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COMPARISON OF SEVERAL ADIPOSITY - RELATED ANTHROPOMETRIC INDICES IN PREDICTING MUSCULAR FITNESS IN SCHOOLCHILDREN ABSTRACT

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(Original scientific paper)

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Abstract
Childhood increases in body fat are often accompanied by a decline in physical functioning, but we still do not know clearly which anthropometric indicators predict muscular fitness most accurately in school-aged children. This study aimed to compare the relationship between several commonly used and newer bodycomposition indices and children’s performance in various muscular fitness tasks. The study involved children aged 6 to 10 years, who underwent standard anthropometric measurements together with tests assessing muscular strength, power, and local endurance. The indices examined in the analysis included BMI, WHtR, the Conicity Index (C-index), the Tri-Ponderal Mass Index (TMI), Relative Fat Mass for children (RFMp), and the ratio of handgrip strength to BMI (Grip-to-BMI). Multiple linear regression was applied to evaluate the extent to which each index explained variations in muscular fitness outcomes. The findings of this study show that indicators that integrate the relationship between muscle strength and body mass, as well as those that more accurately assess adipose tissue, are the most useful for predicting motor fitness in children. TMI and RFMp, which reflect adiposity more accurately, also demonstrated stable associations with strength and endurance results. Taken together, the results indicate that indices that blend muscular strength with body mass, or those that offer a more precise estimate of body fat, provide clearer insight into children’s motor fitness. These observations may help improve early screening practices and support the design of more individualized intervention programs, in which Grip-to-BMI, TMI, and RFMp could

Keywords: *adiposity, muscular fitness, TMI, RFMp, Grip-to-BMI*

Introduction

Health risks from chronic diseases become more understandable through body mass index measurements and waist circumference assessments and other body fat indicators. Multiple research studies identify these measures as metabolic problem indicators for children and teenagers and as future cardiometabolic risk indicators for adults (Lee et al., 2021; Shen et al., 2017; Wang et al., 2017). The medical community uses these measurements to detect high blood pressure in teenagers and to study waist fat distribution in relation to adult heart disease. The World Health Organization (WHO) supports BMI as their primary body fatness assessment tool but scientists acknowledge its multiple flaws. The BMI measurement fails to distinguish between body fat and muscle mass while it does not demonstrate how body fat distributes throughout the body. Multiple new body fat measurement tools have emerged during the last few years because of existing index limitations. The tri-ponderal mass index (TMI) and relative fat mass (RFM) and waist-to-BMI ratio serve as new body composition assessment tools which provide enhanced accuracy (Ashwell & Gibson, 2016; Liu et al., 2021). Health-related fitness includes two essential components which are muscular strength and cardiorespiratory fitness. These two health indicators demonstrate robust connections to multiple health advantages while serving as effective predictors for future wellness (Howley, 2001; Ortega et al., 2023). The physical performance and success in different physical activities depend on motor skills which include agility and balance and coordination. The health value of agility and speed continues to grow as researchers now recognize their potential to serve as health markers for children. Research indicates that these abilities create better bone health outcomes and enhance motor skill development in children (Ortega et al., 2008; Schmidt & Lee, 2005; Palou et al., 2019). The 4 × 10 m shuttle run test serves as a standard assessment for these abilities while showing high reliability and validity and can be adapted for coordination testing through minor adjustments (Sheppard & Young, 2006; Ortega et al., 2008; Ortega et al., 2015). The nervous system development during childhood between ages 8 to 10 makes this period optimal for physical activity benefits. Research indicates that brief high-intensity physical activities enhance brain processing speed and accuracy through changes in hippocampal-related neurological processes (Malina et al., 2003; Donnelly et al., 2016). The inclusion of agility and speed tests occurs early in various fitness test batteries which schools worldwide implement (Ortega, Artero et al., 2008; Castro-Piñero et al., 2010; Ruiz et al., 2011). Multiple studies from recent years demonstrate that RFMp and TMI and Cindex and Grip-to-BMI ratio serve as effective tools to detect cardiometabolic risks starting from childhood (Woolcott & Bergman, 2018; Paek et al., 2019). Based on this background, the present study aims to compare the ability of traditional indices (BMI and WHtR) with several newer ones (TMI, waist–BMI ratio, RFMp, C-index, and Grip-to-BMI ratio) to predict motor fitness in children aged 6–10 years. Assessing how well these measures capture differences in motor abilities is key for developing early screening tools and interventions that encourage healthy growth in children.

Methods

Participants

The research involved 2,197 children from nine primary schools located in the Skopje area of North Macedonia's Republic. The research participants consisted of 1,096 boys and 1,101 girls who were between 8.1 ± 1.3 years old. The research included all students who received parental consent and had no health issues and attended physical education classes regularly. The research team executed the procedures based on the Declaration of Helsinki (1964, revised 2013, Brazil).

Anthropometric Measurements and Assessment of Motor Fitness

The trained personnel conducted all measurements through established standardized procedures. The measurement procedures for body weight (BW) and body height (BH) and body fat percentage (%BF) and waist circumference (WC) and cardiorespiratory fitness (CRF) through the 20-m shuttle run test and handgrip strength test (Grip-to-BMI ratio calculation) have been fully explained in previous research studies. The stadiometer and anthropometric tape enabled the measurement of body height and waist circumference with 0.001 m precision. The Tanita BC-418MA device with 50 Hz single frequency conducted bioelectrical impedance analysis (BIA) to measure body fat percentage.

The 4 × 10 m shuttle run test served as the motor fitness assessment tool which proved effective for youth population assessment (Vicente-Rodríguez et al., 2011). The test requires participants to sprint between two lines that are 10 meters apart while picking up a sponge at the end of each sprint before returning to the starting point. The participants performed the test twice to obtain their fastest time which they recorded in seconds. The researchers reversed all performance values to create a scoring system where better results produced higher numbers.

Statistical Analysis

Based on the anthropometric measurements, indices for assessing adiposity were calculated as follows:

BMI = body weight (kg) / height (m)^2 (1)

TMI = body weight (kg) / height (m)^3 (2)

WHtR = waist circumference (cm) / height (cm) (3)

Waist–BMI ratio = waist circumference (cm) / BMI (kg/m^2) (4)

Conicity Index (CI) = WC (m) / (0.109 × √(BW (kg) / BH (m))) (5)

Grip-to-BMI ratio = Handgrip strength (kg) / BMI (kg/m^2) (6)

RFMp (for girls and boys) = 74 − (22 × (height/waist)) + (5 × sex*) (7)

*Sex was coded as 0 for boys and 1 for girls.

The study calculated arithmetic means and standard deviations (SD) and minimum (Min) and maximum (Max) values for all variables. The research findings showed results from the entire study group and individual results for male and female participants.

The study used regression analysis to identify relationships between body dimensions and fat percentage and their impact on shuttle run performance. The research team developed nine separate models which analyzed boys and girls through sequential measurements of anthropometric variables and indices. The researchers added age as a controlling factor to prevent age-related influences on the results.

The study evaluated the predictive power of anthropometric measurements and indices through R^2 coefficient analysis. The study established $p \leq 0.05$ as the threshold for statistical significance. The research team conducted all statistical computations through SPSS version 26.

Results

The characteristics of the participants (N = 2,197, including 1,101 girls with a mean age of 8.0 years, SD = 1.4, and 1,096 boys with a mean age of 8.1 years, SD = 1.4), in relation to anthropometric measurements, the indices used in the analysis, and the results of the motor fitness assessment (4 × 10 m shuttle run), are presented in Table 1.

To address the primary aim of the study, nine independent regression models were applied separately for male and female participants. In these analyses, the criterion variable was the 4 × 10 m shuttle run test, while the predictor variables included age, waist circumference, body fat percentage, and anthropometric indices: BMI, WHtR, TMI, waist-to-BMI ratio, RFMp, C-index, and Grip-to-BMI ratio.

Among male participants (Table 2), all proposed regression models demonstrated statistically significant predictive effects of the selected anthropometric indices on performance in the 4 × 10 m shuttle run test ($p < 0.0001$ for all models). The coefficients of determination (R^2), ranging from 18.6% to 33.8%, indicate a moderate to relatively high level of explained variance in the criterion variable, depending on the combination of predictors included in each model.

Table 1. Anthropometric measurements and indices of the analyzed group.

Descriptive Statisticsa	Boys				Girls			
	Mean	**SD**	**Min**	**Max**	**Mean**	**SD**	**Min**	**Max**
BH	133,0	9,7	110,4	164,0	132,5	10,2	109,8	163,0
BW	33,6	10,3	19,0	85,2	32,5	9,5	18,1	71,7
WC	61,4	9,1	38,8	95,0	59,2	8,2	43,0	96,0
WHtR	0,5	0,1	0,0	0,7	0,4	0,0	0,3	0,7
BMI	18,6	3,7	13,1	36,5	18,2	3,3	12,1	32,9
TPI	14,0	2,4	5,5	27,1	13,7	2,2	6,4	26,4
Waist–BMI-ratio	3,3	0,3	1,3	5,3	3,3	0,3	2,1	4,8
RFMp	73,5	0,1	73,2	73,7	78,5	0,1	78,3	78,7
C-index	1,1	0,1	0,6	2,0	1,1	0,1	0,9	1,6
BF%	23,8	7,9	6,0	44,3	22,9	8,2	5,4	51,2
Grip-to-BMI-ratio	0,7	0,2	0,2	1,4	0,7	0,2	0,2	1,3
4x10 m	14,9	2,0	10,8	22,6	15,8	2,0	10,9	25,7

Body weight (BW), body height (BH); body fat percentage (%BF); waist circumference (WC), body mass index (BMI); relative fat mass pediatric (RFMp); tri-ponderal mass index (TMI); waist ircumference (WC); waist-to-height ratio (WHtR); conicity index (C-index); handgrip strength kg and BMI kg/m^2 (Grip-to-BMI-ratio).

The highest R^2 value was evident in the model that included age and the grip strength to body mass index (Grip-to-BMI) ratio, where the explained variance reached 33.8%, accompanied by the highest F-test value (F = 272.3), indicating a strong and statistically consistent predictive influence. Similar high levels of explanation were also observed in the models that included TMI (R^2 = 23.7%; F = 166.9) and relative fat mass percentage (RFMp; R^2 = 23.7%; F = 165.2).

The waist-to-BMI ratio produced the lowest coefficient of determination which reached 18.6% while still showing a statistically significant relationship with motor performance. The results indicate that body composition ratios which include muscular strength measurements such as Grip-to-BMI ratio demonstrate better predictive ability for measuring muscular fitness among male participants aged similarly to this study. The statistical models for female participants in Table 3 demonstrated significant relationships between their anthropometric measurements and their 4 × 10 m shuttle run performance at $p < 0.0001$. The coefficients of determination (R^2) in these models spanned between 20.6% and 30.9% which indicates they have moderate to strong predictive ability. The model that used age and Grip-to-BMI ratio as predictors achieved the highest explanation of the criterion variable with an R^2 value of 30.9% and an F-test value of 242.6 which made it the most effective model for female performance prediction.

Table 2. Prediction of results of the test for assessing muscular fitness (shuttle run test) through specific anthropometric indices, regression analysis results for male participants.

Models	Factors (Independent)	Regression Models— Statistics		
		R^2	F	p
1	Age, WC	21,8%	149,0	<0.0001
2	Age, BMI	22,4%	155,3	<0.0001
3	Age, WHtR	23,2%	161,3	<0.0001
4	Age, TMI	**23,7%**	166,9	<0.0001
5	Age, waist–BMI ratio	18,6%	121,0	<0.0001
6	Age, RFMp	**23,7%**	165,2	<0.0001
7	Age, %BF	23,1%	151,2	<0.0001
8	Age, C-index	19,2%	125,9	<0.0001
9	Age, Grip-to-BMI-ratio	**33,8%**	272,3	<0.0001

Table 3. Prediction of 4 × 10 m Shuttle Run Performance Using Specific Anthropometric Indices: Regression Analysis Results for Female Participants

Models	Factors (Independent)	Regression Models— Statistics		
		R^2	F	p
1	Age, WC	23,1%	162,2	<0.0001
2	Age, BMI	23,0%	162,2	<0.0001
3	Age, WHtR	**24,5%**	175,5	<0.0001
4	Age, TMI	**24,4%**	175,0	<0.0001
5	Age, waist–BMI ratio	20,6%	140,3	<0.0001
6	Age, RFMp	**24,4%**	174,8	<0.0001
7	Age, %BF	**24,4%**	162,5	<0.0001
8	Age, C-index	21,9%	151,4	<0.0001
9	Age, Grip-to-BMI-ratio	**30,9%**	242,6	<0.0001

The models including WHtR, TMI, RFMp, and %BF all exhibited relatively high predictive power ($R^2 \approx 24.4$–24.5%), highlighting that fat-related variables play a key role in determining motor performance outcomes.

In contrast, the lowest explained variance was observed in the model with the waist-to-BMI ratio ($R^2 = 20.6\%$), although this model remained statistically significant. Nevertheless, compared to the Grip-to-BMI ratio, its predictive capacity was substantially more limited.

Discussion

The research findings demonstrate that Grip-to-BMI ratio together with TMI and RFMp serve as the most reliable and stable indicators to assess muscular fitness in children who attend school. The three indices provide better assessment of body composition and functional strength because they distinguish between fat mass and lean mass whereas BMI and WHtR fail to make this distinction. The lower predictive value of these measures stems from their inability to combine muscular function data with fat distribution information (Manzano-Carrasco et al., 2023; Chen et al., 2023; Zadarko-Domaradzka et al., 2023).

The Grip-to-BMI ratio proved to be the strongest predictor which worked equally well for both male and female participants because relative strength measurements based on body mass ratios determine muscular fitness at this age. Research from around the world demonstrates that body fat accumulation creates strength-to-weight imbalances which impair motor performance even when overall strength levels remain stable (Steffl et al., 2017; Palacio-Agüero et al., 2020).

The research results show that functional strength performance depends more on body composition metrics than on absolute weight measurements or individual anthropometric values. The study used TMI and RFMp as new body fat measurement tools which proved to be highly effective for predicting body fat in children. The authors agree that TMI provides better body fat measurement in children than BMI because it shows less sensitivity to growth changes and biological development (Chen et al., 2023; Zhang et al., 2023). The study used RFMp as a sensitive index which measures central body fat to achieve high prediction accuracy for physical performance according to Polish research findings (Zadarko-Domaradzka et al., 2023).

The discriminative power of BMI and WHtR and Conicity Index remained lower than the other indices. The indicators show weight-height relationships and central fat accumulation but they do not measure functional strength performance. The developing populations show wide variations in muscle mass and biological maturation which makes these indices less effective for predicting fitness because they combine different body compositions into single categories. The study shows that these indices produce statistically significant results but they explain only a small portion of the variation in motor performance.

The research findings from 2018 to 2024 match international studies which show that body fat growth leads to decreased muscular strength and speed and endurance performance (Manzano-Carrasco et al., 2023; Llagjeviq-Govori et al., 2025). Children who are overweight show stronger handgrip measurements but their strength performance relative to body weight and their test results are lower than average which indicates that excess body fat creates performance obstacles. The biological explanation supports this mechanism because fat tissue acts as an unproductive weight while muscle tissue functions as the performance-generating force thus higher body fat percentage results in weaker relative strength and increased work requirements for similar activities. The results between different indices show variations because of different developmental stages in children. The prepubertal stage of children between 6 and 10 years old shows greater fat mass variations than muscle mass changes which makes adiposity indicators effective for fitness prediction. The study results show identical patterns for boys and girls which confirms the stability of these findings across both sexes.

The research findings show that Grip-to-BMI and TMI and RFMp serve as effective screening tools for schools and primary healthcare facilities because they are affordable and produce accurate results. The screening tools help doctors identify children who have weak muscles even when their BMI appears normal. The prevention of sarcopenic obesity in children and adolescents requires immediate action because this condition continues to grow in importance. The screening method enables healthcare providers to deliver specific interventions through exercise programs and activity modifications and surveillance programs. Cross-sectional designs of the study, however, preclude causal deductions. Biological maturation was not controlled, therefore it may impact the link between adiposity and muscle strength. Not included, which would have given a more thorough assessment of fitness, were other biomarkers such physical activity levels. Longitudinal studies are required to follow developmental trajectories and show cause-and - effect connections. Biological maturation markers, direct muscle mass assessments, and objective physical activity data should all be included. Moreover, assessing their sensitivity to change would be helped by testing measures such Grip-to- BMI in intervention studies.

Conclusion

The findings of this research suggest that, among conventional anthropometric measures including BMI and WHtR, the Grip-to-BMI, TMI, and RFMp indices most closely predict muscular fitness in school-aged children. More precisely reflecting body composition and the link between muscle mass and fat tissue, these indicators let one more successfully evaluate the physical capabilities of children. The results have significant practical ramifications since they might be used in monitoring, screening, and intervention programs in healthcare and educational settings. Early identification and prevention of possible health risks in the pediatric population is facilitated by the inclusion of these indices into regular health check-ups and physical activity programs.

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