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The link between body mass index (BMI) and bone properties, muscle strength, and motor coordination in boys and girls aged 7−9

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A Study Design
B Data Collection
C Statistical Analysis
D Data Interpretation
E Manuscript Preparation
F Literature Search
G Funds Collection

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abstract

Background: Obesity affects health parameters that are related to physical activity. The present study examined the relationship between weight and three such parameters in young boys and girls, bone properties, muscle strength, and motor coordination.

Material and methods: The study consisted of second- and third-grade 286 students – 144 boys and 142 girls participants. Bone properties were measured at the distal radius and tibia shaft by Speed of Sound technology. Tests were conducted to measure muscle strength and motor coordination.

Results: Obese boys were characterized by lower bone properties ($p < .01$) in the tibia bone than normal-weight boys. They were significantly ($p < .05$) weaker than normal-weight boys on muscle strength tests. Obese boys scored significantly ($p < .05$) lower on coordination tests than the normal weight boys. Underweight girls maintained higher bone properties than did the girls in all other BMI categories. Normal-weight girls scored significantly ($p < .05$) higher than obese girls on muscle strength tests. Obese girls scored significantly ($p < .05$) lower than normal-weight girls on motor coordination tests.

Conclusions: The findings emphasize the need to identify obese children and refer them to special weight loss and exercise programs.

Key words: bone properties, motor coordination, muscle strength, weight.

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INTRODUCTION

Obesity is a worldwide pathological epidemic in affecting both children and adolescents [1]. Obesity has been linked to risk factors associated with cardiovascular disease, hypertension, high cholesterol, and joint and posture complications [2]. The present study examined the relationship between weight and three health indicators: bone properties, muscle strength and motor coordination that are crucial for young children during their developmental stages.

The term bone properties (BP) refers to the quantity, quality, and mineral density of bones and bone mass. During childhood and adolescence, bones grow in length and width, and their mass increases and becomes stronger [3]. It is recognized that maximizing peak bone mass in ages up to the mid-twenties may provide important protection against fracture risks later in life [4]. Findings on the link between obesity in children and bone properties are equivocal. It has been argued that, compared with normal children, obese children maintain either lower [5] or higher [6] bone properties.

Muscle strength (MS) is defined as the ability of the muscle to exert force during general activity. Strong muscles enable easy execution of motor skills, increased endurance activities, a balanced posture, and prevention of injury, and help in preparing the body for future sports activities. Low muscle strength can lead to restricted mobility and distorted posture [7]. Research findings clearly indicate a negative correlation between obese children and muscle strength [8].

Motor coordination (MC) is the degree to which various parts of the body are synchronized to perform one task aimed at attaining the most efficient movement outcomes [9]. Lack of MC can result in activity avoidance and sedentary behavior. It has been found that obese children are less physically active and spend more time in sedentary activities than normal-weight children [10]. Studies that address the relationship between weight and MC in children are unanimous in their conclusion that the greater a child's weight, the poorer his or her movement coordination [11].

We examined young children newly enrolled in the education system, a cohort that represents unique challenges for researchers due to the children's young age. Only a limited number of studies have been carried out on this age cohort, and thus we aimed in the current study at determining the link between weight categories of young boys and girls and their bone properties, muscle strength, and motor coordination.

MATERIAL AND METHODS

The study was approved by the Helsinki Committee of the Hillel Yaffe Hospital in Hadera, Israel (Request no. 0043-11HYMC. The study registered in NHI request no. NCTD1407458 August 2011) and by the national education authorities in Israel.

All children from the participating schools, and their parents, received information about the study through school meetings and written information. At least one parent of each child signed an informed consent form in accordance with the Helsinki Declaration of the Human Ethics Board.

The study sample consisted of 286 second- and third-grade students – 144 boys (M_{age} = 7. 6, SD = 0.58) and 142 girls (M_{age} = 7.50, SD = 0.60), who were recruited from two primary schools that represented the urban population of the center of Israel, with a middle-class socioeconomic background.

All students took part in physical education classes twice a week throughout the entire school year. Table 1 presents the participants' demographic and anthropometric data.

Table 1. Means and SDs for the study sample's demographic and physical characteristics by gender

Variable	Boys (*n* = 144)		Girls (*n* = 142)	
	M	SD	M	SD
Age (yrs)	7.62	0.58	7.55	0.61
Weight (kg)	29.26	6.25	27.21	6.65
Height	128.68	6.06	126.14	5.56
BMI	17.54	2.77	16.94	3.11
BMI%	65.78	27.31	56.13	31.43

RESEARCH INSTRUMENTS

Bone properties (BP)
A quantitative ultrasound method (QUS) was used to measure bone properties, using a Sunlight Omnisense device [12]. This method examines bone properties and offers the advantage of being unbiased concerning the bone size and surrounding soft tissue in young children. It does not involve radiation and is portable and inexpensive; therefore, it is appropriate for use with children in a school setting [13].

Bone properties were determined bilaterally – at the dominant and non-dominant sides at the distal one-third of the radius (DR) and at the mid-shaft of the tibia (TS). The dominant limb was determined by asking the participants which hand they used for writing and which leg they preferred for kicking. For a detailed description of the QUS method, see Falk [13].

Muscle strength (MS)
Four commonly-used tests were conducted to measure MS:

Standing long-jump test (SLJT). The SLJT measures the strength of the lower extremities. The participant takes off on two legs, jumping as far as possible from a marked line on the floor onto a mat. The distance of the jump is then measured with a yardstick. The best of three attempts performed one minute apart is taken as the maximal measure [14]. In our study the test-retest reliability was reported to be .97 [14].

Vertical jump test (VJT). The VJT measures the vertical strength of the lower extremities. The participant stands in a starting position, with one side of the body against the wall and both feet on the ground. One arm is extended against the wall, with the hand held high above the head, holding a piece of chalk. A vertical blackboard affixed to the wall enables the participant to mark the height that the hand reaches. The participant then jumps as high as possible, using the chalk to mark the blackboard at the highest point reached. A measuring tape is affixed vertically to the wall so that the height of the jump can be accurately measured. The distance between the normal standing point and the highest jumping point is regarded as the VJT score. The best of three attempts is recorded (7, 14). In our study the reported temporal stability of the VJT was very strong (r = .93) [15].

Bent arm hang test (BAHT). The BAHT measures the strength and endurance of the upper extremities. The participant hangs by his or her hands from a horizontal bar, feet off the ground, elbows bent, and chin above the bar, until he or she is unable to maintain the position any longer. The time lapse is considered to be the BAHT score. Since body weight is considered as a confounder, the final score is determined by time/body-weight. In our study the temporal stability of the BAHT was reported to be .85 [16].

Modified pull-up test (MPUT). Similar to the BAHT, the MPUT is also used to measure the strength of the upper extremities. The measurement is executed as the participant assumes a supine position on a mat beneath a horizontal bar. Before the measurement is taken, the participant extends his or her arms straight upwards to that the height of the bar can be adjusted. The participant then grabs the bar and pulls him/herself up, heels on the floor, elbows bent, and chin above the bar. The participant then lowers him/herself back to the supine position on the mat and repeats the pull-up motion. The pull-ups are performed as many times as possible without a rest, and the number of pull-ups performed is recorded. The test ends when the participant stops or experiences pain or discomfort [17].

Motor coordination (MC)
MC was measured using three components of the Kiphard-Schilling body coordination test for children (KTK) [18]. This test is used extensively by field researchers, despite its inability to discriminate between muscle strength and body mass]19]. The KTK was found to be reliable (temporal stability = .97) and valid for children 5–15 years old [20].

Three components of the test were used: jumping sideways over a wooden beam test (JSWT), moving sideways on boxes test (MSBT), high jump on right foot/left foot test (HJRT/HJLT). See in detail Kiphard and Vandorpe [18, 20].

Anthropometrics measurements – body mas index (BMI)

The children, who were wearing light clothing, were weighed twice to the nearest 0.1 kg using a portable electronic medical scale. Height was measured twice to the nearest 0.1 cm using a wall-mounted stadiometer, with the children standing with their back straight against the wall without shoes, to align the spine with the stadiometer. The head was positioned with the chin parallel to the floor. The means of the two weight and height measurements were used to calculate BMI, which is defined as the weight in kilograms divided by the square of the height in meters (kg/m^2).

BMI-for-age percentile growth charts are the most common indicator used to measure the size and growth patterns of children and teens in the United States [2].

BMI-for-age percentile was generated from the specific age and sex criteria of the Centers for Disease Control. According to the National Center for Health Statistics/World Health Organization (NCHS/WHO) guidelines and cutoff points for BMI-for-age percentile [21], a child is regarded as being overweight or obese if the BMI is ≥85th or ≥95th percentile for age and sex respectively. Children below the 5th percentile for age and sex are classified as underweight [2]. Since the sample size did not enable us to divide the sample into more detailed categories, we chose to use the CDC categories [2]. Table 2 presents the distribution of participants by age and BMI category.

Table 2. Distribution of participants by age and the BMI category

	BMI percentile category	Boys (n = 144)		Girls (n = 142)	
		n	%	n	%
Underweight	<5	–	–	11	7.7%
Normal-weight	5–85	99	68.8%	97	68.3%
Overweight	85–95	23	16.0%	20	14.1%
Obese	>95	22	15.3%	14	9.9%
	Total	144		142	100.0%

Procedure

Information on the age and gender of the children was provided by their respective school secretariat. Physical measurements were performed in the school gymnasiums at the beginning of the school year, according to a predetermined class order. The tests were performed at testing stations, each of which had four examinees and two qualified examiners. The examiners provided standardized instructions and demonstrations, according to the test's guidelines. The children were encouraged to perform to the best of their ability. At a prearranged signal, all children at all stations moved on to the next station. Bone measurements were taken in a separate room for each examinee individually, rather than in a group setting. The measurements were taken simultaneously on consecutive days, starting in the morning and lasting throughout the school day. The tests were performed over a period of one week in each school.

Statistical analysis

To test the link between the BMI and the BP, MS, and MC, three multiple analysis of variance (MANOVA) procedures were performed separately for boys and girls. The MANOVAs referred to three clusters: bone properties, muscle strength, and motor coordination. The grouping cluster consisted of three BMI weight percentile categories, namely, 5%–85%, 85%–95%, 95%+. The MANOVAs were followed by an ANOVA and a Tukey's post-hoc multiple comparison test, which were performed when the multivariate F-test was significant ($p < .05$). Cohen's d coefficients were calculated to reveal significant differences between pairs of means.

Results

Boys

Bone properties

Two variables, distal radius (DR) and tibia shaft (TS), were subjected to a MANOVA procedure, which revealed a significant effect of the BMI categories factor, Wilks' λ = .85, F (4, 260) = 5.45, p = .00, η^2 = .08. Follow-up ANOVAs for DR and TS separately revealed a tendency toward significance among the three BMI categories for DR, F(2, 131) = 2.72, p = .07, η^2 = .04, and a significant mean difference for TS, F(2, 131) = 6.70, p = .00 , η^2 = .09.

Tukey's post-hoc mean comparisons resulted in one significant effect ($p < .01$): obese boys exhibited lower bone properties than normal-weight boys ($d = 0.92$). Table 3 presents the boys' mean DR and TS values and corresponding SDs.

Muscle strength

Four variables represented the muscle strength cluster: BAHT, MPUT, SLJT, and VJT. The MANOVA revealed a significant effect of the BMI categories factor, Wilks' $\lambda = .76$, $F(8, 270) = 5.84$, $p = .00$, $\eta^2 = .13$. Follow-up ANOVAs performed for each variable revealed significant mean differences among the three BMI categories on BAHT, MPUT, and LJT, but not on VJT; BAHT, $F(2, 138) = 8.49$, $p < .01$, $\eta^2 = .23$; MPUT, $F(2, 138) = 9.03$, $p < .01$, $\eta^2 = .34$; SLJT, $F(2, 138) = 13.25$, $p < .01$, η2 = .16; VJT, $F(2, 138) = 2.31$, $p > .05$, $\eta^2 = .03$. Tukey's post-hoc comparisons of means revealed significant effects ($p < .01$) as follows: obese boys were weaker than normal weight boys on BAHT ($d = 0.93$), MPUT ($d = 0.95$), and SLJT ($d = 1.18$), and they were weaker than overweight boys on SLJ ($d = 0.81$). Table 3 presents means and SDs for the four muscle strength variables.

Motor coordination

Four variables defined the motor coordination cluster: HJLT, HJRT, JSWT, and MSBT. The MANOVA revealed a non-significant effect for the BMI categories, Wilks' $\lambda = .92$, $F(8, 272) = 1.40$, $p = .20$, $\eta^2 = .04$. Despite this omnibus non-significant effect, the four groups differed significantly in their effect on JHLT, $F(2, 138) = 3.37$, $p < .04$, $\eta^2 = .05$, and on JHRT, $F(2, 138) = 4.92$, $p < .01$, $\eta^2 = .07$, but not on JSWT or MSBT ($p < .19$ and $p < . 59$, respectively). Tukey's post-hoc comparisons of means revealed a significant effect whereby obese boys scored lower on HJLT and on HJRT than did normal-weight boys ($d = 0.63$ and $d = 0.75$, respectively). Table 3 presents means and SDs for the motor coordination variables.

Table 3. Means and SDs for bone properties, muscle strength and motor coordination by the BMI category – Boys

BMI Category / Variable	Normal weight (*n* = 96)		Overweight (*n* = 23)		Obese (*n* = 22)	
	M	SD	M	SD	M	SD
Bone Properties						
DR	3778.77	103.73	3829.45	99.28	3803.89	122.61
TS	3697.61	108.98	3672.63	103.68	3594.10	128.03
Muscle Strength						
BAHT	0.20	0.19	0.13	0.16	0.03	0.04
MPUT	3.62	2.95	2.52	2.35	1.00	1.77
SLJT	136.15	16.60	130.22	16.72	116.41	17.55
VJT	53.96	6.25	56.09	6.00	52.05	6.90
Motor Coordination						
JSWT	46.93	15.44	47.96	15.36	40.57	14.12
MSBT	26.53	10.80	25.22	10.01	23.50	8.90
HJLT	6.25	3.74	5.96	3.82	3.77	3.72
HJRT	6.90	3.71	6.35	3.49	3.86	4.32

DR = radius properties; TS = tibial shaft; BAHT = bent arm hang test; MPUT = modified pull-up test; SLJT = standing long jump test; VJT = vertical jump test; HJLT = high jump on left foot; HJRT = high jump on right foot; JSWT = jumping sideways over a wooden beam; MSBT = moving sideways on boxes.

GIRLS

Bone properties

BP was measured for the DR and the TS. The two variables were normally distributed within the designated values. The MANOVA for the two BP-dependent variables revealed a significant effect of the BMI categories factor, Wilks' λ = .89, F(6, 242) = 1.42, p = .03, η^2 = .06. Follow-up ANOVAs performed separately for DR and TS revealed a non-significant effect of the four BMI categories on DR, F(3, 122) = 0.46, p = .71, η^2 = .01, and significant mean differences among the BMI categories with respect to TS, F(3, 122) = 3.58, p = .02 , η^2 = .08. Tukey's post-hoc comparisons of means revealed significant effects of BMI categories on TS. Specifically, underweight girls were characterized by stronger bones than were the girls in all other BMI categories: normal-weight girls (d = 0.83), overweight girls (d = 1.11), and obese girls (d = 1.65). Table 4 presents the means and SDs for the two BP indicators.

Muscle strength

Four variables represented the muscle strength cluster: BAHT, MPUT, SLJT, and VJT. Results were subjected to MANOVA according to the BMI percentiles categories. The MANOVA revealed a significant main effect for the BMI categories grouping factor, Wilks' λ = .80, F(12, 339) = 2.50, p < .05, η^2 = .07. Follow-up MS univariate F tests were performed for each of the MS variables, as well as a Tukey's multiple comparison test of means. The analysis revealed significant mean differences among the three BMI categories for BAHT (F(3, 131) = 4.68, p < .00, η^2 = .10), MPUT (F (3, 131) = 2.38, p = .07, η^2 = .05), and SLJT (F(3, 131) = 4.69, p < .00, η^2 = .10), but not for VJT (F(3, 131) = 1.06, p > .05, η^2 = .02). Tukey's post-hoc mean comparisons procedure for BAHT, MPUT, and SBJT revealed one significant effect: normal weight girls scored significantly higher than obese girls (d = 0.85, d = 0.76, d = 1.01, respectively) on all three tests. Table 4 presents the means and SDs of the muscle strength variables for each of the BMI categories.

Table 4. Means and SDs for bone properties, muscle strength and motor coordination by the BMI category – Girls

BMI Category / Variable	Underweight (n = 11)		Normal weight (n = 97)		Overweight (n = 20)		Obese (n = 14)	
	M	SD	M	SD	M	SD	M	SD
Bone Properties								
DR	3750.45	113.70	3774.93	108.16	3801.47	101.21	3760.33	69.29
TS	3746.82	85.02	3656.37	111.52	3633.31	110.75	3592.92	99.35
Muscle Strength								
BAHT	0.22	0.25	0.26	0.29	0.10	0.13	0.03	0.06
MPUT	2.64	1.91	2.86	2.74	2.30	2.30	0.86	1.56
SLJT	118.45	19.16	120.35	18.60	117.20	22.14	102.07	13.86
VJT	47.73	7.60	51.33	6.74	50.68	5.14	52.00	7.66
Motor Coordination								
JSWT	42.30	17.93	46.42	13.53	46.25	12.08	35.71	15.78
MSBT	24.82	11.46	25.76	8.39	21.15	6.96	18.21	6.70
HJLT	4.09	3.18	5.11	3.59	4.65	3.82	2.71	3.17
HJRT	5.82	2.52	6.10	3.39	5.35	3.79	2.93	2.81

DR = radius properties; TS = tibial shaft; BAHT = bent arm hang test; MPUT = modified pull-up test; SLJT = standing long jump test; VJT = vertical jump test; HJLT = high jump on left foot; HJRT = high jump on right foot; JSWT = jumping sideways over a wooden beam; MSBT = moving sideways on boxes.

Motor coordination

A MANOVA performed on the four variables comprising motor coordination – HJLT, HJRT, JSWT, and MSBT – revealed a significant BMI categories effect, Wilks' $\lambda = .85$, $F(12, 352) = 1.84$, $p = .04$, $\eta^2 = .05$. Follow-up BS univariate F tests performed for each MC test revealed significant differences among the four BMI categories for MSBT, $F(3, 136) = 4.31$, $p < . 00$, $\eta^2 = .09$ and for HJRT, $F(3, 136) = 3.76$, $p < .05$, $\eta^2 = .08$, and a tendency towards a significant difference for JSWT, $F(3, 136) = 2.59$, $p < .06$, $\eta^2 = .05$, but not for HJLT ($p < .12$). Tukey's post-hoc comparison of means indicated that obese girls scored significantly ($p < .05$) lower than normal-weight girls on JSWT ($d = 0.77$), MSBT ($d = 0.92$), and HJRT ($d = 0.95$), with a tendency towards a significant difference on HJLT ($p < .08$) ($d = 0.68$). Table 4 presents the means and SDs for the motor coordination variables by BMI percentiles categories for girls.

DISCUSSION

This research examined the link between weight categories of children aged 7- to 9-years-old and their bone properties, muscle strength, and motor coordination. Our research revealed significant differences starting at the early stages of life between obese children both boys and girls and children in other weight categories in bone properties, muscle strength, and motor coordination.

An inverse linkage was revealed between the tibia shaft and weight. Obese boys and girls demonstrated a significant low difference of the tibia shaft compared to normal-weight boys who exhibited high tibia shaft values, as did underweight girls. Indeed, underweight girls had higher tibia shaft values than girls in all other weight categories. Our findings were consistent with previous reports [13, 22] and were different from those in other studies [6, 23].

The study is unique by using the quantitative ultrasound (QUS) method, which examines bone properties via Speed of Sound technology without radiation, and overcomes the unreliable values obtained by the DXA method regarding bone size and the surrounding soft tissue in pre-pubertal children [13]. QUS reflects both quantitative and qualitative properties of bones [24] and has also been used to demonstrate the effect of growth and various health conditions on the bones [13, 25].

Our findings indicate that the link between weight and bone properties in children essentially differs from that of adults. Due to the children's young age, body weight has not yet resulted in a prolonged and significant impact on their bones. Moreover, the amount of physical activity performed by children, and its intensity, affect this relationship as well [3, 26]. Specifically, obese children tend to engage in physical activities less often and at a lower intensity than normal-weight children, who tend to engage more often in physical activities and at a higher intensity [10]. Thus, normal-weight children have more opportunities to affect the bone properties of their lower body extremities. Moreover, the bones of underweight girls are affected by the load of physical activity more than the bones of normal-weight children, overweight children, and obese children [27]. One possible explanation for this is that lean children tend to be more physically active. The literature provides evidence that the bones of underweight children or of children with low body mass are positively impacted by the loads of physical activity: the lower the child's body mass, the greater the probability of normal skeleton development. Indeed, the factor that predicts high bone parameters in both sexes is low body mass

[28, 29]. Support for this notion was also provided in studies showing that the combination of low weight and performing physical activity results in stronger bones [28, 29]. Unlike in the tibia shaft values, the findings failed to show any link between children's distal radius values and their weight. One study found that children in all weight categories do not exercise their upper body often enough to increase bone properties [30].

Differences among the weight categories were also found in muscle strength. Obese children exhibited poorer performance on both upper body tests – the MPUT and the SLJT, and also on the lower body test – SLJT, than the other three children's weight categories, in line with a number of other studies [8, 31]. Obese children were reported to spend more time on sedentary activity [32] and devote less time than other children to physical activity [10]. This, presumably, was reflected in their weaker muscles as found in the current study.

Significant differences were found between obese boys and normal-weight boys in the coordination tests, HJRT, and HJLT. Obese and normal-weight girls significantly differed in their performance in the JSWS, MSBT, and HJLT. The HJLT and HJRT require coordination that involves elevating the center of gravity, as well as calling for erupting force and muscle endurance [10, 20]. This means that poor performance in terms of muscle strength has a detrimental effect on coordination abilities as well. The JSWS and MSB tests oblige the participant to withstand time pressure conditions and to exhibit a high level of response speed and agility, which are difficult requirements for overweight children. Our findings support the notion and findings that the greater the children's weight, the poorer their motor coordination abilities.

The strengths of the study were that the study was conducted in regular classes where the children were divided into weight categories for the study. The students represented a cohort of a normal population in children's health, which enhances the importance of the findings.

A few limitations in our study are noted. Underweight and obesity concerned a very small number of children each, and thus the conclusions drawn from the findings must be reviewed with caution. In addition, the tests were performed during the children's regular school day and consisted of field tests. Although we chose to use existing tests that are customarily used in such studies, these tests do not represent other components of physical fitness.

Our research revealed several significant differences, starting at the early stages of life, between obese children and children in other weight categories in bone properties, muscle strength, and motor coordination. Children in the overweight category were similar to those in the normal-weight category, but different from those in the obese category. Consequently, it seems important to separate the two categories when recommendations for exercising are provided. Furthermore, the findings indicate that girls and boys differ in their weight-related bone properties, muscle strength and motor performance. Thus, a new outlook is needed for designing exercises aimed at strengthening bones and muscles in young children which must take into account gender and weight interactively. In addition, longitudinal studies should accompany implementation of such programs.

CONCLUSIONS AND RECOMMENDATIONS

Physical education teachers and health professionals in schools need to start the process by using structured observations to monitor the duration and intensity of physical activity of just for young obese children. It is important that group or individual activities for obese children include impact exercises that apply loads to bones of the upper and lower body, exercises that strengthen upper and lower body muscles, and coordination exercises.

Following are some sample exercises:

Load on bones:
Lower body:
Jump up and down on one leg; gradually increase the number of jumps.

Upper body:
1. Starting position – on all fours, forward: shift your weight to hands
2. Starting position – on all fours, rear: move backwards, leading with your hands

Muscle strength:
1. Climb a pole in the playground.
2. Starting position – hang with your face to the ladder: climb using only your hands.

Coordination:
1. Pass over and under obstacles in different ways
2. Make various asymmetric movements with your limbs simultaneously, gradually increasing the speed.

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