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ORIGINAL ARTICLE

Association of objectively measured physical activity and sedentary behavior with bone stiffness in peripubertal children

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Abstract

Introduction Physical activity (PA) is a key factor of bone mass acquisition in peripubertal children. Sedentary behavior (SB) has been shown to influence bone outcomes. This study aimed to examine the association between objectively measured PA and SB and bone stiffness in Japanese children.

Materials and Methods Participants were fifth-grade children aged 10–11 years from Project Koshu. The stiffness index (SI) of the calcaneus was measured by quantitative ultrasound; PA and SB were evaluated by an accelerometer. Each PA parameter was divided into sex-specific tertile or stratified by recommended PA guideline [≥60 min/day of moderate-to-vigorous PA (MVPA)]. The SI was compared among PA and SB through analysis of covariance with Bonferroni correction.

Results Of 174 children, complete data were obtained from 134 (60 boys and 74 girls). The SI in boys was higher in the highest tertile of MVPA than that in the other groups. A similar association was found in girls but was not significant. Children who met the PA guideline had higher SI than those who did not, but there was no significant difference. A negative relation was observed in girls, with the SI gradually decreasing along with increasing SB (p for trend = 0.038). This association was not observed among boys.

Conclusion This study suggests that MVPA is positively associated with bone stiffness in Japanese schoolchildren in boys and SB is negatively associated with that in girls. Reducing SB might be a brief modifiable factor for preventing lower peak bone mass in girls, in addition to increasing MVPA.

Keywords Physical activity · Sedentary time · Quantitative ultrasound · Schoolchildren · Bone stiffness

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Introduction

Osteoporosis is an important public health problem for Japan and other countries with rapidly aging populations. One of the strong predictors for osteoporosis risk in old age is the optimization of peak bone mass (PBM) during the growth period. Acquiring a high PBM may decrease the risk of osteoporotic fractures in later life by 50% [1]. The peripubertal stage is an important period for attaining PBM [2, 3], in which a 5–10% change may result in a 25–50% difference in hip fracture later in life [4]. Although non-modifiable genetic factors have been shown to mainly contribute to PBM, environmental and lifestyle factors are estimated to influence 20–40% of adult PBM [5–7].

Physical activity (PA), particularly high-impact PA such as weight bearing, has been identified as the most important modifiable factors associated with improved bone health outcomes [5–9]. However, globally, 81% of school-age children and adolescents aged 11–17 years do not meet the recommended guideline [10] of at least 60 min of moderate-to-vigorous PA (MVPA) daily [11]. Among Japanese children, 46.0% of boys and 69.4% of girls in fifth grade (aged 10–11 years) engage in exercise for less than 420 min/week, not including that in physical education classes [12]. Hence, the majority of Japanese school-aged children do not achieve PA recommendations.

Moreover, in recent years, the time previously spent in MVPA has been replaced by the increased time children spend in sedentary behaviors (SB) characterized as screen-based behaviors including watching TV, using computers/smartphones, playing video games, and/or viewing social media [13]. Independent of time spent on MVPA, SB has been shown to influence several major chronic diseases and all-cause mortality in adults [14, 15]. SB also contributes to reduced physical and psychosocial health and that low sedentary time leads to reductions in body mass index (BMI) in children and adolescent [16]. Thus, the effects of SB on several metabolic diseases have received much attention, but little is known about the effect of SB on bone health [17]. Recently, although several studies have indicated that objectively measured SB is negatively associated with bone outcomes in schoolchildren, there was insufficient evidence to fully support an association [18]. Moreover, to the best of our knowledge, no studies on the association of SB and bone mass in Japanese peripubertal children are available.

Therefore, this study aimed to investigate whether objectively measured PA, particularly MVPA, and SB are associated with bone stiffness in Japanese peripubertal children as measured by calcaneus quantitative ultrasound (QUS), which is valued for its high correlation with bone mineral density (BMD) measurements [19] and is widely used for bone measurement in schoolchildren, because it is radiation-free and easy to measure [20].

Materials and methods

Participants

The participants were from Project Koshu, a community-based prospective birth cohort study. Project Koshu is an ongoing study (started in 1988) in which all expectant mothers who responded to a survey during the obligatory visit at the city office for pregnancy registration were recruited into the cohort. The children were followed from birth onwards. Further details of the project have been reported elsewhere [21]. The bone mass survey for elementary school grade 4 to junior high school grade 3 (aged 9–15 years) has been conducted every August and September since 2006 as part of a survey of Project Koshu. The data of the present study were based on an annual bone mass survey carried out in 2015 ($n = 836$). A PA survey using an accelerometer as an extra module to the annual bone mass survey was conducted for all fifth-grade children ($n = 287$) in 13 schools in Koshu City in December 2015. In this study, 174 children (82 boys and 92 girls) who participated in both bone mass and PA surveys were enrolled.

This study was approved by the ethics committee of the Faculty of Medicine, University of Yamanashi (approval no. 1398), and conducted in accordance with the cooperation of the Health Promotion Division and the Board of Education of the Koshu City administration office. All principals of participating schools provided ethical approval. All participants provided their informed assent to participate, and written informed consent was obtained from their guardians.

Measurements

Objectively measured PA and SB

PA and SB were measured with uniaxial accelerometers [Lifecorder (LC) GS; Suzuken, Nagoya, Japan] worn on clothes over the right waist during waking hours for 2 weeks, except when bathing, swimming, or while playing sports with high risk of injury. LC is a well-accepted measure of total daily PA in children and adults [22, 23]. Movement counts were recorded in 2-min epochs. Activity data were categorized by intensity into 11 levels (0, 0.5, and 1.0–9.0). Level 0 indicates immobility and levels 0.5–9.0 reflect movement by intensity level. In this study, the corresponding MET values classified the activity intensity as sedentary (0–0.5; < 1.5 METs), light (1–3; ≥ 1.5 to < 3 METs), moderate (4–6; ≥ 3 to < 6 METs), or vigorous (7–9; ≥ 6 METs). Continuous zero counts ≥ 20 min was considered as not wearing the LC and invalid data. Data recorded on the first day were not included owing to some reactivity risks. Participants were included for analysis if wear time was more than 10 h per day and they had complete data for a minimum of 4 days (3 weekdays and 1 weekend day). Individual representative value of each PA parameter was calculated by the following formula: (weekday average $\times$ 5 + weekend day average $\times$ 2)/7. Time spent in MVPA (≥ 3 METs) was calculated as the sum of both time in moderate and vigorous activity. SB time was divided into sex-specific tertiles, as cutoffs are not consensual. MVPA, light PA (LPA), moderate PA (MPA), and vigorous PA (VPA) were also divided into sex-specific tertiles and additionally classified as non-active and active according to the PA guideline for children, which recommends ≥ 60 min/day of MVPA [10].

Bone stiffness index by QUS

Bone stiffness was assessed by QUS. QUS measurements were performed with an Achilles A-1000 Insight (GE Healthcare, Milwaukee, WI, USA). This portable device measures bone stiffness using ultrasound waves and presents three parameters: (1) broadband ultrasound attenuation (BUA) reflects the absorption of sound waves (dB/MHz); (2) speed of sounds (SOS) expresses the stiffness of a material by the ratio of the traversed distance to the transit time (m/s); (3) stiffness index (SI) is the automatically calculated parameter that combines BUA and SOS values [$SI = (0.667 \times BUA) + (0.278 \times SOS) - 417$]. The SI of the right foot calcaneus was used as the bone mass parameter in this study.

To equalize the measurement conditions, setup was completed 20 min before the start of measurement for children; the room temperature at the time of measurement in each school was controlled at 25–27 °C; calibration was performed; and the stability of the measurement results was confirmed. In addition, measurement was made according to the standard procedure provided by the manufacturer, and the real-time image of the calcaneus and the region of interest were confirmed. The coefficients of variation (CVs), evaluated by duplicate measurements in 215 children (aged 9–15 years), were 2.3% for BUA, 0.2% for SOS, and 2.0% for SI.

Covariates

Age in month, body weight, calcium intake, puberty status, and socioeconomic (SES) status were identified as potential confounders based on the previous studies [7, 24].

Body composition measurements

Age and body weight of children were collected via physical measurements taken during medical checkups conducted at elementary schools, which are measured annually in April for each grade, in accordance with Japanese School Health and Safety Law. BMI (kg/m^2) was calculated from height and weight.

Calcium intake

Calcium intake was estimated from a self-assessment table for calcium intake [25]. The table consists of questions asking the frequency of lack of meal and food intake of the following nine items: milk, yogurt, dairy products, soy and natto, tofu, green vegetables, seaweed, whole eatable fish, and small fish.

The participants of this study were elementary schoolchildren, and milk was provided daily at school lunch; hence, the items related to milk intake frequency at school lunch were added, and items related to whole eatable fish and small fish intake were integrated. In addition, because breakfast skipping is an important problem for elementary schoolchildren [26], the lack of meal item was modified to asking breakfast skipping as follows: eat everyday (3 points), sometimes do not eat occasionally (2 points), often do not eat (1 point), and every day do not eat (0 point). According to the frequency of food intake, 0, 0.5, 1, 2, or 4 points are given, which adds up to 0–3 points for the breakfast skipping item. It is scored, so that 1 point becomes calcium intake equivalent to 40 mg.

Pubertal status

As an indicator of puberty development, the presence of menarche and the school grade and month at first menarche were obtained from the self-reported questionnaire. Pubertal status was classified as dichotomous variables (pre- or post-menarche) because of the low percentage of post-menarche girls.

SES status

To assess family SES, the family affluence scale (FAS), which has been validated in the European Health Behavior in School-aged Children study [27], was used. The FAS is based on four questions: family car ownership; number of family trips per year; having one's own bedroom; total number of computers at home. The scores on these four factors were then summed to provide a continuous affluence variable with possible scores ranging from 0 to 7. The scores were classified into three levels: low (0–3), medium (4, 5), and high (6, 7) [28]. The FAS is considered easy to complete and an accurate, non-sensitive method of addressing the issue of material affluence; hence, it has widespread use in children's surveys [29].

Statistical analysis

Data were analyzed separately for boys and girls based on the results of a previous study that revealed sex differences in bone mass [7]. Pearson's correlation coefficient was used to examine the relationship between the participants' characteristics and SI. Analysis of covariance was used to compare the mean SI among PA and SB tertiles and active or non-active. The analyses were adjusted for age in months, body weight, calcium intake score, pubertal status (for girls), wearing time of the accelerometer, and SES. The model for SB analysis was additionally adjusted for time spent on MVPA. Bonferroni correction was performed for multiple comparisons. The p values for trend were calculated from a linear model using the PA and SB tertiles as a continuous variable.

All statistical analyses were performed using SPSS version 19.0 (IBM Corp., Armonk, NY, USA). A p value < 0.05 (two-sided) was considered statistically significant.

Results

Participant characteristics

The flow of schools and participants is shown in Fig. 1. A total of 174 children participated in the study. Of those, children who had invalid accelerometer data ($n = 27$) and missing data ($n = 13$) were excluded. Therefore, 134 children were included in the final analysis. There were no significant differences between those with complete data compared with the missing data, except for body height in boys and weight and BMI in girls (Online Resource 1). Table 1 shows the characteristics of the study participants by sex. There were no differences between boys and girls in bone parameter, calcium intake score, and family SES. Boys had higher mean MVPA and VPA values. Girls were less likely than boys to meet recommendations for PA guidelines (≥ 60 min MVPA/day) and engaged in more SB than boys.

Table 2 shows the Pearson's correlation coefficients between the characteristics of the participants and SI. In boys, the correlation of SI with MVPA was highest, followed by VPA, and then MPA. In girls, age (in months), menarche, and body shape (height, weight, and BMI) were in relatively high correlation with SI. Among physical activity levels, the correlation with SB was highest.

Association of PA and SB with bone stiffness

Table 3 shows the associations of each PA intensity level and whether or not it met the PA guideline and SI. The SI in boys was significantly higher in the third tertile (highest) of MVPA compared with the first (lowest) and second tertiles (middle), and showed a positive association with time spent on MVPA (p for trend = 0.008). In girls, no significant difference was observed among the categories, but a positive relation was observed, with the SI gradually increasing along with increasing MVPA (p for trend = 0.058). With regard to SB, a negative relation was observed, with the SI gradually decreasing along with increasing SB (p for trend = 0.038) in girls. No significant difference was observed among each category for boys. Participants who met PA guideline had higher SI compared with those who did not, but no statistical significance was observed. The association of VPA and MPA with SI showed a similar trend as MVPA and SI, except for VPA in girls. No significant differences were observed between LPA categories and SI in both sexes.

Discussion

This study examined whether objectively measured PA and SB were associated with bone stiffness in peripubertal children. The results demonstrated that the highest tertile of MVPA (approximately > 77 min MVPA/day) showed significantly higher SI compared with the groups with < 77 min

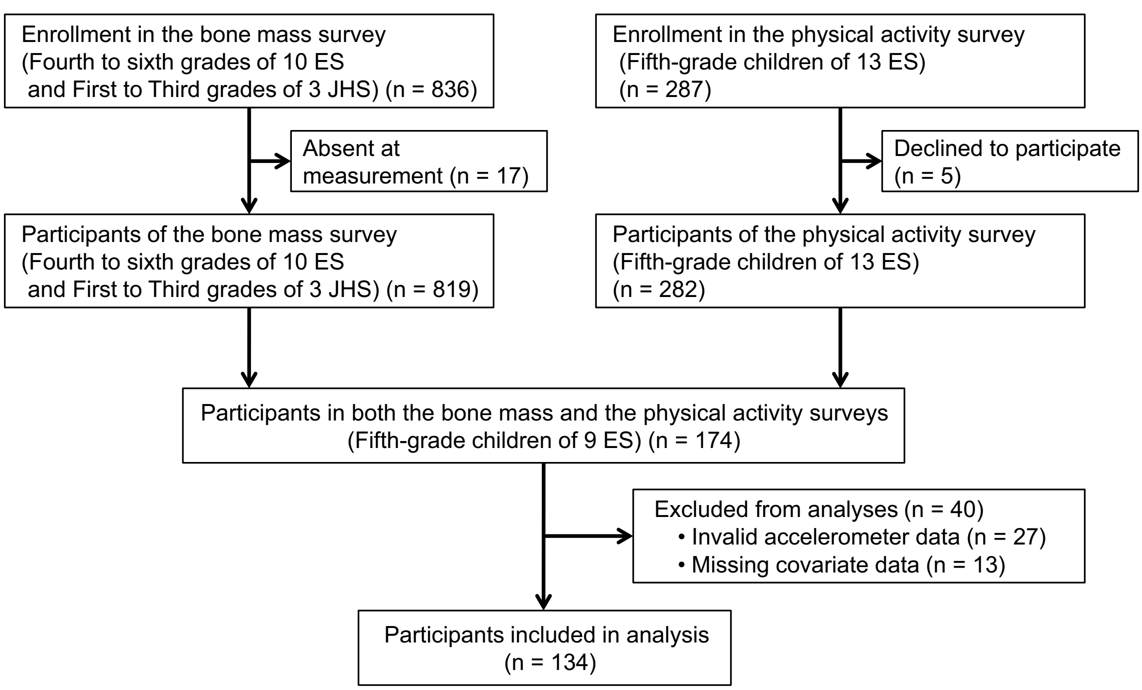

Fig. 1 Flowchart of the participant selection of this study. *ES* elementary school, *JHS* junior high school

Table 1 Characteristics of study participants

	Boys ($n=60$)	Girls ($n=74$)	p
Age (years)	10.8 ± 0.4	10.8 ± 0.4	0.786
Age in month (months)	134.0 ± 3.5	134.3 ± 3.3	0.657
Height (cm)	138.1 ± 5.9	137.9 ± 5.9	0.899
Weight (kg)	33.1 ± 6.7	32.3 ± 5.3	0.445
BMI (kg/m^2)	17.2 ± 2.6	16.9 ± 2.1	0.397
Bone parameters			
SI	83.6 ± 10.2	81.9 ± 10.3	0.331
BUA (dB/MHz)	101.2 ± 11.5	97.7 ± 10.9	0.079
SOS (m/s)	1558.0 ± 16.6	1560.3 ± 21.4	0.500
Objectively measured PA and SB			
MVPA (min/day)	68.3 ± 20.4	58.9 ± 16.4	0.004
Vigorous PA (min/day)	27.4 ± 12.8	20.8 ± 8.5	0.001
Moderate PA (min/day)	40.9 ± 11.3	38.1 ± 11.0	0.141
Light PA (min/day)	104.4 ± 21.9	98.5 ± 19.9	0.102
SB (hours/day)	7.2 ± 0.9	7.7 ± 0.9	0.003
Meeting guideline (≥60 min/day MVPA)	38 (63.3)	34 (45.9)	0.045
Wearing time of accelerometer (h/day)	13.6 ± 0.9	13.9 ± 0.8	0.048
Calcium intake score (points)	15.4 ± 5.1	14.3 ± 4.4	0.172
Menarche	–	9 (12.2)	–
Family SES			
Low	7 (11.7)	7 (9.5)	0.909
Middle	16 (26.7)	21 (28.4)	
High	37 (61.7)	46 (62.2)	

Values are presented as mean ± standard deviation or n (%)

The t test was used for continuous variables, and the Chi-square test was used for categorical variables

BMI body mass index, *SI* stiffness index, *BUA* broadband ultrasound attenuation, *SOS* speed of sounds, *PA* physical activity, *SB* sedentary behavior, *MVPA* moderate-to-vigorous physical activity, *SES* socioeconomic status

Table 2 Pearson's correlation coefficients between participant characteristics and bone stiffness index

	Boys ($n=60$)		Girls ($n=74$)	
	r	p	r	p
Age (months)	0.187	0.152	0.223	0.056
Height (cm)	0.160	0.222	0.240	0.040
Weight (kg)	0.113	0.391	0.261	0.025
BMI (kg/m^2)	0.077	0.559	0.193	0.099
MVPA (min/day)	0.361	0.005	0.162	0.167
Vigorous PA (min/day)	0.326	0.011	0.112	0.342
Moderate PA (min/day)	0.281	0.030	0.155	0.188
Light PA (min/day)	0.136	0.300	−0.012	0.920
SB (h/day)	−0.093	0.482	−0.207	0.077
Calcium intake score (points)	−0.049	0.709	−0.097	0.410
Menarche	–	–	0.195	0.095
Family SES (points)	−0.034	0.797	−0.125	0.290

BMI body mass index, *MVPA* moderate-to-vigorous physical activity, *PA* physical activity, *SB* sedentary behavior, *SES* socioeconomic status

MVPA/day in boys. Although no significant association with MVPA was found in girls, there were positive dose–response trends across MVPA levels for SI in both boys and girls. Meanwhile, a negative trend was observed in the association between SB and SI in girls, but this trend was not observed in boys.

Several systematic reviews have provided solid evidence for the effects of PA interventions on bone mass acquisition in children [8, 30], and the best (grade A) evidence was assigned for the benefit of PA and exercise on bone mass and density in the peripubertal period [7]. Furthermore, many studies have also reported positive associations between the objectively measured habitual MVPA and bone density [30–38] and ultrasound bone measurement (SI) [39–41], especially in VPA [42, 43]. The results of this study were consistent with those of previous studies in boys. However, no significant difference was observed in girls. This may be explained by the difference in PA intensity between boys and girls, aside from limited statistical power. Despite the importance of high-impact and weight-bearing PA in increasing bone mass [3, 9], the time spent in MVPA by girls

Table 3 Association between physical activity intensity level and bone stiffness index

	Boys					Girls				
	n	Cut points (min/day)	SI	95% CI	*p**	*n*	Cut points (min/day)	SI	95% CI	*p**
MVPA (min/day)										
First tertiles (lowest)	20	< 57	80.6	(76.1–85.0)	0.023	24	< 52	80.1	(76.1–84.1)	0.175
Second tertile	20	57–77	80.8	(76.4–85.2)	0.029	25	52–64	80.1	(76.1–84.2)	0.195
Third tertile (highest)	20	> 77	89.5	(84.9–94.0)		25	> 64	85.6	(81.5–89.6)	
				p for trend	0.008				*p* for trend	0.058
SB (h/day)										
First tertile (lowest)	20	< 6.8	83.7	(78.4–88.9)	1.000	24	< 7.2	85.4	(80.8–90.0)	0.114
Second tertile	20	6.8–7.7	83.6	(78.9–88.3)	1.000	25	7.2–8.1	82.5	(78.6–86.4)	0.378
Third tertile (highest)	20	> 7.7	83.5	(78.4–88.7)		25	> 8.1	77.8	(73.4–82.3)	
				p for trend	0.969				*p* for trend	0.038
Meeting PA guideline										
Not meeting	22	< 60	80.8	(78.9–88.3)	0.128	40	< 60	79.9	(76.8–83.1)	0.082
Meeting	38	≥ 60	85.2	(78.4–88.9)		34	≥ 60	84.1	(80.7–87.5)	
VPA (min/day)										
First tertile (lowest)	20	< 20	79.9	(75.2–84.7)	0.044	24	< 16	82.2	(78.2–86.3)	1.000
Second tertile	20	20–32	82.2	(77.7–86.8)	0.153	25	16–22	79.2	(75.1–83.3)	0.276
Third tertile (highest)	20	> 32	88.6	(84.0–93.2)		25	> 22	84.1	(80.1–88.1)	
				p for trend	0.015				*p* for trend	0.523
MPA (min/day)										
First tertile (lowest)	20	< 37	81.6	(77.9–86.2)	0.125	24	< 31	79.2	(75.2–83.2)	0.090
Second tertile	20	37–45	80.8	(76.1–85.6)	0.095	25	31–42	80.9	(76.9–84.9)	0.356
Third tertile (highest)	20	> 45	88.4	(83.7–93.0)		25	> 42	85.4	(81.5–89.3)	
				p for trend	0.042				*p* for trend	0.030
LPA (min/day)										
First tertile (lowest)	20	< 94	82.7	(77.7–87.6)	1.000	24	< 88	80.3	(76.0–84.5)	0.946
Second tertile	20	94–116	82.7	(77.8–87.6)	1.000	25	88–107	81.9	(77.8–86.0)	1.000
Third tertile (highest)	20	> 116	85.4	(80.3–90.5)		25	> 107	83.4	(79.1–87.6)	
				p for trend	0.462				*p* for trend	0.315

Values are presented as adjusted mean and 95% CI

The models adjusted for age in month, body weight, calcium intake score, family socioeconomic status, wearing time of accelerometer, menarche (on girls' model), and time spent on MVPA (on SB model) using analysis of covariance

SI stiffness index, *CI* confidence interval, *PA* physical activity, *MVPA* moderate-to-vigorous PA, *MPA* moderate PA, *VPA* vigorous PA, *LPA* light PA

**p* value compared with T3 after Bonferroni correction

was less than that by boys. Thus, boys and girls in the same tertile were not exposed to the same amount of time spent in MVPA. Especially for VPA, the difference among tertile groups in girls was smaller compared with those of boys.

In our study, although there was no significant difference, active children who met the PA recommendations (≥ 60 min MVPA/day) had higher SI than non-active children. Unfortunately, very few studies have examined the association between meeting PA guidelines using objectively measured MVPA and bone mass in children. Similar to our study, no significant differences were observed in the reports of adolescents who participated in the HELENA study [44]. They also showed that more than 78 min of MVPA and more than 32 min of VPA were associated with increased BMD at the femoral neck. Coincidentally, since the cut point is almost the same value with our findings in boys, it may be important for Japanese children to also spend 60 min or more on MVPA to obtain high bone mass. Further studies focused on detecting the optimal dose of habitual PA on bone accrual in Japanese children are needed.

Regarding the association between SB and bone health in schoolchildren, a recent systematic review has indicated that objectively measured total SB was negatively associated with lower extremity bone outcomes such as femoral neck BMD, independent of MVPA [18], used dual-energy X-ray absorptiometry (DXA) and QUS. In the two European reports that examined objective SB and SI in peripubertal children using QUS [39, 41], SB showed a negative relationship with SI, but did not examine those association stratified by sex. Therefore, the reason for the difference between boys and girls observed in this study is unclear, but it may be due to the difference in PA intensity. The previous studies indicated that MVPA was associated with a 3.3 times greater increase in femoral neck BMD compared with reducing sedentary time, suggesting that 1 h less of sedentary time per day has the same effect as 18 min of MVPA in boys [18, 37]. Thus, in our study, the positive effect of MVPA may exceed the negative impact of SB in boys. Meanwhile, in girls, since significant associations were observed even after adjusting for MVPA, a combination of increasing MVPA and decreasing SB is recommended for girls with low MVPA.

Strength and limitations

To the best of our knowledge, this is the first study to indicate associations between objectively measured PA and SB and bone stiffness in Japanese children. However, our study had the following limitations. First, the participants of this study were relatively small in number and limited to one rural area. Therefore, the observed findings might have incurred type 2 errors due to inadequate power to detect significant differences, and the conclusions cannot be generalized to all Japanese children. Future studies with different populations and more participants are required. Second, because the study design was cross-sectional, the findings of this study cannot provide causality. Further longitudinal studies are needed. Third, assessment of bone mass utilized QUS instead of DXA, which is a standard diagnostic method for osteoporosis. Regarding the clinical usefulness of QUS in children, insufficient evidence has been reported to support other clinimetric properties [45, 46]. However, QUS is correlated with DXA in children and is used as a valid tool for predicting the risk of osteoporosis fractures [19, 47]. In addition, because QUS is a quick, low-cost, portable, and safe device, it is more suitable for measuring the bone mass of a large number of children at school than DXA [46, 47]. Therefore, using QUS to examine factors related to increasing PBM in children can contribute to the prevention of osteoporosis and has public health significance. Fourth, assessment of the pubertal stages in girls was not sufficient and that in boys did not provide any information. Although menarche has been evaluated in girls, the stage of maturity at this time contributes strongly to bone mass [7]; therefore, it should use a more detailed evaluation method, such as the Turner stage [48]. Finally, although we adjusted for several important confounders, we could not exclude unmeasured confounding variables, such as genetic factors and dietary information other than calcium intake.

Conclusion

This study suggests that objectively measured MVPA is positively associated with bone stiffness in Japanese school children in boys and SB is negatively associated those in girls. Although longitudinal or intervention studies are needed, reducing SB might be a brief modifiable factor for preventing lower PBM in girls, in addition to increasing MVPA.

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Author contributions Study design: MY, DA, MS, and ZY. Study conduct and data collection: MY, DA, YA, MS, and KS. Data analysis: MY and AY. Data interpretation and drafting manuscript: all authors. MY and AY take responsibility for the integrity of the data analysis. All authors read, revised, and approved the final manuscript.

Compliance with ethical standards

Conflict of interest All authors have no conflicts of interest.

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