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Relationship between Skeletal Muscle and Physical Activity in 4- to 6-Year-Olds

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Abstract: Purpose: Physical activity (PA) is likely the most important modifiable element for the growth of skeletal muscle. However, a detailed investigation of PA's impact on preschoolers' of skeletal muscle development is lacking. This study aimed to determine whether PA level is related to skeletal muscle thickness among preschool children. **Methods**: 275 healthy preschoolers between the ages 4–6 were instructed to wear an accelerometer for 4 consecutive days. The daily steps and minutes spent in moderate-to-vigorous PA (MVPA) and total PA (TPA) were examined. Muscle thickness (MT) was measured by B-mode ultrasonography. The MT was measured at the anterior (AT) and posterior thigh (PT) and the anterior (AL) and posterior lower leg (PL). **Results**: Boys were more physically active and engaged in significantly more TPA and MVPA on weekdays compared with girls. Compared with that on the weekends, more physical activity, and significantly greater number of daily steps and higher TPA and MVPA were recorded for both boys and girls on the weekdays. Multivariable regression analyses, after adjusting for daylight duration, indicated that a daily increase in the TPA and MVPA would lead to higher muscle size in AT (β=1.11 and β=1.37, $p<0.05$), and PL (β=1.18 and β=0.94, $p<0.05$) among preschool children. **Conclusions**: The time spent involved in most of the different categories of MVPA was significantly higher for boys than for girls on the weekdays and weekends. MVPA was positively correlated with greater skeletal muscle development in the lower body.

Keywords: accelerometer; muscle thickness; growth; development

1. Introduction

It is increasingly acknowledged that physical activity (PA) and physical inactivity may represent distinct constructs with respect to body composition and health-related quality of life (1). The health benefits of PA in both adults and children are well-known (2, 3). The absence of PA directly influences metabolism, bone mineral content (4), vascular health and overall cardiometabolic dysfunction, with mechanisms biologically distinct from those associated with the cardiometabolic benefits of PA (5). PA has independent and qualitatively different effects on human metabolism, such as muscle mass, fat mass (6), and body composition (7), and has been linked with adult hypertension, type 2 diabetes and their premorbid risk factors. Moreover, emerging evidence suggests that PA declines with age throughout adolescence, although evidence on the magnitude of the decline is equivocal. In addition, inactivity may track into adulthood (8), resulting in a higher risk of health complications later in life (9). Thus, early assessment of PA can help children, especially preschool children to develop a good personal healthy lifestyle.

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Muscle thickness (MT) is often considered a surrogate measure for skeletal muscle mass. Two large muscle groups are located in the thigh: the quadriceps femoris muscles in the anterior of the thigh, and the hamstring in the posterior. The quadriceps muscles play an important role in the lateral rotation of the leg, flexion of the thigh, and extension of the leg. During the last several decades, the quadriceps muscle group has been commonly used as a marker of age-related changes in muscle size and lower limb strength (10),(11). The maintenance of skeletal muscle throughout a life span is important from both a functional and metabolic perspective (12). Skeletal muscle can react to a range of stimuli and is quite malleable, and it is an important predictor of several physiological capacities expressed in absolute terms (13). Thus, there are many important PA interrelationships between health and aging that may contribute to the age-related muscle mass decrease in middle- and old-aged populations. Scott et al (14) reported that ambulatory activity is correlated with both leg strength and leg muscle quality in women aged 50–79 years. The relationship between ambulatory activity and both leg strength and leg muscle quality were nonsignificant in men. Moreover, studies on the relationship between PA and skeletal muscle mass have focused mainly on elderly people, who have less physical inactivity and decreased muscle mass due to the natural physiological process of aging (15). Gender, body composition (i.e., fat-free mass), and pubertal status have an impact on muscle strength for adolescent. Several studies have reported that PA as a significant stimulant for the musculoskeletal system to increase fat-free mass, which in turn improves muscular strength (16, 17). Although several studies have assessed the influence of age and gender on skeletal muscle (18),(19),(20),(21), the relationship of the quantity and quality of PA with the distribution of skeletal muscle mass has not been thoroughly investigated, especially in preschool children. Understanding the interrelationships between PA and skeletal muscle may be useful in the development of therapeutic strategies designed to increase skeletal muscle and to improve functional capacity for preschool children.

Therefore, the objectives of this study were to determine whether PA level is related to skeletal muscle thickness among preschool children. Our hypothesis was that there would be a positive correlation between of muscle mass and habitual PA (number of daily steps and duration of moderate -to- vigorous PA) in our assessments. To the best of our knowledge, this is the first study investigating the association between skeletal muscle and PA in Japanese preschoolers.

2. Methods

2.1. Participants

A total of 275 healthy preschoolers between the aged of 4–6 year participated in the study. Attendance at the preschool under research, parental consent to participate in the study, and lack of injuries or existing illnesses were the requirements for admittance to the study. Parents/guardians of the child's provided informed consent for participating in this study, which adheres to the guidelines of the Declaration of Helsinki and was approved by the ethics committee of Juntendo University.

2.2. Anthropometrics Data

Body mass, wearing only minimal clothing, was measured on a digital balance to the nearest 0.1 kg, and height was measured on a stadiometer to the nearest 0.1 cm. BMI (kg/m^2) was calculated as body weight/height squared.

2.3. Muscle Thickness

B-mode ultrasonography was used to measure MT with a 5-18 MHz scanning head (Noblus; Hitachi, Tokyo, Japan). A water-soluble transmission gel was used to prepare the scanning head, allowing for acoustic contact without depressing the skin surface. MTs was obtained at four sites for the anterior and posterior surfaces of the body. The sites included the anterior and posterior thigh, and the anterior and posterior lower leg. The anatomical landmarks for the chosen sites were defined as follows: anterior (AT) and posterior (PT) thigh was on the anterior and posterior surfaces of the upper leg, midway between the lateral condyle of the femur near the knee and the greater trochanter

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at the hip; anterior (AL) and posterior (PL) lower leg was about 30% proximally between the lateral malleolus of the tibia close to the knee and the lateral malleolus of the fibula close to the ankle.

2.4. Physical Activity

We measured PA using a uniaxial accelerometer (AC), the Kenz Lifecorder GS (Suzuken Co., Ltd, Nagoya, Japan; weight 60 g). Preschoolers attached the AC to the waist and wore it from the time they woke up until bedtime. They were instructed to wear the AC while providing data for consecutive days. The accelerometer had previously been proven reliale in children and adolescents (22, 23). Intensity levels were classified as light (LPA, AC intensity levels of 1–3 and 1.5–2.9 METs), moderate (MPA, AC intensity levels of 4–6 and 3.0–5.9 METs) or vigorous (VPA, AC intensity levels of 7–9 and ≥6.0 METs)(24, 25). We recorded crude step counts to estimate activity levels, and the time spent in MVPA (≥3.0 METs) was calculated as the sum of the MPA and VPA minutes. Total PA (TPA) was calculated as the daily sum of LPA, MPA and VPA. For inclusion in the following study, there has to be a minimum of 10 hours of wear time pre day over the course of at least two days of recording (including a weekend day)(26). Furthermore, we excluded days during when no signal was detected for more than one hour; this time was regarded as non-wearing time.

2.5. Statistical Analyses

All data were analyzed using SPSS Statistics Version 22.0. (IBM Corporation, USA). For descriptive analyses, the results are presented as the mean ± SD. Gender differences in BMI and MT variables were analyzed using independent t-tests. The effects of sex and day of the week on PA outcomes were examined using two-way ANOVA models. An ANOVA was utilized with the Bonferroni post hoc test was to establish significance. Multivariate linear and linearity-using residual plots were used to investigate the relationships between PA and muscle size . Each variable of PA behavior per week (daily steps, TPA, LPA, MVPA) and muscle size (AT, PT, AL, PL) was subjected to regression analyses (AT, PT, AL and PL). Variables that were reported and objectively measured were examined and presented individually. Covariates included age, height weight and PA monitor wear time. We adjusted for age, height, and weight to the original model (Model 1). The second model was modified to account for daylight hour (Model 2). Thus, the daily step, TPA, LPA, and MVPA per week were calculated as [(weekday average values*5) + (weekend average values*2)]/7. Boys and girls were included in the analyses since there was no moderating effect of gender on the relationship between PA and muscle size. Standardized parameters, p-values and R2 increase are presented. The significance level was set at P<0.05 for all statistical analyses.

3. Results

Characteristics of the 275 participants are shown in Table 1. The sample was 45.1% boys and the mean age of participants was 5.5±0.6 years. Independent t-tests revealed no significant gender differences in BMI and MT variables. Compared with girls, boys were more physically active and engaged in significantly more TPA and MVPA on weekdays (p<0.05). Furthermore, compared with weekends, weekdays showed more physical activity and significantly more daily steps, TPA, LPA and MVPA in both boys and girls.

Table 1. Descriptive statistics for characteristics, muscle thickness, and physical activity in both boys and girls.

	All	Boys	Girls	Sex	Daily
	n=275	n=124	n=151	Difference	Difference
Age	5.5±0.5	5.5±0.6	5.5±0.5		
Height (cm)	109.5±5.0	109.7±5.0	109.4±5.0	P=0.25	
Weight (kg)	18.4±2.7	18.3±2.6	18.4±2.8	P=0.16	
BMI (kg/m^2) [a]	15.2±1.5	15.2±1.4	15.3±1.5	P=0.12	
Muscle thickness [a]					

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AT (mm)	24.1±2.7	23.6±2.6	24.4±2.8	P=0.16	
PT (mm)	33.5±2.9	34.0±3.0	33.0±2.8	P=0.10	
AL (mm)	13.3±1.3	13.6±1.2	13.2±1.4	P=0.22	
PL (mm)	37.9±3.0	38.1±2.8	37.7±3.2	P=0.19	
Physical activity on weekdays [b]					
Daylight duration (hour/day)	11.1±1.3	10.9±2.1	11.2±1.5	P=0.33	
Daily step (step)	15373±3392	16206±3546	16488±3108	P=0.16	
TPA (min)	153.8±33.0	161.8±33.8	147.2±31.0	P=0.07	
LPA (min)	102.6±20.5	106.8±20.4	99.1±20.0	P<0.05	
MVPA (time)	51.2±15.9	55.0±17.4	48.0±13.8	P<0.05	
Physical activity on weekends [b]					
Daylight duration (hour/day)	10.5±1.1	10.3±1.2	10.5±1.0	P=0.29	P=0.35
Daily step (step)	10629±4016	10514±3913	10724±4110	P=0.16	P<0.05
TPA (time)	109.0±40.0	108.6±39.7	109.3±40.3	P=0.07	P<0.05
LPA (time)	77.3±26.3	77.4±26.3	77.2±26.4	P=0.31	P<0.05
MVPA (time)	32.2±16.2	31.2±16.2	32.1±11.7	P=0.25	P<0.05

Data are present as mean ± SD. BMI: body mass index; AT: anterior thigh; PT: posterior thigh; AL: anterior lower leg; PL: posterior lower leg; TPA: total physical activity; LPA: light physical activity; MVPA: moderate to vigorous physical activity. [a] Tested with t-test.[b] Tests with Bonferroni-corrected analyses of variance.

Table 2 presents the outcomes of models 1 and 2 for variables that were assessed objectively and subjectively, respectively. Adjusting for height, weight, and daylight duration had little to no effect on the regression coefficients (Model 2).

When classified in PA intensities and based on model 2, we found a positive relationship between PA and muscle size. Our fundings suggest that AT's muscle size would increase with a daily increase in TPA (β=1.11, p<0.05) and PL (β=0.94, p<0.05) for preschool children. With the same increase in MVPA, the correlation with muscle size in AT and PL was as positive relationship between TPA and muscle size in AT (β=1.37, p<0.05) and PL (β=1.18, p<0.05) for preschool children. However, the number of daily steps and LPA showed no clear correlation with muscle size for preschool children, respectively.

Table 2. Multivariate linear regression investigating the association of accelerometer-based PA data with muscle size.

	Model 1 a			Model 2		
	Adjusted for sex, age, height and weight			Model 1 + adjusted for daylight duration		
	β	p value	R^2	β	p value	R^2
Anterior thigh						
Daily steps (steps/day)	0.11	0.15	0.151	-0.84	0.75	0.169
LPA (min/day)	0.13	0.21	0.175	-0.05	0.89	0.183
MVPA (min/day)	0.76	<0.05	0.181	1.37	<0.05	0.242
TPA (min/day)	1.23	<0.05	0.177	1.11	<0.05	0.238
Posterior thigh						
Daily steps (steps/day)	1.86	0.87	0.156	1.02	0.86	0.157
LPA (min/day)	0.68	0.96	0.227	0.43	0.15	0.225
MVPA (min/day)	0.55	0.93	0.238	1.74	0.98	0.263
TPA (min/day)	-0.91	0.74	0.167	0.94	0.26	0.267
Anterior lower leg						

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Daily steps (steps/day)	0.72	0.56	0.208	-1.33	0.45	0.296
LPA (min/day)	0.45	0.38	0.342	0.09	0.69	0.263
MVPA (min/day)	0.01	0.92	0.174	-0.44	0.11	0.272
TPA (min/day)	0.05	0.22	0.237	-0.04	0.50	0.184
Posterior lower leg						
Daily steps (steps/day)	0.72	0.56	0.208	-0.03	0.45	0.196
LPA (min/day)	0.45	0.38	0.142	-0.01	0.35	0.242
MVPA (min/day)	1.61	<0.05	0.248	1.18	<0.05	0.190
TPA (min/day)	0.81	<0.05	0.246	0.94	<0.05	0.186

TPA: total physical activity; LPA: light physical activity; MVPA: moderate to vigorous physical activity. The standardized regression coefficient (β), P value, and coefficient of determination (R2) are given for each association. PA: physical activity. [a] In Model 1, the independent variables were adjusted as follows: sex, age, height and weight. [b] In Model 2, the independent variables were (in addition to Model 2) adjusted as follows: daily steps and time of accelerometer based MVPA and TPA per week.

4. Discussion

Preschool children are always subject to dynamic physical growth and development. Due to the significant impacts of PA on the health of preschool children, an accurate understanding of the association between PA and skeletal muscle size of great importance. The results indicate that, over the course of a week, higher mean levels of MVPA are correlated with thicker muscle size in the thigh and lower leg. This is not surprising, given that the muscles in the lower body are required for most common actives (i.e., walking, running, stair climbing). In addition, our results indicate, that skeletal muscle size development can be promoted by MVPA for preschool children.

The relationship of PA with muscle size is poorly understood especially in preschool children. Interestingly, a recent study observed positive correlations between vigorous PA and lower-body muscle strength in tests of adolescents and adults (10, 27). The adolescents who were involved in resistance training had significantly higher muscular strength scores than the young in the low and medium tertials of PA, but no significant differences were found when they were compared with non-lifters from the highest tertial of PA (28). Moreover, it has been observed that an age-related site-specific loss of skeletal muscle mass is observed in men and women, especially for the anterior upper-leg muscles (29). Similarly, one longitudinal study found significant reductions in the quadriceps muscle cross-sectional areas, whereas, the posterior thigh muscle mass did not change with increasing age (30). The results of the present study and the previous studies together suggest that the duration of PA is an important predictor of, and may be strongly associated with, age-related, site-specific increase of thigh muscle.

The distinct natures of PA and muscle size include physiological responses and adaptations that are not merely opposites of one another. However, there is a lack of evidence determine the optimal amount of PA for an adequate skeletal development in preschoolers.. Our study indicates that MVPA was correlated with muscle size in the thigh and lower leg, especially in boys. Furthermore, a recent study has demonstrated that an additional 10 min/day of MPA or VPA increased the bone stiffness by 1–2% on average based on a large sample of children aged 2–10 years (31). Park et al (32) demonstrated that muscle mass in the lower extremities as measured by whole-body dual-energy X-ray absorptiometry was associated with physical activity such as the daily step count based on a sample of children aged 2–3 years. Katzmarzyk et al analyzed 356 boys and 284 girls (9–18 years) from the Quebec Family Study and found a weak association between PA and the static strength of the legs in a maximal voluntary isometric contraction at a knee angle of 90° and a low/no significant correlation between PA and the sum of skinfolds (33). It is challenging to distinguish between the effects of muscular forces and the effects of physical impact brought on by growth and development because higher levels of PA should, in theory, result in stronger muscles.

In this study, the distribution of muscle mass differed between boys and girls. In individuals with similar body height and weight, boys had larger lower- and smaller upper-extremity muscles as compared to girls. These differences may partly be caused by the fact that most boys performed PA, predominantly doing more MVPA, and the kind of PA may play an important role for MT. For example, previous studies reported a consistent mean increase of 3–4% in thigh muscle volume following a 5-week training program in boys and girls (34),(35). However, it is important to consider that most children do not engage in highly structured training regimens such as those imposed in exercise training studies; therefore, the importance of considering the influence of habitual, free-living PA over a period of time (i.e., the preschoolers growth spurt) is a novel and practical aspect of the present study. Nevertheless, our findings suggest the influence on PA with thigh muscle tended to increase with age, both in boys and girls. This finding is important, since preschoolers represents not only the period of the lifespan when PA levels increase substantially (36),(37), but also a time when substantial changes in body composition are occurring, so it becomes more important to ascertain the positive influence of habitual PA. Furthermore, the development of skeletal mass has important implications for metabolic health (38).

There are some limitations of this study. First, since our sample was only in urban areas, our findings may not apply to preschool in other regions of Japan. Secondly, the cross-sectional design makes it impossible to establish a causal relationship between high PA and greater skeletal muscle mass content. Thirdly, accelerometers also have some limitations with respect to assessing the overall activity levels. We also acknowledge that a shorter accelerometer period (e.g. 5s) is strongly recommended for children because their PA is often intermittent (39). Therefore, the amount of sedentary time and vigorous PA may have been underestimated, and moderate PA may have been overestimated. Finally, we acknowledge the limitation of a cross-sectional design and recognize that longitudinal studies are needed to better understand the associated between PA and MT of children from an early age.

In conclusion, this study examined the relationship between preschool children's skeletal muscle development and PA by objective measurements and whether their gender made a difference. Moreover, the data shows that the times spent in most of the different categories of MVPA by boys were significantly higher than those of girls on both weekdays and weekends. MVPA was positively correlated with higher skeletal muscle in the lower body. The relationship of PA and skeletal muscle should play a greater role in questions of obesity and osteoporosis prevention undertaken during childhood.

Author Contributions: P.D., H.O., T. N., Y. I., D. K., K. S., H.N. conceived and designed the study. P.D., H.O. and T.N. performed the data collection. D.P., H. O. and Y. I. analyzed the data. P.D. and H.O. wrote the manuscript. T. N., Y. I., D. K., K. S. and H.N. reviewed and critically revised the manuscript. All authors have read and agreed to the published version of the manuscript.

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Institutional Review Board Statement: The study was conducted according to the guidelines of the Declaration of Helsinki and approved by the Institutional Review Board of Juntendo University (HSS #28-91).

Informed Consent Statement: Informed consent was obtained from the parents for each young child.

Data Availability Statement: The data presented in this study are available on request from the corresponding author. The data are not publicly available due to privacy restrictions.

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References

1. Rennie K. L., Wells J. C., McCaffrey, T. A., Livingstone, M. B. The effect of physical activity on body fatness in children and adolescents. Proc Nutr Soc. 2006;65(4):393-402.
2. Janssen I. and Leblanc A. G. Systematic review of the health benefits of physical activity and fitness in school-aged children and youth. INT J Behav Nutr Phys Act. 2010;7:40.
3. Warburton D. E., Nicol C. W., Bredin, S. S. Health benefits of physical activity: the evidence. CMAJ 2006;174(6):801-9.
4. Bailey D. A., Faulkner R. A., McKay, H. A. Growth, physical activity, and bone mineral acquisition. Exerc Sport Sci Rev. 1996;24:233-66.
5. Tremblay M. S., Colley R. C., Saunders, T. J., Healy, G. N., Owen, N. Physiological and health implications of a sedentary lifestyle. Appl Physiol Nutr Me. 2010;35(6):725-40.
6. Snyder W. S., Cook M. J., Nasset, E. S., Karhausen, L. R., Howells, G. P., Tipton, I. H. Report of the Task Group in Reference Man (International Commission on Radiological Protection No. 23). Pergamon Press. Now York. 1984.
7. Huang T. T., Johnson M. S., Figueroa-Colon, R., Dwyer, J. H., Goran, M. I Growth of visceral fat, subcutaneous abdominal fat, and total body fat in children. Obes Res. 2001;9(5):283-9.
8. Telama R., Yang X., Viikari, J., Valimaki, I., Wanne, O., Raitakari, O. Physical activity from childhood to adulthood: a 21-year tracking study. Am J Prev Med. 2005;28(3):267-73.
9. Khaw K. T., Wareham N., Bingham, S.,. Combined impact of health behaviours and mortality in men and women: the EPIC-Norfolk prospective population study. PLoS Med. 2008;5(1):e12.
10. Abe T., Sakamaki M., Yasuda, T., et al. Age-related, site-specific muscle loss in 1507 Japanese men and women aged 20 to 95 years. J Sports Sci Med. 2011;10(1):145-50.
11. Frontera W. R., Hughes V. A., Fielding, R. A., Fiatarone, M. A., Evans, W. J., Roubenoff, R. Aging of skeletal muscle: a 12-yr longitudinal study. J Appl Physiol (1985). 2000;88(4):1321-6.
12. Booth F. W., Chakravarthy M. V., Gordon, S. E., Spangenburg, E. E. Waging war on physical inactivity: using modern molecular ammunition against an ancient enemy. J Appl Physiol. 2002;93(1):3-30.
13. Armstrong N. and Welsman J. R. Peak oxygen uptake in relation to growth and maturation in 11-to 17-year-old humans. Eur J Appl Physiol. 2001;85(6):546-51.
14. Scott D., Blizzard L., Fell, J., Jones, G. Ambulatory activity, body composition, and lower-limb muscle strength in older adults. Med Sci Sports Exerc. 2009;41(2):383-9.
15. Kim B. C., Kim M. K., Han, K., et al. Low muscle mass is associated with metabolic syndrome only in nonobese young adults: the Korea National Health and Nutrition Examination Survey 2008-2010. Nutr Res. 2015;35(12):1070-8.
16. Baxter-Jones A. D. G., Eisenmann J. C., Mirwald, R. L., Faulkner, R. A., Bailey, D. A. The influence of physical activity on lean mass accrual during adolescence: a longitudinal analysis. J Appl Physiol. 2008;105(2):734-41.
17. Ara I., Vicente-Rodriguez G., Jimenez-Ramirez, J., Dorado, C., Serrano-Sanchez, J. A., Calbet, J. A. L. Regular participation in sports is associated with enhanced physical

fitness and lower fat mass in prepubertal boys. Int J Obesity. 2004;28(12):1585-93.
18. Cohn S. H., Vartsky D., Yasumura, S., et al. Compartmental body composition based on total-body nitrogen, potassium, and calcium. Am J Physiol. 1980;239(6):E524-30.
19. Gallagher D. and Heymsfield S. B. Muscle distribution: variations with body weight, gender, and age. Appl Radiat Isot. 1998;49(5-6):733-4.
20. Gallagher D., Visser M., De Meersman, R. E., et al. Appendicular skeletal muscle mass: effects of age, gender, and ethnicity. J Appl Physiol (1985). 1997;83(1):229-39.
21. Kehayias J. J., Fiatarone M. A., Zhuang, H., Roubenoff, R. Total body potassium and body fat: relevance to aging. Am J Clin Nutr. 1997;66(4):904-10.
22. Adachi M., Sasayama K., Hikihara, Y., et al. Assessing daily physical activity in elementary school students used by accelerometer: a validation study against doubly labeled water method. Jpn. J. Phys. Fitness Sport Med. 2007;56(3):347 - 55.
23. Jimenez-Pavon D., Kelly J., Reilly, J. J. Associations between objectively measured habitual physical activity and adiposity in children and adolescents: Systematic review. Int J Pediatr Obes. 2010;5(1):3-18.
24. Hikihara Y., Sasayama K., Okishima, K., et al. The difference of relationships between physical activity variables and physical fitness in children and adolescents: with special reference to amount and intensity of physical activity. Jpn J Phys Fitness Sports Med. 2007;56(3):327-39.
25. Adachi M., K. S., Ando, K. Relationship between walking or running speed and exercise intensity measured by Accelerometer on Japanese school children and adolescens (Japanese). Bull Fac Eudc Okayama Univ. 2005;128:141-5.
26. Trost S. G., McIver K. L., Pate, R. R. Conducting Accelerometer-Based Activity Assessments in Field-Based Research. Med Sci Sports Exerc. 2005;37(Supplement):S531-S43.
27. Moliner-Urdiales D., Ortega F. B., Vicente-Rodriguez, G., et al. Association of physical activity with muscular strength and fat-free mass in adolescents: the HELENA study. Eur J Appl Physiol. 2010;109(6):1119-27.
28. Martinez-Gomez D., Welk G. J., Puertollano, M. A., et al. Associations of physical activity with muscular fitness in adolescents. Scand J Med Sci Sports. 2011;21(2):310-7.
29. Ogawa M., Yasuda T., Abe, T. Component characteristics of thigh muscle volume in young and older healthy men. Clin Physiol Funct imaging. 2012;32(2):89-93.
30. Frontera W. R., Reid K. F., Phillips, E. M., et al. Muscle fiber size and function in elderly humans: a longitudinal study. J Appl Physiol (1985). 2008;105(2):637-42.
31. Herrmann D., Buck C., Sioen, I., et al. Impact of physical activity, sedentary behaviour and muscle strength on bone stiffness in 2-10-year-old children-cross-sectional results from the IDEFICS study. Int J Behav Nutr Phys Act. 2015;12:112.
32. Park H., Park S., Shephard, R. J., Aoyagi, Y. Yearlong physical activity and sarcopenia in older adults: the Nakanojo Study. Eur J Appl Physiol. 2010;109(5):953-61.
33. Katzmarzyk P. T., Malina R. M., Song, T. M., Bouchard, C. Physical activity and health-related fitness in youth: a multivariate analysis. Med Sci Sports Exerc. 1998;30(5):709-14.
34. Eliakim A., Scheett T., Allmendinger, N., Brasel, J. A., Cooper, D. M. Training, muscle volume, and energy expenditure in nonobese American girls. J Appl Physiol (1985).

2001;90(1):35-44.
35. Eliakim A., Brasel J. A., Baxter-Jones, A. D., Tremblay, M. S. Increased physical activity and the growth hormone-IGF-I axis in adolescent males. Am J Physiol. 1998;275(1 Pt 2):R308-14.
36. Sherar L. B., Esliger D. W., et al. Age and gender differences in youth physical activity: does physical maturity matter? Med Sci Sports Exerc. 2007;39(5):830-5.
37. Trost S. G., Pate R. R., Sallis, J. F., et al. Age and gender differences in objectively measured physical activity in youth. Med Sci Sports Exerc. 2002;34(2):350-5.
38. Wolfe R. R. The underappreciated role of muscle in health and disease. Am J Clin Nutr. 2006;84(3):475-82.
39. Edwardson C. L. and Gorely T. Epoch length and its effect on physical activity intensity. Med Sci Sports Exerc. 2010;42(5):928-34.