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ORIGINAL ARTICLE

Physical activity, calcium intake and childhood bone mineral: a population-based cross-sectional study

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Abstract
Summary In a free-living cohort of 4-year old children, mean daily time in moderate–vigorous physical activity and daily calcium intake at 3 years, were positively related to hip bone size and density. Relationships between physical activity and bone indices were stronger when calcium intake was above compared with below median (966 mg/day).
Introduction We examined the cross-sectional relationships between childhood physical activity, dietary calcium intake and bone size and density.
Methods Children aged 4 years were recruited from the Southampton Women's Survey. They underwent measurement of bone mass by DXA (Hologic Discovery). Physical activity was assessed by accelerometry (Actiheart, Cambridge Neurotechnology Ltd, Cambridge, UK) for seven continuous days.
Results Four hundred twenty-two children (212 boys) participated. In a cross-sectional analysis, after adjusting for gender, daily mean time(minutes per day) spent in moderate to very vigorous activity (MVPA) was positively related to hip BA (R^2=3%, p<0.001), BMC (R^2=4%, p<0.001), aBMD (R^2=3%, p=0.001) and estimated vBMD (R^2=2%, p=0.01), but not height (r_s=0.04, p=0.42) or weight (r_s=0.01, p=0.76). Mean daily calcium intake (assessed at 3 years old) positively predicted bone indices in those with a calcium intake below the median (966 mg/day),

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but there was a much attenuated relationship in those above this. These associations persisted after inclusion of total energy, protein and phosphorus in multivariate models. The relationships between MVPA and bone indices were stronger in children with calcium intakes above the median. Thus, for aBMD, the variance explained by MVPA when daily calcium intake was below the median was 2% (p=0.1) and above median was 6% (p=0.001).

Conclusions These results support the notion that adequate calcium intake may be required for optimal action of physical activity on bone development and that improving levels of physical activity and calcium intake in childhood may help to optimise accrual of bone mass.

Keywords Accelerometer · Calcium · Childhood · DEXA · Osteoporosis · Physical activity

Introduction

The marked secular increase in childhood obesity over recent decades [1] has generated much debate about possible reciprocal changes in physical activity. Recent systematic reviews have suggested that levels of physical activity in children have actually been reasonably stable over the last decade or two in the USA [2] and Europe [3]. Obesity itself is a risk factor for childhood fracture [4], and it is unclear whether current general levels of physical activity provide the optimal stimulus for bone development; public health strategies aimed at increasing physical activity in childhood might potentially help to improve bone health and reduce obesity. Recent work has suggested that factors in early life, starting in utero, influence the accrual of bone mineral in childhood and thus the peak bone mass achieved in the third decade of life [5–7]. Peak bone mass is a strong determinant of osteoporosis risk in later life [8], and thus measures to improve childhood bone health to peak represent an important public health agenda. There are few data on the relationship between habitual free-living physical activity and bone mineral in young children [9]. The effect of exercise interventions has been examined in several studies, but these have shown only short-term results [10, 11], and there are few data examining physical activity and dietary factors, such as calcium intake, in free-living young children. In older children, recent work has suggested a positive relationship between habitual physical activity and bone mineral accrual, but that high levels of physical activity are an independent risk factor for childhood fracture, presumably because of associated trauma [12]. Calcium intake has been shown in some, but not all, studies to be positively related to childhood bone mineral density [13, 14]; furthermore, there is some evidence that the associations between bone mineral density and physical activity may be modified by daily calcium intake [15, 16]. In this paper, we have used a large free-living population cohort, the Southampton Women's Survey (SWS), to examine the relationships between objectively measured childhood physical activity, calcium intake and bone size and density measured by dual-energy X-ray absorptiometry (DXA).

Methods

Participants

The SWS is a unique, prospective cohort study of 12,583 women aged 20–34 years recruited from the general population [17]. At enrolment, the participants were characterised in detail in terms of diet, lifestyle, health, physical activity and anthropometric measurements. Of these women, 3,159 became pregnant and were studied in similar detail several times during gestation. The subsequent children are being followed and characterised at regular intervals, with the oldest children now reaching 8 years old. Nine hundred children underwent assessment by DXA at 4 years old, and of these, 422 had their habitual physical activity measured, forming the cohort presented in this paper.

Childhood dietary assessment

At 3 years of age, diet was assessed using an 80-item food frequency questionnaire (FFQ), administered at interview by trained research nurses, to record the average frequency and quantity of the foods consumed over the preceding 3 months. Daily milk consumption was recorded separately at the end of the FFQ. In a validation study of 887 SWS children aged 3 years, in which nutrient intakes estimated from the FFQ were compared with intakes estimated from 2-day prospective food records, the Spearman's rank correlation coefficient for calcium intake was 0.55 (data unpublished). Total energy, phosphorus and protein intakes were also derived.

Four-year DXA assessment

The mother and child were invited to visit the Osteoporosis Centre at Southampton General Hospital for assessment of bone mass. At this visit, written informed consent for the DXA scan was obtained from the mother or father. Details of health, medications and milk intake were assessed by questionnaire. The child's height (using a calibrated Leicester height measurer stadiometer) and weight (in underpants only, using calibrated digital scales [Seca Ltd]) were measured. A DXA scan at whole body, lumbar spine

and hip sites was obtained, using a Hologic Discovery instrument (Hologic Inc., Bedford, MA, USA) with paediatric software. To encourage compliance, a sheet with appropriate coloured cartoons was laid on the couch first; to help reduce movement artefact, the children were shown a suitable DVD cartoon. The total radiation dose for the scans was 4.7 μSv for whole body measurement (paediatric scan mode). The manufacturer's coefficient of variation (CV) for the instrument was 0.75% for whole body bone mineral density, and the experimental CV when a spine phantom was repeatedly scanned in the same position 16 times was 0.68%.

Four-year physical activity assessment

In a consecutive subset of the children who attended for DXA, an Actiheart combined accelerometer and heart rate monitor (Cambridge Neurotechnology Ltd, Cambridge, UK) was fitted to the child. The main component of the Actiheart unit is approximately 1.5 cm across and 3-mm thick, which is attached with a 70 to 100-mm wire to a smaller clip. Both of these parts were secured to the skin via standard electrocardiograph electrode pads. The main unit was positioned in the midline just below the xiphisternum and the smaller clip horizontally to the left chest wall. The mother was asked to persuade the child to wear the monitor continuously for 7 days except during bathing and swimming; thus, sedentary time includes time asleep overnight. Monitors were returned by post. The mother was asked to estimate how long the child spent watching television daily (none, <1, 1–2, 2–3, 3–4, 4–5 and >5 h). The Actiheart accelerometry data, rather than the heart rate output, was used to assess physical activity as, a priori, one would not expect heart rate to predict bone-forming impact activity. The acceleration output from the Actiheart has previously been validated in children [18, 19]. The accelerometer in this device has a linear (R^2=0.999) response to acceleration [20] and was oriented to measure acceleration along the body's longitudinal axis using a 1-min epoch.

The output was derived as counts per minute (cpm) and thresholds for low (20 cpm), moderate (400 cpm), vigorous (600 cpm) and very vigorous activity (800 cpm) were used to categorise the data into average daily time at each threshold. These levels were defined experimentally in both laboratory and free-living conditions using the Actigraph GT1M accelerometer (Actigraph, Pensacola, FL, USA) as the comparator [18, 19]. Thus, these thresholds are broadly equal to 100, 2,000, 3,000 and 4,000 cpm obtained from the Actigraph GT1M accelerometer (Actigraph, Pensacola, FL, USA). Moderate, vigorous and very vigorous activity levels were grouped to give the primary exposure measure (MVPA).

Statistical analysis

All variables were checked for normality. Non-normally distributed variables were transformed logarithmically. Mann–Whitney U tests and *t* tests were used to test the difference between normally and non-normally distributed variables, respectively. Correlation and regression methods were used to explore the cross-sectional relationships between physical activity and bone mass, and the longitudinal associations between calcium intake at 3 years and bone indices at 4 years. Bone outcomes used at 4 years include bone area (BA), bone mineral content (BMC), which represent the absolute size and total mineral content of the bone, respectively, areal bone mineral density (aBMD, a partly size-corrected measure) and estimated volumetric bone mineral density (vBMD, BMC adjusted for BA, height and weight to correct for body size as fully as possible), at the whole body minus head, lumbar spine and total hip sites. The bone outcomes are presented as units of measurement (e.g. grammes per square centimetre) rather than Z-scores as the analysis was within group, and no comparison was made to a reference range. Total hip was used rather than femoral neck, as it was found to be a more reliable outcome in these small subjects.

Results

Characteristics of the mothers and children

Four hundred twenty-two children (212 boys) took part. Table 1 summarises the characteristics of the mothers and the children. Boys spent more time in moderate to very vigorous physical activity (MVPA) than girls (70 min/day vs. 61 min per day, p=0.04). Figure 1 shows the distribution of time spent in each level of physical activity in boys and girls. On average, children wore the Actiheart monitors for 19.5 h/day for 6.9 days. The boys tended to have greater bone indices at the hip and so the outcomes were adjusted for gender as well as the age of the child. Comparison of mothers of children who underwent DXA assessment at 4 years with those of children who did not revealed that the former were, on average, slightly older at the birth of their child (mean age 31.2 vs. 30.6 years, respectively, p=0.007), better educated (24.8% with higher degree vs. 20.6%, respectively; p= 0.002) and smoked less (8.5% smoked before pregnancy vs. 17.4%, respectively; p<0.001).

Relationships between calcium intake and bone size and density

Mean daily calcium intake, as a continuous variable, assessed at 3 years old, positively predicted 4-year bone indices at the hip, and was more weakly associated with

Table 1 Characteristics of mothers and children

Mothers (n=422)	Mean (SD) or median (IQR)		
Age (years)	35.4 (3.6)		
Height (cm)	164.0 (6.2)		
Weight (kg)	65.4 (59.4–73.2)		
BMI (kg/m^2)	24.0 (22.1–27.4)		
Children	Boys (n=212)	Girls (n=210)	P difference
	Mean (SD) or median (IQR)	Mean (SD) or median (IQR)	
Age (years)	4.1 (4.07–4.16)	4.1 (4.06–4.14)	0.07
Height (cm)	104.3 (3.8)	103.9 (4.2)	0.2
Weight (kg)	17.4 (16.4–19.0)	17.5 (16.0–18.8)	0.5
BMI (kg/m^2)	16.1 (15.3–16.9)	16.0 (15.3–16.9)	0.9
Calcium intake at 3 year (g/day)[a]	985 (796–1251)	935 (752–1208)	0.1
Phosphorus intake at 3 years (mg/day)[a]	1,136.8 (962–1,363.4)	1,090.4 (892.5–1,291.4)	0.048
Protein intake at 3 years (g/day)[a]	57.4 (14.1)	53.2 (13.6)	0.004
Energy intake at 3 years (kcal/day)[a]	1,635.5 (366.04)	1,484.2 (343.2)	<0.001
Sedentary (min/day)	837 (93)	860 (84)	0.009
Active (min/day)	603 (93)	580 (84)	0.009
Lightly active (min/day)	532 (73)	516 (72)	0.026
Moderately active (min/day)	34 (26–46)	31 (24–39)	0.008
Vigorously active (min/day)	16 (10–21)	14 (10–19)	0.049
Very vigorously active (min/day)	15 (10–24)	15 (8–23)	0.3
MVPA (min/day)	70 (47–90)	61 (45–83)	0.037
Hip BA (cm^2)	12.8 (1.9)	12.6 (2.0)	0.6
Hip BMC (g)	7.5 (1.6)	7.0 (1.7)	0.003
Hip aBMD (g/cm^2)	0.59 (0.06)	0.55 (0.06)	<0.001
Hip vBMD (~units)	7.3 (0.8)	6.9 (0.05)	<0.001

MVPA mean time per day spent in moderate, vigorous and very vigorous physical activity, *BA* bone area, *BMC* one mineral content, *aBMD* areal bone mineral density, *vBMD* estimated volumetric BMD

[a] n=188 (boys) and 187 (girls)

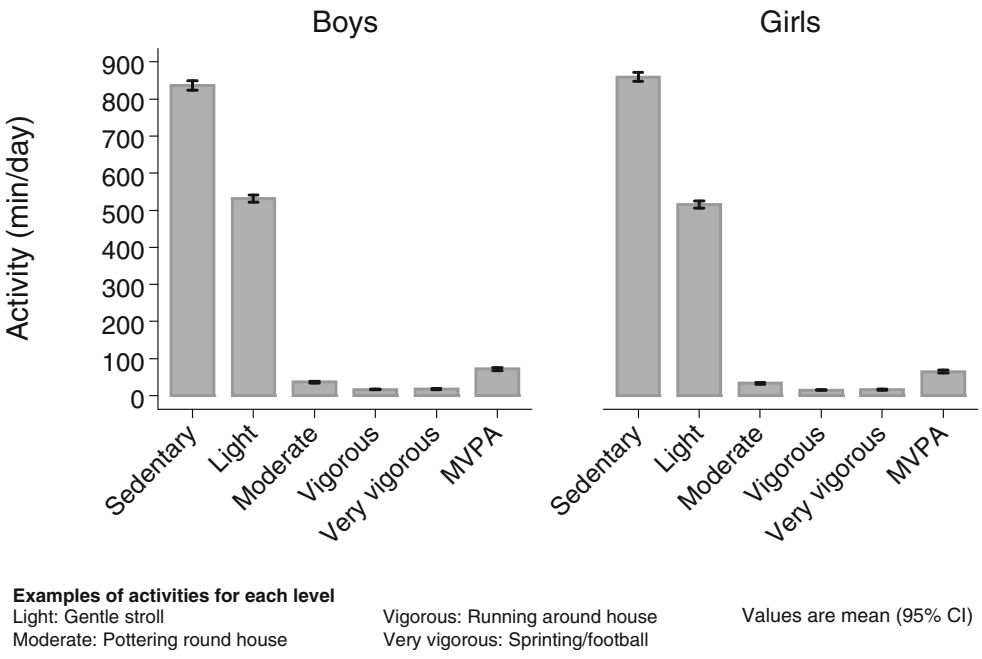

Fig. 1 Distribution of time spent in different levels of physical activity in boys and girls. Figure shows mean and 95% CI

whole body minus head BMC (R^2=1.2%, p=0.04). No statistically significant associations were observed with bone indices at the lumbar spine. The relationships between calcium intake at 3 years and 4-year bone indices at the hip were stronger for those children below than above the median calcium intake (966 mg/day). Thus, for daily calcium intakes below the median, the variance explained and p values were: BA 3%, p=0.02; BMC 7%, p<0.001; aBMD 10%, p<0.001; estimated vBMD 6%, p=0.001. For daily calcium intakes above the median, the corresponding values were: BA 0%, p=0.4; BMC 1%, p=0.1; aBMD 2%, p=0.1; estimated vBMD 1%, p=0.1. These associations persisted after inclusion of total energy, protein and phosphorus in multivariate models; indeed, these nutritional factors did not statistically significantly predict bone indices at 4 years. The contribution of total calcium intake at 3 years compared with that of milk intake at 3 years appeared similar when both were included in a multivariate model (for example hip BMC and calcium intake: R^2=2%, p=0.004; hip BMC and milk intake; R^2=2%, p=0.009).

Relationships between physical activity and bone size and density

Mean minutes per day in MVPA was positively related to hip BA (R^2=3%, p<0.001), BMC (R^2=4%, p<0.001), aBMD (R^2=3%, p=0.001) and estimated vBMD (R^2=2%, p=0.01), but not height (r_s=0.04, p=0.4) or weight (r_s= 0.01, p=0.8). MVPA was not statistically significantly related to bone indices at whole body and lumbar spine sites. Although the magnitude of associations between time spent in MVPA and bone indices appeared somewhat stronger in boys than girls (Table 2), the MVPA×sex interaction term was not statistically significant for any bone outcome at the hip (BA p=0.9, BMC p=0.8, aBMD p= 0.7, estimated vBMD p=0.5). There was a negative association between hours of television watched per day and hip BA and BMC. Thus, for each category increase in television watching, BA decreased by 0.2 cm^2 (p=0.041) and BMC by 0.2 g (p=0.036).

MVPA and DXA outcomes by calcium intake

There was no association between time spent in MVPA and calcium intake (p=0.3). However, the relationships between mean daily MVPA and bone indices were stronger when calcium intake was above compared with below the median (966 mg/day). Thus, for aBMD, the variance explained by MVPA when daily calcium intake was below the median was 2% (p=0.1) and above median was 6% (p=0.001). The respective values for the remaining bone indices at the hip are summarised in Table 3. The difference was more marked for measures of mineralisation (BMC, aBMD, estimated vBMD) than bone size (BA). However, the formal interaction terms testing these relationships (whether the association between MVPA and bone indices varied by calcium intake) did not achieve statistical significance (BA p=0.5, BMC p=0.3, aBMD p=0.3, estimated vBMD p= 0.3). Figure 2 shows the relationships between time spent in MVPA (dichotomised for illustrative purposes and ease of interpretation into those with less or more than 1 h of MVPA per day) and bone size and density by calcium intake. The median MVPA was 64 min/day, and when this cut-off was used, the results were not materially different.

Maternal factors

We explored the effect of adding maternal social class, education, smoking, body mass index, height, parity as covariates in the regression models relating MVPA to offspring bone indices and found that the relationships remained robust.

Discussion

We have shown, in a free-living population cohort, that levels of daily moderate to very vigorous physical activity were positively associated with hip size and density at 4 years old. These associations were more marked in those children consuming more than the median intake of calcium

Table 2 Mean daily time spent in MVPA and bone indices at hip, by sex

MVPA	4 year hip BA		4 year hip BMC		4 year hip aBMD		Hip vBMD	
	R^2 (%)	P value	R^2(%)	P value	R^2(%)	P value	R^2(%)	P value
Girls and boys	3	<0.001	4	<0.001	3	0.001	2	0.01
Boys	4	0.005	5	0.001	4	0.005	2	0.03
Girls	2	0.03	3	0.02	2	0.05	1	0.2

MVPA mean time per day spent in moderate, vigorous and very vigorous physical activity, *BA* bone area, *BMC* bone mineral content, *aBMD* areal bone mineral density, *vBMD* estimated volumetric BMD (BMC adjusted for BA, height and weight)

Table 3 Relationships between time spent in MVPA and bone indices at total hip, dichotomised by median calcium intake at 3 years (966 mg/day)

MVPA	4 year hip BA		4 year hip BMC		4 year hip aBMD		Hip vBMD	
	Calcium <966 mg/day	Calcium >966 mg/day	Calcium <966 mg/day	Calcium >966 mg/day	Calcium <966 mg/day	Calcium >966 mg/day	Calcium <966 mg/day	Calcium >966 mg/day
R^2(%)	2	5	3	7	2	6	1	4
P value	0.04	0.003	0.03	<0.001	0.05	0.001	0.1	0.006

MVPA mean time per day spent in moderate, vigorous and very vigorous physical activity, *BA* bone area, *BMC* bone mineral content, *aBMD* areal bone mineral density, *vBMD* estimated volumetric BMD (BMC adjusted for BA, height and weight)

per day, consistent with the notion that adequate dietary calcium may be necessary for optimal action of physical activity (PA) on bone development.

There are several limitations that should be taken into account when interpreting our results. Firstly, measurement of physical activity in free-living children presents some difficulties. Children may remove monitors and we did not ask the parents to keep a diary of this. However, children were asked to wear the monitor for 24 h per day except during water activities. On average, children wore the monitors for 19.5 h per day for 6.9 days, indicating excellent compliance. The mothers did not keep a diary of childhood activities, so we could not directly compare the accelerometer data with specific events. However, the

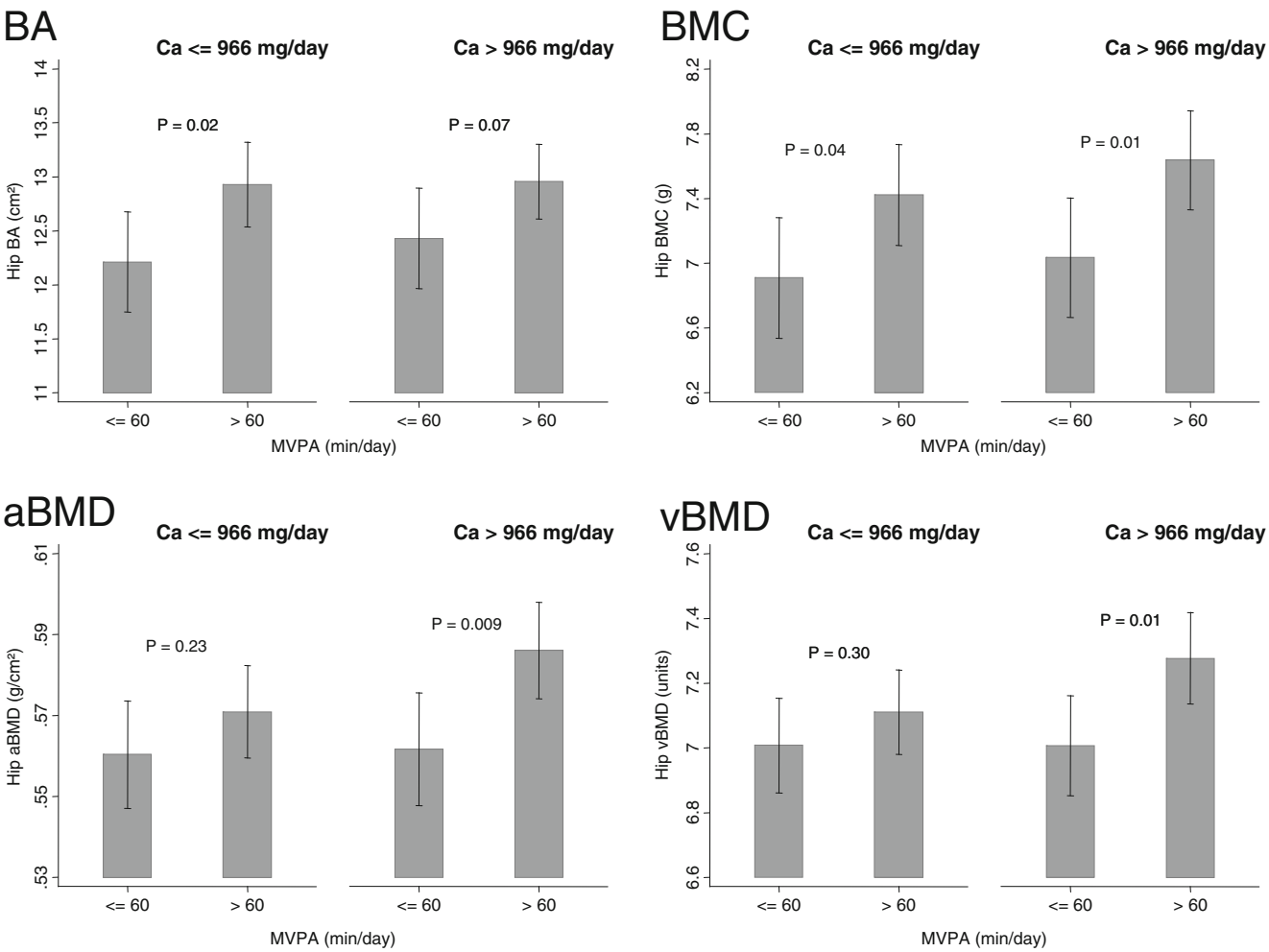

Fig. 2 Childhood MVPA and hip bone size and estimated volumetric density by daily mean calcium intake below or above median (966 mg/day). Values are mean (95%CI)

thresholds derived have been previously validated in both laboratory and free-living conditions [18, 19]. Secondly, measurement of bone mineral in young children is hampered by their tendency to move and also by their low absolute BMC. However, we used specific paediatric software, and movement artefact was modest and uniform across the group; in this cohort of children with both physical activity measurement and DXA, four children with excessive movement at the hip scan site were excluded from the analysis. A sensitivity analysis including these children did not yield significantly different results. The accuracy of DXA for the assessment of bone mineral in small animals has been demonstrated in piglets [21, 22]. Thirdly, we assessed diet using a FFQ in a subset of the children at 3 years. Although there is concern that FFQs are prone to measurement error, calcium intakes assessed by this FFQ were highly correlated with intakes determined using detailed prospective food records, and it is unlikely that measurement error could explain the differences in relationships with bone status that we observed. Detailed assessment of calcium intake was not performed when the child was 4 years old, but there was a good correlation (r= 0.44, p<0.0001) between calcium intake at 3 years and milk intake at 4 years (the predominant determinant of dietary calcium intake). The relationships between MVPA and bone outcomes did not appreciably change when the cohort was limited to those children who had had calcium intake assessed at 3 years. Fourthly, the study cohort was a subset of the SWS, but mothers whose children underwent DXA scanning and those whose babies did not were broadly similar: The former were on average slightly older and smoked slightly less. There is no reason to suppose, however, that relationships between MVPA, calcium intake and bone mineral would differ between these two groups. Fifthly, the use of DXA does not allow measurement of true volumetric bone density, thus making it difficult to be certain about differential determinants of skeletal size and volumetric density. Within the limitations of DXA, we used a staged approach to size correction with BA as a measure of skeletal size, BMC as a measure of the total calcium mineral, areal bone mineral density as a partly size-corrected measure and estimated volumetric bone density to fully adjust for body size (BMC adjusted for BA, height and weight). We were unable to use the femoral neck site as preliminary investigation suggested unacceptable variation caused by the software's placement of markers; total hip was found to be a more consistent and reliable measure. Most importantly, much of the analysis was cross-sectional and so reverse causality remains a possible caveat in the interpretation of our results.

Several reports in children and adolescents involved in competitive sport or ballet indicate that intense exercise is associated with an increase in bone mineral accrual at weight-bearing skeletal sites [23–25]. Prospective studies of moderate exercise programmes undertaken in schools have demonstrated a positive effect on bone mineral [10, 11], but the long-term benefit of such interventions remains unclear. Much less is known about the influence of physical activity on bone mass in younger children, and in particular, whether bone mineral accrual varies significantly within the normal range of habitual activity for a healthy population.

Our results indicate that up to 7% of variance in hip BMC might be accounted for by MVPA, given a calcium intake of >966 mg/day, and up to 4% across all calcium intake, and suggest that an increase in MVPA of 10 min per day might be associated with a 100 mg increase in hip BMC at 4 years old. These figures are comparable to those found in other observational studies, in particular, the one other study to examine the relationship between PA and bone indices in a similar free-living paediatric population. In this study of 368 children aged 4–6 years, statistically significant positive associations were found between physical activity and BMD at the hip; hours of television viewing per day inversely predicted hip BMD in girls (r= −0.15, p<0.01) [9]. Additionally, femoral neck cross sectional area was positively associated with physical activity in this US population and relationships were similar in boys and girls [26]. In this study, there was a weak association with BMC at the whole body site in boys only and stronger associations with BMC at the lumbar spine in both genders. In contrast, we only found associations between MVPA and bone indices at the total hip site. Indeed, in many of the studies linking PA to bone mineral have found associations primarily at weight-bearing sites such as the hip; the children in the Iowa study were on average, a year older than in our study, and thus, it is possible that the ability to detect a relationship between PA and spinal bone indices may have been limited by the smaller size and lower mineral content at this younger age. Our study has replicated the finding that increasing hours of daily television watching are associated negatively with BMC at the hip. Given the cross-sectional nature of the study, it is possible that the MVPA-bone relationships could be explained by larger children being more physically active. However, we found no statistically significant relationships between MVPA and either height or weight at 4 years, suggesting that this was not the case.

Several, but not all studies have indicated a positive relationship between dietary calcium intake and bone mineral [13, 14, 27–33]. In the most recent meta-analysis, which included 21 trials, an increased calcium intake only appeared to have a positive effect on BMC in those children who had the lowest intakes at baseline, suggestive of a threshold effect, consistent with our findings [14]. An earlier meta-analysis, including 19 trials, demonstrated only

a modest effect of calcium intake on upper limb BMD, but that these associations were not modified by sex, baseline calcium intake or physical activity [13]. Individual intervention studies have suggested at least short-term benefits from additional calcium supplementation, with some evidence of more persisting (3 years) improvements for those supplements derived from milk [32, 33]. In our study, there was little difference in the relationships between total calcium intake and bone indices and those with milk intake, but this reflected short-term associations rather than the long-term results of an intervention programme.

We demonstrated differences in the relationship between PA and bone mineral according to mean daily calcium intake. Consistent with this finding, Specker et al. randomised young children (age 3–5 years) to either gross or fine motor exercises and either low or high calcium intake, measuring tibial cortical bone thickness and area by PQCT at 12 months. They found that children in the high exercise, high-calcium group had an increase in these parameters, but children on no calcium supplement in the high activity group had lower cortical thickness and area than children in the low-activity group [34]. The same group demonstrated similar interactions between calcium intake and bone response to physical activity in toddlers aged 6–18 months [16], and a review of the studies available at the time supported the notion that a daily calcium intake in the region of 1,000 mg is necessary for optimal bone mineral accrual in response to physical activity [15]. The effect of calcium in our study seemed most marked on measures of bone that included mineral, aBMD and vBMD, rather than bone area. In contrast, physical activity appeared marginally more strongly related to bone size than estimated volumetric density, with the size relationship less dependent on calcium intake. This suggests that, whilst physical activity may influence size and mineralisation of the skeleton, with the former being possibly the stronger influence, sufficient dietary calcium intake may be necessary for optimal volumetric mineralisation in response to skeletal loading.

We found some evidence of stronger associations between MVPA and bone indices in boys than girls, but that the MVPA×sex interaction term was not statistically significant. The influence of gender on the relationship between physical activity and bone indices have been reported in both directions in pre-pubertal children [35–38]. Additionally, levels of habitual physical activity have been shown to positively predict bone mass longitudinally over puberty, with a greater effect in girls than boys after adjusting for maturational and anthropometric differences [39]. The nature of the activity undertaken may also be important. In a cohort of 8-year old children, physical work capacity predicted BMD at the hip and spine in girls, but in boys, these indices were predicted by either sports participation or muscle strength [40]. Thus, the role of gender in physical activity-bone influences may depend on age, site and exercise type, but clearly, the current evidence base does not allow definitive conclusions to be made.

The significance of physical activity for bone health can be considered in the context of childhood and the longer term. Work from several countries has demonstrated that children who fracture are likely to have lower bone density than those who do not [4, 41–44]; a meta-analysis from the UK yielded similar results [45]. Additionally, these fracture children are more likely to be obese [41, 42, 44, 46, 47]. Given the positive associations between bone density and physical activity in childhood, it might be expected that increased physical activity would be associated with decreased risk of childhood fracture. However, this ignores one of the other risk factors for fracture, which is physical activity itself. Indeed, examination of the children in the ALSPAC (UK) cohort showed that although increased physical activity (measured by questionnaire) was associated with increased bone mineral density, it also predicted an increased risk of childhood fracture [12]. Thus, the children who are most active have the strongest bones, but are also putting greatest forces through them and so at greatest risk of traumatic fracture.

If an individual can sustain increased physical activity appropriate to bone growth throughout childhood, adolescence and young adulthood to peak bone mass, then peak bone mass should be improved. Recent work has suggested that peak bone mass is a critically important determinant of osteoporosis risk in later life [8]. Indeed, if the difference in hip BMD between bottom and top quartiles of MVPA (0.4 SD) were to be sustained into adulthood, this could equate to a 30–50% reduction in risk of fracture [48]. Although current clinical practice focuses mainly on identification of those individuals most at risk of fracture, we have previously demonstrated factors in early life, such as maternal lifestyle, body build and 25(OH)-vitamin D status [5, 6] which influence intrauterine bone mineral accrual and skeletal geometry in the offspring. Taken together, these data suggest that attention should be given to optimising bone health throughout the life course to reduce the risk of osteoporotic fracture in old age.

In conclusion, we have demonstrated, in a free-living population cohort, that levels of habitual daily physical activity are positively associated with total hip bone size and density at 4 years old. Additionally, the effects were greatest in those with a mean daily calcium intake above the median of 966 mg/day. Although the formal interaction terms did not achieve statistical significance, these findings are consistent with previous data suggesting that adequate dietary calcium intake is required for the optimal influence of physical activity on bone formation. These results support the notion that increasing habitual childhood

physical activity and calcium intake is likely to be a sensible public health strategy to improve child bone health and potentially reduce the burden of osteoporotic fracture in future generations.

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