TITLE

Lifetime physical activity, neuromuscular performance and body composition in healthy young men

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ABSTRACT

The purpose of the current study was to determine the relationships between *lifetime* physical activity participation, neuromuscular performance and body composition in men at musculoskeletal maturity. Fifty healthy men (age 25.2 ± 4.5 years) volunteered to participate. Lifetime physical activity was determined from the Bone-specific Physical Activity Questionnaire. Impulse generated during a maximal vertical jump was calculated as an index of neuromuscular performance. Bone mineral density (BMD), lean and fat mass were determined from dual-energy x-ray absorptiometry (XR800, Norland). A subsample of participants ($n=13$) additionally underwent peripheral quantitative computed tomography (pQCT, XCT3000, Stratec) measures. Results demonstrated that those in the highest tertile for lifetime physical activity exhibited the greatest lumbar spine BMD ($\mu_{\text{diff}} = 0.12 \text{ g/cm}^2$, $p=0.005$) and lean body mass index (LBMI) ($p=0.04$). Those in the highest tertile for impulse also exhibited the highest whole body ($\mu_{\text{diff}} = 0.08 \text{ g/cm}^2$), lumbar spine ($\mu_{\text{diff}} = 0.14 \text{ g/cm}^2$), and femoral neck BMD ($\mu_{\text{diff}} = 0.15 \text{ g/cm}^2$) ($p \leq 0.05$). All BMD differences exceeded the least significant change. Childhood physical activity was positively related to LBMI ($r=0.28$, $p=0.05$) whereas sedentary activity was inversely related to femoral neck BMD ($r=-0.33$, $p=0.02$). Results support recommendations for sustained physical activity participation during the growing years.

Key words: bone mass; exercise; impulse; lean mass; peripheral quantitative computed tomography.

INTRODUCTION

It is well-known that participation in regular physical activity promotes healthy ageing. Strong evidence has accumulated to suggest that active people have lower rates of all-cause mortality and chronic disease [11,48]. Global Health Observatory data highlights that worldwide physical inactivity causes 6 to 10% of major non-communicable diseases and up to 9% of premature deaths [24]. Osteoporosis and sarcopenia are two non-communicable conditions that are strongly age-related and may be prevented with adequate physical activity participation [47,49].

Osteoporosis is a progressive bone disease characterised by low bone mass and density [47]. When measured by dual-energy x-ray absorptiometry, a hip bone mineral density (BMD) greater than 2.5 standard deviations below the average for a healthy young adult is considered to be indicative of osteoporosis. Such deficiency corresponds to increased fracture risk at the hip, spine and forearm and results in an estimated lifetime fracture risk of 30 to 40% [47]. Osteoporotic hip fractures in particular are linked to premature death in the years following the event [16]. In 2007/2008 an estimated 692,000 Australians (3.4% of total population) had medically-diagnosed osteoporosis, while the estimated annual cost of all osteoporotic fractures in Australia amounts to more than \$7 billion [30,37].

Sarcopenia is characterised by a progressive loss of skeletal muscle mass, strength and quality with age. Reduced leg muscle mass and more extensive intramuscular fat is related to poorer lower extremity performance in older men and women [41]. Sarcopenia is also associated with abnormal BMD and is an established risk factor for osteoporosis [49]. Physical activity participation is beneficial to bone and muscle quality at every stage of life, and thus, may be protective against osteoporosis and sarcopenia [2,24,41]. Better bone and muscle quality may also confer neuromuscular and functional benefits [34]. The

interrelationships between lifetime physical activity and bone, muscle and performance, however, are yet to be clearly established.

Despite strong evidence for the benefits of physical activity, many Australians are not participating adequately. For example, in 2007/2008 approximately 60% of Australians 18 to 35 years of age did not meet the recommended National Physical Activity Guidelines for Adults [1]. Common methods to measure physical activity participation (e.g. pedometers, accelerometers, and questionnaires) tend to quantify only very recent participation (e.g. previous week or previous year) and may under-represent true *lifelong* physical activity [17,38]. The bone-specific physical activity questionnaire (BPAQ), however, is a musculoskeletal relevant tool that captures participation across a full lifetime. BPAQ scores have been shown to predict DXA measures of bone at clinically-relevant sites [43].

The over-arching purpose of the current study was to investigate the relationships between lifetime physical activity participation, neuromuscular performance and body composition in healthy young adult men. We hypothesised that: 1) Individuals with the greatest lifetime physical activity scores will exhibit greater lean mass, lean body mass index (LBMI; i.e. lean mass as a function of body size) and BMD than those with the lowest lifetime physical activity scores; and 2) Individuals exhibiting the greatest neuromuscular performance (i.e. impulse calculated from vertical jump performance) will exhibit greater lean mass, LBMI and BMD measures than those with the poorest neuromuscular performance.

MATERIALS AND METHODS

Participants and participant selection

Healthy young men between 18 and 35 years of age were recruited to the study using flyer advertisements and word of mouth. The age range was chosen to correspond with the

adult years around which peak bone mass is attained and prior to the onset of common degenerative musculoskeletal pathologies. Volunteers were excluded if they had any of the following: musculoskeletal conditions likely to affect physical performance; unstable cardiovascular disease; known diagnosis of cancer; cognitive impairment; or metal implants. Individuals who had undergone more than two x-ray examinations or had radiation treatment in the previous 12 months were excluded to eliminate the risk of over exposure to ionising radiation. Written informed consent was obtained from each volunteer, and all experimental procedures were approved by the XXXXX Human Research Ethics Committee (XXXX).

Anthropometrics

Height was measured to the nearest millimetre using the stretch stature method with a wall-mounted stadiometer (HART Sport & Leisure, Australia). Weight was measured to the nearest 0.1 kg using a Seca-700 mechanical balance scale (Seca GmbH, Hamburg, Germany). Body mass index (BMI) was subsequently calculated using the accepted formula ($\text{BMI} = \text{weight}/\text{height}^2, \text{kg.m}^{-2}$).

Physical activity

Bone-specific Physical Activity Questionnaire (BPAQ)

Lifetime physical activity participation was recorded with the self-administered BPAQ [43]. Participants were asked to record type, frequency and years of any regular physical activity involvement during their life; including sports, recreational, occupational and household related activities. Participants then recorded type, frequency and bout duration of any regular activity in the preceding 12 months, including sedentary activities. Questionnaires were scored using a custom-designed Microsoft Visual Basic 2010 Express program (Microsoft, Redmond, WA, USA) to generate bone-specific scores (unitless) for past,

childhood (0-15 years of age), current (previous 12 months) and overall participation (total BPAQ). The bone load ratings assigned to the different activities were developed previously by Weeks and Beck [43]. The algorithms in the program apply weightings to the exercise parameters recorded on the questionnaire.

International Physical Activity Questionnaire (IPAQ)

The self-administered IPAQ was used to describe our cohort based on a recognised index of activity level [18]. Thus, we determined the metabolic load for all physical activities performed over the last seven days. Responses were combined to derive domain sub-scores, and a total physical activity score for weekly energy expenditure in MET-minutes per week [14,18].

Body composition

Dual-Energy X-ray Absorptiometry (DXA)

Lumbar spine and femoral neck BMD were obtained from dual-energy x-ray absorptiometry (XR-800, Norland Medical Systems, Inc., USA). Whole body BMD, lean mass and fat percentage were determined from the WB scan.

Peripheral Quantitative Computed Tomography (pQCT)

Peripheral quantitative computed tomography scans of the non-dominant leg were performed in a subsample of participants to obtain morphometric measures of bone, muscle and fat (XCT3000, Stratec Medizintechnik GmbH, Pforzheim, Germany; 0.5 mm voxels and host software version 6.2). The skeletally non-dominant leg was chosen to correspond with the dominant arm reported by the participant [7]. Trabecular area and density was determined 4% from the distal end of the tibia, whilst cortical area and density and periosteal circumference were examined at the 38% tibial site. Muscle area was determined at the 66%

site. All scans were performed by a qualified technician and all devices underwent daily calibration and quality control.

Neuromuscular performance

Neuromuscular performance was examined by calculating impulse from a maximal vertical jump (VJ) task. Participants stood barefoot on a force plate (AMTI, Watertown, MA, USA), and were asked to perform a VJ, while three-dimensional ground reaction forces for the loading and take-off phase were collected at 1000 Hz using Vicon Nexus software (Vicon, Oxford Metrics, Oxford, UK). Prior to undertaking the jumping trials, participants performed a 5-minute warm-up on a cycle ergometer (Ergomedic 818E, Monark, Sweden) at 50 watts (60 RPM). Following the warm-up, three practice vertical jumps were allowed in order to familiarize participants with jump technique before collecting 6 to 8 trials separated by 30 second rest periods. For each trial, participants were instructed to adopt a stationary standing position, before performing a maximal effort counter-movement squat jump. Participants were permitted to swing their arms during each VJ. To encourage maximal effort, participants were asked to aim to touch the peg of a YardStick vertical jump device (Swift Performance Equipment, Brisbane, Australia), positioned approximately five centimetres above their maximal jump height (i.e. determined from practice efforts). Data were analysed using custom written software in Matlab version 7.13 (The MathWorks, Natick, MA, USA), where impulse was calculated as the integral of the vertical ground reaction force from standing to the instant of take-off [26]. The VJ used in our analysis was based on the greatest impulse achieved. In order to account for the known influence of muscle mass and body size, we additionally calculated relative impulse by dividing by lean body mass index.

Statistical analyses

Statistical analyses were performed using SPSS version 20.0 for Windows (SPSS, Chicago, IL, USA). Participant characteristics were examined using descriptive statistics. Differences between tertile groups based on neuromuscular performance and lifetime physical activity scores were tested using univariate analysis of variance. Height was used as a covariate in BMD analyses in order to account for body size. Pearson's correlation was used to determine associations between body composition measures, neuromuscular performance and BPAQ results. Results were considered statistically significant at or below a *p*-value of 0.05. Previously reported effects sizes and standard deviations informed *a priori* power analyses which indicated that in order to detect mean differences between physical activity tertile groups for LBMI of $2.3 \pm 2.0 \text{ kg/m}^2$, femoral neck BMD of $0.16 \pm 0.03 \text{ g/cm}^2$, and lean mass of $4.6 \pm 3.9 \text{ kg}$, a minimum of 39 participants were required ($\beta = 80\%$, $\alpha = 0.05$) [5,22,45]. Based on DXA measurement precision in our laboratory for the whole body BMD (CV = 1.4%), lumbar spine BMD (CV = 1.1%), and femoral neck BMD (CV = 1.3%), least significant change was calculated as 3.9%, 3.1%, and 3.6%, respectively.

RESULTS

Participant characteristics

A total of 50 healthy 18- to 35-year-old men (age 25.2 ± 4.5 years) participated in the study (Table 1). Thirty-four participants (i.e. 68%) were classified as healthy BMI (BMI < 25 kg/m²) and 16 (i.e. 32%) were overweight (BMI 25-30 kg/m²). The mean fat percentage of the group was 12.8%, which was within the healthy range for 18- to 35-year-old men (i.e. 8-20%). On average, participants were classified as highly active by the IPAQ (i.e. highest category of physical activity [18]).

Table 1 Participant characteristics (mean $\pm$ SD) for healthy young adult men (n=50).

Variable	Mean $\pm$ SD
Age (yrs)	25.2 $\pm$ 4.5
Height (m)	1.79 $\pm$ 0.07
Weight (kg)	77.2 $\pm$ 9.6
BMI (kg/m ²)	24.2 $\pm$ 2.6
Lean mass (kg)	62.5 $\pm$ 7.5
Fat (Siri UWE) %	12.8 $\pm$ 6.2
LBMI (kg/m ²)	19.6 $\pm$ 2.1
FMI (kg/m ²)	4.2 $\pm$ 2.1
WB BMD (g/cm ²)	1.07 $\pm$ 0.08
FN BMD (g/cm ²)	1.08 $\pm$ 0.10
LS BMD (g/cm ²)	1.27 $\pm$ 0.13
tBPAQ score	19.9 $\pm$ 18.9
IPAQ (MET-min/week)	5598 $\pm$ 5164

BMI, body mass index; LBMI, lean body mass index; FMI, fat mass index; BMD, bone mineral density; WB, whole body; FN, femoral neck; LS, lumbar spine; tBPAQ, total Bone-specific Physical Activity Questionnaire; IPAQ, International Physical Activity Questionnaire.

Lifetime physical activity

Greater lumbar spine BMD was observed for participants in the highest lifetime physical activity tertile (1.34 $\pm$ 0.13 g/cm²) compared to those in the middle (1.24 $\pm$ 0.13 g/cm²) and lowest (1.22 $\pm$ 0.10 g/cm²) lifetime physical activity tertiles ($p < 0.05$) (Figure 1). Such differences exceeded the least significant change of 3.1%. When comparing lifetime physical activity tertiles for LBMI, no main effect was observed; however, T-test comparison revealed greater LBMI in participants in the highest tertile compared to those in the lowest

tertile (20.4 ± 1.4 vs. 19.0 ± 2.2 kg/m², $p = 0.04$). No other differences were observed between lifetime physical activity tertiles and any other bone, muscle or fat measure.

[Figure 1]

Lifetime physical activity exhibited a moderate positive relationship with LBMI ($r = 0.31$, $p = 0.03$). A similar positive relationship was observed for childhood physical activity and LBMI ($r = 0.28$, $p = 0.05$) and for past BPAQ score and LBMI ($r = 0.32$, $p = 0.03$). No significant relationships, however, were found between physical activity scores (current, childhood, past or total) and any other body composition measures or neuromuscular performance. An inverse relationship was observed between time spent sitting and femoral neck BMD ($r = -0.33$, $p = 0.02$). Sitting, however, was not significantly related to any of the other body composition parameters or impulse, nor was time spent sleeping.

Neuromuscular performance

When the cohort was stratified into tertiles based on relative impulse, greater whole body BMD was observed in participants in the highest tertile than those in the lowest tertile (1.03 ± 0.08 vs. 1.11 ± 0.08 g/cm², $p = 0.01$) (Figure 2A). For femoral neck BMD, participants in both the middle (1.11 ± 0.11 g/cm²) and highest tertiles (1.17 ± 0.16 g/cm²) exhibited greater bone mass than those in the lowest tertile (1.01 ± 0.10 g/cm²) ($p < 0.05$) (Figure 2B). The same effect was observed for lumbar spine BMD, whereby participants in both the middle (1.29 ± 0.13 g/cm²) and highest tertiles (1.32 ± 0.13 g/cm²) exhibited greater bone mass than those in the lowest tertile (1.19 ± 0.08 g/cm²) ($p < 0.05$) (Figure 2C). All observed BMD differences based on neuromuscular performance exceeded the least significant change.

[Figure 2]

Bone and muscle quality

Thirteen participants underwent pQCT measures of bone and muscle in their non-dominant leg (Table 2). Based on relative impulse, no relationships were identified between performance and pQCT measures of bone and muscle. Based on absolute impulse, however, positive relationships were observed between performance and total tibial area ($r = 0.67$, $p = 0.01$), tibial cortical area ($r = 0.69$, $p = 0.009$), and tibial periosteal circumference ($r = 0.69$, $p = 0.01$) at the 38% site. Similarly, absolute impulse was positively related to muscle area at the 66% site ($r = 0.69$, $p = 0.009$). Positive relationships were also observed at the 38% site between LBMI and total tibial area ($r = 0.79$, $p = 0.001$), tibial cortical area ($r = 0.73$, $p = 0.004$), and tibial periosteal circumference ($r = 0.80$, $p = 0.001$). As would be expected, LBMI was positively related to muscle area at the 66% site ($r = 0.63$, $p = 0.02$).

Table 2 Tibia and leg muscle measures from pQCT (mean $\pm$ SD) for a subsample of healthy young adult male participants (n=13).

Variable	Mean $\pm$ SD
4% trabecular area (mm ²)	907.6 $\pm$ 146.3
4% trabecular density (mg/mm ³)	284.3 $\pm$ 30.8
38% total area (mm ²)	451.9 $\pm$ 50.5
38% cortical area (mm ²)	354.6 $\pm$ 38.2
38% cortical density (mg/mm ³)	1149.1 $\pm$ 25.2
38% periosteal circumference (mm)	75.2 $\pm$ 4.3
66% muscle area (mm ²)	477.1 $\pm$ 58.8

Note: 4%, 38%, and 66% refer to the tibial region of interest as a percentage of whole tibia length from the distal end.

DISCUSSION

Our aim was to determine the nature of relationships between lifetime physical activity participation, body composition and neuromuscular performance in healthy young adult men. We found that lifetime physical activity participation recorded with the BPAQ was positively related to parameters of bone and lean mass. Specifically, those with the greatest lifetime physical activity scores exhibited greater spine BMD and lean body mass index (LBMI) than those with the lowest lifetime physical activity scores. LBMI was similarly related to childhood physical activity participation. We also found relationships between neuromuscular performance and bone mineral density, such that those with the greatest performance during a maximal vertical jump had greater whole body, femoral neck, and lumbar spine BMD than those with the lowest performance. We additionally found positive relationships between impulse during the maximal vertical jump and pQCT-derived indices of bone and muscle quality.

Numerous studies have established that current physical activity participation is related to musculoskeletal health. Further, some studies have reported positive associations between indices of musculoskeletal health and retrospectively-examined snapshots of historical physical activity participation, including whole body lean mass in girls [12] and bone mass at the femoral neck [4,6,27] and lumbar spine [3,8,40] in adults. Our study, however, is the first to examine the relationships of bone, muscle and fat mass to physical activity participation across the whole life. Our findings confirm that similarly positive

relationships exist. In fact, the differences we observed between physical activity tertile groups in lumbar spine BMD were greater than the least significant change, suggesting that the findings are also clinically significant.

The combination of adequate bone strength and neuromuscular performance is particularly important for older people given their increased propensity to fall [25,33]. For instance, low bone mass in older people is associated with an increased fracture risk [32], however, the strongest single risk factor for fractures is falling [20,21]. Thus, maintaining sufficiently high functional and neuromuscular performance throughout life is critical to avoid fall-related morbidity. The positive relationship that we observed between neuromuscular performance and bone strength is therefore significant and highlights the important nexus of the two characteristics for healthy ageing. Furthermore, all BMD differences we observed between tertiles for neuromuscular performance exceeded the least significant change and suggest the findings also hold clinical meaning.

Given that childhood represents a potential window of opportunity for maximising health outcomes later in life [35,44], consideration of physical activity participation early in life is especially important. Our data highlights a positive relationship between childhood physical activity and several body composition parameters, findings that corroborate previous work [9,10,19]. Childhood physical activity participation may be particularly important for maximising bone health, as the childhood years represent a critical period for bone mass accrual and heightened skeletal mechanosensitivity [5,29,46]. In contrast to previous studies, however, we did not observe relationships between childhood physical activity and adult bone mineral density [6,27,28]. Although the lack of relationship may be a function of recall bias [13], it more likely reflects the relatively homogenous level of childhood activity of our participants. Nonetheless, our results support recommendations for regular and sustained physical activity across the lifespan with an emphasis on childhood high-impact activities for

the optimisation of adult musculoskeletal health. Such recommendations, however, require further support from controlled intervention and longitudinal studies to refine optimal exercise dosage including type, intensity, duration and timing.

Sedentary behaviour has a direct influence on metabolism, bone mass and vascular health [39]. Previous research indicates that inactivity has strongly deleterious effects on bone mass [23,50] and sedentary behaviour during the pre-pubertal years has been negatively associated with femoral neck BMD [42]. Accordingly, we found that recent sedentary activity (i.e. previous 12 months) was inversely related to femoral neck BMD in healthy men. As mechanical loading stimulates bone adaptation, displacement of physical activity with sedentary behaviour will have negative consequences for bone.

Our study extends previous work in the field by identifying relationships between pQCT-derived muscle and bone strength parameters and neuromuscular performance. Using pQCT enables the independent characterisation of cortical and trabecular bone and the quantification of important bone geometric parameters that are not possible with DXA. Whilst BMD and whole body lean mass were related to neuromuscular performance, we also found strong positive relationships between absolute impulse and geometric measures of bone and muscle, although significant relationships for relative impulse were not forthcoming. Others have reported similar relationships between neuromuscular performance and bone and muscle geometry [34]. Our results suggest that not only tissue quantity, but also tissue quality warrants consideration when investigating the relationship between body composition and neuromuscular performance.

Our findings were limited by a number of factors. Firstly, we used questionnaires as our method of quantifying physical activity participation, which can be limited by subject recall and result in under- or overestimation of participation [13,36]. While doubly-labelled water is the gold standard measurement of physical activity [31], it is limited to the

assessment of activity across only very short periods of time and therefore fails to capture lifetime participation. We chose to use an established questionnaire that has been validated for recording lifetime physical activity of specific relevance to musculoskeletal outcomes. Secondly, our sample was very active which may have reduced the sensitivity of the physical activity questionnaire. That is, inadequate heterogeneity in BPAQ scores may have limited our ability to detect a relationship between physical activity and femoral neck BMD. Our ability to detect a relationship at the spine however, suggests sufficient instrument sensitivity to detect a real and meaningful effect of physical activity on the skeleton at a clinically-relevant site. Thirdly, the counter-movement jump with arm swing involves a degree of coordinated movement that cannot be fully accounted for in our results. Nonetheless, we gave standard instructions to each participant, provided a standard warm-up and familiarisation procedure, and established the same target for performance relative to each participant's maximal jump height in order to minimise variation in technique. Finally, we did not incorporate dietary measures in our study. Total energy consumption or elements such as calcium may be important contributors to bone health and body composition. Previous studies, however, suggest that in healthy young cohorts, dietary factors are either non-significant or only weak predictors of body composition parameters [15,44].

CONCLUSION

The findings of the current study highlight the interrelationships between lifetime physical activity participation, body composition and neuromuscular performance, and contribute to our understanding of healthy ageing. That lifetime physical activity participation was positively related to indices of bone and muscle mass, and childhood participation predicted lean BMI in adulthood, reinforces the importance of early and continued participation throughout life. The observed relationships between physical activity,

neuromuscular performance and measures of bone and muscle have important implications for fracture prevention in old age. Future work will examine similar measures in older cohorts to determine if the observed relationships persist into the later stages of life.

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FIGURE LEGENDS

Figure 1 Comparison of lumbar spine BMD (mean $\pm$ SD) between tertiles for total BPAQ score for healthy young adult men (n = 50).

*indicates group differences (p<0.05).

Key: BMD, bone mineral density; BPAQ, bone-specific physical activity questionnaire score.

Figure 2 Comparison of (A) whole body BMD (mean $\pm$ SD) and (B) femoral neck BMD (mean $\pm$ SD) and (C) lumbar spine BMD (mean $\pm$ SD) among tertiles for relative impulse, in healthy young adult men (n = 50).

*indicates group differences (p<0.05).

Key: BMD, bone mineral density.

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