001	Age	−0.044	0.805
				APAS	0.146	0.526
				Body fat-free mass	0.626	0.001 *
				Stature	0.194	0.435
				Sitting height	−0.113	0.632

The models were not adequate to explain the variable; APAS attainted predicted adult stature; * $p < 0.05$.

4.4 Discussion

The purpose of this investigation was to analyze the interaction between chronological age, somatic maturation, and anthropometric characteristics to explain the performance in young judo athletes. Chronological age had a significant effect on all physical tests, with older judokas performing better, except on abdominal strength. However, somatic maturation attenuated its effect in most of the tests (aerobic and anaerobic performances, upper body, lower body, and handgrip strengths) and its main effect was significant and positive on upper body and handgrip strengths. Furthermore, regression models with anthropometric variables better explain physical performance since chronological age and maturation significance decreased when anthropometric variables were included in the model. Among them, body fat mass was negatively related to tests associated with running (aerobic, anaerobic and agility tests), and to abdominal strength, while chronological age and body fat-free mass were positively related to upper body strength, and only body fat-free mass to handgrip strength.

Judo is characterized by intermittent strength and power actions interspersed with moments of recovery. The athlete, through grappling techniques, seeks to throw the opponent to the ground, whereby the contest occasionally continues until one of the athletes is immobilized or surrenders (Escobar-Molina et al., 2016). According to the results, maturity status could be deemed as having greater importance than chronological age in relation to the performance of young male judokas aged 11–15. Upper body and handgrip strength are considered critical to successful judo performance, since the sport involves pulling and pushing the opponent to allow the application of throwing, immobilizing, and blocking techniques (Bonitch-Góngora et al., 2013; Franchini et al., 2005). However, current literature provides limited evidence regarding the influence of maturity on muscular strength in young judo athletes. One of the few studies on the subject, which involved testing a sample similar to the present study (66 young male judokas, mean age: 13.9 years), found that somatic maturation, along with body mass and stature, significantly explained handgrip strength, but not upper body strength (Detanico et al., 2020). Comparable results have also been observed in previous studies conducted on young male athletes from different sports (Coelho E Silva et al., 2010; Matthys et al., 2012; Myburgh et al., 2016).

Maturity-related differences in medicine ball throw and handgrip strength were observed, after age control, in young basketball players aged 12–13 years (Coelho E Silva et al., 2010). Significant differences between contrasting maturity groups in terms of handgrip strength were evidenced among 14-year-old handball players (Matthys et al., 2012). In support of the present research, another investigation found significant and positive correlations, when controlling for chronological age, between maturity and handgrip strength and various medicine ball throw tasks in young tennis players aged 8–16 years (Myburgh et al., 2016).

Inter-individual differences in maturity can either positively or negatively affect performance in neuromuscular tests. Additionally, the nature of the association may vary depending on the age and sex of the individual, in addition to the characteristics of the task (Beunen et al., 1997; Katzmarzyk et al., 1997). One of the first studies relating to biological maturation, growth variables, and physical tests performance suggested that while maturation of the neuromuscular system may contribute positively to the development of motor skill, maturity-related changes in both size and body composition could also negatively affect performance, particularly on tests requiring body displacement (Katzmarzyk et al., 1997). In the present study, body composition had a significant impact on performance. Body fat mass significantly explained aerobic, anaerobic, and agility performance, with heavier judokas performing worse. On the other hand, body fat-free mass significantly and positively explained superior limb strength (upper body and handgrip strengths tests), which are variables most associated to the maturity effect. The importance of body composition, namely with low fat mass and high fat-free mass, is well-established as being a determinant of successful judo performance (Ceylan et al., 2018; E. Franchini et al., 2011; Emerson Franchini et al., 2011). However, grouping young judokas into weight categories using total body mass disregards body composition, which can vary significantly between weight categories (Torres-Luque et al., 2015), and seems to be relevantly related to biological maturation, as already been observed in a previous study (Giudicelli et al., 2020), and evidenced in the present investigation. These findings may reinforce doubts about the effectiveness of the young athlete's distribution in weight categories for equalization of competition conditions and training routines, evidencing the need to control the effect of maturation in judo with/bio-banding strategies, and raising the possibility of using other anthropometric characteristics as a categorization criterion, such as the APAS itself or components of body composition.

Previous studies have investigated the relationship between morphological characteristics, biological maturation, and motor performance in young judo athletes using regression analysis methods (Detanico et al., 2020; Kuvačić et al., 2017; Mekić et al., 2009). However, few studies have adopted the hierarchical procedure in regression analyses, such as the present study. This involved the current research team deciding which variables should enter first in the regression models, based on previous knowledge, with such an approach considered more adequate compared with stepwise methods (Field, 2013). However, there are some limitations that should be considered for the present investigation. The lack of power analyses to determine whether the sample size was adequate may limit statistical inferences. The use of indirect tests to measure physical capacity may also limit the investigation. Notably, fat mass was significantly associated to judokas performance in running tests, which involve displacement of total body mass, with heavier judokas having presented significantly lower performance. The Special Judo Fitness Test (SJFT) is an alternative widely used in the literature for the physical evaluation of judo athletes, but in addition to also involving running in its execution, there is still no consensus on its discriminating power in the young population (Courel-Ibnez et al., 2018). In several studies that involve the use of APAS as a maturational indicator, including this one, the statures of the participants' parents were verified by self-reporting, a procedure that has support in the literature (Malina et al., 2012) but might introduce bias (Malina et al., 2015). The error between predicted and actual mature stature at 18 years of age is reported to be 2.1% (Khamis and Roche, 1994). As explained earlier, predicted adult stature has been used instead of peak of height velocity in studies on bio-banding, since the latter seems to have limited application depending on age at the peak of height velocity for both boys and girls (Kozieł and Malina, 2018). Considering the above, the present study used APAS to avoid the impact of the wide range of age at the peak of height velocity promoted by the biological variability at this auxological period. Moreover, the predicted adult stature is being used in most of the studies related with the bio-banding approach and this can allow the present study to be more objective compared with further research in the literature.

4.5 Conclusions

The results of the present study corroborate the findings of previous research and add value not only because they support the significant effect of the somatic maturation on young judo athletes' physical performance, mainly on upper body and handgrip strengths tests. These findings suggest that bio-banding may be an effective strategy to reduce the implications of maturation on judo performance, preventing those that are less mature being at a physical disadvantage, assisting trainers in the construction of training routines appropriate to the youth's development, supporting sporting entities in proposing fairer tournaments, reducing injury risk, and promoting engagement in sports for the long-term. Additionally, anthropometric characteristics, such as body fat mass and body fat-free mass, may need to be considered regarding biological maturational effect. Future studies should assess bio-banding strategies for categorizing young judo athletes and other combat sports, in the search for more appropriate training and competition conditions. This may promote positive sporting experiences for young athletes, precluding unfair disadvantages and improving performance. Other research approaches may involve further investigating the role of anthropometric variables over the maturation effect on young judo athletes controlling for age and body mass (the traditional criteria for bio-banding in combat sports). Furthermore, an avenue for future research may be to evaluate the impact of participating in bio-banding tournaments on the performance and on the quality of the experience perceived by young judo and other combat sport athletes.

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CHAPTER 5

Study 3

(Published version available in Annex 3)

Bio-Banding in Judo: The Mediation Role of Anthropometric Variables on the Maturation Effect

Published in the International Journal of Environmental Research and Public Health (2020)

ABSTRACT

Young judo athletes are bio-banding based on age and body mass and compete in weight classes. The purposes of this study were to investigate the influences of maturation on physical performance in young judokas through controlling the chronological age and body mass, and to examine the mediating role of anthropometric variables. Sixty-seven judokas, aged 11.0–14.7, were measured for 11 anthropometric and seven physical performance variables. Pearson partial correlations were conducted to verify the relationship between the maturational indicator and the dependent variables. Mediation analyses were performed to identify the extent to which anthropometric variables mediate the relationship. The maturation effect remained on the aerobic capacity and handgrip strength ($p < 0.05$). Fat mass (b = 80.335, 95%CI 11.580–204.270) and fat-free mass (b = 108.256, 95%CI 39.508–207.606) totally mediated the effect on aerobic capacity. Fat mass (b = 0.023, 95%CI 0.004–0.057), fat-free mass (b = 0.029, 95%CI 0.011–0.058), stature (b = 0.031, 95%CI 0.008–0.061), arm span (b = 0.021, 95%CI 0.003–0.044), and inferior members length (b = 0.022, 95%CI 0.005–0.049) totally mediated the effect on handgrip strength. The effect of biological maturation is noticeable even after age and body mass control, being mediated by anthropometric variables related to body composition and size.

Keywords: biological maturation; bio-banding; judo; combat sports; rapid weight loss; mediation analysis.

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5.1 Introduction

Chronological age is traditionally used in youth sports for the purpose of matching competitors or teams (Lloyd et al., 2014). However, this approach has various limitations that at any given age there can be large maturity-associated variations in size and functional capacities among children (Bailey et al., 2003; Figueiredo et al., 2010; Malina et al., 2004; Sherar et al., 2007). Being advance in maturity may provide an advantage for young male athletes in sports characterized by power, strength, and speed (Malina et al., 2015). In girls, it is associated with greater size and strength (Malina et al., 2011; Rogol et al., 2018; Söğüt et al., 2019). Therefore, several maturity-based classification methods have been proposed in the context of training and competition (Anderson and Ward, 2002; Cumming et al., 2017; Rotch, 1909). The latest attempt to advocate the biological maturity-based matching is denominated bio-banding. Bio-banding refers to the process of grouping young athletes into bands according to attributes related to growth and maturation status rather than chronological age (Malina et al., 2019). The predicted mature status (PMS), a noninvasive method to estimate somatic maturity (Khamis and Roche, 1994), is the most current method employed to assess maturity. Studies and implementations of bio-banding, on the other hand, are limited to the training or unofficial tournaments of young male soccer players (Abbott et al., 2019; Cumming et al., 2018; Reeves et al., 2018).

The concern of grouping young athletes on the physical attributes is common in combat sports (e.g., boxing, judo, taekwondo, and wrestling) where young athletes are matched based on age and body mass and compete in a series of weight classes. This form of bio-banding classification could facilitate fair competition and reduce potential injuries (Langan-Evans et al., 2011; Pettersson et al., 2013). However, doubts may be raised about the suitability of body mass-based classification to guarantee fair play in combat sports due to evidence of maturation effect within weight categories in young combat sports (Branco et al., 2019), although there is an important gap in studies on this subject, and to the widespread adoption of rapid weight loss (RWL) as a common competitive strategy (Barley et al., 2019; Oppliger and Tipton, 1988).

RWL refers to the strategy adopted by most combat sports athletes to temporally reduce their body mass, typically about 2–10%, but with reports of reductions greater than 12% (Barley et al., 2018; Morales et al., 2018), a few days before competitions to fit in a lower weight category, in an attempt to gain an advantage against lighter, smaller, and weaker opponents (Barley et al., 2019). Achieved only through the combination of aggressive dehydration and starvation methods (Anyżewska et al., 2018; Barley et al., 2018; Dugonjić et al., 2019; Kons et al., 2017; Reale et al., 2018), it is a well-established common practice among combat sports athletes (Matthews et al., 2019) whose harmful effects are already known and well documented in the literature (Anyżewska et al., 2018; Crighton et al., 2016; Franchini et al., 2012; Mountjoy, 2008; Oppliger et al., 1996). RWL is not an issue restricted to adult or professional sports as children and adolescents from 10 years old also use RWL for competitive advantage ((Artioli et al., 2010; Constantini et al., 2011). Therefore, it was proposed that the sports community should frame RWL as doping and ban it from combat sports because of its detrimental health effects and for causing unfair competition (Artioli et al., 2016).

In youth combat sports, at the same time that there is a need to verify the efficacy of body mass-based categorization to control the maturity effect providing fair competitions, reducing the injury risk, and promoting engagement in sports for the long-term, it is imperative to find alternatives to body mass as a bio-banding strategy because of the RWL consequences. In this sense, among possible research designs, mediation studies can be used to understand which characteristics associated with body growth and biological maturation most strongly affect the physical performance of young athletes. Mediation analysis has recently been used in studies with children to evaluate the effect of biological maturation on motor competence performance through the mediation of anthropometric characteristics [Luz et al., 2018, 2016]. Therefore, the purposes of this study were: (1) to investigate whether there is an effect of biological maturation on the performance of young judo athletes after controlling chronological age and body mass; and (2) in the situation where the maturation effect is evidenced, to investigate anthropometric variables that can mediate this effect. Two hypotheses were submitted for confirmation: (1) the effect of maturation on the physical performance is significant even after age and body mass control; and (2) variables associated with body size mediate the effect of maturation on physical performance.

5.2. Methods

The participants were 67 young male judokas aged 11.0–14.7 years from eight Portuguese judo clubs. To be included in the investigation, it was necessary to have at least 12 months of judo training. Prior to data collection, parents or legal guardians signed informed consent. In addition, verbal consent was obtained from participants after the presentation of the aim and procedures. The study was approved by the Scientific Council of the Faculty of Sports Sciences and Physical Education of the University of Coimbra and was conducted in accordance with the Declaration of Helsinki for human studies of the World Medical Association.

The present study adopted common anthropometric procedures (Gordon et al., 1988). Stature and sitting height were measured using a portable stadiometer (Seca Bodymeter 206) and a segmometer (Rosscraft), respectively. The lower limb length was estimated as stature minus sitting height. Arm span was measured assessing the distance between right and left dactylion points with both arms abducted 90 degrees labeled with chalk on the wall using an anthropometric tape. The hand length was measured as the distance between the stylion and dactylion, while the foot length was measured as straight distance between the acropodion and pterion points. Arm circumference and calf circumference were measured with an anthropometric tape. All measures were taken to the nearest 0.1 cm. Body mass was measured to the nearest 0.1 kg using a portable digital scale (Seca Bella 840). Skinfold thickness was assessed to the nearest 0.1 mm using a Rosscraft skinfold calipers in the following references: triceps, subscapular, suprailiac, and calf. Estimates of fat mass percentage were obtained from the sex-specific equation derived from the sum of the triceps and subscapular skinfolds (Slaughter et al., 1988). Afterward, estimated fat and fat-free masses were calculated to the nearest 0.1 kg.

The predicted mature stature (PMS) was the maturational indicator used to classify the judokas according to the maturational state. It has been used in investigations about the biological maturation effect on physical fitness of young people in general (Coelho-E-Silva et al., 2013; Cumming et al., 2012; Luz et al., 2016), in research focusing on youth performance in sport (Howard et al., 2016; Myburgh et al., 2019) and as a criterion for bio-banding in experimental training and tournaments (Abbott et al., 2019; Cumming et al., 2018; Reeves et al., 2018) due to the advantages it presents compared to more valid but invasive indicators (Beunen et al., 1997; Coelho et al., 2004; Malina et al., 2012). The PMS was calculated by the Khamis–Roche method (Khamis and Roche, 1994). The protocol requires decimal age, stature, and body mass of the participant and average parental stature. The stature of the parents was collected through questionnaire attached to the informed consent sent to the parents or legal guardians. The current stature was expressed as a percentage of PMS (%PMS). It is assumed that among children of the same chronological age, individuals closer to the PMS are more advanced in biological maturation compared with individuals who are farther (Malina et al., 2004). From the %PMS, the z-score was calculated on the mean and standard deviation from the sample itself to classify the evaluated judokas by maturity status. Two groups contrasting in somatic maturation were derived from z-scores of attained %PMS: more mature ($P > 50\%$) and less mature ($P \leq 50\%$).

The aerobic performance of the judokas was evaluated using the Pacer (Progressive Aerobic Cardiovascular Endurance Run Test) test, with the number of completed laps being used as a performance indicator. The anaerobic performance was assessed using the line-drill test, with the recording in seconds of each judokas' time to complete the course. The agility was evaluated through the application of the 10 x 5m shuttle-run test, recording the total time of completed laps. The following indicators were used for the assessment of the subjects' muscle strength: abdominal muscle strength (AMS) applying the 60-s sit-ups test; lower body muscle strength (LBS) using the standing long jump test; upper body muscle strength (UBS) through the 2-kg medicine ball throw; and handgrip strength (HgS) measured by a dynamometer Lafayette model 78–10, through two attempts using the dominant hand. The best of the two attempts in kilograms was recorded.

All data were collected between April and May 2014 by the authors and a team trained by them specifically for this purpose, in a single visit where the anthropometric measurements were carried out initially, followed by physical performance evaluation. Measurements and tests were performed in circuit form. When completing all anthropometric stations, the young judoka were asked to perform warm-up exercises under the guidance of a trainee researcher and then sent to the physical performance evaluation stations in the following order: (1) Pacer; (2) 2 kg standing medicine ball throw; (3) stand broad jump test; (4) 10 _ 5 m shuttle-run test; (5) sit-ups; (6) handgrip strength with a dynamometer; and (7) line-drill test.

Descriptive statistics (ranges, means, standard deviations, and 95% confidence intervals) were used for describing the anthropometric profile, the physical fitness, and the maturational status of judokas in the total sample. To test normality Kolmogorov–Smirnov was used, and appropriate log transformations (log 10) were adopted to normalize distributions. Pearson partial correlations were calculated between biological maturation and anthropometry and physical performances adjusting by chronological age and body mass, the common bio-banding strategy used in judo competitions. From the significant partial correlations established amid the maturational state and the physical performance variables, the physical variables that had their partial correlations with the anthropometric measurements estimated were selected.

Mediation analyses aim to infer whether the relationship between a predictor and an outcome depends on the mediation of other variables. This type of analysis is based on correlation and regression tests to establish relationships among predictor, mediator, and outcome, and can be performed by different methods. In this study, mediation analyses were performed using Process (v3.3 by Andrew F. Hayes). The choice of variables to be tested as mediators and outcomes met the criterion of having a significant correlation with the predictor and correlation with each other. All linear regression models were adjusted by chronological age and body mass. Significance of $p < 0.05$ was adopted in the analyses. IBM SPSS 22.0 software (SPSS, Inc., Chicago, IL, USA) was used in the study.

5.3 Results

The descriptive statistics for the total sample and the results of normality tests are presented in Table 1. Body fat mass, agility, lower body strength, and handgrip strength tests presented significant values in the Kolmogorov–Smirnov test. Logarithmic transformation was performed in these variables for inferential statistics.

Table 1. Descriptive statistics for the total sample and test of normality (*n* = 67).

Variables	Range		Mean		*sd*	Kolmogorov–Smirnov	
	Minimum	Maximum	Value	95%CI		Value	*p*
Chronological age (years)	11.01	14.70	12.54	12.30–12.78	0.99	-	-
Predicted mature stature (cm)	161.9	198.3	182.6	180.2–184.3	7.2	-	-
Attained PMS (%)	77.0	94.0	84.4	83.2–85.5	4.7	-	-
Training experience (years)	1	9	3.33	2.74–3.91	2.40	-	-
Body mass (kg)	27.6	79.6	47.6	44.7–50.5	11.2	0.102	0.081
Body Fat mass (kg)	2.1	34.4	9.6	8.0–11.1	6.3	0.150	<0.01
Body Fat free mass (kg)	25.5	65.1	38.0	36.1–39.9	7.8	0.099	0.173
Stature (cm)	134.8	176.5	154.0	151.6–156.4	9.9	0.075	0.200
Sitting height (cm)	71.5	93.2	80.0	78.8–81.2	5.1	0.078	0.200
Arm span (cm)	133.0	180.0	154.1	151.5–156.7	10.8	0.060	0.200
Superior members length (cm)	36.2	70.8	60.2	58.9–61.5	5.4	0.086	0.200
Hand length (cm)	14.1	21.3	16.9	16.5–17.2	1.5	0.074	0.200
Inferior members length (cm)	60.3	85.5	74.0	72.7–75.4	5.5	0.057	0.200
Foot length (cm)	20.1	29.0	24.4	24.0–24.9	2.0	0.098	0.185
Arm circumference (cm)	19.0	36.0	25.3	24.5–26.1	3.3	0.068	0.200
Calf circumference (cm)	27.0	40.1	32.6	31.8–33.4	3.3	0.071	0.200
Pacer test (m)	140	1740	757	680–835	318	0.094	0.200
Line-drill test (s)	30.09	46.60	36.14	35.36–36.92	3.20	0.074	0.200
Agility 10×5 shuttle runs)	15.88	26.25	19.44	18.93–19.96	2.12	0.139	<0.01
60-s sit-ups (count)	15	61	41	39–44	10	0.089	0.200
2-kg ball throw (m)	3.19	8.79	5.22	4.93–5.52	1.22	0.077	0.200
Standing long jump (m)	1.12	5.65	1.69	1.55–1.83	0.57	0.179	<0.01
Hand grip strength (kg)	14.0	40.0	24.8	23.4–26.2	5.8	0.158	<0.01

95%CI, confidence interval; *sd*, standard deviation; PMS, predicted mature stature; * in runtime tests, lower value represents better performance.

Table 2 summarizes the partial correlation coefficients among biological maturation, anthropometric, and physical performance variables. Concerning the correlation between maturity status and physical performance, only aerobic performance ($r = 0.273$, $p < 0.05$) and handgrip strength ($r = 0.292$, $p < 0.05$) presented significant correlation; therefore, they were selected to have their partial correlations with the anthropometric variables estimated. Two mediation analysis models were derived from the correlations. The first model as a predictor the maturity status, as an outcome the aerobic performance, and as variables to be tested as mediators the anthropometric variables that partial correlated simultaneously with both, namely body fat mass, body fat free mass, stature, sitting height, and inferior members length. The second model maintained the biological maturation as a predictor, but the outcome variable was handgrip strength, being tested as mediators body fat mass, body fat-free mass, stature, sitting height, arm spam, superior members length, and inferior members length.

Table 2. Partial correlation coefficients (controlling for chronological age and body mass) among biological maturity (given by the z-score of the attained %PMS), anthropometric, and physical variables; and partial correlation coefficients between aerobic performance and handgrip strength with anthropometric variables (n = 67).

		Physical Fitness	
Variables	**Biological Maturation**	**Aerobic Performance**	**Handgrip Strength**
Anthropometry			
Body Fat mass (kg) #	−0.303 ***	−0.432 ***	−0.461 ***
Body Fat free mass (kg)	0.387 **	0.451 ***	0.453 ***
Stature (cm)	0.497 ***	0.305 *	0.395 **
Sitting height (cm)	0.400 **	0.263 *	0.322 **
Arm span (cm)	0.387 **	0.191	0.359 **
Superior members length (cm)	0.288 *	0.116	0.296 *
Hand length (cm)	0.236	0.352 **	0.247 *
Inferior members length (cm)	0.443 ***	0.258 *	0.348 **
Foot length (cm)	0.103	0.260 *	0.245
Arm circumference (cm)	−0.168	−0.040	−0.200
Calf circumference (cm)	−0.126	−0.190	−0.282
Physical fitness			
Pacer test (m)	**0.273 ***		
Line-drill test (s)	−0.225 ##		
Agility 10 × 5 shuttle run (s) #	−0.053 ##		
60-s sit-ups (count)	−0.069		
2-kg ball throw (m)	0.074		
Standing long jump (m) #	0.217		
Hand grip strength (kg) #	**0.292 ***		

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$; Bold – physical performance variables selected to have partial correlation with the anthropometry variables tested; # test was performed on log-transformed variable; ## in runtime tests, lower value represents better performance.

The mediation analyses performed are shown in Figure 1. They were adjusted by chronological age and body mass, as were the correlation analyses, also considering that these variables are utilized in judo to band youth athletes in age–weight categories. In the mediation model having biological maturation as predictor and aerobic performance as an outcome, the first regression equation showed a positive total effect between them ($p < 0.05$); the second equation negatively associated maturation with body fat mass ($p < 0.05$); and the third equation, where maturation and body fat mass simultaneously participate in the model, showed a negative association between body fat mass and aerobic performance ($p < 0.01$), a loss of significance in the association between predictor and outcome (direct effect) and a significant indirect effect (95%CI [11.580–204.270]), indicating a total mediation. Total mediation was also found between maturation and aerobic performance with body fat-free mass as a mediator, given that there was a positive association between maturation and fat-free mass ($p < 0.01$), a positive association between body fat-free mass and aerobic performance ($p < 0.01$), and a not significant direct effect, whereas the indirect effect calculated had significance (95%CI [39.508–207.606]).

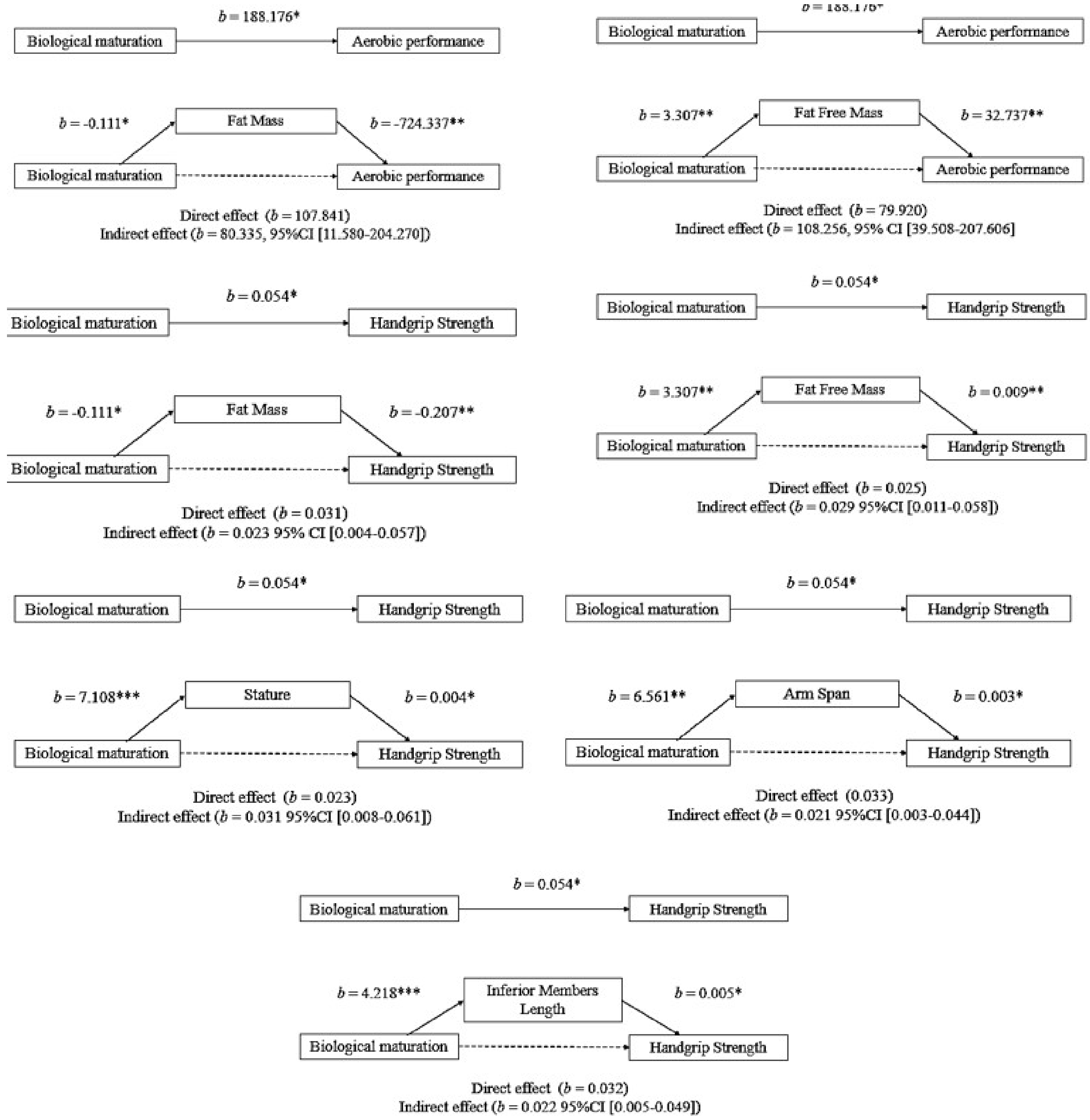

Figure 5.1. Models of body fat mass, body fat free mass, stature, arm span, and inferior members length mediation on the maturational effect on aerobic performance and handgrip strength. * p < 0.05; ** p < 0.01; *** p < 0.001; solid line, significant effect; dash line, non-significant effect

In Figure 1, the second group of mediation analysis itemized as predictor the biological maturation and as an outcome the handgrip strength. The first regression equation reported a positive association between maturation and handgrip strength ($p < 0.05$). The analysis of mediation resulted in five anthropometric variables exerting total mediation between the predictive and outcome variables. The second regression equations in the models indicated for biological maturation negative relationship with body fat mass ($p < 0.05$) and positive with body fat-free mass ($p < 0.01$), stature ($p < 0.001$), arm span ($p < 0.01$), and lower members length ($p < 0.001$). In all cases, the direct effects, i.e., the effect of the predictor variable on the outcome adjusted by the mediator variable, became non-significant, and the indirect effects were significant: body fat mass (95%CI [0.004–0.057]), body fat-free mass (95%CI [0.011–0.058]), stature (95%CI [0.008–0.061]), arm spam (95%CI [0.003–0.044]), and inferior members length (95%CI [0.005–0.049]). Sitting height and inferior members length, in the first model, and superior members length in the second model, are not shown in Figure 1 because their mediation effects were not found in their respective predictors and/or outcomes.

5.4. Discussion

The aim of this study was to investigate the effect of biological maturation and the role of anthropometric variables as possible mediators of this effect on young judokas physical performance, inasmuch as there is evidence that the current criteria used to grouping these athletes for training and competition, i.e., chronological age and body mass, may not be effective to control the maturation effect, but also lead to the practice of RWL. Through the partial correlations and mediation analyses, it became evident that in this sample the biological maturation still influences performance variables even with the adjustment of chronological age and body mass. The partial correlations and the two mediation models showed significant and positive maturation effect on aerobic performance and handgrip strength. The first model results exposed total mediation role of the body fat mass and body fat free mass on the maturation effect over aerobic performance, while the second model demonstrated total mediation role of these two variables, as well as of stature, arm span, and inferior members length, on the maturation effect over handgrip strength.

Aerobic performance and handgrip strength are two physical capabilities considered important for success in judo, since the sport is characterized by intermittent actions of great strength and power, interspersed with moments of recovery, where the athlete through grappling techniques seeks to throw the opponent to the ground and occasionally immobilize him/her or make him/her surrender in the ground fight (Franchini et al., 2011; Escobar-Molina et al., 2016). The duration of a judo match in competitions can vary from a few seconds, when an applied technique reaches the maximum score, up to 8 min, when there is a regular 5-min tie and extra time is used to define the winner. In international competition, an athlete can perform up to seven matches. Considering the nature of motor actions, duration, and number of bouts, judo is considered a modality with both anaerobic and aerobic energy demands (Franchini et al., 2011). The aerobic system contributes to the judoka sustaining the effort for the duration of the combat and to recovering in the brief moments of effort reduction between techniques and in the rest periods between matches (Franchini et al., 2009; Krstulovic, 2012). In addition to the energy demand, for pulling and pushing the opponent allowing the application of throwing, immobilizing, and blocking techniques, the development of the handgrip strength is considered critical to successful judo performance (Bonitch-Góngora et al., 2013).

Although their objective is to equalize training routines and competitions, the distribution of young judokas and young athletes of other combat sports in age–weight categories could be inappropriate for biological maturation effect control. Previously, in an investigation regarding the relationship between chronological age and maturation effect in 54 young karateka of both sexes aged 7–16 years, maturity-advanced athletes in several weight categories were found, which would, according to the authors, lead to competitive inadequacy and evidence the need for other criteria for organizing young combat athletes (Branco et al., 2019). As of this writing, we were unable to find further studies that investigated the existence or otherwise of the maturation effect on weight categories in young combat sports, which highlights an important gap that this study can help fill. Studies on relative age effect (RAE) in combat sports, on the other hand, are more common and show a possible RAE within weight categories, but the results of these investigations are still divergent (Albuquerque et al., 2013; Delorme, 2014) and, although often associated, maturational status and RAE appear to be independent (Figueiredo et al., 2009; Figueiredo et al., 2019). Nevertheless, it seems appropriate to state that the use of body mass for the distribution of combat sports athletes in categories that seek equal conditions among them is affected by several factors that go beyond genetics, such as diet, lifestyle, level of physical activity, and psychological state, among others (Malina et al., 2004), even within athletes, which brings a variability that could prevent the efficient control of biological maturation, not avoiding the performance imbalance among young athletes of the same age. It is precisely the body mass possibility of manipulation that allows the adoption of the RWL strategy, where purposely and as a competitive strategy athletes undergo extreme dehydration and starvation to compete in categories with lighter opponents. The adoption of RWL only, apart from the possibility of not controlling the maturational effect, could be enough to consider weight categories as ineffective in ensuring proper training routines and fair competitions. Further, banning RWL as a competitive strategy is necessary from a public health perspective, as there are reports of combat sport athlete deaths associated with this practice (Dubnov-raz et al., 2015; Prevention, 1998).

PMS as an indicator of biological maturation has gained prominence in investigations of young athletes for its noninvasive aspect and greater practicality of application, compared with classical evaluation methods (Khamis and Roche, 1994). In a bio-banding experience at a young men's soccer tournament in the UK, 66 athletes aged 11–14 years were divided into categories according to the percentage of PMS attained (85–90%) at the time of the measurement (Cumming et al., 2018). All young participants described the experience as positive and recommended that the Premier League incorporate bio-banding into their official tournaments. Furthermore, compared to chronological age-oriented tournaments, athletes advanced in maturity reported that they were more physically demanding, which required a greater emphasis on game technique and tactics, while less mature athletes reported that they enjoyed the experience the most because they had more opportunities to apply their technical and tactical knowledge as they were less physically pressured. This, according to the authors, advocates in favor of bio-banding as it allows for a holistic development of young soccer athletes. The use of PMS as bio-banding in judo and other combat sports, as in the soccer example, could be effective for controlling the maturational effect and for extinguishing the practice of RWL in these modalities, but there are no reports of experiences in this regard in the literature. However, this would not cause any change in the adoption of RWL in adult judo and combat sports. Therefore, it makes sense to search for an alternative criterion for athlete's categorization that can be used to control maturation in combat sport for young people and to eradicate RWL in combat sport from young to adult. In fact, the search for anthropometric variables that could exert control over the maturation in youth combat sports is recurrent and several studies have been interested in seeking anthropometric variables associated with success in judo (Franchini et al., 2005; Nabofa, 2012; Stefanovsky et al., 2017; Torres-Luque et al., 2015).

The results evidenced in this investigation are limited by the lack of a larger sample size and the use of indirect tests to measure physical capacity. Further, in several studies that involve the use of PMS as maturational indicator, including this one, the stature of the parents of the investigated youngsters was verified by self-reporting, a procedure that also has support in the literature (Malina et al., 2012), but might bring bias (Malina et al., 2015). The error between predicted and actual mature stature at 18 years of age is reported to be 2.1% (Khamis and Roche, 1994).

5.5 Conclusions

This study sought to verify if the effect of maturation is evidenced in a sample of young judokas even with control of chronological age and body mass and, if so, which anthropometric variables mediate this effect. The effect of maturation was evidenced on aerobic capacity and handgrip strength, variables considered important for success in judo. By exerting total mediation effect on these capacities, body fat mass and body fat-free mass were evidenced in relation to the aerobic capacity, and body fat mass, body fat-free mass, stature, arm span, and lower limbs' length in relation to the handgrip strength. More investigations and intervention projects are needed to analyze bio-banding possibilities in judo and other combat sports. Attention is drawn to the search for variables with the double potential of bio-banding in youth combat sports and body mass substitution as a categorization criterion for young and adult combat athletes, aiming at the extinction of RWL as a sports strategy.

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CHAPTER 6

General Discussion

6.1. General Discussion

The general aim of this study was to verify the effect of biological maturation on growth and physical performance of young judo athletes, something that has been extensively documented in the literature regarding team sports, but whose academic production is still scarce about combat sports (Detanico et al., 2020). As explained in detail in the introduction, to achieve the general objective three studies were conducted, with different but complementary research proposals.

Study 1 aimed to assess the independent and combined effect of chronological age and biological maturation on growth and physical performance of young judo athletes. At this point, the interest was to verify the hypothesis that there would be an independent and significant effect of biological maturation on anthropometric and performance variables, what once confirmed would justify further studies on the maturation effect on judokas and the possible need for bio-banding (Cumming et al., 2017) in young combat sports.

Among the few studies that have investigated the effects of age and maturation on young combat sport athletes, Torres-Luque et al. (2015) studied 146 judo athletes aged 14-17 years aiming to examine differences in anthropometry and neuromuscular function by sex, age, and weight category, and noticed an age effect with older judokas presenting significant higher handgrip strength than younger judokas, although it is not clear whether this age effect can be partly explained by maturational differences, since maturation was not controlled. Additionally, Fukuda *et al.* (2018) investigated the influence of somatic maturation and training experience on muscular morphology, biomechanical variables, and bilateral asymmetry in a sample of 26 judo athletes, both sexes, aged 8-18 years (12.9 ± 2.6 yrs), observing that somatic maturation rather than training experience had a predominant impact on lower body strength (plyometric ability), handgrip performance, and size indicators, suggesting that maturational status should be considered in the categorization of young athletes in combat sports. Nevertheless, the small size of the sample, having chosen to use maturity offset as the method for assessing biological maturation in a sample of great age range (Malina; Koziel, 2014), and apparently not having controlled the age effect, brings the need for caution in interpreting these results. Notwithstanding, attentive to the possible need to control of biological maturation in young combat sports athletes, Branco et al. (2019) analyzed the association between chronological age and biological maturation and searched for anthropometric parameters that could be used as maturational indicators in a sample of 20 females (11.76 ± 2.49 yrs) and 34 males (11.74 ± 2.49 yrs) karate athletes. The authors concluded that despite showing a strong correlation between chronological age and sexual maturation, in several age categories the presence of mature advanced athletes was noted, which according to them could impair competitive equity, and found that height, weight and arm circumference were fit to explain the maturity effect in young karate athletes.

Considering these findings, our study pointed to significant independent effects of age and maturity on growth and physical performance of the young judokas evaluated. Independent effects of chronological age and somatic maturation were significant in all anthropometric variables assessed, with older and more mature judokas reaching higher values, except for body fat mass, whose difference within age groups and within somatic groups were not significant, something predictable considering the effects of training on the reduction of body mass and the expected stabilization or slight increase in fat mass in males during pubertal growth spurt (Malina; Bouchard; Bar-Or, 2004). Regarding physical performances, independent effects of age and maturation were significant in most of them, with older and more mature judokas achieving better results in aerobic and anaerobic performances, in upper and lower body strength, and in handgrip strength, indicative that older and/or more mature judokas may have a competitive advantage over their younger and/or less mature peers. Only in the results of agility and abdominal strength tests there were no significant effects of age and maturation.

Nonetheless, it was in the combined analysis between chronological age and biological maturation that the latter assumed greater importance in the growth and performance of young judokas. In the analyzes with maturation control, the age effect was no longer significant in any growth and performance variables. Conversely, when controlling for age, maturational effect still significantly impacted all anthropometric variables, except body fat mass and superior members length, and impacted most of the performance variables, including aerobic and anaerobic performances, and upper and handgrip strengths. Therefore, more mature judokas are heavier, taller and have better physical performance than their less mature peers, regardless of age in a sample of 11-14 years old judokas, which leads to the need to control the maturity effect in categorization of young judokas to ensure competitive fairness and training routines suitability to the level of athletes' development, at least in the first years of puberty.

Confirmed Study 1 hypothesis' that biological maturation have a significant independent impact on growth and performance of young judokas, despite chronological age, **Study 2** aimed to understand the relative contribution of chronological age, somatic maturation, and anthropometric variables on the performance of young judokas, considering that studies in several sports, including combat sports, investigated the use of anthropometric variables, among other characteristics, to detect young talents and predict sports success (Pion et al., 2014; Sánchez-Muñoz et al., 2012; Shariat et al., 2017). The identification of anthropometric variables relevantly associated with biological maturation and performance of young judokas simultaneously can provide possibilities for bio-banding application to proper categorization of these athletes, mitigating the effect of biological maturation present regardless of chronological age.

Considering the characteristics of judo as a sport, where grappling, blocking and immobilization techniques are used to throw to the ground and control the opponent in actions of intermittent muscle strength and power, aerobic and anaerobic capacities, upper body and handgrip strengths are considered capabilities critical for success (Bonitch-Góngora *et al.*, 2013; Escobar-Molina *et al.*, 2016; Franchini *et al.*, 2005; Torres-Luque *et al.*, 2015). However, current literature provides limited evidence regarding the influence of maturity on neuromuscular strength of young judo athletes. One of the few studies which involved testing a Brazilian sample similar to the present study (66 young male judokas, mean age: 13.9 years), found that somatic maturation, along with body mass and stature, significantly explained handgrip strength, but not general upper body strength (Detanico et al., 2020). Comparable results have also been observed in previous studies conducted on young male athletes from different sports (Coelho E Silva et al., 2010; Matthys et al., 2012; Myburgh et al., 2016).

In addition to neuromuscular strength, judo is considered a modality with both anaerobic and aerobic energy demands, considering the nature of motor actions, duration, and number of bouts (Franchini *et al.*, 2011). While the anaerobic system contributes to the execution of judo techniques in speed and power, the aerobic system contributes to judokas sustaining the effort for the duration of the combat and to recovering in the brief moments of effort reduction between techniques and in the rest periods between matches (Franchini *et al.*, 2009; Krstulovic, 2012). In studies with samples formed by young soccer athletes, there seems to be an inverse relationship between aerobic capacity and biological maturation, with less mature athletes performing better than their more mature peers (Doncaster et al., 2018; Teixeira et al., 2018). However, in both studies, the authors point to a reduction or cessation of the maturational effect on aerobic capacity when considering body size variables, once the lower body mass of less mature athletes compared to more mature ones may be related to energy economy (Teixeira et al., 2018). Nonetheless, body composition, with a decrease in fat mass and an increase in lean mass, seems to be relevant for success in judo (Franchini et al., 2011). Furthermore, evaluating the relationship between anthropometric profile, Wingate and SJFT performances of Olympic judo athletes, Ceylan et al. (2018) concluded that the higher the percentage of body fat, the lower the performance in activities that involve body displacement.

The findings in **Study 2** seem to corroborate the idea mentioned above, in addition to confirming the relevance of growth and maturation on the performance of the young judokas evaluated. It was observed that somatic maturation attenuated the effect of age on aerobic and anaerobic capacities, on upper and lower body strengths, and handgrip strength, confirming the findings in Study 1. Furthermore, the subsequent regression models with the inclusion of anthropometric variables better explain physical performance since chronological age and maturation significance decreased. Among them, body fat mass was negatively related to tests associated with running (aerobic, anaerobic and agility tests), and to abdominal strength, while body fat-free mass was positively related to upper body and handgrip strengths. Considering that the anthropometric variables with the highest correlation with maturation and performance variables were chosen for the regression models, and that the effect of maturation ceases with the introduction of these variables, it is possible that the maturity effect on the performance of young judokas be mediated by anthropometric profile, especially body composition. Grouping young judokas into weight categories using total body mass disregards body composition, which can vary significantly between weight categories (Torres-Luque et al., 2015). These findings reinforce doubts about the effectiveness of the young athlete’s distribution in weight categories for equalization of competition conditions and training routines, evidencing the need to control the maturational effect in judo with bio-banding strategies, and raising the possibility of using indicators of growth and maturation as categorization criterion.

Considering, on the one hand, the findings in Study 1 and Study 2, which cast doubts about the effectiveness of body mass to control the maturational effect in young judo athletes’ performance and, on the other hand, the practice of RWL among young athletes, what can be considered a public health issue, justified the realization of **Study 3**, which aimed to (1) investigate whether there is an effect of biological maturation on the performance of young judo athletes after controlling for chronological age and body mass, both traditional criteria used in judo training and competitions to categorize young athletes; and (2) if the maturation effect was evidenced, to investigate anthropometric variables that could mediate this effect on the judoka's performance and could be used as bio-banding criterion.

Study 2 results showed that body composition, towards less fat mass and more lean mass, significantly influenced the performance of the young judokas, and decreased the relative importance of maturation. Therefore, grouping young judo and other young combat athletes in weight categories may control the influence of body mass and, consequently, biological maturation on the performance (Albuquerque *et al.*, 2012; Delorme, 2014). However, there are divergent results in studies with combat sports athletes in this regard. Studies that verified the effect of weight categories on the control of the relative age effect (RAE) in combat sports, an independent phenomenon, but related to biological maturation, found no evidence of its effectiveness (Albuquerque *et al.*, 2016; Cobley *et al.*, 2009). As previously highlighted, Branco et al. (2019) identified the presence of advanced mature karate athletes in weight categories, while contradictorily highlighted that some anthropometric characteristics, including body mass, were fit to explain the maturity effect in young karate athletes. More recently, (Detanico et al., 2021) in a study with 66 young Brazilian judokas showed that body mass did not discriminate the judokas competitive level.

The use of body mass for the distribution of combat sports athletes in categories that seek equal conditions among them, in addition to disregarding body composition, which appears to be related to the maturity effect as demonstrated in Study 1 and Study 2, is affected by several factors that go beyond genetics, such as diet, lifestyle, level of physical activity, and psychological state, among others (Malina et al., 2004), even within athletes, which brings a variability that could prevent the efficient control of biological maturation, not avoiding the performance imbalance among young athletes of the same age. Besides, it is precisely the body mass possibility of manipulation that allows the adoption of the RWL strategy, where purposely and as a competitive strategy athletes undergo extreme dehydration and starvation prior to official weighing to compete in categories with lighter opponents. The adoption of RWL only, apart from the possibility of not controlling the maturational effect, could be enough to consider weight categories as ineffective in ensuring proper training routines and fair competitions. Banning RWL as a competitive strategy is also necessary from a public health perspective, as there are reports of combat sport athlete deaths associated with this practice (Dubnov-Raz *et al.*, 2015; CDC, 1998).

Results from **Study 3** demonstrated that biological maturation still influences the young judokas performance even with the adjustment of chronological age and body mass. The simple mediation analyses showed significant and positive maturation effect on aerobic performance and handgrip strength. It was evidenced a mediation role of body fat mass (negatively) and body fat free mass (positively) on the maturation effect over aerobic performance, and a mediation role of body fat mass (negatively) and body fat free mass (positively), as well as of stature, arm span, and inferior members length (all positively) on the maturation effect over handgrip strength, partially corroborating the findings of other studies focused on verifying the influence of growth and maturation on the performance of young athletes in combat sports (Branco et al., 2019; De la Fuente, 2018; Detanico et al., 2021, 2020; Dubnov-raz et al., 2015), what supports the idea of bio-banding for an adequate distribution of young combat athletes into sporting categories, and points to variables associated with growth and maturation that could be used with this intention.

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CHAPTER 7

Conclusions

7.1. Conclusions

The present doctoral thesis aimed to verify the effect of biological maturation on growth and physical performance of young judo athletes, understanding that the extensive literature on the subject has not focused sufficiently on combat sports, such as judo. From the point of view of human and athlete development for engaging in sports and in physical activities in various contexts throughout life, controlling the effect of maturation seems to be a condition to ensure adequate training routines and fairness in sport competitions (Cumming et al., 2017; Malina et al., 2015), considering the enormous individual maturational variability among young people of the same age, with important impacts on the improvement of functional capacities, acquisition of skills, progress or withdrawal from sports (Figueiredo et al., 2009b).

From the analyzes and discussions underwent in the three studies that composed the thesis, it was evidenced that:

- Biological maturation significantly influenced growth and performance of the young judokas participating in the study regardless of age, in a clear trend that more mature athletes are taller, have greater body mass and greater muscle mass, and perform better than their less mature colleagues in all applied physical tests, predominantly in aerobic performance, general upper body strength and handgrip strength.

- Hierarchical linear regression models confirmed the effect of maturation on the performance of the evaluated judokas, attenuating the effect of age. However, when included in the model as predictors, the variables associated with growth better explained performance and attenuated the maturation effect on the physical capacity tests performed, indicating that the anticipated development of more biologically mature young athletes can translate into performance gains depending on the task. In this perspective, may be necessary to adopt criteria in addition to chronological age to banding young judokas and, by extension, young athletes from other combat sports.

- When chronological age and body mass were controlled, two criteria widely used in judo and other combat sports for banding young athletes in competitive categories aiming at equality of conditions, the maturation effect on aerobic performance and handgrip strength remained, creating disparity of conditions between athletes with different maturity status. This situation is aggravated by the prospect of manipulating body mass as a competitive strategy, as in the case of the RWL, widely used in adult athletes, but also in young athletes, with yet not cleared consequences for the health and development of adolescents. In this perspective, the adoption of bio-banding in judo and other combat sports could potentially guarantee more adequate conditions for selection, training, and progression of these athletes.

- Considering the analyzes with age and body mass control, the evidenced effects of biological maturation on aerobic and handgrip tests best performances seem to be mediated by growth variables. There were mediating effects of fat mass and fat-free mass in the aerobic performance test, and mediating effects of fat mass, fat-free mass, stature, arm span, and lower limbs length in the handgrip strength test. These growth-associated variables have the potential to be used as bio-banding criteria.

The effect of maturation was evidenced on aerobic capacity and handgrip strength, variables considered important for success in judo, even with control of body mass and age. By exerting total mediation effect on these capacities, body fat mass and body fat-free mass were evidenced in relation to the aerobic capacity, and body fat mass, body fat-free mass, stature, arm span, and lower limbs' length in relation to the handgrip strength. Such variables have the potential to be used in the field by teachers and coaches to form homogeneous groups of young judokas for training and competition, especially those associated with body composition, which could replace the weighing routines of young athletes and their distribution into weight categories, with routines for measuring body composition and respective categories based on these variables.

Notwithstanding the large number of studies demonstrating the effect of biological maturation on the performance of young athletes from various collective and individual sports (Carvalho et al., 2018; Cumming et al., 2017; Doncaster et al., 2018; Myburgh et al., 2016; Towlson et al., 2018), and despite studies on the subject in combat sports (Branco et al., 2019; Detanico et al., 2021, 2020), only one experience of bio-banding of young athletes for competition is known. A bio-banding experience was realized in an unofficial young men's soccer tournament in the United Kingdom, where 66 athletes aged 11–14 years were divided into categories according to the percentage of PMS attained (85–90%) at the time of the measurement (Cumming et al., 2018). All young participants described the experience as positive and recommended that Premier League incorporate bio-banding into their official tournaments. Furthermore, compared to chronological age-oriented tournaments, athletes advanced in maturity reported that they were more physically demanding, which required a greater emphasis on game technique and tactics, while less mature athletes reported that they enjoyed the experience the most because they had more opportunities to apply their technical and tactical knowledge as they were less physically pressured. This, according to the authors, advocates in favor of bio-banding as it allows for a holistic development of young soccer athletes.

The use of PMS or other maturity indicator as bio-banding in judo and other combat sports, as in the soccer example, could be effective for controlling the maturational effect and for extinguishing the practice of rapid weight loss in these modalities, but there are no reports of similar experiences in this regard in the literature. However, two studies focused on combat sports simulated the impact of adopting stature as criterion for banding young karate (Dubnov-raz et al., 2015) and taekwondo athletes (De la Fuente, 2018), but not with the intention of controlling the maturational effect, but of replacing body mass due to the harmful effects of the RWL strategies adopted by athletes of these modalities. Both studies concluded that stature can be used to categorize young athletes in these modalities as replacement of body mass, maintaining equality of conditions among athletes and helping to avoid eating disorders resulting from the practice of RWL.

In conclusion, bio-banding strategies could be adopted in judo and other combat sports to control the maturational variability of young athletes regardless of chronological age and body mass, as well as due to the need to eradicate RWL strategies. The percentage of predicted mature stature reached at the time of competition, and other growth indicators, have potential as criterion for bio-banding, requiring further investigations and implementation of more intervention proposals focused on bio-banding to understand its potential and limitations.

7.2. References

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APPENDIX AND ANNEXES

APPENDIX A

Written Informed Consent

CONSENTIMENTO INFORMADO, ESCLARECIDO E LIVRE PARA PARTICIPAÇÃO EM ESTUDOS DE INVESTIGAÇÃO

(de acordo com a Declaração de Helsinquia e a Convenção de Oviedo)

Título do estudo: Estudo multidimensional do jovem português atleta masculino de desportos de combate.

Enquadramento: Doutoramento em Ciências do Desporto – Ramo Treino Desportivo – da Faculdade de Ciências do Desporto e Educação Física da Universidade de Coimbra.

Orientador: Prof. Doutor António José Barata Figueiredo.

Explicação do estudo: O objetivo é analisar o efeito do processo de desenvolvimento morfológico e maturacional no treino, no desempenho, no clima motivacional e na permanência na prática de desportos de combate de jovens atletas masculinos com idades entre 11 e 14 anos. Os dados poderão permitir que treinadores, pais e atletas possuam uma mais vasta compreensão sobre as possibilidades e limites do treino com jovens atletas em desportos de combate, incrementando assim a qualificação dos seus métodos, minimizando o risco de lesões e garantindo maior sucesso e permanência destes jovens na prática do desporto. Os dados serão recolhidos através de única seção de aproximadamente duas horas, composta por avaliação antropométrica (massa corporal, estatura, comprimento de membros superiores etc.), testes físicos (capacidade aeróbia e anaeróbia, força e agilidade), e questionário (clima motivacional). Caso o número de atletas seja grande, pode ser necessário um tempo maior ou mais de uma seção para recolha dos dados.

Condições de participação: A participação no estudo é voluntária, podendo o participante a qualquer momento retirar o consentimento aqui firmado, sem qualquer prejuízo. Este estudo mereceu parecer favorável da Comissão de Ética da Faculdade de Ciências do Desporto e Educação Física da Universidade de Coimbra.

Confidencialidade e anonimato: Os dados recolhidos são confidenciais e destinados apenas à utilização neste estudo e nas publicações científicas dele decorrentes. Nenhum dado de identificação será tornado público e servem apenas para contato com os pais (encarregados de educação) dos avaliados em ambiente de privacidade, após o que serão destruídos.

Desde já agradeço a atenção e coloco-me à disposição para esclarecer quaisquer dúvidas.

Mestre Bruno Barbosa Giudicelli.
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Respeitando o carácter voluntário de participação na pesquisa, pretende-se com esta declaração obter o respectivo consentimento por parte dos atletas e dos seus encarregados de educação.

CONSENTIMENTO DO ATLETA

Eu, ____, atleta do ______________________________(*nome do clube*) do escalão de __________________, declaro que pretendo participar no estudo que se encontra acima descrito.

Data: / / ____

(assinatura do atleta)

CONSENTIMENTO DO (A) ENCARREGADO (A) DE EDUCAÇÃO

Eu, ____, encarregado(a) de educação de ______________________________, atleta do ______________________________________ (*nome do clube*) do escalão de ________________, declaro autorizar a sua participação no estudo que se encontra acima descrito e aceito prestar as seguintes informações:

a) Estatura do pai __________ cm (conforme bilhete de identidade);
b) Estatura da mãe ___________ cm (conforme bilhete de identidade);

Data: / / ____

(assinatura do(a) encarregado(a) de educação)

ANNEX 1

Study 1

Giudicelli, B.B., Luz, L.G. de O., Santos, D.H.B., Sarmento, H., Massart, A.G.M., Júnior, A.T. da C., Field, A., Figueiredo, A.J.B., 2021. Age and Maturity Effects on Morphological and Physical Performance Measures of Adolescent Judo Athletes. J. Hum. Kinet. 80, 131–143. https://doi.org/10.2478/hukin-2021-0090

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Age and Maturity Effects on Morphological and Physical Performance Measures of Adolescent Judo Athletes

by
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Studies assessing age and maturation effects on morphological and physical performance measures of young judokas are scarce. This study aimed to assess the independent and combined effects of chronological age and biological maturation on anthropometry and physical performance of 67 judokas aged 11-14. Participants' anthropometric profiles were assessed, and physical performance tests were completed. Multivariate analyses of variance revealed an independent effect of age (anthropometry: F = 1.871; p < 0.05; Pillai's trace = 0.545; η^2_p = 0.272; physical performance: F = 2.876; p < 0.01; Pillai's trace = 0.509; η^2_p = 0.254) and maturity (anthropometry: F = 10.085; p < 0.01; Pillai's trace = 0.669; η^2_p = 0.669; physical performance: F = 11.700; p < 0.01; Pillai's trace = 0.581; η^2_p = 0.581). There was no significant combined effect of age and maturity. The maturation effect remained significant when controlled for age (anthropometry: F = 4.097; p < 0.01; Pillai's trace = 0.481; η^2_p = 0.481; physical performance: F = 3.859; p < 0.01; Pillai's trace = 0.0.318; η^2_p = 0.318). In young judokas, the maturation effect on growth and physical performance seems to be more relevant than the age effect, leading to the need to control this effect in training routines and competitive events. As in studies with youth soccer players and other youth athletes, bio-banding can be a strategy for controlling maturation.

Key words: *anthropometry, aerobic performance, anaerobic performance, agility, muscle strength, biological maturation.*

Introduction

For children and adolescents competing in sport, chronological age has been used as a criterion for aggregating young athletes into competitive age groups, to provide adequate physical and technical training routines and facilitate fairness in competition. Previous research suggests that there are many growth and maturity-associated effects to movement mechanics (Towlson et al., 2020), potentially resulting in impairment of motor coordination and physical performance of youth athletes (Cumming et al., 2017). In competitive sports, athletes who are younger tend to be less developed physically and psychologically, which may place them at a performance disadvantage (Malina et al., 2004). Furthermore, biologically mature youth athletes tend to be taller and heavier than their age-matched peers, which has advantages, in particular for contact sports (Till et al., 2014). While several studies have been conducted on the influence of growth and maturation on sporting performance of youth athletes, relatively few have focused their

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attention on the impact of these variables on youth athletes competing in combat sports such as judo (Nabofa, 2012; Zubitashvili, 2011).

Due to the inadequacy of chronological age as a criterion for dividing youth athletes into competitive categories, alternative strategies which use physical attributes as criteria have been examined for their effectiveness and applicability (Cumming et al., 2017). In general, these strategies are based on the use of body size and/or maturational status together with chronological age. A strategy called bio-banding does not neglect other factors which should be considered when it comes to the distribution of youth athletes in competitive categories, such as their skill level and psychological profile (Branco et al., 2019; Cumming et al., 2017).

In judo and other combat sports, using body weight as a criterion for distribution of youth athletes into competitive categories is a common bio-banding strategy. This approach could reduce the maturity effect and contribute to the adequacy of training routines and competitions. This could help protect the development and well-being of youth athletes facilitating the maintenance of a long-term career in sport. Furthermore, few studies have examined the independent effect of age and maturation on the morphology and physical performance of young judokas. Such research appears warranted to develop an understanding of the impact of age and maturation on the anthropometric profile and performance of young judokas, and the efficacy of using body mass as a bio-banding strategy. For this reason, the objective of this study was to assess the independent and combined effect of chronological age and biological maturation on the anthropometric profile and physical performance of young judo athletes. The hypothesis was that biological maturation would improve performance of young judokas, regardless of chronological age.

Methods

Participants

The sample included 67 youth male judokas aged 11.0-14.7 years from eight different judo clubs in Portugal (2 dropouts). To be included in the study, the judoka needed to be between 11 and 14 years old, have at least one year of judo training experience and have no contraindications to exercise. Judokas were divided into three age groups: U12 (11.0 and 11.9 years), U13 (12.0 and 12.9 years) and U15 (13.0 and 14.9 years). The study was conducted in accordance with the Declaration of Helsinki for human studies of the World Medical Association and was approved by the Ethics Committee of the Faculty of Sports Sciences and Physical Education of the University of Coimbra [CE/FCDEF-UC/00452019]. Prior to data collection, parents or legal guardians signed informed consent. In addition, verbal assent was obtained from participants after the presentation of the aim and procedures of the study.

Anthropometric Measures

The anthropometric procedures described by Lohman et al. (1988) were adopted in the present study. Stature and sitting height were measured using a portable stadiometer (Seca Bodymeter 206, Seca GmBH & Co Kg, Hamburg, Germany) and a segmometer (Rosscraft Innovations, Spokane, Washington), respectively. The lower limb length was determined as stature minus sitting height. The arm span was measured assessing the distance between right and left dactylion points with both arms abducted 90 degrees. Hand length was determined by measuring the distance between the stylion and dactylion, while foot length was measured by the distance between the acropodion and pterion points. The arm and calf circumferences were measured with an anthropometric tape. All length measures were made to the nearest 0.1 cm. Body mass was evaluated to the nearest 0.1 kg using a portable digital scale (Seca Bella 840, Seca GmBH & Co Kg, Hamburg, Germany). Skinfold thickness was assessed to the nearest 0.1 mm using Rosscraft skinfold calipers (Rosscraft Innovations Inc, Vancouver, Canada). Assessments were conducted in the following order: triceps, subscapular, suprailiac and calf. Thereafter, fat and fat-free masses were calculated based on sex-specific equations derived from the sum of the triceps and subscapular skinfolds (Slaughter et al., 1988).

Biological maturation

The Khamis-Roche method was used to predict the mature stature (PMS) (Khamis and Roche, 1994). The protocol requires decimal age, stature, and body mass of the participant and average parental stature. The stature of parents was collected through a questionnaire sent via e-mail to the parents or legal guardians. The current stature was expressed as a percentage of PMS (%PMS). It is assumed that among children of the same chronological age, individuals closer to the PMS are more advanced in biological maturation (Malina et al., 2004). To classify the evaluated judokas by maturity status, the %PMS was expressed as the z-score of the mean and standard deviation from the sample itself. Two groups contrasting in somatic maturation were derived from z-scores of attained %PMS: early maturing (P > 50%) and late maturing (P ≤ 50%).

Physical Performances

Aerobic performance and agility of the judokas were evaluated through the application of the multi-stage fitness test, with the number of completed laps being used as a performance indicator, and the 10 x 5 m shuttle-run test, recording the total time in seconds to cover 10 laps on a 5 m course (Eurofit, 1996). The line-drill test was used to evaluate anaerobic performance, with the time for course completion recorded in seconds (Carvalho et al., 2011). Muscle strength was evaluated by abdominal muscle strength (AMS; 60-s sit-ups test) (Cesario et al., 2018), upper body muscle strength (UBS; 2-kg medicine ball throw) (Vossen et al., 2000), lower body muscle strength (LBS; standing long jump test) (Eurofit, 1996) and handgrip strength (HgS; dynamometer Lafayette model 78-10), through two attempts using the dominant hand (Eurofit, 1996). The best of the two attempts in kilograms was recorded for further analysis.

Procedures

All data were collected between April and May by the same trained team, during a single visit. Anthropometric measurements were carried out initially, followed by the physical performance tests. Data collection was organized in the form of a circuit. When passing through all anthropometric stations, judokas performed warm-up exercises under the guidance of a trainee researcher before undertaking stations in the following order: (1) multi-stage fitness test; (2) 2 kg standing medicine ball throw; (3) standing broad jump; (4) 10 x 5 m shuttle-run; (5) sit-ups; (6) handgrip strength with a dynamometer; and (7) a line-drill test.

Statistical analysis

Descriptive statistics (ranges, means, standard deviations and 95% confidence intervals) were used for delineating the anthropometric profiles, physical fitness, and maturational status of judokas. Means, 95% confidence intervals and standard deviations were used to characterize the age groups, while means and standard deviations were calculated within the maturity groups. The Kolmogorov-Smirnov test was used to test normality of the total sample and appropriate log transformations (log 10) were adopted to normalize distributions.

The independent effects of chronological age and maturity on the anthropometric and physical performance variables were tested using multivariate analyses of variance (MANOVA), with analyses of variance (one-way ANOVA) performed when significance was detected. To determine the effect of age, a Bonferroni *post hoc* test was used to verify which age groups differed significantly. Age and maturity combined effects were assessed using a two-way MANOVA. A multivariate analysis of covariance (MANCOVA) was used to verify the independent effects of chronological age and maturity status on the dependent variables when controlling for maturity and age, respectively. Data were analyzed using IBM SPSS 22.0 (SPSS, Inc., Chicago, IL). The level of significance was set at $p \leq 0.05$.

Results

The descriptive statistics for the total sample and the results of the normality tests are presented in Table 1.

The descriptive statistics of the age groups are presented in Table 2. In absolute values, older judokas reached a higher percentage of their PMS, performed better than their younger peers, and had higher absolute measurements in most anthropometric measures.

Table 3 shows the effect of chronological age on anthropometry and physical performance. Significant effects were found in the two sets of variables (anthropometry: $F = 1.871$; $p < 0.05$; Pillai's trace = 0.545; $\eta^2_p = 0.272$; physical performance: $F = 2.876$; $p < 0.01$; Pillai's trace = 0.509; $\eta^2_p = 0.254$). The *post hoc* comparison (Bonferroni) indicated a tendency in the anthropometry measurements where U12 had significantly smaller measurements than U13 and U15 in almost all the anthropometric variables.

The exception was body fat mass as the U12 group was significantly thinner than U13 (F = 3.854; $p < 0.05$; $\eta^2_p = 0.107$). Upper and lower body strength in the U12 group was significantly lower than in U13 and U15 (UBS - F = 18.220; $p < 0.01$; η^2_p = 0.363; LBS - F = 5.817; $p < 0.01$; $\eta^2_p = 0.154$). Considering aerobic and anaerobic performance and handgrip strength, U15 judokas performed significantly better than U12 (aerobic - F = 6.568; $p < 0.01$; $\eta^2_p = 0.170$; anaerobic - F = 7.005; $p < 0.01$; $\eta^2_p = 0.180$; HgS - F = 7.977; $p < 0.01$; $\eta^2_p = 0.200$).

Maturation, anthropometry, and physical performance data are presented in Table 4. More mature judokas presented greater anthropometric measurements in all variables and better performance in all physical performance tests. Maturation had a significant effect on anthropometry (F = 10.085; p < 0< 0.01; Pillai's trace = 0.669; η^2_p = 0.669) and physical performance (F = 11.700; $p < 0.01$; Pillai's trace = 0.581; $\eta^2_p = 0.581$). Subsequent ANOVA showed a significant maturity effect on all anthropometric variables except for body fat mass, and on all physical tests except for agility and abdominal strength.

The combined effects of chronological age and maturation on anthropometric and physical performance variables are presented in Table 5. No significant effect of interaction between age and maturational status was observed. However, even after controlling for chronological age, the maturity effect on anthropometric (F = 4.097; $p < 0.01$; Pillai's trace = 0.481; $\eta^2_p = 0.481$) and physical performances variables (F = 3.859; $p < 0.01$; Pillai's trace = 0.0.318; η^2_p = 0.318) was observed. A reduction in the maturation effect was noted with age control, but it remained significant in aerobic performance (F = 4.928; $p < 0.05$; $\eta^2_p = 0.071$), upper body strength (F = 5.894; $p < 0.05$; $\eta^2_p = 0.084$) and handgrip strength (F = 6.522; $p < 0.05$; $\eta^2_p = 0.092$).

Discussion

The present study evaluated the independent and combined effect of chronological age and biological maturation on anthropometric and physical performance variables in a sample of young Portuguese judokas. Significant independent effects of chronological age and maturity status on all anthropometric variables were evidenced, with older and more maturing judokas reaching higher anthropometric measurements. There were also significant differences between age groups and maturational groups in most of the physical performance variables. Older and more mature judokas demonstrated better performance in all variables, except for agility and abdominal strength tests, supporting the hypothesis that older and more mature individuals are physically superior (Malina et al., 2015). When maturation was controlled, the effect of age was no longer noticeable. On the contrary, after controlling for the effect of age, the impact of maturation on anthropometric and physical performance variables remained significant, which may indicate that in performance of youth judo athletes maturation has a greater impact than age.

The current data suggest that maturation has a greater impact on the judokas' morphology and physical performance than chronological age. Studies which verified the effect of age and maturation on anthropometric variables and physical performance also suggest a greater impact of biological maturation in youth athletes than chronological age. In a sample of 58 basketball players aged 9.5 to 15.5 years, Carvalho et al. (2018) found a significant variation in body size and functional capacities due to maturity status. Meylan et al. (2014) studying 74 youth athletes aged 11 to 15 years from different sports found a significant influence of maturity status on strength and power performance. Towlson et al. (2018) evaluated 969 soccer players aged 8 to 18 years to identify moments of greater and lesser influence of chronological age and biological maturation on the anthropometry and physical performance of these athletes. They concluded that biological maturation reached higher impact rates at different times for different anthropometric and physical performance variables. Therefore, the distribution of youth athletes in competitive categories requires to consider the impact of biological maturation. Nevertheless, a recent study with 146 young soccer players found a significant prevalence of athletes presenting normal maturity status, emphasizing the need for further studies on the impact of biological maturation on youth athletes' performance (Altimari et al., 2021).

Table 1

Descriptive statistics for the total sample and test of normality (n = 67).

Variables	Range		Mean		Standard deviation	Kolmogorov-Smirnov	
	Minimum	Maximum	Value	95%CI		Value	p
Chronological age (years)	11.01	14,70	12.54	12.30 to 12,78	0.99	-	-
Predicted mature stature (cm)	161.9	198.3	182.6	180.2 to 184.3	7.2	-	-
Attained PMS (%)	77.0	94.0	84.4	83.2 to 85.5	4.7	-	-
Training experience (years)	1	9	3.33	2.74 to 3.91	2.40	-	-
Body mass (kg)	27.6	79.6	47.6	44.7 to 50.5	11.2	0.102	0.081
Fat mass (kg)	2.1	34.4	9.6	8.0 to 11.1	6.3	0.150	< 0.01
Fat free mass (kg)	25.5	65.1	38.0	36.1 to 39.9	7.8	0.099	0.173
Stature (cm)	134.8	176.5	154.0	151.6 to 156.4	9.9	0.075	0.200
Sitting height (cm)	71.5	93.2	80.0	78.8 to 81.2	5.1	0.078	0.200
Arm span (cm)	133.0	180.0	154.1	151.5 to 156.7	10.8	0.060	0.200
Superior members length (cm)	36.2	70.8q	60.2	58.9 to 61.5	5.4	0.086	0.200
Hand length (cm)	14.1	21.3	16.9	16.5 to 17.2	1.5	0.074	0.200
Inferior members length (cm)	60.3	85.5	74.0	72.7 to 75.4	5.5	0.057	0.200
Foot length (cm)	20.1	29.0	24.4	24.0 to 24.9	2.0	0.098	0.185
Arm circumference (cm)	19.0	36.0	25.3	24.5 to 26.1	3.3	0.068	0.200
Calf circumference (cm)	27.0	40.1	32.6	31.8 to 33.4	3.3	0.071	0.200
Pacer test (m)	140	1740	757	680 to 835	318	0.094	0.200
Line-drill test (s)	30.09	46.60	36.14	35.36 to 36.92	3.20	0.074	0.200
Agility 10x5 shuttle run (s)	15.88	26.25	19.44	18.93 to 19.96	2.12	0.139	< 0.01
60-s sit-ups (count)	15	61	41	39 to 44	10	0.089	0.200
2-kg ball throw (m)	3.19	8.79	5.22	4.93 to 5.52	1.22	0.077	0.200
Standing long jump (m)	1.12	5.65	1.69	1.55 to 1.83	0.57	0.179	< 0.01
Hand grip strength (kgf)	14.0	40.0	24.80	23.38 to 26.23	5.85	0.158	< 0.01

95% CI (confidence interval); Attained PMS (predicted mature status).

Table 2

Descriptive statistics for the total sample contrasting for age groups (n = 67).

Variables	U12 (n=23)			U13 (n=22)			U15 (n=22)		
	Mean	95%CI	SD	Mean	95%CI	SD	Mean	95%CI	SD
Chronological age (years)	11.43	11.28 to 11.59	0.35	12.59	12.45 to 12.73	0.32	13.7	13.5 to 13.9	0.5
Predicted mature stature (cm)	183.8	180.8 to 186.8	6.9	184.6	182.2 to 187.0	5.4	179.3	175.5 to 183.0	8.3
Attained PMS (%)	79.5	78.7 to 80.3	1.8	85.0	83.9 to 86.1	2.4	88.9	87.3 to 90.5	3.6
Training experience (yrs)	3	2 to 4	2	4	2 to 5	3	3	2 to 4	2
Body mass (kg)	39.3	35.8 to 42.8	8.1	51.7	47.4 to 56.0	9.7	52.2	46.5 to 57.8	12.7
Fat mass (kg)	7.5	5.0 to 10.0	5.8	11.5	8.9 to 14.1	5.9	10.0	6.9 to 13.0	7.0
Fat free mass (kg)	31.8	30.4 to 33.3	3.4	40.2	37.4 to 43.0	6.4	42.2	38.4 to 46.0	8.6
Stature (cm)	146.1	143.7 to 148.5	5.6	156.9	153.8 to 160.1	7.1	159.5	154.7 to 164.2	10.7
Sitting height (cm)	76.3	75.1 to 77.5	2.8	81.4	79.5 to 83.3	4.3	82.5	80.1 to 84.9	5.5
Arm span (cm)	146.3	143.2 to 149.4	7.2	156.2	152.0 to 160.4	9.4	160.1	155.5 to 164.8	10.5
Superior members length (cm)	57.3	55.9 to 58.8	3.2	61.7	59.8 to 63.6	4.2	61.7	58.6 to 64.8	7.0
Hand length (cm)	15.9	15.3 to 16.5	1.4	17.2	16.5 to 17.9	1.5	17.6	17.1 to 18.1	1.1
Inferior members length (cm)	69.8	68.3 to 71.2	3.4	75.5	73.9 to 77.2	3.8	77.0	74.3 to 79.6	6.0
Foot length (cm)	23.3	22.5 to 24.1	1.9	24.9	24.1 to 25.7	1.8	25.1	24.3 to 25.9	1.8
Arm circumference (cm)	23.3	22.0 to 24.5	2.9	26.3	25.0 to 27.6	2.9	26.4	24.9 to 27.9	3.3
Calf circumference	30.6	29.4 to 31.7	2.7	33.9	32.7 to 35.2	2.8	33.5	32.0 to 34.9	3.3
Pacer test (m)	617	511 to 722	243	731	606 to 856	282	931	776 to 1085	349
Line-drill test (s)	37.68	36.22 to 39.14	3.38	36.26	35.18 to 37.34	2.44	34.41	33.12 to 35.70	2.91
Agility 10x5 shuttle run (s)	20.04	18.93 to 21.15	2.57	19.42	18.67 to 20.16	1.69	18.84	18.00 to 19.67	1.88
60-s sit-ups (count)	39	35 to 43	9	42	38 to 47	11	42	38 to 46	9
2-kg ball throw (m)	4.27	3.88 to 4.65	0.89	5.43	5.03 to 5.83	0.90	6.01	5.50 to 6.53	1.16
Standing long jump	1.46	1.36 to 1.56	0.23	1.86	1.46 to 2.25	0.89	1.76	1.64 to 1.88	0.27
Hand grip strength (kgf)	21.6	20.0 to 23.2	3.7	25.0	22.6 to 27.3	5.2	28.1	25.1 to 31.0	6.6

95%CI (95% confidence interval); Attained PMS (attained predicted mature status).

Table 3

Results of multivariate analyses of variance (MANOVA) and univariate analyses of variance (ANOVA) to examine the effects of chronological age on anthropometrics and physical performances variables (n = 67).

Dependent variables	Analyses of variance					Post-hoc comparisons
	Test	Pillai's trace	F	p	η^2_p	
Anthropometry	MANOVA	0.545	1.871	0< 0.05	0.272	
Body mass	ANOVA		11.311	0< 0.01	0.261	U12 < U13 & U15
Body Fat mass*	ANOVA		3.854	< 0.05	0.107	U12 < U13
Body Fat free mass	ANOVA		16.435	< 0.01	0.339	U12 < U13 & U15
Stature	ANOVA		17.717	< 0.01	0.356	U12 < U13 & U15
Sitting height	ANOVA		13.251	< 0.01	0.239	U12 < U13 & U15
Arm span	ANOVA		13.800	< 0.01	0.301	U12 < U13 & U15
Superior members length	ANOVA		5.719	< 0.01	0.152	U12 < U13 & U15
Hand length	ANOVA		10.093	< 0.01	0.240	U12 < U13 & U15
Inferior members length	ANOVA		15.980	< 0.01	0.333	U12 < U13 & U15
Foot length	ANOVA		6.524	< 0.01	0.169	U12 < U13 & U15
Arm circumference	ANOVA		7.704	< 0.01	0.194	U12 < U13 & U15
Calf circumference	ANOVA		8.847	< 0.01	0.217	U12 < U13 & U15
Physical fitness	MANOVA	0.509	2.876	< 0.01	0.254	
Pacer test	ANOVA		6.568	< 0.01	0.170	U12 < U15
Line-drill test	ANOVA		7.005	< 0.01	0.180	U12 > U15
Agility 10x5 shuttle run*	ANOVA		1.824	0.170	0.054	
60-s sit-ups	ANOVA		0.739	0.482	0.023	
2-kg ball throw	ANOVA		18.220	< 0.01	0.363	U12 < U13 & U15
Standing long jump*	ANOVA		5.817	< 0.01	0.154	U12 < U13 & U15
Hand grip strength*	ANOVA		7.977	< 0.01	0.200	U12 < U15

*η^2_p (partial eta square); * the test was performed on the log-transformed variable.*

Table 4

Descriptive statistics (mean and standard deviation), results of multivariate analyses of variance (MANOVA) and univariate analyses of variance (ANOVA) to examine the effects of maturity status on anthropometry and physical fitness variables (n = 67).

Dependent variables	Contrasting Maturity Group: Latest Maturing (n=35)		Earliest Maturing (n=32)		Analyses of variance				
	Mean	SD	Mean	SD	Test	Pillai's trace	F	p	η^2_p
Anthropometry					MANOVA	0.669	10.085	< 0.01	0.669
Body mass (kg)	41.3	8.5	54.4	11.2	ANOVA		29.027	< 0.01	0.309
Body Fat mass (kg)*	8.5	5.6	10.8	6.9	ANOVA		2.931	0.092	0.043
Body Fat free mass (kg)	32.9	4.1	43.6	7.1	ANOVA		58.426	< 0.01	0.473
Stature (cm)	147.1	6.0	161.6	7.4	ANOVA		76.719	< 0.01	0.541
Sitting height (cm)	76.7	2.7	83.7	4.5	ANOVA		62.067	< 0.01	0.488
Arm span (cm)	147.7	7.8	161.1	9.0	ANOVA		42.323	< 0.01	0.394
Superior members length (cm)	58.0	3.5	62.6	6.1	ANOVA		15.082	< 0.01	0.188
Hand length (cm)	15.9	1.2	17.9	1.1	ANOVA		45.298	< 0.01	0.411
Inferior members length (cm)	70.5	4.2	77.9	3.9	ANOVA		56.441	< 0.01	0.465
Foot length (cm)	23.5	1.9	25.4	1.6	ANOVA		18.646	< 0.01	0.223
Arm circumference (cm)	23.8	2.7	26.9	3.2	ANOVA		18.399	< 0.01	0.221
Calf circumference (cm)	31.1	2.6	34.2	3.1	ANOVA		19.170	< 0.01	0.228
Physical fitness					MANOVA	0.581	11.700	< 0.01	0.581
Pacer test (m)	615	217	913	340	ANOVA		18.684	< 0.01	0.223
Line-drill test (s)	37.24	3.04	34.94	2.96	ANOVA		9.750	< 0.01	0.130
Agility 10x5 shuttle run (s)*	19.61	2.27	19.26	1.95	ANOVA		0.421	0.519	0.006
60-s sit-ups (count)	40	9	43	10	ANOVA		1.086	0.301	0.016
2-kg ball throw (m)	4.49	0.85	6.03	1.05	ANOVA		43.757	< 0.01	0.402
Standing long jump (m)*	1.53	0.27	1.86	0.74	ANOVA		9.101	< 0.01	0.123
Hand grip strength (kgf)*	21.71	3.85	28.19	5.84	ANOVA		29.203	< 0.01	0.310

*SD (standard deviation); η^2_p (partial eta square); * the test was performed on the log-transformed variable.*

Table 5

Results of two-way MANOVA to examine the interaction effect (chronological age × maturity status) and results of MANCOVA to assess the maturity effect when controlling by age on anthropometry and physical performance variables (n = 67).

Dependent variables	Test	Interaction effect Age x Maturity				Maturity effect (controlling for age)			
		Pillai's trace	F	p	η^2_p	Pillai's trace	F	p	η^2_p
Anthropometry	MANOVA*	0.281	1.843	0.070	0.281				
Physical fitness	MANOVA*	0.110	0.991	0.447	0.110				
Anthropometry	MANCOVA					0.481	4.097	< 0.01	0.481
Body mass	ANCOVA						9.278	< 0.05	0.127
Body Fat mass**	ANCOVA						1.226	0.272	0.019
Body Fat free mass	ANCOVA						14.677	< 0.01	0.187
Stature	ANCOVA						23.046	< 0.01	0.265
Sitting height	ANCOVA						20.055	< 0.01	0.239
Arm span	ANCOVA						11.538	< 0.01	0.153
Superior members length	ANCOVA						3.513	0.065	0.052
Hand length	ANCOVA						16.402	< 0.01	0.204
Inferior members length	ANCOVA						15.715	< 0.01	0.197
Foot length	ANCOVA						5.043	< 0.05	0.073
Arm circumference	ANCOVA						4.685	< 0.05	0.068
Calf circumference	ANCOVA						7.613	< 0.01	0.106
Physical fitness	MANCOVA					0.318	3.859	< 0.01	0.318
Pacer test	ANCOVA						4.928	< 0.05	0.071
Line-drill test	ANCOVA						0.031	0.861	0.000
Agility 10x5 shuttle run**	ANCOVA						2.320	0.133	0.035
60-s sit-ups	ANCOVA						0.018	0.894	0.000
2-kg ball throw	ANCOVA						5.894	< 0.05	0.084
Standing long jump**	ANCOVA						0.378	0.541	0.006
Hand grip strength**	ANCOVA						6.522	< 0.05	0.092

*η^2_p (partial eta square); * two-way MANOVA; ** the test was performed on the log-transformed variable.*

Similar studies with youth judokas and other youth martial arts athletes are scarce. Torres-Luque et al. (2015) studied 146 judo athletes aged 14-17 years and noticed an age effect, with older judokas presenting higher handgrip strength than younger judokas, which are results comparable to those of the present study. Branco et al. (2019) in the search for alternatives of classification of youth karate athletes which would consider biological maturation (bio-banding), evidenced maturational differences within weight categories in a sample of 20 females (11.76 ± 2.49 yrs) and 34 males (11.74 ± 2.49 yrs). Fukuda et al. (2018) in a study which investigated the influence of somatic maturation on indicators of muscular morphology, biomechanical variables, and bilateral asymmetry, evidenced that somatic maturity had the greatest relationship with handgrip performance and lower-body plyometric ability. However, research examining individual and combined contribution of chronological, biological, and training age to performance in judo is limited. The present study intended to contribute to fill this gap. The apparently greater effect of biological maturation on the anthropometry and physical performance of youth judokas, in comparison with the age effect, corroborates the literature and points to the need to maturation control in training and competition of youth judo athletes.

Training experience is another variable that deserves consideration in studies assessing the impact of maturation on youth judo and combat sports athletes. In a recent study investigating a sample of youth judokas with a similar age range, but with greater training experience than in the present study, it was found that growth and maturation predicted performance in generic neuromuscular tests, except for the standing long jump, while growth, maturation and training experience explained the variation in a judo-specific test (Detanico et al., 2020). Courel-Ibnez et al. (2018) indicated that the accumulated training experience improved the ability to perform the required judo technique. In the present study, which used generic tests to assess physical performance of youth judokas, where the application of a specific technique is not required, training experience was considered only for the inclusion of participants in the sample. This is a limitation that should be addressed in future studies, with the inclusion of accumulated judo training experience as a relevant variable.

Although the age-independent effect was evidenced, analyses performed allow us to understand that the maturational effect had a greater impact on the morphology and physical performance of youth judokas evaluated, since this effect remained after controlling for age. The opposite did not occur with the effect of age disappearing upon maturation control. Furthermore, no significant effect of the interaction between chronological age and maturation was evidenced, which could have been caused by the small sample size due to the difficulty of recruiting more youth judo athletes. The maturation effect on physical performance evidenced in the present study converges with the cited investigations, most notable on upper body and handgrip strength and aerobic and anaerobic performance, characteristics which are among the foremost to be developed in judokas (Bonitch-Góngora et al., 2013; Franchini et al., 2009; Thomas et al., 1989), and on which the maturation effect remained even after controlling for age, notably in the aerobic performance tests and in the upper limb and handgrip strength tests.

A major limitation of this study refers to predicting/estimating biological maturation as opposed to direct measurements. PMS has been used in several studies as a non-invasive indicator of biological maturation, and was reported with a reasonable validity when compared with gold-standard methods (Coelho et al., 2004). However, this method requires the stature of the biological parents to predict the adult stature of the evaluated individual. In this study, this information was obtained through self-report, which might cause bias.

It has been suggested that within combat sports, such as judo, chronological age, weight categories and skill levels could minimize the maturity effect over the youth judokas performance (Fukuda, 2015; Krstulović et al., 2005). However, due to the little number of investigations on the subject it cannot be refuted nor proved whether this was the case. In addition, there are studies that outline the possibility of maturation effect and relative age effect on performance of youth judokas despite the division into weight categories

Moreover, investigators and sports organizations are critical to the use of body mass as a criterion for youth combat sports athletes as a consequence of the increasing use of rapid weight loss in the pre-competitive period as a strategy to gain competitive advantage, with possible health and performance implications (Dubnov-Raz et al., 2015). Future investigations should consider the effectiveness of categorization by chronological age and body mass in the control of the maturational effect, as well as the search for classification criteria which could substitute the use of weight.

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ANNEX 2

Study 2

Giudicelli, Bruno B, Luz, L.G.O., Sogut, M., Sarmento, H., Massart, A.G., Júnior, A.C., Field, A., Figueiredo, A.J., 2021. Chronological Age, Somatic Maturation and Anthropometric Measures: Association with Physical Performance of Young Male Judo Athletes. Int. J. Environ. Res. Public Health 18, 6410. https://doi.org/10.3390/ijerph1812641

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Article

Chronological Age, Somatic Maturation and Anthropometric Measures: Association with Physical Performance of Young Male Judo Athletes

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Abstract: Sport for children and adolescents must consider growth and maturation to ensure suitable training and competition, and anthropometric variables could be used as bio-banding strategies in youth sport. This investigation aimed to analyze the association between chronological age, biologic maturation, and anthropometric characteristics to explain physical performance of young judo athletes. Sixty-seven judokas (11.0–14.7 years) were assessed for anthropometric and physical performance. Predicted adult stature was used as a somatic maturation indicator. A Pearson's bivariate correlation was performed to define which anthropometric variables were associated with each physical test. A multiple linear hierarchical regression was conducted to verify the effects of age, maturity, and anthropometry on physical performance. The regression models were built with age, predicted adult stature, and the three most significantly correlated anthropometric variables for each physical test. Older judokas performed better in most of the physical tests. However, maturation attenuated the age effect in most variables and significantly affected upper body and handgrip strength. Anthropometric variables attenuated age and maturity and those associated with body composition significantly affected the performance in most tests, suggesting a potential as bio-banding strategies. Future studies should investigate the role of anthropometric variables on the maturity effect in young judokas.

Keywords: adolescent athlete; combat sports; body composition; bio-banding

1. Introduction

The complex process of growth and maturation must be considered for children and adolescents in sport to ensure suitable training and competition routines. Chronological age is the traditional strategy to categorize young athletes appropriately for their level of development [1]. While growth is the process of increasing body size in whole or in parts, biological maturation refers to physiological and cognitive development towards adulthood. Although maturational events have an established order in which they happen, the moment when they occur and their duration have immense variability between individuals, even at the same age, which affect the physical, technical, and psychological performance of young athletes. This happens more prominently in boys between 13 and 16 years old [2], which may increase the risk of injury [3] and impair motivation due to the performance discrepancy [4], influencing whether the young athlete will continue in sports practice long-term [5]. In sports where strength, power, and speed are paramount, and in those where physical contact is inevitable, mature individuals tend to have a physical advantage over their less mature peers, since young people that mature and develop early tend to be taller and heavier [6].

Several investigations have been carried out to examine the effect of growth and maturation on young athletes' performance and to seek alternative strategies to chronological age for the categorization of young athletes, namely those that are based on the use of body size and/or maturational status [7–9]. These strategies are called bio-banding and do not disregard other aspects that must be considered regarding the allocation of young athletes in competitive categories, such as skill level and psychological profile [10]. However, most of these investigations focus on team sports, mainly in soccer, some with support from official sporting entities, and have already resulted in the first experiences of unofficial tournaments using bio-banding to distribute young athletes in competitive categories, with positive results [11]. In combat sports, less research attention has been given to the plausible effect of maturation over performance [12,13], and to the applicability of bio-banding to different modalities. Nonetheless, grouping young combat athletes based on physical attributes is common (e.g., boxing, judo, taekwondo, wrestling). In these modalities, athletes are grouped based on chronological age and body mass, and compete in weight classes to promote fair competition and reduce potential injuries [14]. Although studies on the topic are still scarce [13], there is evidence of maturation effect within weight categories in young combat sports [15], raising questions about the suitability of body mass as criteria to guarantee equal conditions among athletes, justifying research on the topic.

In addition, various research investigated the use of anthropometric variables for detection and prediction of success in young athletes [16], which can potentially also be used as bio-banding alternatives instead of body mass for categorizing young athletes in various sports, including combat sports. Based on the above-mentioned factors, the aim of the present investigation was to analyze the association between chronological age, biological maturation, and anthropometric characteristics to explain the physical performance of young judo athletes. Assuming that anthropometric characteristics may mitigate the effect of chronological age and biological maturation on the performance of young judo athletes, bio-banding strategies in judo and other combat sports could be developed using anthropometric variables, aiming to promote training and competition routines best suited to the development stages of young combat sport athletes.

2. Materials and Methods

2.1. Participants

This is a cross-sectional study with a convenience sample, consisting of 67 young male judokas aged 11.0–14.7 years old selected from eight clubs in Portugal. To be included in the study, the participants needed to be between 11.0 and 14.9 years old, have at least one year of judo training, and have no physical or psychological contraindications to participation. Parents or legal guardians provided signed informed consent prior to data collection. Verbal consent was also obtained from participants. Two participants from different clubs dropped out of the study once data collection had commenced. The study was conducted in accordance with the Declaration of Helsinki for Human Studies of the World Medical Association and approved by the Ethics Committee of the Faculty of Sports Sciences and Physical Education of the University of Coimbra [CE/FCDEF-UC/00452019].

2.2. Anthropometric Measures

Common anthropometric procedures [17] were adopted. Stature and sitting height (SH) were measured using a portable stadiometer (Seca Bodymeter 206; Seca Deutschland, Hamburg, Germany) and a segmometer (Rosscraft, T.E. and B. Ross, Perth, Australia), respectively. The inferior members' length (IML) was estimated as stature minus SH. Arm span (AS) was measured using a metallic anthropometric tape by assessing the distance between right and left dactylion points, with both arms abducted 90 degrees. The hand length (HL) was measured as the distance between the stylion and dactylion, while the foot length (FL) was measured as a straight distance between the acropodion and pterion points using an anthropometer. Arm circumference (AC) and calf circumference (CC) were measured with a metallic anthropometric tape. All measures were taken to the nearest 0.1 cm. Body mass (BM) was measured to the nearest 0.1 kg using a portable digital scale (Seca Bella 840; Seca Deutschland, Hamburg, Germany). Skinfold thickness was assessed to the nearest 0.1 mm using a Rosscraft skinfold calipers in the following references: triceps, subscapular, suprailiac, and calf. Estimates of fat mass percentage were obtained from the sex-specific equation derived from the sum of the triceps and subscapular skinfolds [18]. Thereafter, estimated body fat mass (BFM) and body fat-free mass (BFFM) were calculated.

2.3. Biological Maturation

Predicted adult stature (PAS) was used as a maturational indicator [19]. It has been adopted in investigations on the biological maturation effect on physical fitness of children in general [20] and in research focusing on youth performance in sport [21], due to the feasibility compared with more valid but invasive indicators [22]. Predicted adult stature has been used instead of peak of height velocity (PHV) in studies on bio-banding, since both have correspondence with pubertal status given by stage of pubic hair [10], but the latter seems to have limited application depending on chronological age and actual age at the peak of height velocity [23]. The PAS protocol requires the participants' decimal age, stature, and body mass, as well as the average parental stature. The stature of the parents was collected through a questionnaire attached to the informed consent form. The PAS variable was also expressed as the percentage of predicted adult stature attained (APAS). It is assumed that among children of the same chronological age, individuals with higher APAS are more advanced in somatic maturation compared with individuals with lower APAS [2].

2.4. Physical Performance

The pacer test was used to evaluate aerobic performance, with the number of completed laps being used as performance indicator. Agility was measured using a 10 × 5 m shuttle-run test, with the time to complete all laps recorded in seconds [24]. The line-drill test was used to evaluate anaerobic performance, with the time taken to complete the course expressed in seconds [25]. Strength was assessed using the following indicators: abdominal muscle strength (AMS), 60-s sit-up test [26]; upper body muscle strength (UBS), 2-kg medicine ball throw [27]; lower body muscle strength (LBS), standing long jump test [24]; and dominant-hand grip strength (HgS), measured by a dynamometer (Lafayette) [24]. The best of two attempts was recorded in kilograms for HgS.

2.5. Procedures

All data were collected by the same trained team, in a single visit for each judo club, where the anthropometric measurements were carried out initially, followed by the physical performance assessments. Participants completed a warm-up, under the guidance of a trainee researcher, before each station was completed in circuit form, in the following order: (1) pacer; (2) 2 kg standing medicine ball throw; (3) stand broad jump test; (4) 10 × 5 m shuttle-run test; (5) sit-ups; (6) handgrip strength; and (7) line-drill test.

2.6. Statistical Analysis

Descriptive statistics (ranges, means, standard deviations, and 95% confidence intervals) were used for chronological age (CA), APAS, anthropometric characteristics, and physical test performance. The Kolmogorov–Smirnov test was used to test normality: body fat mass, agility, lower body strength, and handgrip strength were significant. A Pearson's bivariate correlation, with 95% bias corrected and accelerated confidence limits based on 1000 bootstrap samples, to correct data normality [28], was performed to assess the level of association between all variables. Multiple linear regression, which does not assume the assumption of data normality [28], was conducted to verify the influence of the maturity indicators and anthropometric variables on physical performance. CA and APAS were previously selected for the first and second regression models, respectively, based on their impact on the performance of young athletes described in the literature [2]. For each performance test, the three anthropometric variables with the highest correlation coefficient were selected for the third model. Independent variables were inserted into the regression models hierarchically: Model 1 was constituted by CA; Model 2 by CA and APAS; and Model 3 by CA, APAS, and the three anthropometric variables with the highest correlation coefficients for each physical performance test. Most models met all assumptions for the multiple linear regression [28]: error independence (Durbin-Watson values between 1–3), non-multicollinearity (Tolerance values >0.1; VIF values <10), homoscedasticity (standardized residual values between −3 and 3) and non-influential cases (Cook's distance values <1). The exception was LBS, which failed on the assumption of non-influential cases. Significance of $p < 0.05$ was adopted in the analyses. IBM SPSS 26.0 software (SPSS, Inc., Chicago, IL, USA) was used in the study.

3. Results

Table 1 presents the descriptive statistics for the total sample, showing ranges, means, standard deviations, and 95% confidence intervals for CA, APAS, anthropometric characteristics, and physical test performance.

Table 1. Descriptive statistics for the total sample ($n = 67$).

Variables	Range		Mean		*sd*
	Minimum	Maximum	Value	95%CI	
Chronological age (years)	11.01	14.70	12.54	12.30 to 12.78	0.99
APAS (%)	77.0	94.0	84.4	83.2 to 85.5	4.7
Body mass (kg)	27.6	79.6	47.6	44.7 to 50.5	11.2
Body fat mass (kg)	2.1	34.4	9.6	8.0 to 11.1	6.3
Body fat-free mass (kg)	25.5	65.1	38.0	36.1 to 39.9	7.8
Stature (cm)	134.8	176.5	154.0	151.6 to 156.4	9.9
Sitting height (cm)	71.5	93.2	80.0	78.8 to 81.2	5.1
Arm span (cm)	133.0	180.0	154.1	151.5 to 156.7	10.8
Superior members length (cm)	36.2	70.8	60.2	58.9 to 61.5	5.4
Hand length (cm)	14.1	21.3	16.9	16.5 to 17.2	1.5
Inferior members length (cm)	60.3	85.5	74.0	72.7 to 75.4	5.5
Foot length (cm)	20.1	29.0	24.4	24.0 to 24.9	2.0
Arm circumference (cm)	19.0	36.0	25.3	24.5 to 26.1	3.3
Calf circumference (cm)	27.0	40.1	32.6	31.8 to 33.4	3.3
Pacer test (m)	140	1740	757	680 to 835	318
Line-drill test (sec) *	30.09	46.60	36.14	35.36 to 36.92	3.20
Agility 10 × 5 shuttle run (sec) *	15.88	26.25	19.44	18.93 to 19.96	2.12
60-s sit-ups (count)	15	61	41	39 to 44	10
2-kg ball throw (m)	3.19	8.79	5.22	4.93 to 5.52	1.22
Standing long jump (m)	1.12	5.65	1.69	1.55 to 1.83	0.57
Hand grip strength (kgf)	14.0	40.0	24.8	23.4 to 26.2	5.8

95%CI, confidence interval; *sd*, standard deviation; APAS, attained predicted mature stature; * Runtime tests—lower value represents better performance.

Table 2 summarizes the Pearson's bivariate correlation coefficient between maturational indicators and anthropometric variables, and the physical performance. Significant moderate to high correlations were found for CA and APAS with the performance variables, except for agility, in which only CA was significant, and except for abdominal strength. Among the measured anthropometric variables, body fat mass correlated with all physical tests associated with running, and with abdominal strength. Body fat-free mass correlated with the neuromuscular strength performance, except for abdominal strength. Body mass, arm circumference, and calf circumference were not selected for any regression model, as no significant correlations were found.

Table 2. Pearson bivariate correlation coefficients between maturational indicators and anthropometric variables, and physical tests performance variables, with 95% bias corrected and accelerated confidence limits based on 1000 bootstrap samples ($n = 67$).

Independent Variables	Dependent Variables (Physical Tests Performance)						
	Pacer Test (m)	Line-Drill test (s) +	Agility 10 × 5 Shuttle Run (s) +	60-s Sit-Ups (*n*)	2-kg Ball Throw (m)	Stand Long Jump (m)	Handgrip Strength (kg)
Maturational indicator							
Age	0.41 ** (0.21; 0.59)	−0.45 *** (−0.61; −0.24)	−0.25 * (−0.48; 0.02)	0.15 (−0.07; 0.37)	0.63 *** (0.42; 0.80)	0.47 *** (0.25; 0.67)	0.52 *** (0.29; 0.68)
APAS (%)	0.39 ** (0.18; 0.57)	−0.41 ** (−0.58; −0.21)	−0.19 (−0.43; 0.12)	0.06 (−0.20; 0.30)	0.68 *** (0.47; 0.83)	0.47 *** (0.24; 0.68)	0.65 *** (0.49; 0.77)
Anthropometry							
Body mass (kg)	−0.07 (−0.29; 0.19)	0.02 (−0.22; 0.21)	−0.10 (−0.14; 0.33)	−0.09 (−0.32; 0.17)	0.66 *** (0.48; 0.79)	0.10 (−0.14; 0.34)	0.66 *** (0.49; 0.78)
Body fat mass (kg)	−0.41 ** (−0.56; −0.19)	0.40 ** (0.16; 0.57)	0.32 ** (0.05; 0.53)	−0.27 * (−0.50; 0.03)	0.22 (0.01; 0.42)	−0.31 * (−0.50; −0.10)	0.26 * (0.01; 0.46)
Body fat-free mass (kg)	0.23 (0.04; 0.42)	−0.29 * (−0.46; −0.14)	−0.11 (−0.34; 0.10)	0.08 (−0.16; 0.32)	0.82 *** (0.71; 0.89)	0.40 ** (0.15; 0.61)	0.78 *** (0.66; 0.86)
Stature (cm)	0.25 * (0.06; 0.43)	−0.34 ** (−0.48; −0.17)	−0.19 (−0.40; 0.04)	0.05 (−0.22; 0.31)	0.71 *** (0.55; 0.82)	0.37 ** (0.16; 0.57)	0.73 *** (0.61; 0.82)
Sitting height (cm)	0.20 (−0.02; 0.40)	−0.25 * (−0.40; −0;07)	−0.14 (−0.31; 0.06)	0.05 (−0.20; 0.30)	0.69 *** (0.51; 0.82)	0.33 ** (0.13; 0.52)	0.71 *** (0.54; 0.82)
Arm span (cm)	0.16 (−0.02; 0.37)	−0.34 ** (−0.50; −0.18)	−0.21 (−0.43; 0.01)	0.11 (−0.16; 0.34)	0.73 *** (0.60; 0.82)	0.52 ** (0.13; 0.55)	0.70 *** (0.56; 0.81
Superior members length (cm)	0.13 (−0.08; 0.38)	−0.30 * (−0.54; −0.08)'	−0.26 * (−0.45; −0.10)	−0.01 (−0.23; 0.24)	0.58 *** (0.38; 0.78)	0.40 ** (0.19; 0.59)	0.56 *** (0.35; 0.79)
Hand length (cm)	0.38 ** (0.20; 0.55)	−0.31 * (−0.45; −0.16)	−0.15 (−0.35; 0.07)	0.31 * (0.10; 0.55)	0.55 *** (0.29; 0.74)	0.28 * (0.02; 0.53)	0.53 *** (0.29; 0.72)
Inferior members length (cm)	0.27 * (0.09; 0.44)	−0.38 ** (−0.53; −0.20)	−0.21 (−0.43; 0.04)	0.04 (−0.21; 0.29)	0.64 *** (0.48; 0.75)	0.36 ** (0.14; 0.55)	0.66 *** (0.55; 0.77)
Foot length (cm)	0.26 * (0.08; 0.46)	−0.22 (−0.40; −0.04)	−0.15 (−0.36; 0.09)	0.28 * (0.05; 0.51)	0.49 *** (0.26; 0.70)	0.21 (−0.01; 0.44)	0.50 *** (0.29; 0.69)
Arm circumference (cm)	−0.09 (−0.30; 0.13)	0.03 (−0.20; 0.24)	0.12 (−0.14; 0.36)	−0.05 (−0.28; 0.19)	0.66 *** (0.48; 0.78)	0.12 (−0.15; 0.35)	0.57 *** (0.37; 0.71)
Calf circumference (cm)	−0.15 (−0.37; 0.09)	0.06 (−0.18; 0.25)	0.16 (−0.09; 0.39)	−0.16 (−0.38; 0.12)	0.57 *** (0.38; 0.72)	0.01 (−0,22; 0.25)	0.53 *** (0.35; 0.68)

APAS attainted predicted adult stature; * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$; + Runtime tests—lower value represents better performance; BCa, bootstrap 95% CLs reported in brackets.

Table 3 showed the multiple linear regression models for the aerobic, anaerobic and agility physical test performances. Model 1 significantly explained 16.8% of the aerobic performance, 19.9% of the anaerobic performance, and 6.2% of the agility performance. The effect of age on these tests was mitigated with the inclusion of the somatic maturation indicator. Model 2 was not significantly associated with the agility test since there was no significant correlation between agility and APAS. Model 3 explained the performance relative to aerobic (44.6%), anaerobic (47.6%), and agility (24.3%) tests significantly better than the other models. The inclusion of the anthropometric variables attenuated the effects of CA and APAS. Body fat mass (β = −0.507, $p < 0.001$) and hand length (β = 0.262, $p = 0.046$) explained aerobic performance better than the other variables. For anaerobic performance, only body fat mass (β = 0.536, $p < 0.001$) was highlighted with a significantly effect. For agility test performance, body fat mass (β = 0.360, $p = 0.003$), and superior members length (β = −0.290, $p = 0.034$) emerged as being significantly associated.

Table 3. Hierarchical multiple linear regression models for physical performance tests (aerobic, anaerobic, and agility) in youth male judokas.

Physical Test	Multilinear Regression Models					
	Model	R^2	*p*	Independent Variables	β	*p*
Pacer Test (m)	Model 1	0.168	0.001	Age	0.410	0.001 *
	Model 2	0.171	0.637	Age APAS	0.307 0.116	0.215 0.637
	Model 3	0.446	<0.001	Age APAS Body fat mass Hand length Inferior members length	0.127 0.254 −0.507 0.262 −0.037	0.553 0.330 <0.001 * 0.046 * 0.816
Line-drill test (s) +	Model 1	0.199	<0.001	Age	−0.446	<0.001 *
	Model 2	0.200	0.753	Age APAS	−0.379 −0.076	0.120 0.753
	Model 3	0.476	<0.001	Age APAS Body fat mass Arm span Inferior members length	−0.326 0.040 0.536 −0.267 −0.118	0.124 0.876 <0.001 * 0.152 0.533
Agility 10 × 5 shuttle run (s) +	Model 1	0.062	0.042	Age	−0.250	0.042 *
	Model 2 #	-	-	Age APAS	- -	- -
	Model 3	0.243	0.002	Age APAS Body fat mass Superior members length	−0.365 0.213 0.360 −0.290	0.145 0.436 0.003 * 0.034 *

* $p < 0.05$; APAS attainted predicted adult stature; + Runtime tests—lower value represents better performance; # The models were not adequate to explain the variable.

The regression models for neuromuscular strength were presented in Table 4. Model 1, containing only CA, explained lower body strength better than other models. Model 2 was better suited for UBS (46.3%) and HgS (44.4%) to explain performance than Model 1. With its inclusion in Model 2, APAS attenuated the CA effect, while remaining significant (β = 0.544, $p = 0.008$ for UBS; β = 0.897, $p < 0.001$ for HgS). Model 3 explained performance better in the majority of the neuromuscular strength tests, except for LBS. The addition of the anthropometric variables attenuated age and maturity effects and significantly explained 23.9% of AbS, 71.6% of the UBS, and 79% of the HgS. Body fat mass better explained AbS (β = −0.295, $p < 0.05$), while age (β = 0.402, $p < 0.011$) and body fat-free mass (β = 0.747, $p < 0.001$) better explained UBS. Only body fat-free mass was significantly related to HgS (β = 0.626, $p < 0.01$). Superior members length was the only variable significantly related to LBS (β = 0.318, $p < 0.05$).

Table 4. Hierarchical multiple linear regression models for physical performance tests (neuromuscular strength) in youth male judokas.

Physical Test	Multilinear Regression Models					
	Model	R^2	*p*	Independent Variables	β	*p*
60-s sit-ups (count)	Model 1 #			Age		
	Model 2 #			Age APAS		
	Model 3	0.239	0.003	Age APAS Hand length Foot length Body fat mass	0.359 −0.442 0.296 0.157 −0.295	0.147 0.102 0.236 0.493 0.016 *
2-kg ball throw (m)	Model 1	0.399	<0.001	Age	0.632	<0.001 *
	Model 2	0.463	0.008	Age APAS	0.150 0.544	0.450 0.008 *
	Model 3	0.716	<0.001	Age APAS Body fat-free mass Arm span Stature	0.402 −0.239 0.747 0.250 −0.238	0.011 * 0.235 <0.001 * 0.130 0.210
Stand long jump (m)	Model 1	0.286	<0.001	Age	0.535	<0.001*
	Model 2	0.317	0.093	Age APAS	0.199 0.379	0.374 0.093
	Model 3	0.375	0.143	Age APAS Arm span Body fat-free mass Superior members length	0.274 0.208 −0.213 0.114 0.318	0.233 0.464 0.336 0.615 0.034 *
Handgrip Strength (kg)	Model 1	0.270	<0.001	Age	0.520	<0.001 *
	Model 2	0.444	<0.001	Age APAS	−0.275 0.897	0.175 <0.001 *
	Model 3	0.790	<0.001	Age APAS Body fat-free mass Stature Sitting height	−0.044 0.146 0.626 0.194 −0.113	0.805 0.526 0.001 * 0.435 0.632

The models were not adequate to explain the variable; APAS attainted predicted adult stature; * $p < 0.05$.

4. Discussion

The purpose of this investigation was to analyze the interaction between chronological age, somatic maturation, and anthropometric characteristics to explain the performance in young judo athletes. Chronological age had a significant effect on all physical tests, with older judokas performing better, except on abdominal strength. However, somatic maturation attenuated its effect in most of the tests (aerobic and anaerobic performances, upper body, lower body, and handgrip strengths) and its main effect was significant and positive on upper body and handgrip strengths. Furthermore, regression models with anthropometric variables better explain physical performance since chronological age and maturation significance decreased when anthropometric variables were included in the model. Among them, body fat mass was negatively related to tests associated with running (aerobic, anaerobic and agility tests), and to abdominal strength, while chronological age and body fat-free mass were positively related to upper body strength, and only body fat-free mass to handgrip strength.

Judo is characterized by intermittent strength and power actions interspersed with moments of recovery. The athlete, through grappling techniques, seeks to throw the opponent to the ground, whereby the contest occasionally continues until one of the athletes is immobilized or surrenders [29]. According to the results, maturity status could be deemed as having greater importance than chronological age in relation to the performance of young male judokas aged 11–15. Upper body and handgrip strength are considered critical to successful judo performance, since the sport involves pulling and pushing the opponent to allow the application of throwing, immobilizing, and blocking techniques [30,31]. However, current literature provides limited evidence regarding the influence of maturity on muscular strength in young judo athletes. One of the few studies on the subject, which involved testing a sample similar to the present study (66 young male judokas, mean age: 13.9 years), found that somatic maturation, along with body mass and stature, significantly explained handgrip strength, but not upper body strength [32]. Comparable results have also been observed in previous studies conducted on young male athletes from different sports [33–35].

Maturity-related differences in medicine ball throw and handgrip strength were observed, after age control, in young basketball players aged 12–13 years [33]. Significant differences between contrasting maturity groups in terms of handgrip strength were evidenced among 14 year old handball players [34]. In support of the present research, another investigation found significant and positive correlations, when controlling for chronological age, between maturity and handgrip strength and various medicine ball throw tasks in young tennis players aged 8–16 years [35].

Inter-individual differences in maturity can either positively or negatively affect performance in neuromuscular tests. Additionally, the nature of the association may vary depending on the age and sex of the individual, in addition to the characteristics of the task [36,37]. One of the first studies relating to biological maturation, growth variables, and physical tests performance suggested that while maturation of the neuromuscular system may contribute positively to the development of motor skill, maturity-related changes in both size and body composition could also negatively affect performance, particularly on tests requiring body displacement [36]. In the present study, body composition had a significant impact on performance. Body fat mass significantly explained aerobic, anaerobic, and agility performance, with heavier judokas performing worse. On the other hand, body fat-free mass significantly and positively explained superior limb strength (upper body and handgrip strengths tests), which are variables most associated to the maturity effect. The importance of body composition, namely with low fat mass and high fat-free mass, is well-established as being a determinant of successful judo performance [38–40]. However, grouping young judokas into weight categories using total body mass disregards body composition, which can vary significantly between weight categories [41], and seems to be relevantly related to biological maturation, as already been observed in a previous study [42], and evidenced in the present investigation. These findings may reinforce doubts about the effectiveness of the young athlete's distribution in weight categories for equalization of competition conditions and training routines, evidencing the need to control the effect of maturation in judo with/bio-banding strategies, and raising the possibility of using other anthropometric characteristics as a categorization criterion, such as the APAS itself or components of body composition.

Previous studies have investigated the relationship between morphological characteristics, biological maturation, and motor performance in young judo athletes using regression analysis methods [32,43,44]. However, few studies have adopted the hierarchical procedure in regression analyses, such as the present study. This involved the current research team deciding which variables should enter first in the regression models, based on previous knowledge, with such an approach considered more adequate compared with stepwise methods [28]. However, there are some limitations that should be considered for the present investigation. The lack of power analyses to determine whether the sample size was adequate may limit statistical inferences. The use of indirect tests to measure physical capacity may also limit the investigation. Notably, fat mass was significantly associated to judokas performance in running tests, which involve displacement of total body mass, with heavier judokas having presented significantly lower performance. The Special Judo Fitness Test (SJFT) is an alternative widely used in the literature for the physical evaluation of judo athletes, but in addition to also involving running in its execution, there is still no consensus on its discriminating power in the young population [45]. In several studies that involve the use of APAS as a maturational indicator, including this one, the statures of the participants' parents were verified by self-reporting, a procedure that has support in the literature [22] but might introduce bias [46]. The error between predicted and actual mature stature at 18 years of age is reported to be 2.1% [19]. As explained earlier, predicted adult stature has been used instead of peak of height velocity in studies on bio-banding, since the latter seems to have limited application depending on age at the peak of height velocity for both boys and girls [47]. Considering the above, the present study used APAS to avoid the impact of the wide range of age at the peak of height velocity promoted by the biological variability at this auxological period. Moreover, the predicted adult stature is being used in most of the studies related with the bio-banding approach and this can allow the present study to be more objective compared with further research in the literature.

5. Conclusions

The results of the present study corroborate the findings of previous research and add value not only because they support the significant effect of the somatic maturation on young judo athletes' physical performance, mainly on upper body and handgrip strengths tests. These findings suggest that bio-banding may be an effective strategy to reduce the implications of maturation on judo performance, preventing those that are less mature being at a physical disadvantage, assisting trainers in the construction of training routines appropriate to the youth's development, supporting sporting entities in proposing fairer tournaments, reducing injury risk, and promoting engagement in sports for the long-term. Additionally, anthropometric characteristics, such as body fat mass and body fat-free mass, may need to be considered regarding biological maturational effect. Future studies should assess bio-banding strategies for categorizing young judo athletes and other combat sports, in the search for more appropriate training and competition conditions. This may promote positive sporting experiences for young athletes, precluding unfair disadvantages and improving performance. Other research approaches may involve further investigating the role of anthropometric variables over the maturation effect on young judo athletes controlling for age and body mass (the traditional criteria for bio-banding in combat sports). Furthermore, an avenue for future research may be to evaluate the impact of participating in bio-banding tournaments on the performance and on the quality of the experience perceived by young judo and other combat sport athletes.

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ANNEX 3

Study 3

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Bio-Banding in Judo: The Mediation Role of Anthropometric Variables on the Maturation Effect

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Abstract: Young judo athletes are bio-banding based on age and body mass and compete in weight classes. The purposes of this study were to investigate the influences of maturation on physical performance in young judokas through controlling the chronological age and body mass, and to examine the mediating role of anthropometric variables. Sixty-seven judokas, aged 11.0–14.7, were measured for 11 anthropometric and seven physical performance variables. Pearson partial correlations were conducted to verify the relationship between the maturational indicator and the dependent variables. Mediation analyses were performed to identify the extent to which anthropometric variables mediate the relationship. The maturation effect remained on the aerobic capacity and handgrip strength ($p < 0.05$). Fat mass ($b = 80.335$, 95%CI 11.580–204.270) and fat-free mass ($b = 108.256$, 95%CI 39.508–207.606) totally mediated the effect on aerobic capacity. Fat mass ($b = 0.023$, 95%CI 0.004–0.057), fat-free mass ($b = 0.029$, 95%CI 0.011–0.058), stature ($b = 0.031$, 95%CI 0.008–0.061), arm span ($b = 0.021$, 95%CI 0.003–0.044), and inferior members length ($b = 0.022$, 95%CI 0.005–0.049) totally mediated the effect on handgrip strength. The effect of biological maturation is noticeable even after age and body mass control, being mediated by anthropometric variables related to body composition and size.

Keywords: biological maturation; bio-banding; judo; combat sports; rapid weight loss; mediation analysis

1. Introduction

Chronological age is traditionally used in youth sports for the purpose of matching competitors or teams [1]. However, this approach has various limitations that at any given age there can be large maturity-associated variations in size and functional capacities among children [2–5]. Being advance in maturity may provide an advantage for young male athletes in sports characterized by power, strength, and speed [6]. In girls, it is associated with greater size and strength [7–9]. Therefore, several maturity-based classification methods have been proposed in the context of training and competition [10–12]. The latest attempt to advocate the biological maturity-based matching is denominated bio-banding. Bio-banding refers to the process of grouping young athletes into bands according to attributes related to growth and maturation status rather than chronological age [13]. The predicted mature status (PMS), a noninvasive method to estimate somatic maturity [14], is the most current method employed to assess maturity. Studies and implementations of bio-banding, on the other hand, are limited to the training or unofficial tournaments of young male soccer players [15–17].

The concern of grouping young athletes on the physical attributes is common in combat sports (e.g., boxing, judo, taekwondo, and wrestling) where young athletes are matched based on age and body mass and compete in a series of weight classes. This form of bio-banding classification could facilitate fair competition and reduce potential injuries [18,19]. However, doubts may be raised about the suitability of body mass-based classification to guarantee fair play in combat sports due to evidence of maturation effect within weight categories in young combat sports [20], although there is an important gap in studies on this subject, and to the widespread adoption of rapid weight loss (RWL) as a common competitive strategy [21,22].

RWL refers to the strategy adopted by most combat sports athletes to temporally reduce their body mass, typically about 2–10%, but with reports of reductions greater than 12% [23,24], a few days before competitions to fit in a lower weight category, in an attempt to gain an advantage against lighter, smaller, and weaker opponents [22]. Achieved only through the combination of aggressive dehydration and starvation methods [24–28], it is a well-established common practice among combat sports athletes [29] whose harmful effects are already known and well documented in the literature [26,30–33]. RWL is not an issue restricted to adult or professional sports as children and adolescents from 10 years old also use RWL for competitive advantage [34,35]. Therefore, it was proposed that the sports community should frame RWL as doping and ban it from combat sports because of its detrimental health effects and for causing unfair competition [36].

In youth combat sports, at the same time that there is a need to verify the efficacy of body mass-based categorization to control the maturity effect providing fair competitions, reducing the injury risk and promoting engagement in sports for the long-term, it is imperative to find alternatives to body mass as a bio-banding strategy because of the RWL consequences. In this sense, among possible research designs, mediation studies can be used to understand which characteristics associated with body growth and biological maturation most strongly affect the physical performance of young athletes. Mediation analysis has recently been used in studies with children to evaluate the effect of biological maturation on motor competence performance through the mediation of anthropometric characteristics [37,38]. Therefore, the purposes of this study were: (1) to investigate whether there is an effect of biological maturation on the performance of young judo athletes after controlling chronological age and body mass; and (2) in the situation where the maturation effect is evidenced, to investigate anthropometric variables that can mediate this effect. Two hypotheses were submitted for confirmation: (1) the effect of maturation on the physical performance is significant even after age and body mass control; and (2) variables associated with body size mediate the effect of maturation on physical performance.

2. Materials and Methods

The participants were 67 young male judokas aged 11.0–14.7 years from eight Portuguese judo clubs. To be included in the investigation, it was necessary to have at least 12 months of judo training. Prior to data collection, parents or legal guardians signed informed consent. In addition, verbal consent was obtained from participants after the presentation of the aim and procedures. The study was approved by the Scientific Council of the Faculty of Sports Sciences and Physical Education of the University of Coimbra and was conducted in accordance with the Declaration of Helsinki for human studies of the World Medical Association.

The present study adopted common anthropometric procedures [39]. Stature and sitting height were measured using a portable stadiometer (Seca Bodymeter 206) and a segmometer (Rosscraft), respectively. The lower limb length was estimated as stature minus sitting height. Arm span was measured assessing the distance between right and left dactylion points with both arms abducted 90 degrees labeled with chalk on the wall using an anthropometric tape. The hand length was measured as the distance between the stylion and dactylion, while the foot length was measured as straight distance between the acropodion and pterion points. Arm circumference and calf circumference were measured with an anthropometric tape. All measures were taken to the nearest 0.1 cm. Body mass was measured to the nearest 0.1 kg using a portable digital scale (Seca Bella 840). Skinfold thickness was assessed to the nearest 0.1 mm using a Rosscraft skinfold calipers in the following references: triceps, subscapular, suprailiac, and calf. Estimates of fat mass percentage were obtained from the sex-specific equation derived from the sum of the triceps and subscapular skinfolds [40]. Afterward, estimated fat and fat-free masses were calculated to the nearest 0.1 kg.

The predicted mature stature (PMS) was the maturational indicator used to classify the judokas according to the maturational state. It has been used in investigations about the biological maturation effect on physical fitness of young people in general [38,41,42], in research focusing on youth performance in sport [43,44] and as a criterion for bio-banding in experimental training and tournaments [15–17] due to the advantages it presents compared to more valid but invasive indicators [45–47]. The PMS was calculated by the Khamis–Roche method [14]. The protocol requires decimal age, stature, and body mass of the participant and average parental stature. The stature of the parents was collected through questionnaire attached to the informed consent sent to the parents or legal guardians. The current stature was expressed as a percentage of PMS (%PMS). It is assumed that among children of the same chronological age, individuals closer to the PMS are more advanced in biological maturation compared with individuals who are farther [4]. From the %PMS, the z-score was calculated on the mean and standard deviation from the sample itself to classify the evaluated judokas by maturity status. Two groups contrasting in somatic maturation were derived from z-scores of attained %PMS: more mature ($P > 50\%$) and less mature ($P \leq 50\%$).

The aerobic performance of the judokas was evaluated using the Pacer (Progressive Aerobic Cardiovascular Endurance Run Test) test, with the number of completed laps being used as a performance indicator. The anaerobic performance was assessed using the line-drill test, with the recording in seconds of each judokas' time to complete the course. The agility was evaluated through the application of the 10×5 m shuttle-run test, recording the total time of completed laps. The following indicators were used for the assessment of the subjects' muscle strength: abdominal muscle strength (AMS) applying the 60-s sit-ups test; lower body muscle strength (LBS) using the standing long jump test; upper body muscle strength (UBS) through the 2-kg medicine ball throw; and handgrip strength (HgS) measured by a dynamometer Lafayette model 78-10, through two attempts using the dominant hand. The best of the two attempts in kilograms was recorded.

All data were collected between April and May 2014 by the authors and a team trained by them specifically for this purpose, in a single visit where the anthropometric measurements were carried out initially, followed by physical performance evaluation. Measurements and tests were performed in circuit form. When completing all anthropometric stations, the young judoka were asked to perform warm-up exercises under the guidance of a trainee researcher and then sent to the physical performance evaluation stations in the following order: (1) Pacer; (2) 2 kg standing medicine ball throw; (3) stand broad jump test; (4) 10×5 m shuttle-run test; (5) sit-ups; (6) handgrip strength with a dynamometer; and (7) line-drill test.

Descriptive statistics (ranges, means, standard deviations, and 95% confidence intervals) were used for describing the anthropometric profile, the physical fitness and the maturational status of judokas in the total sample. To test normality Kolmogorov–Smirnov was used and appropriate log transformations (log 10) were adopted to normalize distributions. Pearson partial correlations were calculated between biological maturation and anthropometry and physical performances adjusting by chronological age and body mass, the common bio-banding strategy used in judo competitions. From the significant partial correlations established amid the maturational state and the physical performance variables, the physical variables that had their partial correlations with the anthropometric measurements estimated were selected. Mediation analyses aim to infer whether the relationship between a predictor and an outcome depends on the mediation of other variables. This type of analysis is based on correlation and regression tests to establish relationships among predictor, mediator,

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and outcome, and can be performed by different methods. In this study, mediation analyses were performed using Process (v3.3 by Andrew F. Hayes). The choice of variables to be tested as mediators and outcomes met the criterion of having a significant correlation with the predictor and correlation with each other. All linear regression models were adjusted by chronological age and body mass. Significance of $p < 0.05$ was adopted in the analyses. IBM SPSS 22.0 software (SPSS, Inc., Chicago, IL, USA) was used in the study.

3. Results

The descriptive statistics for the total sample and the results of normality tests are presented in Table 1. Body fat mass, agility, lower body strength, and handgrip strength tests presented significant values in the Kolmogorov–Smirnov test. Logarithmic transformation was performed in these variables for inferential statistics.

Table 1. Descriptive statistics for the total sample and test of normality (n = 67).

Variables	Range		Mean		*sd*	Kolmogorov–Smirnov	
	Minimum	Maximum	Value	95%CI		Value	*p*
Chronological age (years)	11.01	14.70	12.54	12.30–12.78	0.99	-	-
Predicted mature stature (cm)	161.9	198.3	182.6	180.2–184.3	7.2	-	-
Attained PMS (%)	77.0	94.0	84.4	83.2–85.5	4.7	-	-
Training experience (years)	1	9	3.33	2.74–3.91	2.40	-	-
Body mass (kg)	27.6	79.6	47.6	44.7–50.5	11.2	0.102	0.081
Body Fat mass (kg)	2.1	34.4	9.6	8.0–11.1	6.3	0.150	<0.01
Body Fat free mass (kg)	25.5	65.1	38.0	36.1–39.9	7.8	0.099	0.173
Stature (cm)	134.8	176.5	154.0	151.6–156.4	9.9	0.075	0.200
Sitting height (cm)	71.5	93.2	80.0	78.8–81.2	5.1	0.078	0.200
Arm span (cm)	133.0	180.0	154.1	151.5–156.7	10.8	0.060	0.200
Superior members length (cm)	36.2	70.8	60.2	58.9–61.5	5.4	0.086	0.200
Hand length (cm)	14.1	21.3	16.9	16.5–17.2	1.5	0.074	0.200
Inferior members length (cm)	60.3	85.5	74.0	72.7–75.4	5.5	0.057	0.200
Foot length (cm)	20.1	29.0	24.4	24.0–24.9	2.0	0.098	0.185
Arm circumference (cm)	19.0	36.0	25.3	24.5–26.1	3.3	0.068	0.200
Calf circumference (cm)	27.0	40.1	32.6	31.8–33.4	3.3	0.071	0.200
Pacer test (m)	140	1740	757	680–835	318	0.094	0.200
Line-drill test (s) *	30.09	46.60	36.14	35.36–36.92	3.20	0.074	0.200
Agility 10 × 5 shuttle run (s) *	15.88	26.25	19.44	18.93–19.96	2.12	0.139	<0.01
60-s sit-ups (count)	15	61	41	39–44	10	0.089	0.200
2-kg ball throw (m)	3.19	8.79	5.22	4.93–5.52	1.22	0.077	0.200
Standing long jump (m)	1.12	5.65	1.69	1.55–1.83	0.57	0.179	<0.01
Hand grip strength (kg)	14.0	40.0	24.8	23.4–26.2	5.8	0.158	<0.01

95%CI, confidence interval; *sd*, standard deviation; PMS, predicted mature stature; * in runtime tests, lower value represents better performance.

Table 2 summarizes the partial correlation coefficients among biological maturation, anthropometric, and physical performance variables. Concerning the correlation between maturity status and physical performance, only aerobic performance (r = 0.273, $p < 0.05$) and handgrip strength (r = 0.292, $p < 0.05$) presented significant correlation; therefore, they were selected to have their partial correlations with the anthropometric variables estimated. Two mediation analysis models were derived from the correlations. The first model as a predictor the maturity status, as an outcome the aerobic performance, and as variables to be tested as mediators the anthropometric variables that partial correlated simultaneously with both, namely body fat mass, body fat free mass, stature, sitting height, and inferior members length. The second model maintained the biological maturation as a predictor, but the outcome variable was handgrip strength, being tested as mediators body fat mass, body fat-free mass, stature, sitting height, arm spam, superior members length, and inferior members length.

Table 2. Partial correlation coefficients (controlling for chronological age and body mass) among biological maturity (given by the z-score of the attained %PMS), anthropometric, and physical variables; and partial correlation coefficients between aerobic performance and handgrip strength with anthropometric variables ($n = 67$).

Variables	Biological Maturation	Physical Fitness	
		Aerobic Performance	Handgrip Strength
Anthropometry			
Body Fat mass (kg) #	−0.303 ***	−0.432 ***	−0.461 ***
Body Fat free mass (kg)	0.387 **	0.451 ***	0.453 ***
Stature (cm)	0.497 ***	0.305 *	0.395 **
Sitting height (cm)	0.400 **	0.263 *	0.322 **
Arm span (cm)	0.387 **	0.191	0.359 **
Superior members length (cm)	0.288 *	0.116	0.296 *
Hand length (cm)	0.236	0.352 **	0.247 *
Inferior members length (cm)	0.443 ***	0.258 *	0.348 **
Foot length (cm)	0.103	0.260 *	0.245
Arm circumference (cm)	−0.168	−0.040	−0.200
Calf circumference (cm)	−0.126	−0.190	−0.282
Physical fitness			
Pacer test (m)	**0.273 ***		
Line-drill test (s)	−0.225 ##		
Agility 10 × 5 shuttle run (s) #	−0.053 ##		
60-s sit-ups (count)	−0.069		
2-kg ball throw (m)	0.074		
Standing long jump (m) #	0.217		
Hand grip strength (kg) #	**0.292 ***		

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$; Bold – physical performance variables selected to have partial correlation with the anthropometry variables tested; # test was performed on log-transformed variable; ## in runtime tests, lower value represents better performance.

The mediation analyses performed are shown in Figure 1. They were adjusted by chronological age and body mass, as were the correlation analyses, also considering that these variables are utilized in judo to band youth athletes in age–weight categories. In the mediation model having biological maturation as predictor and aerobic performance as an outcome, the first regression equation showed a positive total effect between them ($p < 0.05$); the second equation negatively associated maturation with body fat mass ($p < 0.05$); and the third equation, where maturation and body fat mass simultaneously participate in the model, showed a negative association between body fat mass and aerobic performance ($p < 0.01$), a loss of significance in the association between predictor and outcome (direct effect) and a significant indirect effect (95%CI [11.580–204.270]), indicating a total mediation. Total mediation was also found between maturation and aerobic performance with body fat-free mass as a mediator, given that there was a positive association between maturation and fat-free mass ($p < 0.01$), a positive association between body fat-free mass and aerobic performance ($p < 0.01$), and a not significant direct effect, whereas the indirect effect calculated had significance (95%CI [39.508–207.606]).

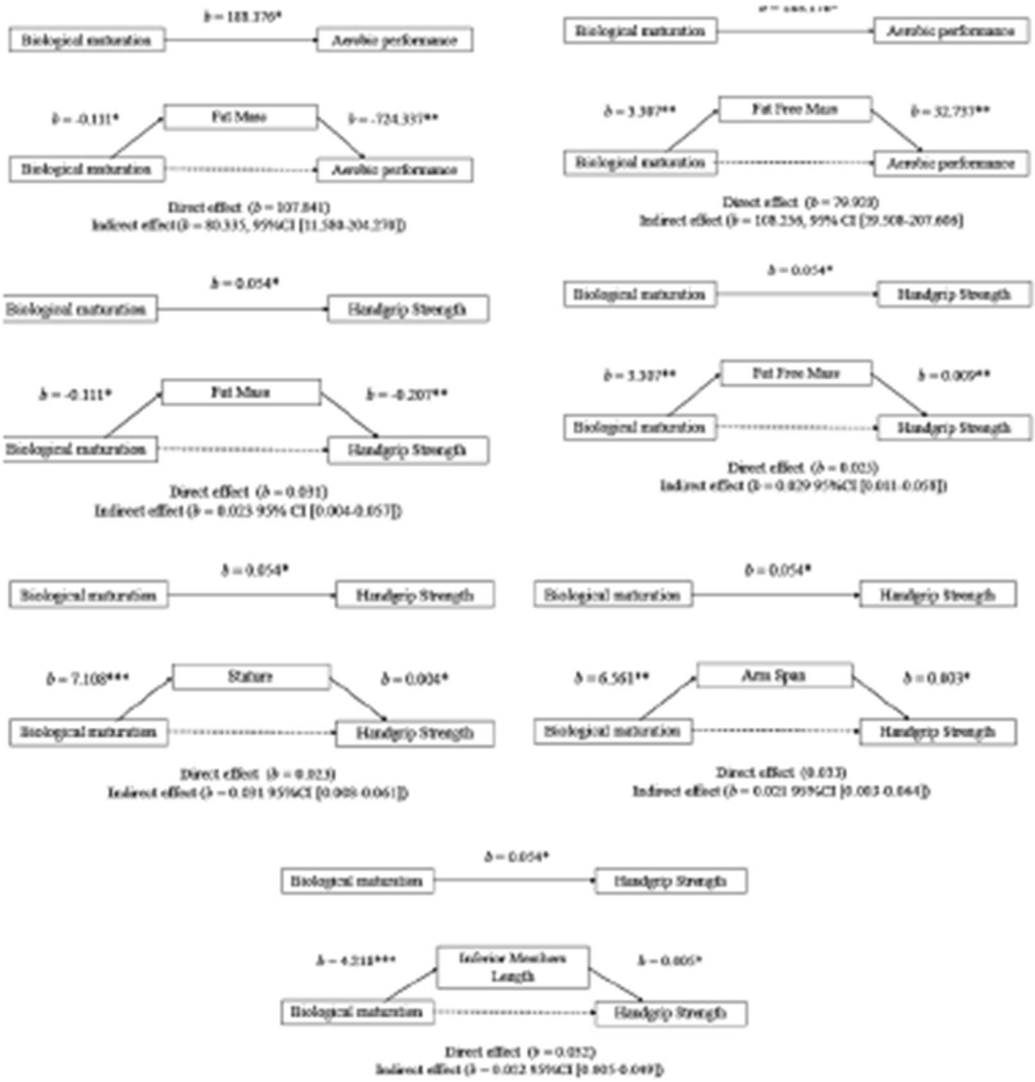

Figure 1. Models of body fat mass, body fat free mass, stature, arm span, and inferior members length mediation on the maturational effect on aerobic performance and handgrip strength. * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$; solid line, significant effect; dash line, non-significant effect.

In Figure 1, the second group of mediation analysis itemized as predictor the biological maturation and as an outcome the handgrip strength. The first regression equation reported a positive association between maturation and handgrip strength ($p < 0.05$). The analysis of mediation resulted in five anthropometric variables exerting total mediation between the predictive and outcome variables. The second regression equations in the models indicated for biological maturation negative relationship with body fat mass ($p < 0.05$) and positive with body fat-free mass ($p < 0.01$), stature ($p < 0.001$), arm span ($p < 0.01$), and lower members length ($p < 0.001$). In all cases, the direct effects, i.e., the effect of the predictor variable on the outcome adjusted by the mediator variable, became non-significant, and the indirect effects were significant: body fat mass (95%CI [0.004–0.057]), body fat-free mass (95%CI [0.011–0.058]), stature (95%CI [0.008–0.061]), arm spam (95%CI [0.003–0.044]), and inferior members length (95%CI [0.005–0.049]). Sitting height and inferior members length, in the first model, and superior members length in the second model, are not shown in Figure 1 because their mediation effects were not found in their respective predictors and/or outcomes.

4. Discussion

The aim of this study was to investigate the effect of biological maturation and the role of anthropometric variables as possible mediators of this effect on young judokas physical performance, inasmuch as there is evidence that the current criteria used to grouping these athletes for training and competition, i.e., chronological age and body mass, may not be effective to control the maturation effect, but also lead to the practice of RWL. Through the partial correlations and mediation analyses, it became evident that in this sample the biological maturation still influences performance variables even with the adjustment of chronological age and body mass. The partial correlations and the two mediation models showed significant and positive maturation effect on aerobic performance and handgrip strength. The first model results exposed total mediation role of the body fat mass and body fat free mass on the maturation effect over aerobic performance, while the second model demonstrated total mediation role of these two variables, as well as of stature, arm span, and inferior members length, on the maturation effect over handgrip strength.

Aerobic performance and handgrip strength are two physical capabilities considered important for success in judo, since the sport is characterized by intermittent actions of great strength and power, interspersed with moments of recovery, where the athlete through grappling techniques seeks to throw the opponent to the ground and occasionally immobilize him/her or make him/her surrender in the ground fight [48,49]. The duration of a judo match in competitions can vary from a few seconds, when an applied technique reaches the maximum score, up to 8 min, when there is a regular 5-min tie and extra time is used to define the winner. In international competition, an athlete can perform up to seven matches. Considering the nature of motor actions, duration, and number of bouts, judo is considered a modality with both anaerobic and aerobic energy demands [50]. The aerobic system contributes to the judoka sustaining the effort for the duration of the combat and to recovering in the brief moments of effort reduction between techniques and in the rest periods between matches [51,52]. In addition to the energy demand, for pulling and pushing the opponent allowing the application of throwing, immobilizing, and blocking techniques, the development of the handgrip strength is considered critical to successful judo performance [53].

Although their objective is to equalize training routines and competitions, the distribution of young judokas and young athletes of other combat sports in age–weight categories could be inappropriate for biological maturation effect control. Previously, in an investigation regarding the relationship between chronological age and maturation effect in 54 young karateka of both sexes aged 7–16 years, maturity-advanced athletes in several weight categories were found, which would, according to the authors, lead to competitive inadequacy and evidence the need for other criteria for organizing young combat athletes [20]. As of this writing, we were unable to find further studies that investigated the existence or otherwise of the maturation effect on weight categories in young combat sports, which highlights an important gap that this study can help fill. Studies on relative age effect (RAE) in combat sports, on the other hand, are more common and show a possible RAE within weight categories, but the results of these investigations are still divergent [54,55] and, although often associated, maturational status and RAE appear to be independent [56,57]. Nevertheless, it seems appropriate to state that the use of body mass for the distribution of combat sports athletes in categories that seek equal conditions among them is affected by several factors that go beyond genetics, such as diet, lifestyle, level of physical activity, and psychological state, among others [4], even within athletes, which brings a variability that could prevent the efficient control of biological maturation, not avoiding the performance imbalance among young athletes of the same age. It is precisely the body mass possibility of manipulation that allows the adoption of the RWL strategy, where purposely and as a competitive strategy athletes undergo extreme dehydration and starvation to compete in categories with lighter opponents. The adoption of RWL only, apart from the possibility of not controlling the maturational effect, could be enough to consider weight categories as ineffective in ensuring proper training routines and fair competitions. Further, banning RWL as a competitive strategy is necessary from a public health perspective, as there are reports of combat sport athlete deaths associated with this practice [58,59].

PMS as an indicator of biological maturation has gained prominence in investigations of young athletes for its noninvasive aspect and greater practicality of application, compared with classical evaluation methods [14]. In a bio-banding experience at a young men's soccer tournament in the UK, 66 athletes aged 11–14 years were divided into categories according to the percentage of PMS attained (85–90%) at the time of the measurement [15]. All young participants described the experience as positive and recommended that the Premier League incorporate bio-banding into their official tournaments. Furthermore, compared to chronological age-oriented tournaments, athletes advanced in maturity reported that they were more physically demanding, which required a greater emphasis on game technique and tactics, while less mature athletes reported that they enjoyed the experience the most because they had more opportunities to apply their technical and tactical knowledge as they were less physically pressured. This, according to the authors, advocates in favor of bio-banding as it allows for a holistic development of young soccer athletes. The use of PMS as bio-banding in judo and other combat sports, as in the soccer example, could be effective for controlling the maturational effect and for extinguishing the practice of RWL in these modalities, but there are no reports of experiences in this regard in the literature. However, this would not cause any change in the adoption of RWL in adult judo and combat sports. Therefore, it makes sense to search for an alternative criterion for athlete's categorization that can be used to control maturation in combat sport for young people and to eradicate RWL in combat sport from young to adult. In fact, the search for anthropometric variables that could exert control over the maturation in youth combat sports is recurrent and several studies have been interested in seeking anthropometric variables associated with success in judo [60–63].

The results evidenced in this investigation are limited by the lack of a larger sample size and the use of indirect tests to measure physical capacity. Further, in several studies that involve the use of PMS as maturational indicator, including this one, the stature of the parents of the investigated youngsters was verified by self-reporting, a procedure that also has support in the literature [45], but might bring bias [6]. The error between predicted and actual mature stature at 18 years of age is reported to be 2.1% [14].

5. Conclusions

This study sought to verify if the effect of maturation is evidenced in a sample of young judokas even with control of chronological age and body mass and, if so, which anthropometric variables mediate this effect. The effect of maturation was evidenced on aerobic capacity and handgrip strength, variables considered important for success in judo. By exerting total mediation effect on these capacities, body fat mass and body fat-free mass were evidenced in relation to the aerobic capacity, and body fat mass, body fat-free mass, stature, arm span, and lower limbs' length in relation to the handgrip strength. More investigations and intervention projects are needed to analyze bio-banding possibilities in judo and other combat sports. Attention is drawn to the search for variables with the double potential of bio-banding in youth combat sports and body mass substitution as a categorization criterion for young and adult combat athletes, aiming at the extinction of RWL as a sports strategy.

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