Relationship between body mass index and lower limb power in children and adolescents

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Abstract

Excess body weight is associated with increased mortality, low physical fitness and low levels of physical activity. The objective this study to verify the linear and nonlinear (quadratic) relationships between Body Mass Index (BMI) and lower limb strength in children and adolescents of both sexes in a region of Chile. A descriptive (cross-sectional) study was carried out in children and adolescents of school age (6 to 17 years) of both sexes. The sample size was 863 schoolchildren (500 males and 363 females). Weight, height and the Horizontal Jump test (HJ) were evaluated. BMI and BMI z -score were calculated according to age and sex. In males, the explanatory power in the linear model [R= 0.15, R2= 0.02, Root Mean Square Error (RMSE)= 39.6] is lower than the non-linear quadratic model (R= 0.22, R^2= 0.05, RMSE= 39.0). In females, the explanatory power in the linear model (R= 0.12, R^2= 0.02, RMSE= 23.2) is lower than the quadratic nonlinear model (R= 0.19, R^2= 0.04, RMSE= 22.9). In the BMI z-score scale, males presented HJ values of: [Low BMI 145.4±39.5cm, normal 164.2±33.6cm, and high BMI 109.0±23.2cm]. In females it was: [Low BMI 108.0±23.0cm, normal 113.5±36.3cm, and elevated BMI 91.5±30.4cm]. The study verified a curvilinear relationship in the form of a parabola (quadratic) between BMI and the HJ test in children and adolescents of both sexes. Schoolchildren in the extreme BMI categories (low and high BMI) reflected low performance in the HJ in relation to school-children with normal BMI.

Key Words: BMI, horizontal jump, children, adolescents.

Eur J Transl Myol 35 (2) 13509, 2025 doi: 10.4081/ejtm.2025.13509

Body Mass Index (BMI) is an anthropometric indicator widely used to assess weight status from infancy to senescence.

Its use in the adult and pediatric population is characterized as a powerful predictor of risk for Cardiovascular Disease (CVD), diabetes mellitus, all-cause mortality, and some types of cancer.[1-3] It is even used as a predictor of physical fitness among young people and adults.[4,5]

In recent years epidemiological studies show that excess body weight is associated with increased mortality, low physical fitness, low levels of physical activity, regardless of age and sex.[6-9]

The importance of understanding how fitness relates to obesity is further highlighted by recent global trends in increasing overweight, obesity, sedentary habits, and deteriorating physical fitness among young people.[4]

In fact, in recent years, studies have evidenced that lean youth may be negatively affected in movement mastery and fitness due to lower muscle mass.[10] Even those children and adolescents who are overweight/obese often reflect negative consequences due to an elevated BMI.[11]

In general, underweight is also associated with physical growth retardation, menstrual irregularity, delayed biological maturation, nutritional deficiencies, among other as-

Eur J Transl Myol 35 (2) 13509, 2025 doi: 10.4081/ejtm.2025.13509

pects.[12,13] On the contrary, excess weight or fat in different body segments alters body geometry and has a profound impact on biomechanics.[14] In addition, it accelerates biological maturation, decreases physical activity levels, reduces motor coordination, as well as affects physical performance at all ages.[15-17]
Consequently, based on that physical fitness tests that require projection of the body through space and movement, such as running, jumping and lifting or holding the body, can often be hindered by the presence of underweight, overweight or obesity.[18,19]
In fact, studying muscular fitness through the Horizontal Jump (HJ) test in school-aged children and adolescents is extremely relevant. For in recent years several studies have given emphasis on investigating the linear and non-linear relationships between BMI with physical fitness tests and especially with the HJ.[8,11,19,20] Where the weight status represented by BMI has often reflected quadratic relationships, evidencing better physical performance in the normal category in relation to the extremes of the weight status category (low and high BMI), respectively. In this sense, studying the relationship between BMI and horizontal jump in schoolchildren is important because it allows us to understand how weight status influences physical performance. Therefore, it is relevant to identify non-linear patterns (quadratic), where in general schoolchildren with a normal BMI tend to have better physical performance compared to those at the extremes (underweight or overweight/obese). This suggests that there is an optimal point in weight status that maximizes physical performance, and allows us to identify specific strategies to promote an adequate balance between body composition and physical fitness in schoolchildren.
Therefore, to confirm these findings, this study aimed to verify the linear and non-linear (quadratic) relationships between BMI and lower limb power in children and adolescents of both sexes in a region of Chile.

Materials and Methods

Type of study and sample

A descriptive (cross-sectional) study was carried out in children and adolescents of school age (6 to 17 years) of both sexes. The students belonged to public schools in the urban area of the Maule region (Chile). The population consisted of 16,202 students (8,035 boys and 8,167 girls). The sample size was determined by systematic selection, being estimated at 863 schoolchildren (10.7% of the total population), being: [500 males (6.2%) and 363 females (4.5%)], with a 95% confidence interval (CI 95%).
One of the investigators requested permission from the management of each school for the collection of anthropometric data and physical tests. Parents and/or guardians were then invited via telephone and email explaining the objective of the research. An informed consent form was also sent to each of them so that they could authorize the participation of their children.
This study included children and adolescents under the age of 6 to 17 years and those who were taking physical education classes. Those who did not complete the anthropometric measurements and physical tests were excluded, as well as those who presented some motor problems and physical injuries that prevented them from performing the horizontal jump test.
The study was developed according to the indications of the Ethics Committee of the Universidad Católica del Maule (protocol no. 100/2019). The protocol was based on the Declaration of Helsinki Agreement for Human Subjects (World Medical Association).

Techniques and procedures

The collection of anthropometric data and physical tests were evaluated at the facilities of each school. The data collection process was carried out during 2019 during school hours (Monday through Friday). The team of evaluators consisted of 4 physical education teachers with extensive experience in anthropometric measurements and physical tests.
To determine decimal age, date of birth (day, month and year) and date of birth (day, month and year) were used. Anthropometric measurements were evaluated according to the protocol described by Ross and Marfell-Jones.[21] The schoolchildren were weighed barefoot, wearing shorts and a T-shirt. A Tanita (Ltd Japan) digital scale with 100g accuracy and a scale from 0 to 150 kg was used. Height (m) was assessed barefoot on the Frankfurt plane. An aluminium stadiometer graduated in millimetres, Seca brand, with a scale of 0-2.50 m and with an accuracy of 0.1 cm, was used. The body mass index (BMI) was calculated using the following formula: BMI = weight (kg)/height2 (m). According to BMI Z-score, patients were classified as follows: underweight with Z-scores < -1, normal weight with Z-scores between -1 and +0.99, overweight Z>+1.[22]
Lower limb power (horizontal jump) was evaluated with sports clothing and after the participants had warmed up (approximately 10 minutes). This consisted of flexibility exercises, smooth running and changes in speed and direction.
The HJ Test (cm) measures the muscular power of the lower limbs.[23] A 3-m metal tape measure with an accuracy of 0.1 cm was used. Participants made two attempts, and the greatest distance was recorded.
To ensure quality control of the anthropometric measurements and the HJ test, 10% of the total sample was evaluated twice. The relative technical error of measurement (TEM) ranged in the anthropometric measurements from 0.8 to 1.2%, while in the HJ it was 1.4%.

Statistical analysis

The normal distribution of the data was verified by the Kolmogorov-Smirnov test. Descriptive statistical analysis of arithmetic mean, standard deviation and range was performed. Differences between genders were determined by Student's test for independent samples. Linear and non-linear (quadratic) regressions were performed between BMI and HJ for both sexes. For quadratic regression, HJ was considered as dependent variable, while BMI as independent variable as follows: $BMI = a + b_1(HJ) +$

$b_2(HJ)^2$, where: a is the intercept, b1 and b2 are regression parameters, estimated from the data. The regression analysis was performed separately for each sex. Correlation (R), explanatory power (R^2) and significance ($p<0.001$) were considered in each model. The mean squared error (MSE) was also considered to help estimate the model's ability to predict the target value (precision). Calculations were performed in Excel spreadsheets and SPSS 18.0.

Results

The anthropometric variables, BMI and HJ test of the schoolchildren studied are shown in Table 1. In body weight, males presented greater weight than females at 6-7 years and 16-17 years ($p<0.05$), in the other ages there were no significant differences. In height, there were differences in the last two age ranges (14-15 and 16-17 years), where males presented greater height than females ($p<0.05$). However, from 6-7 years to 12-13 years, there were no significant differences. In the HJ test, males presented better performance in lower limb explosive strength in relation to females in all age ranges ($p<0.05$; Table 1).

The linear and nonlinear regression values between BMI with HJ can be seen in Table 2 and Figure 1. The R^2 in the linear model is lower than the nonlinear (quadratic) model. The quadratic model showed greater explanatory power than the linear model. Overall, the nonlinear quadratic model reflected a better fit for the sample (RMSE: 3.909 in males and 2.295 in females) for the data set in both sexes relative to the linear model (RMSE: in males 3.955 and in females 2.320).

Table 1. *Anthropometric and physical characteristics of the schoolchildren studied.*

Age (years)	n	Weight (kg)		Height (cm)		BMI (kg/m²)		HJ (cm)	
		X	SD	X	SD	X	SD	X	SD
Males									
6-7 years	54	28.6*	6	124.4	6.9	18.4	2.7	96.8	20.33
8-9 years	77	35.7	8.9	133.1	7.3	19.9	3.7	108.39	23.77
10-11 years	75	43.4	11.1	143.6	8.5	20.8	4.1	126.91	22.37
12-13 years	38	49.7	11.1	153.5	8.4	21	4	143.5	25.38
14-15 years	96	64.8	14.1	166.6*	7.9	23.3	4.4	164.86	29.93
16-17 years	132	71.0*	17.1	170.6*	5.9	24.3	5.3	179.81	26.73
Total	472	53	20.5	152.7	18.7	21.9	4.8	143.76	39.97
Females									
6-7 years	59	25.6	6.1	121.6	7	17.2	3	90.15	20
8-9 years	69	33.8	8.5	131.6	7	19.4	3.7	101.04	20.81
10-11 years	75	41.1	10.6	143.7	8.6	19.7	3.7	118.24	19.63
12-13 years	45	48.9	10.8	153.4	7	20.7	4	110.87	18.62
14-15 years	50	62.9	12.9	158.2	6.7	25.2	5.2	119.34	22.51
16-17 years	56	61.1	9.6	159.9	5.9	23.9	3.2	121.18	21.45
Total	354	44.3	16.6	143.5	15.6	20.8	4.6	109.89	23.31

X, Mean, SD, Standard deviation, BMI, Body mass index, HJ, Horizontal jump.

Table 2. *Values of linear and non-linear relationship between anthropometric indicators and physical fitness tests.*

Model	Males					Females				
	R	R²	F	Sig.	RMSE	R	R²	F	Sig.	RMSE
Linear	0.15	0.02	11.06	0.001	3.955	0.12	0.02	5.86	0.016	2.32
Quadratic	0.22	0.05	11.57	0.001	3.9	0.19	0.04	6.77	0.001	2.295

BMI, Body Mass Index.

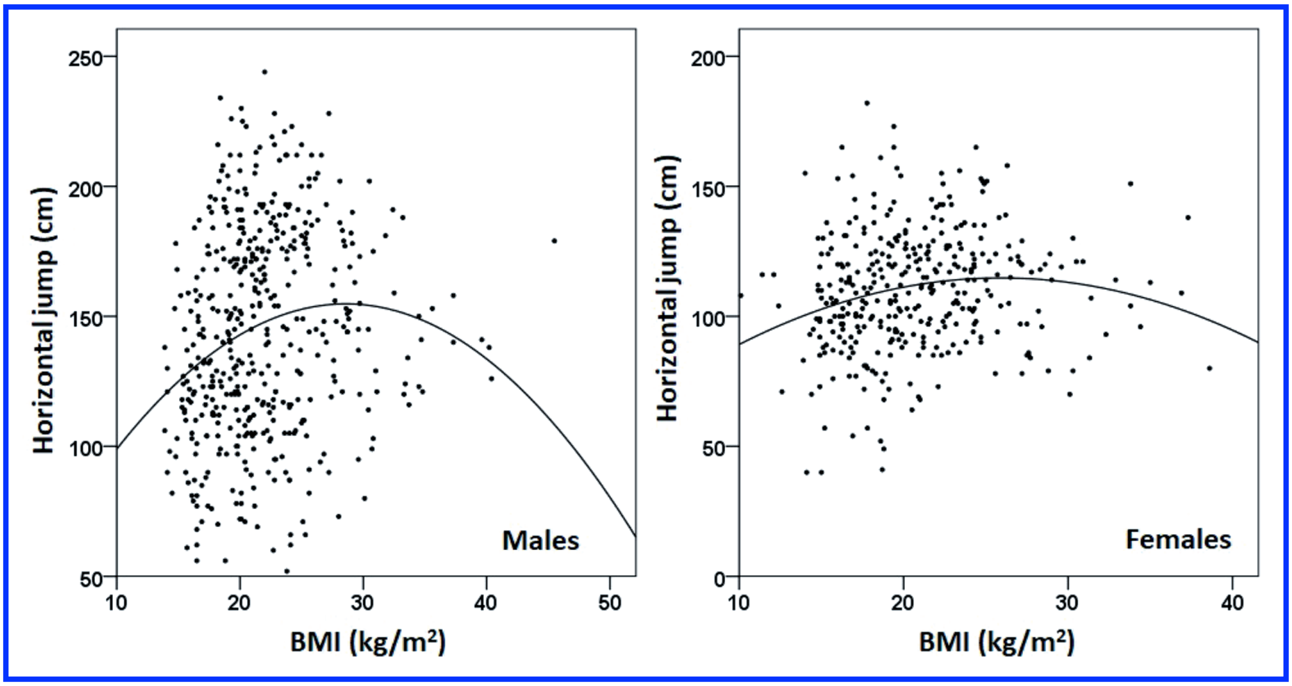

Figure 1. *Non-linear (quadratic) relationship between BMI and HJ in schoolchildren of both sexes.*

The comparisons between the three BMI-Z-Score categories (low, normal and overweight) are shown in Figure 2. In both sexes, it is observed that the HJ is lower at the extremes of the categories when compared to the normal category ($p<0.05$). In addition, schoolchildren with excess weight, presented lower values of HJ in relation to their low BMI peers ($p<0.05$).

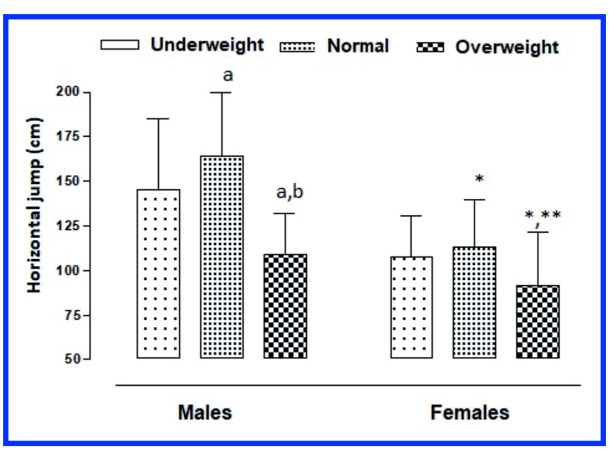

Figure 2. *Comparison of HJ performance according to underweight, normal and overweight categories according to Z-score-BMI in both sexes.*
a,, significant difference in relation to underweight category; b,**, significant difference in relation to normal weight.*

Discussion

The aim of this study was to verify the linear and non-linear (quadratic) relationships between BMI and lower limb strength in children and adolescents of both sexes in a region of Chile.

The results of this study have shown a greater non-linear (quadratic) relationship between BMI and HJ test in children and adolescents of both sexes. The nonlinear quadratic model presented a lower Root Mean Square Error (RMSE) compared to the linear model in both men and women. This indicates that the quadratic model more accurately describes the relationship between the variables studied (between BMI and lower limb power). In addition, we identified that Z-score categorized schoolchildren with underweight and overweight reflected poor performance compared to schoolchildren categorized with normal BMI.

These findings are consistent with other studies conducted in various geographic regions of the world, which have shown quadratic (non-linear) relationships, clearly reflecting that schoolchildren categorized as underweight and overweight according to BMI induce negative effects on physical fitness levels in children and adolescents.[17,19,20,24] On the contrary, in the normal BMI category, the best results in HJ were observed in schoolchildren of both sexes.

In fact, it is widely known that subjects with excess weight (body fat) have their physical performance impaired due to the additional load or dead weight that acts negatively on physical performance.[25] On the contrary, in individuals categorized as underweight, it is possible that physical performance is affected due to a disproportion between muscle mass and total body weight.[10] Thus, both categories may have a detrimental impact on physical fitness, particularly lower limb strength among children and adolescents.

Therefore, screening for thinness, normality, overweight, and obesity are indicators of weight status that are often managed as key components of health in school physical education. Therefore, from our results, we emphasize that schoolchildren should reflect a normal BMI for their age and sex. This can guarantee, not only a better performance in lower limb explosive strength in sports practice,[22,26] but also in relation to health. For example, in cardiovascular diseases, metabolic profiles, skeletal health, body adiposity and in simple tasks of daily life.[27-29]

In general, muscular fitness during childhood and adolescence has been identified as an important determinant of current and future health status.[30] Thus, a stronger, more resilient and powerful musculoskeletal system will enable children and adolescents to perform body movements more efficiently,[31] especially during the performance of activities of daily living, in sports practice and in unforeseen emergencies.[29,32]

Consequently, lower extremity explosive strength has been widely used to assess muscular fitness and general health during physical education classes. Therefore, the functions and capacities of the neuromuscular and musculoskeletal systems play an important role in defining the physical fitness of individuals and populations[33] and for this, it is necessary to achieve an optimal nutritional status (BMI) according to their age and sex as observed in this study.

In general, in school populations where children and adolescents report low levels of physical performance regardless of their nutritional status, it is necessary to promote intervention programs among young people to encourage the maintenance of physical fitness, adaptation of healthy lifestyles, counteracting the stigma of excess body weight among young people. The WHO[34] has also recommended the practice of muscle and bone strengthening in young people, at least three times a week.

This study has some limitations. These have to do firstly with the cross-sectional design used in this study, since future research should develop longitudinal designs, through which, it is possible to verify the causal relationships, with which it is possible to confirm our findings. Secondly, it was not possible to evaluate other lower limb explosive strength tests (e.g., vertical jump), as this information would have allowed us to analyze our results in greater depth. Thirdly, there is a need for a Gold standard method to analyze body composition, as BMI does not have sufficient capacity to distinguish fat mass and/or fat-free mass.

We also emphasize that this research has some strengths, for example, it is one of the first studies carried out on a sample of Chilean schoolchildren. In addition, the type of sample selection allows us to generalize the results to other populations with similar characteristics.

Conclusions

In sum, after the results achieved, this study concludes that there was a curvilinear relationship in the form of a parabola (quadratic) between BMI and the HJ test in children and adolescents of both sexes. In addition, schoolchildren categorized with low and high BMI reflected poor performance in lower limb explosive strength in relation to those categorized with normal BMI. These results suggest that it is necessary to maintain an optimal BMI status to achieve better lower limb power performance among schoolchildren.

List of abbreviations

BMI, Body Mass Index
HJ, Horizontal Jump test
RMSE, Root Mean Square Error
TEM, technical error of measurement
CVD, risk for Cardiovascular Disease

Conflict of interest

The authors declare no potential conflict of interest, and all authors confirm accuracy.

Ethics approval

The Ethics Committee of Catholic University of Maule approved this study (100-2019). The study is conformed with the Helsinki Declaration of 1964, as revised in 2013, concerning human and animal rights.

Informed consent

All patients participating in this study signed a written informed consent form for participating in this study.

Patient consent for publication

Written informed consent was obtained from a legally authorized representative(s) for anonymized patient information to be published in this article.

Availability of data and materials

All data generated or analyzed during this study are included in this published article.

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Submitted: 20 December 2024.
Accepted: 20 January 2025.
Early access: 4 April 2025.