LUND UNIVERSITY

Self-reported recreational exercise combining regularity and impact is necessary to maximize bone mineral density in young adult women : A population-based study of 1,061 women 25 years of age.

Callréus, Mattias; McGuigan, Fiona; Ringsberg, Karin; Åkesson, Kristina

Link to publication

Self-reported Recreational Exercise Combining Regularity and Impact Is Necessary To Maximize Bone Mineral Density in Young Adult Women

A population-based study of 1061 women 25 years of age

Mattias Callréus, Fiona McGuigan, Karin Ringsberg, Kristina Åkesson

Lund University, Department of Orthopaedics, Skåne University Hospital, Malmö, Sweden

Disclosures: NONE

Mini-abstract: Recreational physical activity in 25-year old women in Sweden increases BMD in the trochanter by 5.5 % when combining regularity and impact. Jogging and spinning were especially beneficial for hip-BMD (6.4–8.5%). Women who enjoyed physical education in school maintained their higher activity level at age 25.

Corresponding author:
Prof. Kristina Åkesson, MD, PhD
Dept of Orthopaedics,
Skåne University Hospital,
S-205 02 Malmö, Sweden
Email: kristina.akesson@med.lu.se

ABSTRACT

Purpose: To evaluate effects of recreational exercise on bone mineral density (BMD) and describe how exercise patterns change with time in a normal population of young adult women.

Methods: A population-based study of 1061 women, age 25 (±0.2). BMD was measured at total body (TB-BMD), femoral neck (FN-BMD), trochanter (TR-BMD) and spine (LS-BMD). Self-reported physical activity status was assessed by questionnaire. Regularity of exercise was expressed as recreational activity level (RAL) and impact load as peak strain score (PSS). A permutation (COMB-RP) was used to evaluate combined endurance and impacts on bone mass.

Results: More than half of the women reported exercising on a regular basis and the most common activities were running, strength training, aerobics and spinning. 70% participated in at least one activity during the year. Women with high RAL or PSS had higher BMD in the hip (2.6–3.5%) and spine (1.5–2.1%), with the greatest differences resulting from PSS (p<0.001–0.02). Combined regularity and impact (high-COMB-RP) conferred the greatest gains in BMD (FN 4.7%, TR 5.5%, LS 3.1%; p<0.001) despite concomitant lower body weight. Jogging and spinning were particularly beneficial for hip BMD (+6.4–8.5%). Women with high-COMB-RP scores enjoyed physical education in school more and maintained higher activity levels throughout compared to those with low scores.

Conclusion: Self-reported recreational levels of physical activity positively influence BMD in young adult women but to maximize BMD gains, regular, high-impact exercise is required. Enjoyment of exercise contributes to regularity of exercising which has short- and long-term implications for bone health.

INTRODUCTION

Peak bone mass (PBM) is generally thought to have been reached by the end of the second or by the start of the third decade, the precise age varying by sex and by skeletal site. Current thinking suggests that in women PBM is reached between the age of 16-19 at the hip and just after the age of 30 at the lumbar spine.[1]. The relevance of peak bone mass accrual relates to its implications for future fracture risk. A one standard deviation increase in PBM has the potential to decrease the risk of fracture by as much as fifty percent [2]. From this perspective, identification of factors influencing PBM accretion is crucial as one avenue to reduce the future fracture burden. Individual peak BMD is likely to be defined by the overall programmed growth potential and hence under strong genetic control [3-5], while environmental factors such as physical activity or inactivity will act as positive or negative modifiers.

The effect of physical activity on bone mass is mediated through several mechanisms, with mechanical stimuli playing a key role. It has been proposed that bone adaptation to mechanical stimuli is driven by dynamic rather than static loading, and that only a short duration of mechanical loading is necessary to initiate an adaptive response [6]. Furthermore it is suggested that bone cells accommodate, making them less responsive to routine loading signals. Consequently, load of a high magnitude with few repetitions optimizes the osteogenic response [7-9].

Most studies on the effects of physical activity have investigated bone mass in athletes with emphasis on specific sports and training activities [10-15], but comparatively less is known about the effects of physical activity and exercise in normal populations where the same

individual may practice several types of activities at moderate levels and over variable time periods. One particular problem includes how to incorporate potential effects on the skeleton from activities predominantly improving physical endurance and those which subject the skeleton to impact load. Recent cohort studies have used or developed scoring models to quantify physical activity at different ages and sexes [16-19], nevertheless, capturing physical activity components cross-sectionally, over time-periods stretching up to many years remains a challenge .

Determinants of physical activity are subject to multiple and complex influences, with behavioral patterns among the most important. Personal decisions on both daily and recreational physical activity may hence be founded in habits that are established early in life. Physical education in school is one such contributor to behavioral patterns of physical activity later in life [20] and may also promote an attitude towards future training that should not be underestimated. The effects on bone mass from physical activity during childhood and adolescence have been investigated [21, 22] and in young men engaged in impact load activities the possibility to achieve continuous gains in bone mass after puberty has been suggested [23]. In contrast, potential skeletal benefits from previous and current habitual physical activity level during young adulthood are not well described in women.

The primary aim of this study is to specifically address effects of recreational physical activity on bone mineral density in a normal population of young adult women. The study utilizes the population-based Peak-25 cohort of over one-thousand, 25-year-old women, an important age-group in terms of evaluating bone mass at or around peak BMD since, for the majority, positive determinants are likely to supersede known pronounced negative

effectors. A secondary aim is to describe how young adult women partake in exercise and how their activity levels change from adolescence into the mid-third decade.

SUBJECTS AND METHODS

Subjects

This population-based study uses the Peak-25 cohort of 1061 young adult women. Through a computerized population administrative system, only 25-year-old (range 25.01–25.99) Caucasian women were randomly selected and invited to the study during 1999 to 2004. The first invitation was sent closely after their 25th birthday. Enrollment in the study was continuous throughout the year to avoid seasonal bias. All women were citizens of the city of Malmö in southern Sweden. In all, 1166 women agreed to participate (response rate 49%). After application of the only exclusion criterion – pregnancy at the time of the baseline investigation or during the 12 months prior to inclusion – 102 women were excluded. An additional 3 subjects were excluded for not fulfilling the age criteria.

The study was approved by the local ethics committee and followed the principles of the Declaration of Helsinki. Written informed consent was obtained from all participating subjects.

Questionnaire

A comprehensive questionnaire, consisting of approximately 250 variables, concerning physical activity and other lifestyle factors, work and studies, health and medical status, family history and nutritional factors was completed. The questionnaire response-reliability

was tested by asking 20 subjects to fill out the same questionnaire three months later (12.2 weeks, range 10.6–13.4 weeks) and the values between the two occasions were compared with Sign Test. No significant differences were found (p-value range 0.125–1.0).

Physical activity

Physical activity was assessed by information obtained from the questionnaire. The subjects were asked to grade their own overall activity level; to describe the types of exercise they performed; to estimate the amount of time spent on each specific activity; and to specify seasonal variations in their activity. The questions were directed towards current activity and duration. Questions on specified activities earlier in life were not included. Questions specifically related to walking were also included to differentiate between walking for exercise and as part of routine daily activities. To address behavioral patterns, additional questions asked whether they had been more or less active during childhood and adolescence and whether they enjoyed physical education in school, with school pertaining to their entire school experience in general. In Sweden, the school program consists of a nine-year compulsory education and a three-year upper secondary school, where physical education is scheduled approximately two or three periods per week.

Acknowledging the inherent difficulties in comprehensively estimating global physical activity as well as variance in impact load from different activities, we used the self-reported activity level and the different types of activities reported by the participants in the analysis but not information regarding duration of these activities. This information was analyzed using two different scores: recreational activity level (RAL) and peak strain score (PSS).

Firstly, for recreational activity level, the subjects graded themselves on a scale from 1 to 6, where 1 represents virtually no exercise at all and 6 represents a high activity level on a

regular basis (including sports at a competitive level). In this score duration was not taken into account. A value of ≥4 represents those with exercise on a regular basis and hence this is used as a cut-off between high and low/moderate recreational activity level.

Secondly, to evaluate the impact load from each reported activity, we used the peak strain score model developed by Groothausen et al [24]. Although 'bone-specific' questionnaires have since been developed [19, 25-28] the Groothausen model could be adjusted to our questionnaire created in 1999. In this model, each activity is quantified based on ground reaction forces (GRF) that are multiples of the body weight. For the reported activities we mainly used the GRF listing made by Weeks et al [28] and for activities not previously reported in the literature, GRF was estimated according to same principles (appendix 1). Each activity received a PSS between 0 and 3, depending on impact load. The summed PSS values ranged from 0 to 16, with values ≥5 representing high-impact activity. For the analysis, those with low and moderate impact are merged.

Since the recreational activity level (RAL) does not differentiate between the various types of activities performed, it cannot distinguish between endurance and impact exercise. Similarly, the peak strain score (PSS) only measures impact and does not account for the duration and frequency of the activity. In order to differentiate between overall high and low physical activity effects on the skeleton, RAL and PSS scores were combined (COMB-RP), allowing identification of subjects engaged in high-impact sports on a regular or frequent basis and vice versa. Individuals with high RAL (≥4) and PSS (≥5) scores were designated the High-COMB-RP group, while individuals with low RAL (≤3) and PSS (≤4) scores were designated the Low-COMB-RP group.

Bone mineral density

Bone mineral density (BMD) was measured using dual X-ray absorptiometry (DXA, Prodigy, Lunar Corp., GE, Madison, Wisconsin). Variables of interests were BMD at total body (TB-BMD), femoral neck (FN-BMD), trochanter (TR-BMD) and lumbar spine (L1–L4) (LS-BMD). In addition total body bone mineral content (TB-BMC) was determined. BMD results are expressed in grams/cm^2 and BMC in grams.

To test whether significant site-specific differences in BMD were an expression of generalized increase in bone mass or located at regions exposed to axial impact load, the ratio between the BMD at the region of interest and TB-BMD was calculated according to Morel [29]. A higher ratio indicates site-specific bone gain.

The absolute precision error (CV %) of the DXA measurements in this cohort was determined by re-measuring 15 participants, who were re-positioned between each measurement, resulting in a precision error of 0.90% for femoral neck and 0.65% for lumbar spine. Reproducibility was monitored by daily use of a manufacturer-supplied phantom.

Anthropometry

Anthropometric data were assessed using standardized equipment. BMI was calculated according to the standard formula (kg/m^2). Height is expressed in centimeters and weight in kilograms.

Statistical methods

Descriptive data are presented with mean, standard deviation and range. ANOVA was used to describe differences between physical activity groups and ANCOVA was used when adjusting for covariates. To determine the effect of physical activity on BMD, linear regression analysis was performed, entering the following variables simultaneously into the model: smoking (current smoker vs. non- or previous smoker), alcohol consumption (in g/week for those consuming alcohol) and dietary calcium intake (in mg/day). For non-parametric, dichotomous data, Chi-square test was used. The level of significance was set at $p < 0.05$.

All statistical analysis was performed using SPSS 17.0 software (SPSS Inc., Chicago, Illinois).

RESULTS

Baseline characteristics

Baseline characteristics are reported in table 1. The mean height of the women was 167.6 (6.1) cm, whereas body weight and consequently BMI showed a wider range (15.2–51.2). Of the young women, 26% were current smokers.

In total, the 25-year-old women reported participation in 85 different types of recreational physical activities. The top-five activities were running, strength training, aerobics (low intensity), aerobics (high intensity) and spinning (figure 1), although the frequency varied with the season. During the winter, strength training and aerobics were most common while during the summer running and strength training were most common. There was no difference between the number of women who reported participation in at least one recreational sport and exercise activity during summer (69%) and winter (70%). They participated in organized sports on average 1.7 times a week (range 0–11). Those who walked for exercise (71%) did so an average of twice a week while 30% walked at least 5 kilometers per day back and forth to work. Bicycling, as the single mode of transportation was reported for 28% of the women.

Effect on bone mass of physical activity level

Recreational activity level (RAL) scores were unevenly distributed, with a median of 4 (range 1-6). Only 2.6% (n=27) classified themselves in the lowest group (RAL 1) with virtually no

exercise and 3.1% (n=33) in the highest group (RAL 6). Thus, for analyses two categories were used: low/moderate (RAL 1–3; 49.5%) and high RAL (RAL 4–6; 49.9%).

High recreational activity (RAL 4–6) contributed to significantly higher bone mineral density (BMD) in the hip and lumbar spine compared to less active women; TR-BMD 3.3% (p<0.001), FN-BMD 2.6% (p<0.001) and spine, LS-BMD 1.5% (p=0.0194) (table 2).

Effect on bone mass of impact load

The majority of women (71.3%; n=757), took part in sports which had a low/moderate impact (PSS 0–4), and only 27.2% (n=289) of the women participated in sports which had a high-impact score of ≥5.

Young women with high PSS's had significantly higher BMD at both the hip and spine compared to women with low scores (TR-BMD (3.5%; p<0.001), FN-BMD (2.9%; p<0.001) and LS-BMD (2.1%; p=0.0039) (table 2). Body weight and BMI were significantly lower in those with high PSS compared to those with low.

Effect on bone mass of regular high-impact exercise

The number of women who had both **high** RAL and PSS scores (High-COMB-RP) i.e. took part in high-impact sports over long/regular periods of time was 23.8% (n=246). The majority of women (44.8%; n=476) had both **low** RAL and PSS scores (Low-COMB-RP). All other score combinations accounted for 31.4% (n=339) of the cohort.

When the combined score (COMB-RP) was used to explore the effects of physical activity on skeletal integrity, differences in BMD became more pronounced at all the measured sites. The largest difference in BMD was seen in the trochanteric region, with 4.7% higher BMD values among those in the High-COMB-RP group (p<0.001). Correspondingly, weight and BMI were significantly lower. Adjustment for weight resulted in even greater differences in BMD between women in the Low- and High-COMB-RP groups (TB-BMC 3.5%; TB-BMD 1.8%; FN-BMD 4.7%; TR-BMD 5.5% and LS-BMD 3.1%; p for all <0.001) (figure 2).

Adjusting for the covariates smoking, alcohol and dietary calcium intake in the linear regression analysis, the significances remained, although the effects were attenuated (COMB-RP: 3.1% TR-BMD, 1.6% LS-BMD and 1.3% FN-BMD).

The effects of calcium, smoking or alcohol did not significantly affect BMD at any site (Calcium: (TB, ß=0.01; FN, ß=0.036; TR, ß=0.035; LS, ß=0.006, all ns); Alcohol: (TB, ß=-0.06; FN, ß=0.002; TR, ß=0. 002; LS, ß=0.06, all ns); Smoking: (TB, ß=-0.029; FN, ß=-0.057; TR, ß=-0. 052; LS, ß=-0.023, all ns)).

Skeletal site-specific effects of exercise on bone mass

In order to assess the contribution of physical activity to differences in BMD at specific skeletal sites, ratios against TB-BMD were calculated. Comparing women with High-COMB-RP versus Low-COMB-RP scores, significantly higher BMD was observed at regions exposed to axial impact load, i.e. the femoral neck (+2.7%, p<0.001) trochanter (+3.5%, p<0.001) and lumbar spine (+1.37%, p=0.0162).

Effect on bone mass of specific recreational activities

To evaluate the effect on BMD of specific types of exercise, each of the five most commonly reported activities (7–18%) throughout the whole year was selected for analysis and compared against those women who reported that they did not partake in recreational activities (RAL=1, n=27).

Women who practiced spinning throughout the summer and winter had significantly higher (2.7%) TB-BMD than non-active women. Running increased BMD by 8.5% at the trochanter and 7.2% at the femoral neck, while the corresponding values for women practicing spinning were 6.4% (TR-BMD) and 7.2% (FN-BMD). Of those 54 women reporting spinning as their main activity, only a few (<7) reported running as their second activity, instead strength training dominated. None of these five activities produced significant differences in LS-BMD (table 3).

Physical education in school and behavioral patterns of physical activity

In this study we assessed whether previous levels of physical activity and attitude towards physical activity influenced current activity levels or contributed to changes in activity level, by comparing the Low–COMB-RP and High-COMB-RP groups.

In total, 68% of the young women reported that they liked physical education in school, but the most active women (High-COMB-RP) enjoyed it considerably more than those whose current activity levels were low (Low-COMB-RP) (χ^2 18.5; p<0.001) (figure 3).

Also women with Low-COMB-RP scores showed a significant decline in their physical activity levels between school and age 25, with 79% reporting that they had been more active previously, compared to only 46% of the High-COMB-RP group (χ^2 78.6; p<0.001).

DISCUSSION

The majority of previous studies on the influence of physical activity on bone health in young women have been performed in amateur or elite athletes [10-15], whereas we are studying the effects of ordinary recreational physical activity in a typical and large population of women 25 years of age, an age chosen to be closely representative of peak bone mass. We show that recreational physical activity in general is beneficial for the skeleton in young adult women and, furthermore, that a higher peak bone mass at both the hip and the spine is attained by women who regularly exercise and partake in high-impact activities. This study also provides an insight into exercise patterns in young women, which has consequences for peak bone mass and far-reaching implications in terms of maintenance of bone health throughout adulthood and old age.

It has been shown that regularly participating in exercise which produces high ground reaction forces, even for short periods, significantly increases BMD in the femoral neck and lumbar spine in young women [30, 31]. This suggests that the strain to which bone is subjected as a result of high frequency and magnitude is not dependent on duration to induce an osteogenic response [32]. Therefore, training and exercise with high strain rates such as basketball, which involves abrupt movements and high impacts, is more effective in promoting bone formation than exercise which involves repetitive but low-impact movements such as swimming and walking [33]. Based on this, we have evaluated the individual effect on BMD of overall recreational activity level (RAL) and peak strain score (PSS) and additionally estimated the combined score (COMB-RP).

High recreational activity levels were associated with increased bone mass, particularly in the hip, indicating that regular exercise is important to maintain bone mineral density. That

exercise predominantly exerts its effect at the hip is in line with earlier studies showing the greatest differences between very active and moderately/non-active females in the Ward's triangle and the femoral neck [14, 34]. Weight-bearing activities producing high peak strains had a more pronounced beneficial effect on bone mass accrual in the women in this study. In this respect our results support earlier studies in competitive athletes where weight-bearing, high-impact load exercise appears to provide a more effective stimulus to bone formation at total body and femoral neck than non-weight bearing, low-impact exercise [35-37]. The largest increases in bone mass appear to result from regular participation in sports activities which incorporate high impact, such as volleyball, and we can show that BMD values in young adult women with a high exercise level were 1.8–5.5% higher at the hip, spine and total body compared to women who had a low combined score. This effect was enhanced by adjusting for weight, indicating that less active women compensated to a small extent for the lack of exercise, with body weight. Numerically, these percentage differences can be viewed in the perspective of annual bone loss in old age and may correspond to a 2-5 year advantage.

Furthermore, when evaluating the effects of the types of recreational physical activity that young women are commonly engaged in and when comparing active with non-active women, significant differences appear. For low-intensity aerobics which is mainly focused on coordination and less on jumping, no differences in bone mass were observed. However, when studying the women participating in high-intensity aerobics, which includes jumping and axial strain, one sees a clear bone mass gain. Surprisingly, although neither cycling or spinning produces axial loads on the skeleton, women with spinning as their principal activity had approximately 7% higher BMD in the femoral neck and trochanter compared to non-active women, while regular bicycling which was not associated with higher BMD. This

could be explained by the high muscular strain produced in the thigh by spinning, but not by normal cycling. The effect from spinning may also be enhanced by the fact that strength training was a common co-activity in these women. These observations indicate the importance of the type of activity in order to increase peak bone mass. The importance of weight bearing on BMD is often illustrated by the fact that in studies comparing swimmers and controls [36] no differences in BMD at any site were observed, whereas those engaged in high-impact load training demonstrated significantly higher BMD at all sites. Emslander et al [35] also showed significant positive correlations for weight-bearing activities and TB-BMD and FN-BMD, when comparing runners and swimmers. In Risser et al's study [38] of high-impact sports such as volleyball and basketball compared with swimmers and non-active females, they found higher BMD in the spine and the calcaneus for volleyball and basketball players, using photon absorptiometry. *C*ontradictory findings demonstrating no correlation at all for BMD for women aged 20–25 years were reported by Neville et al [39], but this may be a reflection of low participation in sports activities and a low sample number.

The beneficial effects of exercise on the skeleton are, as might be expected, site-specific, largely affecting regions exposed to axial impact load. In addition to providing information on the contribution of physical activity to bone mass, this study also provides information on psychosocial attitudes to exercise which have implications for bone health across their entire lifespan. Aspects of the relationship between physical activity in childhood and later in adolescence and adulthood have previously been described by others [40-42], with physical activity level in childhood considered a predictor of physical activity later in life. Our results support this line of argument and draw attention to the importance of a physically active childhood in relation to bone health.

Women who were currently highly active had enjoyed physical education in school to a much greater extent than those women who were rated as comparatively inactive. Hence, current activity levels appear to be connected to former activity levels, which may be of particular importance since this time period includes pubertal development, during which time high-impact loads have been demonstrated to be important for skeletal acquisition [43]. We also believe that further accretion may result if bone is exposed to impact load even after puberty. In a recently published study from Pettersson et al [44], physical activity during childhood and adolescence was considered the strongest predictor of calcaneal BMD, explaining 10.1% of the variation in bone mass of young, 18-year-old men.

In the longer term, given that the most active young women had a tendency to maintain their activity level to a greater extent than the inactive women, it can be speculated that this group of women will continue to accrue the benefits of habitual physical activity, with higher BMD maintained during adulthood. The cohort is currently being followed up and in due course will allow us to determine the long-term effects on bone mineral density alongside changing physical activity levels. Attitude to physical activity and exercise has implications for general health, beyond just osteoporosis. If good habits are not ingrained at an early stage, whether because of inadequate exposure or poor teaching, this has far reaching implications for bone health and osteoporosis risk. Nevertheless, this may also highlight the possibility of a physical selection bias, since a subject of a certain body constitution will be prone to participate in a specific sport or in sports in general or alternatively to avoid physical activity.

Our study has some limitations but also strengths. One limitation may be the 49% response rate; however, inclusion is population-based and we have not identified any systematic

reason for non-participation. A limitation of the questionnaire is recall bias and social desirability such that physical activity could easily be overestimated, as is described by Hagströmer et al [45, 46], who report a discrepancy between objectively reported and self-reported physical activity. This has to be taken into consideration when interpreting our results, since half of the women were classified as high RAL. Also, the study relies on areal BMD, hence we cannot comprehensively evaluate other structural effects for example cortical effects on bone strength by recreational exercise. Nevertheless, the cohort represents, to the best of our knowledge, the largest study of young adult women evaluating bone mass in relation to physical activity and is likely to be adequately representative. The unique design whereby all women are of identical age is also regarded as strength since no age adjustments are necessary.

There are recognized methodological difficulties in assessing every aspect of physical activity in normal populations over time. In order to capture both the overall activity level and the skeletal impact, we have chosen scoring models that only take into account the current physical activity level, but as demonstrated, this seems to be a qualified indicator of earlier activity level as well. We also acknowledge that it was not possible to meaningfully analyze the influence of time spent on exercise.

Conclusion

From this large study, firstly we can showcase the exercise patterns in average young adult women. Secondly, we can conclude that bone mineral density in young women is influenced by the overall recreational physical activity level but importantly, demonstrate that activities inducing high impacts (peak strain) have even greater effects. Taken together with a

tendency to maintain their activity levels over time, it is likely that young adult women who are physically active will both achieve and maintain a higher peak bone mass than those who are relatively inactive. Therefore, it is important already during the school years not only to encourage physical activity but to make it enjoyable, since it will promote habitual continuous physical exercise later in life, resulting in advantageous effects on peak bone mass and possibly on other organ systems.

ACKNOWLEDGMENTS

TABLES

Table 1 Baseline characteristics and bone mineral density for 25-year-old women

	N	Mean	SD	Range
Age (years)	1061	25.5	0.2	25.01–25.99
Height (cm)	1060	167.6	6.1	149.6–186.5
Weight (kg)	1060	64.7	11.4	40.0–141.0
BMI (kg/m^2)	1060	23.0	3.8	15.2–51.2
Calcium intake (mg/day)	984	642	377	0-2552
Alcohol (g/week)	579	47	57	0.1-760
TB-BMD (g/cm^2)	1060	1.174	0.073	0.969–1.486
FN-BMD (g/cm^2)	1057	1.053	0.123	0.746–1.604
TR-BMD (g/cm^2)	1057	0.830	0.108	0.537–1.357
LS-BMD (g/cm^2)	1059	1.217	0.128	0.824–1.868
TB-BMC (g)	1060	2 592	337	1649–3932

*TB (total body), FN (femoral neck), TR (trochanter), LS (lumbar spine L1-L4)

Table 2 Crude differences in anthropometry and bone mass for 25-year-old women, categorized according to Recreational Activity Level (A.) and Peak Strain Score (B.)

A.	*Recreational Activity Level (RAL)*							
	High RAL (n=529)		**Low/moderate RAL (n=525)**			**95% CI**		
Variable	**Mean**	**SD**	**Mean**	**SD**	**% Diff**	**Lower**	**Upper**	**p-value**
Height (cm)	167.7	5.9	167.4	6.3	0.21%	-0.23	0.65	ns
Weight (kg)	64.0	10.0	65.4	12.6	−2.10%	-4.20	0.00	ns
BMI (kg/m^2)	22.7	3.3	23.3	4.2	−2.52%	-4.48	-0.55	0.0123
TB-BMD (g/cm^2)	1.178	0.071	1.171	0.076	0.58%	-0.18	1.33	ns
FN-BMD (g/cm^2)	1.067	0.125	1.040	0.120	2.56%	1.14	3.99	<0.001
TR-BMD (g/cm^2)	0.845	0.110	0.817	0.104	3.33%	1.75	4.91	<0.001
LS-BMD (g/cm^2)	1.226	0.130	1.208	0.125	1.52%	0.25	2.80	0.0194
TB-BMC (g)	2606	332	2578	342	1.10%	-0.48	2.68	Ns

B.	*Peak Strain Score (PSS)*							
	High PSS (n=289)		**Low/moderate PSS (n=757)**			**95% CI**		
Variable	**Mean**	**SD**	**Mean**	**SD**	**% Diff**	**Lower**	**Upper**	**p-value**
Height (cm)	167.9	5.7	167.4	6.2	0.29%	-0.20	0.78	ns
Weight (kg)	63.3	8.5	65.3	12.3	−3.18%	-5.55	-0.82	0.0084
BMI (kg/m^2)	22.4	2.7	23.3	4.1	−3.74%	-5.96	-1.52	<0.001
TB-BMD (g/cm^2)	1.182	0.073	1.171	0.073	0.94%	0.09	1.79	0.0300
FN-BMD (g/cm^2)	1.075	0.129	1.044	0.119	2.93%	1.34	4.52	<0.001
TR-BMD (g/cm^2)	0.851	0.108	0.823	0.107	3.47%	1.70	5.24	<0.001
LS-BMD (g/cm^2)	1.235	0.131	1.210	0.126	2.11%	0.68	3.54	0.0039
TB-BMC (g)	2625	320	2580	342	1.75%	-0.02	3.52	ns

*TB (total body), FN (femoral neck), TR (trochanter), LS (lumbar spine L1-L4)

Table 3 Comparisons for subjects exerting specific physical activities on a whole-year basis and non-active subjects

Variable	N	TB-BMD Mean	%	95% CI Lower	95% CI Upper	FN-BMD Mean	%	95% CI Lower	95% CI Upper	TR-BMD Mean	%	95% CI Lower	95% CI Upper	LS-BMD Mean	%	95% CI Lower	95% CI Upper
Non-active (RAL 1)	27	1.155 ± 0.057				1.010 ± 0.080				0.804 ± 0.082				1.196 ± 0.102			
Activities																	
Aerobics (low intensity)	112	1.164 ± 0.062	0.8%	-1.4	3.1	1.042 ± 0.130	3.2%	-1.9	8.4	0.819 ± 0.097	1.8%	-3.2	6.8	1.200 ± 0.105	0.3%	-3.4	4.0
Strength training	89	1.164 ± 0.064	0.8%	-1.5	3.2	1.039 ± 0.103	2.9%	-1.3	7.1	0.809 ± 0.099	0.6%	-4.6	5.7	1.190 ± 0.115	-0.5%	-4.6	3.5
Running	40	1.183 ± 0.075	2.4%	-0.5	5.4	1.082 ± 0.111	7.2%	2.3	12.1	0.873 ± 0.114	8.5%	2.2	14.9	1.210 ± 0.096	1.1%	-2.9	5.2
Spinning	54	1.186 ± 0.072	2.7%	0.0	5.5	1.082 ± 0.129	7.2%	1.8	12.5	0.856 ± 0.104	6.4%	0.8	12.1	1.235 ± 0.143	3.3%	-1.9	8.4
Aerobics (high intensity)	77	1.183 ± 0.071	2.4%	-0.2	5.1	1.068 ± 0.116	5.8%	1.1	10.6	0.857 ± 0.111	6.5%	0.8	12.3	1.236 ± 0.132	3.3%	-1.3	8.0

*TB (total body), FN (femoral neck), TR (trochanter), LS (lumbar spine L1-L4)

FIGURES

Figure 1 The pie charts show the most common physical activities undertaken for recreation in 25-year-old Swedish women during winter and summer

Sports during the winter
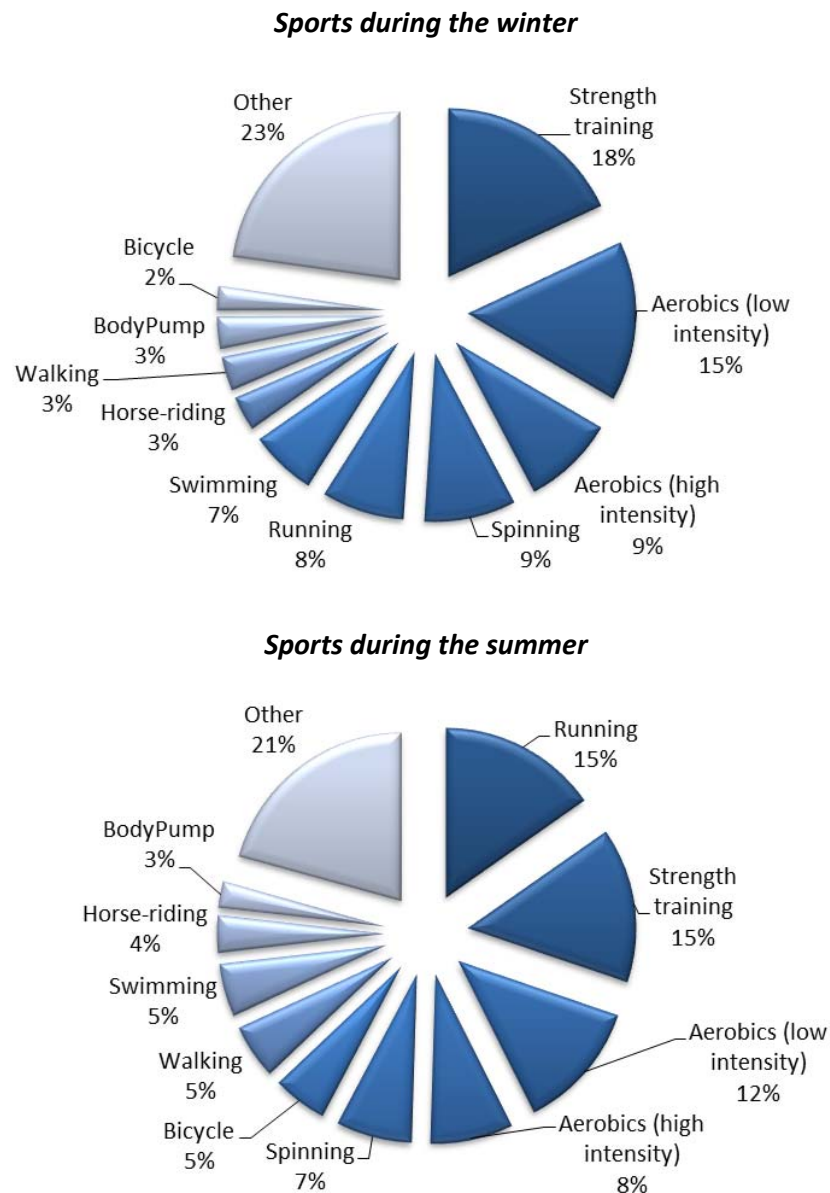

Sports during the summer

Figure 2 Percentage differences with 95% confidence intervals, in bone mass, adjusted for body weight, between **high** and **low COMB-RP** exercise groups
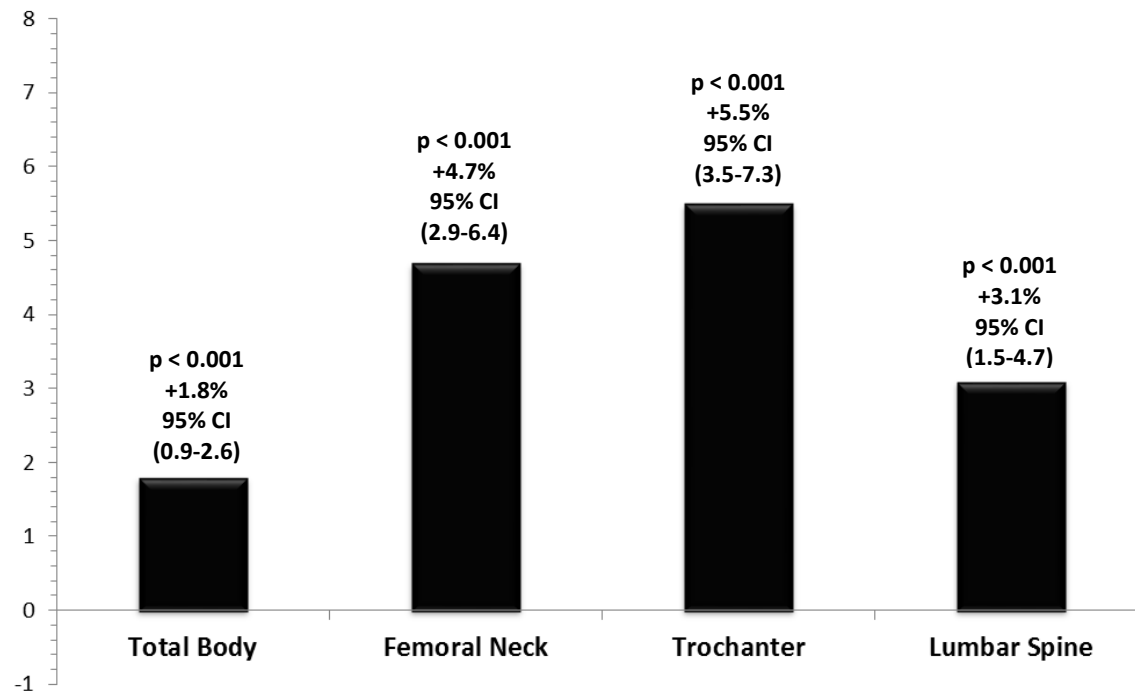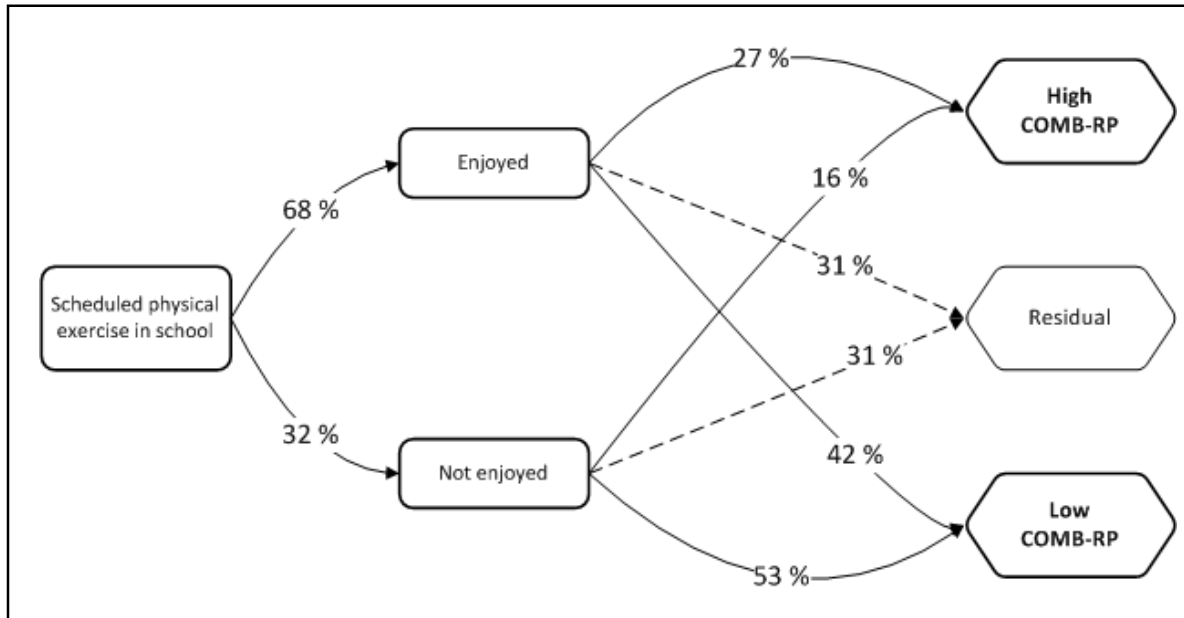
Figure 3 Flowchart describing the outcome of subjects who liked and disliked physical education in school and their distribution into becoming more or less active at age 25 (High-COMB-RP and Low-COMB-RP). The residual group consists of individuals with the combinations low PSS/high RAL and high PSS/low RAL.

APPENDIX

Appendix 1 Model for estimation and classification of Peak Strain Score (PSS), according to Groothausen et al [24].

PSS	GRF	Estimation criteria	Examples
3	> 4	Activities including jumping actions	Basketball, volleyball
2	2–4	Activities including sprinting and turning actions	Badminton, tennis, squash
1	1–2	Weight-bearing activities	Dancing, running
0	< 1	All other activities	Bicycling, swimming

GRF (Ground reaction force)

Appendix 2 Linear regression analysis with regression coefficients for of Recreational Activity Level and Peak Strain Score (PSS)

	RAL			PSS		
	R^2	β	p	R^2	β	p
TB-BMD	0.8%	0.09	0.0034	0.8%	0.09	0.0034
FN-BMD	2.9%	0.17	<0.001	2.0%	0.14	<0.001
TR-BMD	3.3%	0.18	<0.001	2.6%	0.16	<0.001
LS-BMD	1.5%	0.12	<0.001	1.3%	0.11	<0.001

REFERENCES

1.   Berger, C., et al., *Peak bone mass from longitudinal data: implications for the prevalence, pathophysiology, and diagnosis of osteoporosis.* J Bone Miner Res, 2010. **25**(9): p. 1948-57.

2.   Bonjour, J.P., et al., *The importance and relevance of peak bone mass in the prevalence of osteoporosis.* Salud Publica Mex, 2009. **51 Suppl 1**: p. S5-17.

3.   Jouanny, P., et al., *Environmental and genetic factors affecting bone mass. Similarity of bone density among members of healthy families.* Arthritis Rheum, 1995. **38**(1): p. 61-7.

4.   Slemenda, C.W., et al., *Genetic determinants of bone mass in adult women: a reevaluation of the twin model and the potential importance of gene interaction on heritability estimates.* J Bone Miner Res, 1991. **6**(6): p. 561-7.

5.   Eisman, J.A., *Genetics of osteoporosis.* Endocr Rev, 1999. **20**(6): p. 788-804.

6.   Turner, C.H., *Three rules for bone adaptation to mechanical stimuli.* Bone, 1998. **23**(5): p. 399-407.

7.   Lanyon, L.E., *Control of bone architecture by functional load bearing.* J Bone Miner Res, 1992. **7 Suppl 2**: p. S369-75.

8.   O'Connor, J.A., L.E. Lanyon, and H. MacFie, *The influence of strain rate on adaptive bone remodelling.* J Biomech, 1982. **15**(10): p. 767-81.

9.   Rubin, C.T. and L.E. Lanyon, *Regulation of bone mass by mechanical strain magnitude.* Calcif Tissue Int, 1985. **37**(4): p. 411-7.

10.   Nichols, D.L., C.F. Sanborn, and E.V. Essery, *Bone density and young athletic women. An update.* Sports Med, 2007. **37**(11): p. 1001-14.

11.   Nikander, R., et al., *Femoral neck structure in adult female athletes subjected to different loading modalities.* J Bone Miner Res, 2005. **20**(3): p. 520-8.

12.   Nikander, R., et al., *Targeted exercises against hip fragility.* Osteoporos Int, 2009. **20**(8): p. 1321-8.

13.   Kontulainen, S.A., et al., *Does previous participation in high-impact training result in residual bone gain in growing girls? One year follow-up of a 9-month jumping intervention.* Int J Sports Med, 2002. **23**(8): p. 575-81.

14.   Alfredson, H., P. Nordstrom, and R. Lorentzon, *Total and regional bone mass in female soccer players.* Calcif Tissue Int, 1996. **59**(6): p. 438-42.

15.   Alfredson, H., P. Nordstrom, and R. Lorentzon, *Bone mass in female volleyball players: a comparison of total and regional bone mass in female volleyball players and nonactive females.* Calcif Tissue Int, 1997. **60**(4): p. 338-42.

16.   Nilsson, M., et al., *Association of physical activity with trabecular microstructure and cortical bone at distal tibia and radius in young adult men.* J Clin Endocrinol Metab, 2010. **95**(6): p. 2917-26.

17.   Lorentzon, M., D. Mellstrom, and C. Ohlsson, *Association of amount of physical activity with cortical bone size and trabecular volumetric BMD in young adult men: the GOOD study.* J Bone Miner Res, 2005. **20**(11): p. 1936-43.

18.   Daly, R.M. and S.L. Bass, *Lifetime sport and leisure activity participation is associated with greater bone size, quality and strength in older men.* Osteoporos Int, 2006. **17**(8): p. 1258-67.

19. Farr, J.N., et al., *Associations of physical activity duration, frequency, and load with volumetric BMD, geometry, and bone strength in young girls.* Osteoporos Int, 2011. **22**(5): p. 1419-30.

20. Trudeau, F., et al., *Daily primary school physical education: effects on physical activity during adult life.* Med Sci Sports Exerc, 1999. **31**(1): p. 111-7.

21. Bradney, M., et al., *Moderate exercise during growth in prepubertal boys: changes in bone mass, size, volumetric density, and bone strength: a controlled prospective study.* J Bone Miner Res, 1998. **13**(12): p. 1814-21.

22. French, S.A., J.A. Fulkerson, and M. Story, *Increasing weight-bearing physical activity and calcium intake for bone mass growth in children and adolescents: a review of intervention trials.* Prev Med, 2000. **31**(6): p. 722-31.

23. Gustavsson, A., K. Thorsen, and P. Nordstrom, *A 3-year longitudinal study of the effect of physical activity on the accrual of bone mineral density in healthy adolescent males.* Calcif Tissue Int, 2003. **73**(2): p. 108-14.

24. Groothausen, J., et al., *Influence of peak strain on lumbar bone mineral density: An analysis of 15 year physical activity in young males and females.* Pediatr Exerc Sci, 1997. **9**: p. 159-173.

25. Ainsworth, B.E., J.M. Shaw, and S. Hueglin, *Methodology of activity surveys to estimate mechanical loading on bones in humans.* Bone, 2002. **30**(5): p. 787-91.

26. Dolan, S., et al., *Development and Reproducibility of the Bone Loading History Questionnaire.* Med Sci Sports Exerc, 2006. **38**(6): p. 1121-1131.

27. Shedd, K., et al., *Quantifying Leisure Physical Activity and Its Relation to Bone Density and Strength.* Med Sci Sports Exerc, 2007. **39**(12): p. 2189-2198.

28. Weeks, B.K. and B.R. Beck, *The BPAQ: a bone-specific physical activity assessment instrument.* Osteoporos Int, 2008. **19**(11): p. 1567-77.

29. Morel, J., et al., *Bone mineral density of 704 amateur sportsmen involved in different physical activities.* Osteoporos Int, 2001. **12**(2): p. 152-7.

30. Bassey, E.J., et al., *Pre- and postmenopausal women have different bone mineral density responses to the same high-impact exercise.* J Bone Miner Res, 1998. **13**(12): p. 1805-13.

31. Kato, T., et al., *Effect of low-repetition jump training on bone mineral density in young women.* J Appl Physiol, 2006. **100**(3): p. 839-43.

32. Chilibeck, P.D., D.G. Sale, and C.E. Webber, *Exercise and bone mineral density.* Sports Med, 1995. **19**(2): p. 103-22.

33. Heinonen, A., et al., *Bone mineral density in female athletes representing sports with different loading characteristics of the skeleton.* Bone, 1995. **17**(3): p. 197-203.

34. Lee, E.J., et al., *Variations in bone status of contralateral and regional sites in young athletic women.* Med Sci Sports Exerc, 1995. **27**(10): p. 1354-61.

35. Emslander, H.C., et al., *Bone mass and muscle strength in female college athletes (runners and swimmers).* Mayo Clin Proc, 1998. **73**(12): p. 1151-60.

36. Fehling, P.C., et al., *A comparison of bone mineral densities among female athletes in impact loading and active loading sports.* Bone, 1995. **17**(3): p. 205-10.

37. Heinonen, A., et al., *Bone mineral density of female athletes in different sports.* Bone Miner, 1993. **23**(1): p. 1-14.

38. Risser, W.L., et al., *Bone density in eumenorrheic female college athletes.* Med Sci Sports Exerc, 1990. **22**(5): p. 570-4.

39. Neville, C.E., et al., *Relationship between physical activity and bone mineral status in young adults: the Northern Ireland Young Hearts Project.* Bone, 2002. **30**(5): p. 792-8.

40. Trudeau, F., L. Laurencelle, and R.J. Shephard, *Tracking of physical activity from childhood to adulthood.* Med Sci Sports Exerc, 2004. **36**(11): p. 1937-43.

41. Kjonniksen, L., N. Anderssen, and B. Wold, *Organized youth sport as a predictor of physical activity in adulthood.* Scand J Med Sci Sports, 2009. **19**(5): p. 646-54.

42. Jose, K.A., et al., *Childhood and adolescent predictors of leisure time physical activity during the transition from adolescence to adulthood: a population based cohort study.* International Journal of Behavioral Nutrition and Physical Activity, 2011. **8**(1): p. 54-54.

43. Nurmi-Lawton, J., et al., *Evidence of sustained skeletal benefits from impact-loading exercise in young females: A 3-year longitudinal study.* J Bone Miner Res, 2004. **19**(2): p. 314-322.

44. Pettersson, U., et al., *Physical activity is the strongest predictor of calcaneal peak bone mass in young Swedish men.* Osteoporos Int, 2010. **21**(3): p. 447-55.

45. Hagstromer, M., et al., *Comparison of a subjective and an objective measure of physical activity in a population sample.* J Phys Act Health, 2010. **7**(4): p. 541-50.

46. Hagstromer, M., et al., *Levels and patterns of objectively assessed physical activity--a comparison between Sweden and the United States.* Am J Epidemiol, 2010. **171**(10): p. 1055-64.