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Relationship between Body Mass Index and Muscle Strength, Potential Health Risk Factor at Puberty

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Abstract: According to some studies, muscle strength (F) is a predictor of health when this motor quality is associated with body mass index (BMI). Based on this statement, our study aims to find out if there is a significant relationship between the two variables, in the context in which the BMI was determined on 160 subjects, selected from students aged 12-15 and who were subsequently included in 4 subcategories: underweight, normal weight, overweight and obese. For the assessment of muscle strength, we used handgrip strength and standing long jump (broad jump) (respecting the EUROFIT methodology). The results show a moderate positive relationship between the level of muscle strength development and BMI (rho = .44, p ≤ .01; rho = .43, p ≤ .01). Our data shows that there is a significant, moderate-intensity connection between BMI and strength development, the subjects with excess weight (overweight and obese) having lower strength values compared to normal-weight subjects. Although some authors consider that only the relationship between BMI and strength does not provide conclusive data for predicting the health of adolescents, the results of our study still confirm the existence of an inverse relationship between BMI and muscle strength at overweight and obese subjects. Because the studies on this direction are not very numerous yet, we consider that other observational studies with a larger sample size, especially longitudinal and prospective studies, are necessary.

Keywords: *Puberty; overweight; body mass index; muscle strength; health condition.*

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1. Introduction

Studies that focused on body mass index, as a landmark for identifying overweight, have reported an increase in the prevalence of obesity in children worldwide, both in developed, highly industrialized and ongoing countries (Deren et al., 2018; Wang & Lobstein, 2006). In that context, the foresights for the future is not encouraging, with some estimates suggesting that 254 million children aged 5 to 19, will be obese until 2030 (Buoncristiano et al., 2021).

Being overweight (overweight and obesity) has become one of the most common nutritional diseases in the world, being considered the disease of the 21st century (Agustina et al., 2021). By 2017, it has grown to epidemic proportions, with more than 4 million people dying each year from overweight or obesity (World Health Organization, 2017). The same WHO (2020), is the one that militates more and more to encourage the systematic practice of moderate and high intensity physical activity and which, in combination with a healthy diet, can be a global strategy to prevent many diseases, non-transmissible. Myers et al. (2002), since 2001, have highlighted the importance that should be given to physical activity as an element that promotes longevity and quality of life, and contemporary studies have shown an inverse relationship between physical activity and mortality rate.

Excess weight is directly related to caloric intake and, therefore, is related to diet and physical activity, and its main characteristic is given by the increase in body weight. Regarding the practice of physical activities in order to reduce the volume of adipose tissue, it is often recommended aerobic physical exercises, which young people of school age perform mainly during physical education classes (Ross & Janssen, 2001). On the other hand, more and more scientific studies suggest that not only functional endurance capacity but also muscle strength, another major component of fitness, related with health status, is an important factor in the prevention of chronic diseases (Piercy et al., 2018; Williams et al., 2015). Also, in relation to strength, in its manifest form, namely muscular endurance, it has been shown to be an important determinant of insulin sensitivity, and its low levels are associated with suffering from the so-called „metabolic syndrome" (abdominal obesity, glucose intolerance, type 2 diabetes, hypertension, hyperlipidemia and insulin resistance) (Jurca et al., 2005; Metter et al., 2002).

In the same vein, several studies have shown that the decreasing of muscle mass and strength represents a favorable premise for the development of cardiovascular and metabolic disorders in people of all ages (Silventoinen et al., 2009; Ramírez-Vélez et al., 2014; Eckman et al., 2016). As for children and adolescents, in the study conducted by Ruiz et al. (2011), they reported that there is a relationship between the level of development of muscle strength and fitness, especially in the overweight and obese ones. In the same way, Ortega et al. (2012) indicated that the development level of the muscle strength in the lower limbs was inversely proportional to the percentage of abdominal adipose tissue. Similarly, Steene-Johannessen et al. (2009) found that, irrespective of the percentage of adipose tissue and the development level of cardio-respiratory resistance, an increase in strength resistance depending on the body weight has been associated with lower levels of indicators of chronic inflammation, such as C-reactive protein, leptin and tumors necrosis factor alpha (TNF-α).

In order to assess the muscle strength, as an indicator of physical condition, which correlates with health status, numerous tests have been described taking into account the fact that its level of development depends on several factors such as biological differentiation, age, size and number of muscles involved, the number of fibers that are activated, intermuscular coordination, etc. (Kendall et al., 2005). The results of the AVENA studies (Food and Assessment of the Nutritional Status of Spanish Adolescents) (Ortega et al., 2005), HELENA (Healthy Lifestyle in Europe by Nutrition in Adolescents) (Ortega et al., 2008) and ALPHA (Assessing Levels of Physical Activity and Fitness) (Ruiz, 2011) demonstrates that the manual grasping force and standing long jump are the most used tests in epidemiological studies to assess the level of muscle strength development in children and adolescents, due to their high degree of reliability and validity.

In the same vein, but in a narrower direction of research, Rodríguez-Valero et al. (2015) consider that assessing the level of development of muscle strength at an early age, allows - as a complementary means - early detection of risk factors for disease, with reference to issues that may result in better future cardiovascular health.

Based on all the above findings, **the aim** of our study is to identify and analyze from a statistical perspective, the relationship between body mass index and muscle strength, depending on biological differentiation and age, on a sample of students from Brasov, trying to capture by the assigned percentage values, the possible predispositions towards the deterioration of the future state of health at the puberty, according to the criterion given by the correlation between the body mass index and the level of force that they manifest at some point.

2. Methodology

2.1. Research participants

The research was conducted between April and June 2014, at the General School No. 30, from Brașov. We mention that the participation in this study was voluntary, and the subjects have been guaranteed anonymity.

The study was conducted according to the guidelines of the Declaration of Helsinki. Also, the agreement was obtained from the school (no.891/15.10.2014) where the measurements were made and the participation agreements of the tutors of the children included in the study were obtained.

The sample chosen consisted of 160 subjects, 78 girls and 82 boys, aged between 12 and 15 years. Of the 160 subjects, 127 have a normal body mass index (65 girls and 62 boys), 20 are overweight (7 girls and 13 boys) and 13 are obese (6 girls and 7 boys). The body mass index was calculated in order to identify the prevalence of overweight (overweight and obesity), with a level of interpretation of the values obtained according to age and gender, in 4 (four) categories: underweight, normal weight, overweight and obesity. It should be mentioned that from the accessible sample the underweight subjects were eliminated because they are not our object of study.

2.2. Research methodology

To measure the development level of muscle strength we have applied the tests described in the EUROFIT battery, „Handgrip strength", respectively „Standing long jump". As for the quantification of the results, we notice that the performance was recorded using an evaluation scale, in percentiles, according to the gender and age of the subjects, according to the „Fit-calculadora" model (Intef, n.d.). The scores (percentiles) obtained by our subjects, following the mentioned tests, have been transformed, as follows: for the mediocre grade - score <20; for the weak grade - score 20 - 39; for the average grade - score 40 - 59; for the good grade - score 60 - 79; for the very good grade - score> 80.

We used the ANOVA analysis of variance in order to find out if there are significant differences between the dependent variable (strength) and the independent variables (gender, age and body mass index), and the Spearman coefficient to highlight the correlation between the variables. The level of statistical significance was set at $p < 0.05$ and $p < 0.01$, depending on the statistical applied sample (Popa, 2008).

3. Results

As to the evaluation of the static strength by applying the "Handgrip strength" test, it is found out that the obtained average is 24.79 kgF. The results deviate from the average, plus or minus, by 8.30 kgF. A modular value of 20 kgF was the most common result in the subjects from the targeted sample. The results obtained show an asymmetric distribution to the left (.86), extreme values being met to the right, while the positive flattening index (1.39) indicates a leptokurtic curve, with values concentrated around the average (Table 1 and Figure 1).

Table 1. Statistical representation of the *Handgrip strength* test

Handgrip strength test		
N	Valid measurements	160
	Missing measurements	0
Mean		24,79
Median		23,00
Mode		20,00
Standard deviation		8,30
Variance		68,97
Skewness		,86
Kurtosis		1,39
Minimum		10,00
Maximum		60,00

Source: Authors' own conception

A percentage of 43.10% (26.30% - very good and 16.90% - good) of the evaluated subjects has a level of development of the static strength above average, 25% of them have an average level, and 31.90% (20% - poor and 11.90 % - mediocre) one below average (Table 2 and Figure 2).

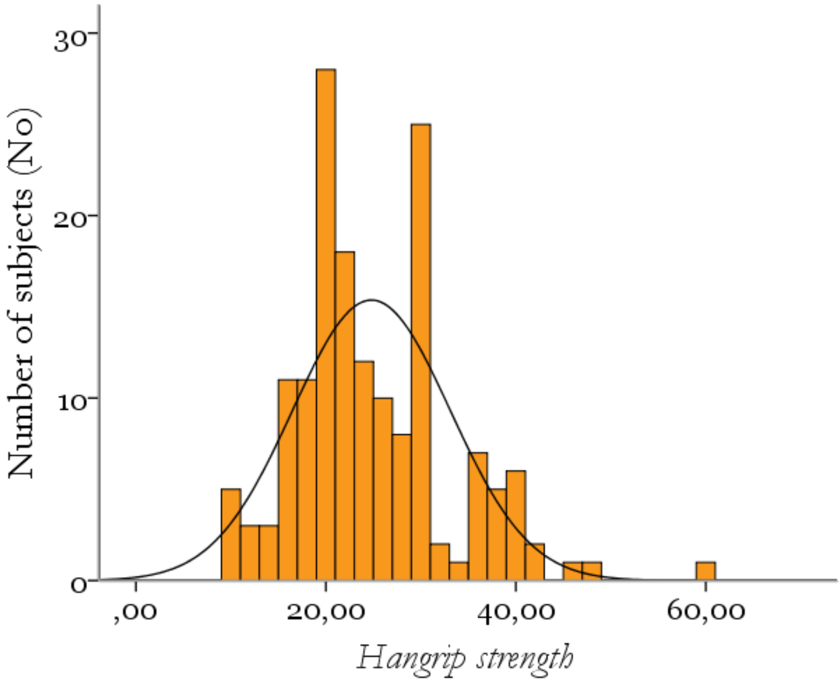

Figure 1. The distribution of frequency scores obtained in the *Handgrip strength* test
Source: Authors' own conception

Table 2. Distribution of the level of development of the static strength evaluated by the *Handgrip strength* test

		Frequency	Percent	Valid percent	Cumulative percent
Handgrip strength	Very good	42	26,30	26,30	26,30
	Good	27	16,90	16,90	43,10
	Average	40	25,00	25,00	68,10
	Weak	32	20,00	20,00	88,10
	Mediocre	19	11,90	11,90	100
	Total	160	100	100	

Source: Authors' own conception

Figure 2. Distribution of the level of development of the static strength evaluated by the *Handgrip strength* test
Source: Authors' own conception

As for the body mass index, 40.90% (25.20% - very good and 15.70% - good) of the subjects with a normal body mass index have a level of development of the static strength above average, 30% (5% - weak and 25% - mediocre) of the overweight subjects and 30.80% (15.40% - weak and 15.40% - mediocre) of the obese subjects have a level below the average (Table 3 and Figure 3).

Table 3. Distribution of the development level of the static strength evaluated by the *Handgrip strength* test, according to the body mass index

			Evaluation scale					
			Very good	Good	Average	Weak	Mediocre	Overall result
BMI (kg/m²)	Normal	No	32	20	34	29	12	127
		(%)	25,20	15,70	26,80	22,80	9,40	100
	Over-weight	No	6	5	3	1	5	20
		(%)	30,00	25,00	15,00	5,00	25,00	100
	Obesity	No	4	2	3	2	2	13
		(%)	30,80	15,40	23,10	15,40	15,40	100
Overall result		No	42	27	40	32	19	160
		(%)	26,30	16,90	25,00	20,00	11,90	100

Source: Authors' own conception

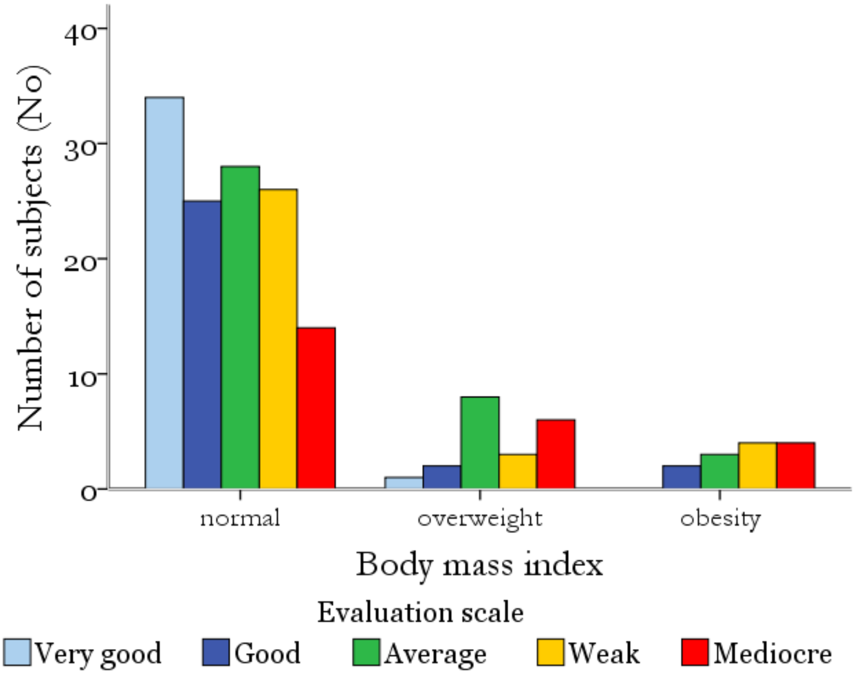

Figure 3. Distribution of the level of development of the static strength evaluated by the test *Handgrip strength* test, according to the body mass index

Source: Authors' own conception

As to the level of development of the static strength, depending on the body mass index and the gender of the subjects, the bifactorial analysis of variance (ANOVA) shows a significant overall effect ($F_{(3)}$ = 14.01, $p \leq .01$, $\eta^2 = .21$) which comes entirely from the main effect of the body mass index factor ($F_{(2)}$ = 17.85, $p \leq .01$, $\eta^2 = .19$) and of the gender factor ($F_{(1)}$ = 0.61, $p = .43$, $\eta^2 = .01$ It can be seen that both, gender and the interaction between body mass index and gender, do not show a statistically significant effect on static force (Table 4).

Table 4. ANOVA variance analysis for the scores obtained in the *Handgrip strength* test, depending on the body mass index and gender

Source	Sum of squares	DF	Mean square	F	p	Partial Eta (η^2)	Observed power [b]
Model	2328.24[a]	3	776.08	14.01	.00	.21	1.00
BMI	197741	2	988.70	17.85	.00	.19	1.00
Gender	34.14	1	34.14	.62	.43	.01	.12

BMI* gender	.00	0	.	.	.	.00	
Error	8640.54	156	55.39				

Dependent variable: *Handgrip strength* test; DF = degrees of freedom; BMI = body mass index;

a. $R^2 = 0.21$ (R^2 adjusted =0.20); b. p = 0.05

Source: Authors' own conception

Depending on the body mass index and the age of the subjects, the results show a significant overall effect ($F_{(6)} = 16.33$, $p \leq .01$, $\eta^2 = .39$) which results entirely from the main effect of the body mass index factor ($F_{(2)} = 4.56$, $p = .01$, $\eta^2 = .06$) and of the age factor ($F_{(3)} = 15.01$, $p \leq .01$, $\eta^2 = .23$). However, the interaction between body mass index and age does not have a statistically significant effect on the static force (Table 5).

Table 5. ANOVA variance analysis for the scores obtained in the *Handgrip strength* test, depending on the body mass index and age

Source	Sum of squares	DF	Mean square	F	p	Partial Eta (η^2)	Observed power [b]
Model	4282.75[a]	6	713.79	16.33	.00	.39	1.00
BMI	398.34	2	19917	4.56	.01	.06	.77
Age	1968.50	3	656.16	15.01	.00	.23	1.00
BMI* age	6.02	1	6.02	.14	.71	.01	.07
Error	6686.03	153	43.70				

Dependent variable: *Handgrip strength* test; DF = degrees of freedom; BMI = body mass index;

a.$R^2 = 0.39$ (R^2 adjusted =0.37); b. p = 0.05

Source: Authors' own conception

Bivariate correlation analysis, based on the Spearman correlation coefficient, shows that there is a significant, moderate-intensity link (rho = .44) between the body mass index and the development level of the handgrip strength, due to the fact that $p \leq .01$ (Table 6).

Table 6. The result of the correlation analysis according to the Spearman coefficient, between the development level of the static strength and the body mass index

Spearman's rho		*Handgrip strength*	BMI (kg/m^2)
Handgrip strength	CC	1.00	.44**
	p	.	.00
	N	160	160
BMI (kg/m^2)	CC	.44**	1.00
	p	.00	.
	N	160	160

*** The correlation is significant at a significance level ≤ 0.01; BMI = body mass index; CC = correlation coefficient*

Source: Authors' own conception

As for the evaluation of the explosive power or of the horizontal detonation by applying the test *Standing long jump*, it is found out that the obtained average is 159.91 cm. The results deviate from the average, plus or minus, by 25.11 cm. A modular value of 150.00 cm was the most common result in the subjects in the sample. The obtained results illustrate an asymmetric distribution to the left (.65), extreme values being met to the right, while the positive flattening index (.92) indicates a leptokurtic curve, with values concentrated around the average. (Table 7 and Figure 4).

Table 7. Statistical representation of the *Standing long jump* test

The *Standing long jump* test

N	Valid measurements	160
	Missing measurements	0
Mean		159,91
Median		155,00
Mode		150,00
Standard deviation		25,11
Variance		630,11
Skewness		,65
Kurtosis		,92
Minimum		100,00
Maximum		243,00

Source: Authors' own conception

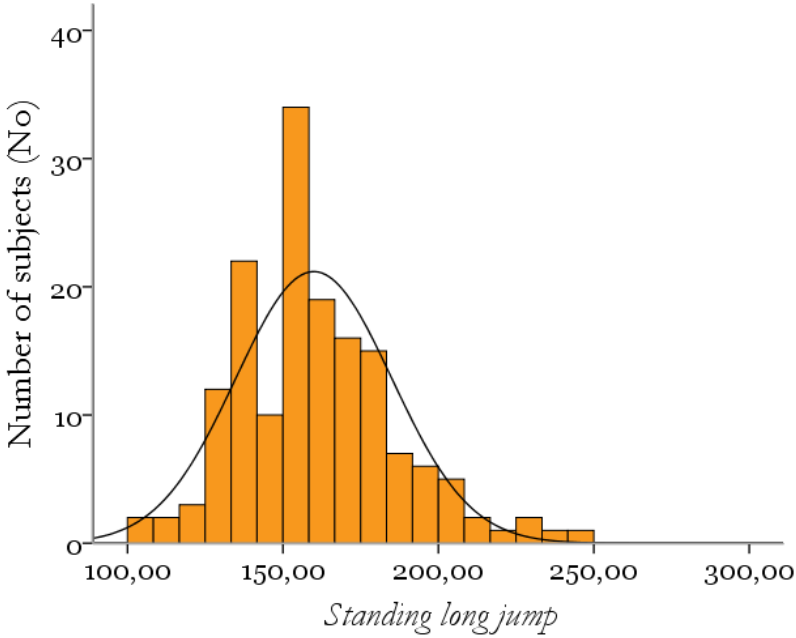

Figure 4. Distribution of the frequencies of the scores obtained in the *Standing long jump* test
Source: Authors' own conception

A percentage of 24.40% of the evaluated subjects has an average level of development of the explosive power, 40% (21.90% - very good and 18.10% - good) of these have an above the average level, and 35.60% (20.60% - weak and 15.00 % - mediocre) show a level below the average (Table 8 and Figure 5).

Table 8. Distribution of the development level of the explosive power by the *Standing long jump* test

		Frequency	Percent	Valid percent	Cumulative percent
S.L.J. [a]	Very good	35	21,90	21,90	21,90
	Good	29	18,10	18,10	40,00
	Average	39	24,40	24,40	64,40
	Weak	33	20,60	20,60	85,00
	Mediocre	24	15,00	15,00	100
	Total	160	100	100	

a. *S.L.J. = Standing long jump* test

Source: Authors' own conception

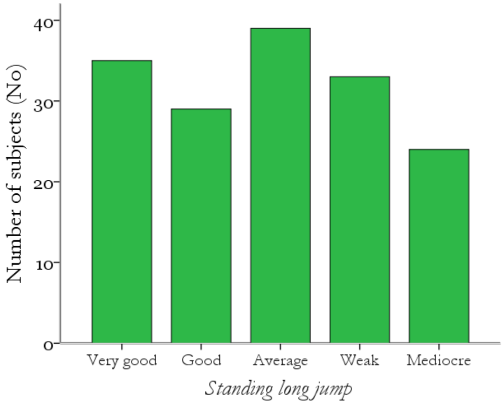

Figure 5. Distribution of the development level of the explosive power by the *Standing long jump* test

Source: Authors' own conception

As for the body mass index, 46.50% (26.80% - very good and 19.70% - good) of the subjects who have a normal body mass index, have a development level of the explosive power above average, 45% (15% - weak and 30% - mediocre) of the overweight subjects and 61.60% (30.80% - weak and 30.80% - mediocre) of the obese subjects present a level below average (Table 9 and Figure 6).

Table 9. Distribution of the development level of the static strength evaluated by the *Standing long jump* test, according to the body mass index

			Evaluation scale					Overall result
			Very good	Good	Average	Weak	Mediocre	
BMI (kg/m^2)	Normal	No	34	25	28	26	14	127
		(%)	26,80	19,70	22,00	20,50	11,00	100
	Over-weight	No	1	2	8	3	6	20
		(%)	5,00	10,00	40,00	15,00	30,00	100
	Obesity	No	0	2	3	4	4	13
		(%)	0,00	15,40	23,10%	30,80	30,80	100
Overall result		No	35	29	39	33	24	160
		(%)	21,90	18,10	24,40	20,60	15,00	100

Source: Authors' own conception

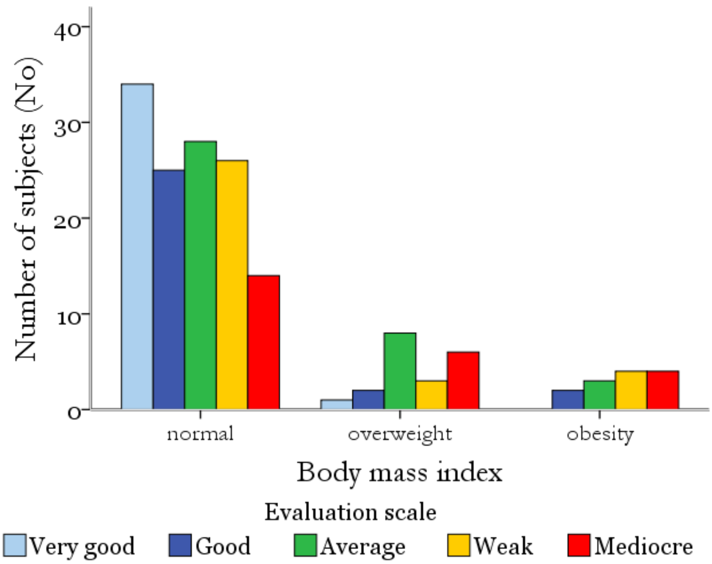

Figure 6. Distribution of the development level of the explosive power evaluated by the test *Standing long jump*, according to the body mass index
Source: Authors' own conception

As to the development level of the explosive power, depending on the body mass index and the gender of the subjects, the bifactorial variance analysis (ANOVA) shows a significant overall effect ($F_{(3)}$ = 16.98, p ≤ .01, η^2 = .25) which results entirely from the main effect of the body mass index factor ($F_{(2)}$ = 14.75, p ≤ .01, η^2 = .16) and of the gender factor ($F_{(1)}$ = 1.83, p = .18, η^2 = .01). It can be noticed that both, the gender and the interaction between the body mass index and the gender, do not indicate a statistically significant effect on the development level of the explosive power (Table 10).

Table 10. ANOVA variance analysis for the scores obtained in the test *Standing long jump*, depending on the body mass index and the gender

Source	Sum of squares	DF	Average of square	F	p	Partial Eta (η^2)	Observed strength [b]
Model	24665.95[a]	3	8221.98	16.98	.00	.25	1.00
BMI	14285.43	2	7142.72	14.75	.00	.16	.99
Gender	886.61	1	886.61	1.83	.18	.01	.27

BMI* gender	.00	0	.	.	.	.00	
Error	75520.82	156	484.11				

Dependent variable: the Standing long jump test; DF = degrees of freedom; BMI = body mass index

a. $R^2 = 0.25$ *(R^2 adjusted =0.23);* b. $p = 0.05$

Source: Authors' own conception

Compared to the body mass index and the age of the subjects, the results show a significant overall effect ($F_{(6)} = 11.88$, $p \leq .01$, $\eta^2 = .32$) which results entirely from the main effect of the body mass index factor ($F_{(2)} = 7.83$, $p = .01$, $\eta^2 = .09$) and of the age factor ($F_{(3)} = 5.58$, $p = .01$, $\eta^2 = .10$). However, the interaction between the body mass index and the age does not illustrate a statistically significant effect ($p = .06$) on the development level of the explosive power (Table 11).

Table 11. ANOVA variance analysis for the scores obtained in the *Standing long jump* test, depending on the body mass index and age

Source	Sum of squares	DF	Average of square	F	p	Partial Eta (η^2)	Observed power [b]
Model	31842.96[a]	6	5307.16	11.88	.00	.32	1.00
BMI	6999.85	2	3499.93	7.84	.01	.09	.95
Age	7483.45	3	2494.48	5.58	.01	.10	.94
BMI* age	1565.84	1	1565.84	3.51	.06	.02	.46
Error	68343.82	153	446.69				

Dependent variable: the Standing long jump test; DF = degrees of freedom; BMI = body mass index;

a. $R^2 = 0.22$ *(R^2 adjusted =0.19);* b. $p = 0.05$

Source: Authors' own conception

The bivariate correlation analysis, based on the Spearman correlation coefficient, shows that there is a significant link, of moderate intensity (rho = .43), between the body mass index and the development level of the explosive power, due to the fact that $p \leq .001$ (Table 12).

Table 12. The result of the correlation analysis according to the Spearman coefficient, between the development level of the explosive power and the body mass index

Spearman's rho		S.L.J.	BMI (kg/m^2)
S.L.J	CC	1.00	.43**
	p	.	.00
	N	160	160
BMI (kg/m^2)	CC	.43**	1.00
	p	.00	.
	N	160	160

*** The correlation is significant at a significance level ≤ 0.01; CC = correlation coefficient*
S.L.J. = Standing long jump test*; BMI = body mass index*

Source: Authors' own conception

4. Limits and Discussions

The nature of this study does not allow us to determine the exact causality of the relationships established between the variables considered. Also, the investigative approach that we carried out was a selective one and it was done at a single educational unit in Brasov. We have focused our attention on directions related only to the possible correlations that can be established between the values of the body mass index and the level of manifestation of the force, and this the latter only for its forms of manual static force, respectively the explosive force of the lower limbs.

The international significance of the study is given by the diversity of findings on the presence in many other studies based on the same topic. Thus, in addition to the studies that showed a relationship - from the perspective of health - between body mass index and the level of manifestation of strength, and which we mentioned briefly in the introductory part of this study, there are some more reserved opinions about this issue. Thus, Silventoinen et al. (2009) found only an insignificant association between strength and cardiovascular disease in Swedish subjects, and Artero et al. (2012) consider that it is not possible to say exactly whether the level of muscle strength development is associated with long-term cardiovascular disease and independent of cardiorespiratory capacity. Likewise, Gonzalez Valero et al., 2018, p. 396) believe that cardiorespiratory endurance can be a good indicator of the general physical condition of young people, if it is assessed at the population level. On the other hand, Ortega et al. (2005), in a cross-sectional study of more than 3 000 adolescents, found that cardiorespiratory endurance is closely associated with other components of physical condition, in both young people and adults, and subjects with a high level of cardiorespiratory endurance had, at the same time, a higher level of muscular strength (upper and lower limbs), speed and flexibility. In the context of those mentioned, the originality of our research paper consists in highlighting data with moderate significance in terms of the relationship between body mass index and muscle strength, being very few studies, strictly in this direction.

Accordingly with those presented, we believe that our research topic remains open to new investigations, which try to highlight which of the components of physical condition has a greater weight in optimizing and/or maintaining health or vice versa, these only addressed in a in an integral way, it is a factor to be taken into account for the decrease of the citizens' morbidity.

Last, but not least, in the context of these limitations, we consider that observational studies with a larger sample size, especially longitudinal and prospective studies, are needed to verify the results obtained in this paper.

5. Conclusions

The conclusions drawn from the research are the following:

• Body mass index and age have a statistically significant effect on static strength, but not if we take into account only their biological differentiation.

• There is a significant connection of moderate intensity between the body mass index and the level of development of the manual grip force, as well as between the body mass index and the level of development of the explosive force that manifests in the lower limbs, and in a large proportion, the excess weight subjects (overweight and obese) show lower values of strength, in both tests (*Handgrip strength* and *Standing long jump*), compared to normal weight subjects.

• From a statistical-mathematical point of view, the level of development of muscle strength, a component of physical condition, is dependent on the body mass index, which can be a predictor of health in overweight adolescents.

• The data obtained in our study can help us to establish comparisons with other school populations, as well as to estimate the proportion of students with changes in the level of development of muscle strength, depending on the excess weight measured at some point.

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