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Research article

THE INFLUENCE OF MUSCLE MASS ON JUMP HEIGHT THROUGHOUT BIOLOGICAL MATURATION

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Mladen Živković[1], Nikola Stojanović[1], Amel Mekić[2], Anđela Došić[1], Danijela Živković[1], Saša Pantelić[1]

[1]Faculty of Sport and Physical Education, University of Niš, Serbia
[2]Faculty of Sport and Physical Education, University of Sarajevo, Bosnia and Herzegovina

ORCID iDs:		
	Mladen Živković	https://orcid.org/0000-0001-9662-0519
	Nikola Stojanović	https://orcid.org/0000-0002-9921-6391
	Amel Mekić	(N/A)
	Anđela Došić	(N/A)
	Danijela Živković	https://orcid.org/0000-0001-8365-0583
	Saša Pantelić	https://orcid.org/0000-0002-4356-1874

Abstract. *This study aims to investigate the influence of muscle mass on jump height based on the stage of biological maturation. The total sample consisted of 71 male athletes with three years of minimum training experience. The athletes were divided into three groups based on biological maturation: PrePHV, MidPHV, and PostPHV. Vertical jump height was assessed using three tests: the countermovement jump (CMJ), the countermovement jump with arm swing (CMJwas), and the squat jump (SJ). The results of the interaction between muscle mass percentage (MM) and peak height velocity (PHV) indicate that the effect of MM on vertical jump variables is greater in the PrePHV and MidPHV groups compared to the PostPHV group. For the PrePHV and MidPHV groups, there was a significant increase in CMJ [b=.83, t(22)=3.77, p=.001 and b=.92, t(14)=3.70, p=.002, respectively] and SJ [b=1.11, t(22)=4.45, p< .001 and b=1.06, t(14)=3.51, p=.003, respectively] when muscle mass percentage increased by one unit, while no significant increments were apparent for the PostPHV group [b=0.71, t=1.98, p=.058 and b=0.48, t(28)=1.65, p=.111, respectively]. Additionally, when muscle mass percentage increased by one unit, the CMJwas performance significantly increased in the PrePHV [b=1.48, t(22)=4.68, p<.001], MidPHV [b=1.15, t(14)=4.59, p<.001], and PostPHV [b=.97, t(28)=2.52, p=.018] groups. This study substantiates muscle mass as an important predictor of explosive power, demonstrating a more pronounced impact in the PrePHV and MidPHV relative to the PostPHV group. The study points out the importance of considering biological maturation when understanding the relationship between muscle mass and explosive power performance in young athletes.*

Key words: *regression, moderation effect, PHV, explosive power*

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Corresponding author: Mladen Živković
Faculty of Sport and Physical Education, University of Niš, Čarnojevićeva 10A, 18000 Niš, Serbia
E-mail: profzile87@gmail.com

INTRODUCTION

Biological maturation is one of the most critical factors influencing somatic growth and physical fitness, thus exerting a significant impact on the physical activity of adolescents (Malina, Bouchard, & Bar-Or, 2004; Sherar, Cumming, Eisenmann, Baxter-Jones, & Malina, 2010). Physiological adaptations occurring in the body over the years determine an individual’s biological maturity, which can differ from chronological maturity (Haibach, Reid, & Collier, 2011). Chronological maturity means the period that passes from an individual's birth and does not include the health status of a person's body (Prieto, Barbería, Ortega, & Magaña, 2005). Assessing biological maturity can be achieved through various methods, and evaluating peak height velocity (PHV) is a non-invasive method that finds extensive application in sports science (Malina, Bouchard, & Bar-Or, 2004). Assessment of PHV is performed based on anthropometric characteristics and age expressed in the decimal system (Mirwald, Baxter-Jones, Bailey, & Beunen, 2002). Maturity timing exerts a significant influence on results in motor ability tests due to considerable anthropometric and physiological differences related to the level of maturation. Athletes who are of older biological maturity achieve better results on tests of motor abilities and skills and they are usually taller than their peers (Coelho-e-Silva, Figueiredo, Carvalho, & Malina, 2008; Rađa, Erceg, & Milić, 2016). Static and explosive power develop rapidly after a growth spurt, and this is a period during which certain players distinguish themselves from their peers in terms of quality and talent (Te Wierike et al., 2014). Greater manifestation of power in accelerative athletes results from better-developed musculature, leading to dominance in motor skill execution and improved athletic performance (Avsiyevich, Plakhuta, & Fyodorov, 2016).

Adolescence is one of the most critical periods in the growth process, during which, under the influence of hormones, there is an increase in somatic characteristics, changes in body proportions, and body composition (Bodzsar & Zsaki, 2002). Rapid changes in body composition in boys manifest around the age of fourteen, and that change includes a reduction in body fat and an increase in the body mass index, which at this age reflects an increase in lean mass (Maynard, Wisemandle, Roche, Chumlea, Guo, & Siervogel, 2001; Malina, 2003). It has been proven that during adolescence, many high-intensity, short-duration anaerobic tasks, such as maximum running speed and jump height, improve (Philippaerts et al., 2006). These changes occur due to alterations in body composition, which influence the success of performing motor tasks that involve moving specific body parts or the whole body (Rađa, Erceg, & Grgantov, 2013). Generally, power development is accompanied by an increase in muscle mass, while an increase in aerobic endurance is often accompanied by a reduction in subcutaneous body fat (Stojiljković, Djordjević-Nikić, & Macura, 2005). Based on the aforementioned, it is known that biologically mature athletes tend to be more dominant in explosive power, and jump height improves due to changes in body composition, specifically an increase in muscle mass. This study represents an attempt to determine the extent of the influence of biological maturity and muscle mass on vertical jump performance, specifically to identify the stage of the PHV where the greatest impact of muscle mass on jump height is achieved. Therefore, the aim of this study was to investigate the influence of muscle mass on jump height based on the stage of biological maturation.

METHOD

The sample of participants

A total of 71 participants took part in this study, consisting of male subjects with a minimum training experience of three years. The athletes were divided into three groups based on biological maturity: PrePHV (N=27; chronological age=12.9±0.7; maturity age @ PHV=13.9±0.6; maturity offset=-1±0.4; body height=157.7±6,7), MidPHV (N=12; chronological age=12.9±0.5; maturity age @ PHV=12.9±0.5; maturity offset=-0.1±0.2; body height=169.3±3.9) and PostPHV (N=32; chronological age=14.8±0.9; maturity age @ PHV=13.1±0.7; maturity offset=1.6±0.8; body height=179.2±7.9). The participants voluntarily took part in the study, which was conducted following the Helsinki Declaration. Parental/guardian consent was obtained for all the participants since they were under the age of 18 at the time of the study. All procedures were approved by the Ethical Board of the Faculty of Sport and Physical Education, University of Niš.

The sample of variables

Anthropometric characteristics

Measurement of anthropometric characteristics was conducted by a physician following a predetermined procedure (Ross & Marfell-Jones, 1991) and included measuring body height, sitting height, and leg length using an anthropometer with a precision of 0.1 cm (Martin anthropometer). Body composition assessment was conducted using an electronic scale (Omron BF 511) and included the following values: body weight (kg), the body mass index (BMI), percentage of muscle mass (MM), and percentage of body fat (% fat).

Maturation Assessment

Maturation was calculated on the day of testing according to the formula established by Mirwald, Baxter-Jones, Bailey, and Beunen (2002). The division of participants into Pre-, Mid-, and Post-PHV groups was based on the Maturity Offset (years), which represents a value expressed in years as an indicator of how much time has passed since the PHV occurred.

BOYS: Maturity offset (years) = -9.236 + (0.0002708 × [Leg Length × Sitting Height]) + (-0.001663 × [Age × Leg Length]) + (0.007216 × [Age × Sitting Height]) + (0.02292 × [weight: height × 100])

The PrePHV group consisted of participants with a Maturity Offset value below -0.5. The Maturity Offset for the MidPHV group ranged from -0.49 to 0.49, while participants in the PostPHV group had a Maturity Offset value above 0.5 (Meyers, Oliver, Hughes, Lloyd, & Cronin, 2017).

Assessment of Explosive Power

Explosive power was tested using three vertical jump tests. Vertical jump performance was assessed using valid and reliable tests (Markovic, Dizdar, Jukic, & Cardinale, 2004): the countermovement jump (CMJ); the countermovement jump with arm swing (CMJwas); and the squat jump (SJ), which were executed following previously described protocols (Hara, Shibayama, Takeshita, Hay, & Fukashiro, 2008). An electric photoelectric cell system was used to determine the height of the executed jumps (Optojump, Microgate, Bolzano, Italy).

Sample Size Calculation

We conducted an a priori multiple regression power analysis using G*Power (Faul, Erdfelder, Buchner, & Lang, 2009) for the moderation analysis with five predictors (muscle mass percentage, MidPHV, PostPHV, and muscle mass percentage*MidPHV and muscle mass percentage*PostPHV interactions) as the input parameters. The given values of alpha (0.05), power (0.80), and expected small effect size (f = 0.20) were the parameters of choice for the sample size calculations. Based on these assumptions, the desired sample size for this study was 70 participants.

Statistical analyses

RStudio was used to process the data (version 2022.07.0.548, Spotted Wakerobin, Boston, MA). Descriptive statistics were produced for each power performance variable (CMJ, CMJA, and SJ). When applicable, means, medians, and standard deviations were estimated to characterize categorical and continuous variables for the whole sample. Multiple moderation models were employed to determine if PHV moderated the relationship between muscle mass percentage and power performance variables (the CMJ, CMJwas, and SJ). Based on Hayes's multi-categorical moderation analysis (model 1), the moderating effect was evaluated using a customized R script (Hayes, 2022). The QuantPsyc package is utilized to center variables and explore the interaction between muscle mass percentage and PHV on power performance variables, with muscle mass percentage and PHV as the dependent variables and the power performance variables as the independent variables. A bootstrapping approach was applied (with 5000 resamples). The threshold of significance was set at 0.05.

RESULTS

The data were checked for outliers and regression assumptions, and no violations were found. The QuantPsyc package was used to center variables and analyze the interaction between muscle mass percentage and PHV, predicting CMJ, CMJwas, and SJ performance.

Each regression model of the association between muscle percentage and power performance variables was significant (see Table 1). Tests of interactions of the highest unconditional order revealed that the moderating influence of muscle percentage was not significant for CMJ [$F(2,64) = 0.11$, $p = .899$], CMJwas [$F(2,64) = 0.11$, $p = .899$], and SJ [$F(2,64) = 1.55$, $p = .219$], and uniquely accounts for 0.0018, 0.0075, and 0.0318 % of the variance, respectively. Additionally, both muscle mass*MidPHV and muscle mass*PostPHV interactions were insignificant for CMJ, CMJwas, and SJ, respectively.

Table 1 Regression results using CMJm CMJwas, and SJ as the criterion

Predictor (CMJ)	b	*B* 95% CI [LL, UL]	sr^2	sr^2 95% CI [LL, UL]	Fit
(Intercept)	24.15**	[22.82, 25.61]			
MM	0.83*	[0.25, 1.26]	.04	[.00, .12]	
MidPHV	-0.08	[-2.16, 2.12]	.00	[.00, .02]	
PostPHV	5.61**	[2.71, 8.28]	.12	[.03, .26]	
MM*MidPHV	0.08	[-0.55, 0.91]	.00	[.00, .02]	R^2= .458**
MM*PostPHV	-0.13	[-1.11, 0.82]	.00	[.00, .06]	95% CI[.33, .63]
Predictor (CMJwas)	**b**	**B 95% CI [LL, UL]**	**sr^2**	**sr^2 95% CI [LL, UL]**	**Fit**
(Intercept)	30.53**	[28.91, 32.15]			
MM	1.48**	[0.78, 2.02]	.10	[.02, .21]	
MidPHV	-1.72	[-4.08, 0.47]	.01	[.00, .03]	
PostPHV	5.61**	[2.53, 8.83]	.08	[.02, .19]	
MM*MidPHV	-0.33	[-0.95, 0.61]	.00	[.00, .02]	R^2= .530**
MM*PostPHV	-0.51	[-1.53, 0.41]	.01	[.00, .06]	95% CI[.40, .69]
Predictor (SJ)	**b**	**B 95% CI [LL, UL]**	**sr^2**	**sr^2 95% CI [LL, UL]**	**Fit**
(Intercept)	24.28**	[22.92, 25.78]			
MM	1.11**	[0.70, 1.52]	.12	[.03, .24]	
MidPHV	-1.04	[-3.50, 1.29]	.00	[.00, .05]	
PostPHV	1.44	[-1.10, 4.12]	.01	[.00, .08]	
MM*MidPHV	-0.05	[-0.77, 0.73]	.00	[.00, .03]	R^2= .345**
MM*PostPHV	-0.63	[-1.48, 0.04]	.02	[.00, .12]	95% CI[.24, .55]

Note. A significant *b*-weight indicates that the semi-partial correlation is also significant, *B*-represents unstandardized regression weights, sr^2-represents the semi-partial correlation squared, *LL* and *UL*-indicate a confidence interval's lower and upper limits, respectively, *-indicates p < .05, **-indicates p < .01.

Nonetheless, it is evident from the estimate of muscle mass percentage and PHV interaction and the conditional effect that the effect of muscle mass percentage on power performance variables is larger for the PrePHV and MidPHV compared to the PostPHV group. For the PrePHP and MidPHV groups, there was a significant increase in CMJ [b=.83, t(22)=3.77, p=.001 and b=.92, t(14)=3.70, p=.002, respectively] and SJ [b=1.11, t(22)=4.45, p<.001 and b=1.06, t(14)=3.51, p=.003, respectively] when muscle mass percentage increased by one unit, while no significant increments were apparent for the PostPHV group [b=0.71, t=1.98, p=.058 and b=0.48, t(28)=1.65, p=.111, respectively]. Additionally, when muscle mass percentage increased by one unit, CMJwas performance significantly increased in the PrePHV [b=1.48, t(22)=4.68, p<.001], MidPHV [b=1.15, t(14)=4.59, p<.001], and PostPHV [b =.97, t(28)=2.52, p=.018] groups. Figure 1 shows the interaction between the predictors.

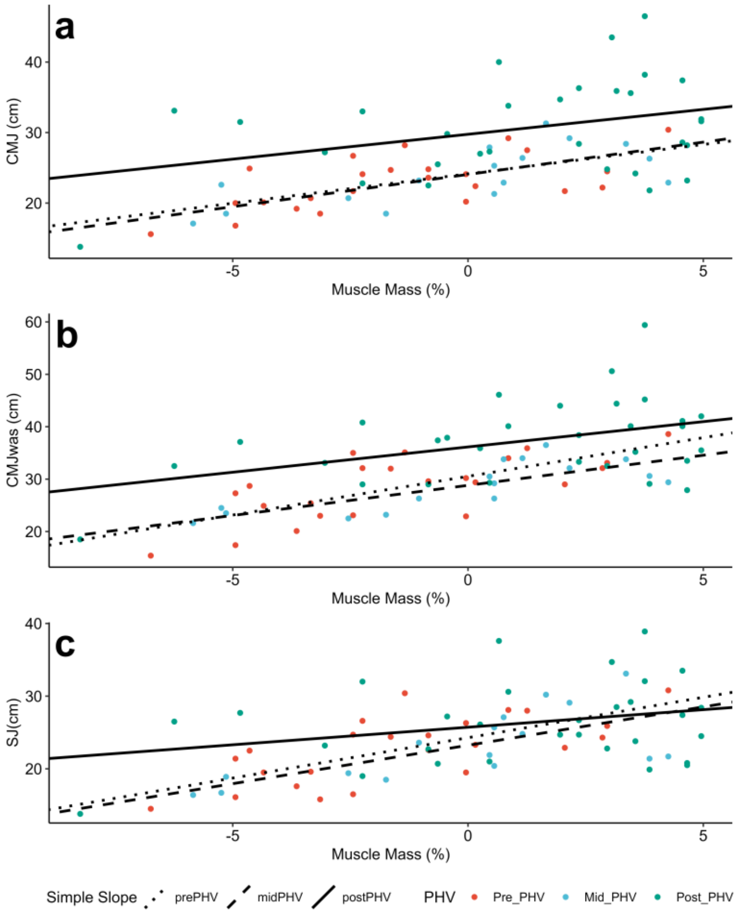

Fig. 1 Moderation plot of the relationship between muscle mass percentage (centered) and power performance variables (CMJ, CMJwas, and SJ) moderated by PHV. The dotted, dashed, and solid lines indicate PrePHV, MidPHV, and PostPHV simple slopes, respectively.

Discussion

This study contributes to the literature by examining the interaction between muscle mass percentage and PHV throughout maturation in predicting explosive power variables. The results suggest that the relationship between muscle mass percentage and explosive power variables varies according to the maturation stage, with a significant impact observed in the PrePHV and MidPHV groups compared to the PostPHV group. Specifically, within the maturity stages, a unit increase in muscle mass percentage was associated with statistically significant CMJ and SJ performance enhancements. Conversely, in the PostPHV, the relationship between muscle mass percentage and jump performance did not reach statistical significance. It is important to underscore that, given the study's observational design, these relations do not imply causal relationships or longitudinal improvements. Instead, they reflect associations within a specific dataset, underscoring a potential link between muscle mass percentage and jump performance in varying maturity stages. Furthermore, this study showed a significant association between muscle mass percentage and CMJwas in all three PHV groups, with the most negligible impact observed in the PostPHV group. The performance technique of this jump should be considered, as the technique involves a coordinated action of legs and arms; thus, training significantly influences jump height. It is necessary to pay greater attention to training during this PHV stage in order to enhance explosive power performance in young athletes, as suggested by Meyers et al. (2017), who point out high neuromuscular focus and force development in relation to body weight as a critical factor.

Almeida-Neto et al. (2021) conducted a study to determine the extent to which muscle mass and biological maturation are strong predictors of power performance in athletes. On a sample of ninety-two athletes of both genders, they assessed biological maturation based on PHV and explosive power based on the vertical jump and CMJ. They concluded that biological maturation and muscle mass are somewhat uncertain predictors of jump height, as the correlation between these two variables and explosive power was not statistically significant for the girls, while it was statistically significant for the boys. Our study demonstrates that the interaction effect of PHV and muscle mass is significant in two stages of biological maturation. Results like this are expected because the improvement in jump height occurs during the adolescence period under the influence of changes in body composition (Rađa et al., 2013), a change that involves a decrease in body fat and an increase in muscle mass (Maynard et al., 2001; Malina, 2003).

The differences that occur in adolescents of the same chronological age is biological maturation and represent an essential factor affecting growth and power performance (Malina et al., 2004). Biologically mature adolescents exhibit anthropometric and physiological dominance compared to their peers, which leads to better power performance results (Coelho-e-Silva et al., 2008; Rađa et al., 2016). The study that examined the influence of maturation on explosive power performance indicates that participants in the PostPHV group achieved better results on explosive strength tests compared to the results of the PrePHV and MidPHV groups (Živković, Stojiljković, Trajković, Stojanović, Đošić, Antić, & Stanković, 2022). Another study by Silva et al. (2010) revealed that maturation significantly correlates with jumping performance in sports-involved adolescents, where biologically mature participants achieve better results than biologically immature counterparts. These are expected findings since it is known that explosive power develops during the PostPHV period, and this is the time when accelerants stand out from their peers in tests of motor ability (Te Wierike et al., 2014). The assumption is that these changes are the result of neural adaptations to training and hormonal shifts associated with pubertal development, which influence muscle mass and muscle strength (Falk & Eliakim, 2003; Faigenbaum, Lloyd, MacDonald, Myer, Citrin, 2016; Avsiyevich, Plakhuta, & Fyodorov, 2016).

A limitation of this study could be the method of bioelectrical impedance used to determine the percentage of muscle mass in the participants. The assumption is that using more sophisticated equipment than an electrical scale could obtain more precise data, although such an apparatus is unsuitable for field tests due to its size and calibration requirements. Another limitation is that the sample of participants comprised basketball, soccer, and handball adolescents. Certainly, it is better to direct research on a specific group (one sport), but to gather a larger number of athletes within this age group (PHV), the chosen approach for participant selection was the only feasible option.

CONCLUSION

In conclusion, this study provides further evidence for the importance of muscle mass in explosive power performance throughout maturation, with a greater impact observed in the PrePHV and MidPHV groups compared to the PostPHV group. Overall, the findings of this study align with previous research and underscore the importance of considering biological maturity in understanding the relationship between muscle mass and explosive power performance among young athletes. These findings have implications for training programs to enhance explosive power performance among young athletes and comprehend the mechanisms underlying puberty-related changes in physical performance. However, further research is needed to confirm these findings and better understand the complex relationship between muscle mass, maturation, and explosive power performance in athletes.

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UTICAJ MIŠIĆNE MASE NA VISINU SKOKA TOKOM BIOLOŠKE MATURACIJE

Cilj ovog istraživanja je ispitivanje uticaja mišićne mase na visinu skoka u zavisnosti od stadijuma biološke maturacije. Ukupan uzorak ispitanika sačinjen je od 71 sportiste, muškog pola, sa minimalnim trenažnim iskustvom od tri godine. Sportisti su podeljeni u tri grupe prema biološkoj zrelosti: PrePHV, MidPHV i PostPHV. Vertikalna skočnost je utvrđivana pomoću tri testa: skok iz stojećeg stava sa rukama na kukovima (CMJ), skok iz stojećeg stava sa zamahom rukama (CMJwas), skok iz polučučnja sa rukama na kukovima (SJ). Rezultati interakcije procenta mišićne mase (MM) i najvećeg prirasta visine (PHV) pokazuju da je efekat MM na varijable vertikalne skočnosti veći kod PrePHV i MidPHV poredeći ih sa PostPHV grupom. Za grupe PrePHP i MidPHV, značajno se povećava CMJ [b=.83, t(22)=3.77, p=.001 i b=.92, t(14)=3.70, p=.002] i SJ [b=1.11, t(22)=4.45, p<.001 i b=1.06, t(14)=3.51, p=.003] kada se procenat mišićne mase poveća za jednu jedinicu, dok se za PostPHV grupu ne povećava značajno [b=0,71, t=1,98, p=0,058 i b=0,48, t(28)=1,65, p=.111]. Pored toga, kada se procenat mišićne mase poveća za jednu jedinicu, CMJwas se značajno povećava u PrePHV [b=1,48, t(22)=4,68, p<.001], MidPHV [b=1,15, t(14)=4,59, p<.001] i PostPHV [b=.97, t(28)=2.52, p=.018] grupama. Ovo istraživanje pruža dodatne dokaze o važnosti mišićne mase u predikciji performansa eksplozivne snage tokom maturacije, sa većim uticajem u grupama PrePHV i MidPHV u poređenju sa grupom PostPHV. Rezultati istraživanja naglašavaju važnost razmatranja biološke zrelosti pri razumevanju odnosa između mišićne mase i performansi eksplozivne snage mladih sportista.

Ključne reči: *regresija, moderacijski efekat, PHV, eksplozivna snaga*