Higher Impact Physical Activity is Associated with Maintenance of Bone Mineral Density but Not Reduced Incident Falls or Fractures in Older Men: The Concord Health and Ageing in Men Project

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Abstract

High-impact physical activities with bone strains of high magnitude and frequency may benefit bone health. This study aimed to investigate the longitudinal associations between changes in loading intensities and application rates, estimated from self-reported physical activity, with bone mineral density (BMD) changes over five years, and also with incident falls over two years and long-term incident fractures, in community-dwelling older men. 1,599 men (mean age 76.8±5.4 years) from the Concord Health and Ageing in Men Project (CHAMP) were assessed at baseline (2005-2007), 2-year and 5-year follow-up. At each time point, hip and lumbar spine BMD were measured by dual-energy x-ray absorptiometry, and physical activity energy expenditure over the past week was self-reported via the Physical Activity Scale for the Elderly (PASE) questionnaire. Sum effective load ratings (ELRs) and peak force were estimated from the PASE questionnaire, reflecting the total and highest loading intensity and application rate of physical activities, respectively. Participants were contacted every 4 months over two years to self-report falls, and over 6.0±2.2 years for fractures. Hip fractures were ascertained by data-linkage for 8.9±3.6 years. Compared to sum ELR and PASE scores, peak force demonstrated the greatest standardised effect size for BMD maintenance at the spine (β=9.77mg/cm$^2$), total hip (β=14.14mg/cm$^2$) and femoral neck (β=13.72mg/cm$^2$) after adjustment for covariates, including PASE components (all p<0.01). Only PASE scores were significantly associated with reduced falls risk (standardised incident rate ratio=0.90, 95% confidence interval=0.81-1.00, p=0.04). All physical activity measures were significantly associated with reduced incident fractures in univariate analyses but none remained significant after multivariable adjustments. Older men who engaged in physical activity of high and rapid impact maintained higher BMD, while higher energy expenditure was associated with reduced falls risk. Coupling traditional physical activity data with bone loading estimates may improve understanding of the relationships between physical activity and bone health.

Keywords: Exercise, aging, osteoporosis, fracture prevention, general population studies
Introduction

Physical activity has been proposed as an inexpensive and effective non-pharmacological approach to prevent bone loss and treat osteoporosis.\(^{(1)}\) However, the most effective exercise modalities for improving bone health appear to differ from those traditionally recommended in physical activity guidelines which are generally focused on improving cardiometabolic health.\(^{(2,3)}\) Activities involving high and rapid impact with multi-directionality have the most significant effects on bone health,\(^{(4)}\) as evident from the large body of research in pre- and post-menopausal women.\(^{(5)}\) Few studies have investigated this effect in older men \(^{(6,7)}\) and the relationship may be influenced by sex-specific differences in age-related bone loss, bone mechano-responsiveness, and preferred exercise modalities.\(^{(8,9)}\)

When determining the skeletal benefits of physical activity, studies have commonly compared specific exercise modes,\(^{(10,11)}\) or utilised traditional physical activity measurement instruments like pedometers or questionnaires that fail to capture mechanical loading intensity or rate, possibly explaining their inconsistent associations with bone mineral density (BMD).\(^{(12,13)}\) Accelerometers capture habitual physical activity loading via impact counts per unit of time, and have demonstrated positive associations between moderate to vigorous physical activity and tibial microarchitecture and bone mass in older men.\(^{(14,15)}\) However, wearable devices introduce participant burden, require rigorous protocols to maintain compliance, and incur financial costs \(^{(16,17)}\) that may otherwise be overcome by utilising physical activity recall by questionnaires. However, to better evaluate the effectiveness of bone-targeted exercises, questionnaire-assessed physical activities need to be quantified by the intensity and frequency of the ground reaction forces they generate based on principles of the evidence-based osteogenic index described by Turner and Robling.\(^{(18,19)}\)

Unlike cross-sectional analyses, studies assessing longitudinal relationships between changes in physical activity and bone parameters are likely to account for long-term heterogenous skeletal changes.\(^{(20,21)}\) However, there remains insufficient and inconsistent evidence in longitudinal studies investigating associations of change in self-reported physical activity, assessed by energy expenditure estimates, with change in BMD in older men.\(^{(12)}\) In addressing the fracture burden of osteoporosis, physical activity has also been identified as a factor in decreasing falls and fractures risk in older adults.\(^{(22-24)}\) However, some modalities of physical activity are more beneficial while others may be detrimental to falls and fracture risk, presenting difficulties in forming public health recommendations.\(^{(25)}\) Notably, load-bearing physical activities were reported to reduce falls and fracture risk in older adults with low BMD\(^{(26)}\) but increased the risk of recurrent falls in physically fit older adults.\(^{(25)}\)
This study aimed to determine whether a) increases in loading intensities and rates of physical activity assessed by a self-administered physical activity questionnaire is prospectively associated with maintenance of BMD at various sites over five years, and whether participation in physical activities with higher loading is associated with b) decreased risk of incident falls over two years, and c) decreased risk of fractures over six years in community-dwelling older men.
Materials and Methods

Study Population

The Concord Health and Ageing in Men Project (CHAMP) is a population-based study of Australian men aged ≥70 years old. Men living in a geographically defined area around Concord Hospital in Sydney, Australia (Burwood, Canada Bay and Strathfield) were selected from the New South Wales (NSW) electoral roll, on which registration is compulsory. The only exclusion criterion was living in a residential aged care facility. Eligible men were sent a letter describing the study and, if they had a listed telephone number, were telephoned about one week later. Of the 2,815 eligible men with whom contact was made, 1,511 participated in the study (54%). An additional 194 eligible men living in the study area learnt about the study from friends or the local media and were recruited after contacting the study investigators prior to being identified through electoral rolls, yielding a total cohort of 1,705 subjects. The study design has been described in detail elsewhere.(27)

Baseline data were collected between January 2005 and June 2007. Data were collected via self-administered questionnaires completed at home, that included questions on demographics, health status, and physical activity. Subsequently, participants attended a clinic at Concord Hospital for assessment of body composition, physical performance, medication use and blood biochemistry. These measurements were repeated at follow-up clinics conducted two (between January 2007 and October 2009) and five years (between August 2010 and July 2013) after baseline. Of the 1,705 subjects at baseline, 1366 had 2-year follow-up assessments and 954 had 5-year follow-up assessments. Death was the main reason for non-attendance at 2 years (99 deaths) and at 5 years (382 cumulative deaths). Fully trained staff collected data and the same equipment was used for all measurements and assessments, which were carried out in a single clinic. Additionally, participants were contacted by telephone every four months from baseline until January 2014 to ascertain incident falls and fractures, as described below. All participants gave written informed consent. The study complied with the World Medical Association Declaration of Helsinki and was approved by the Sydney South West Area Health Service Human Research Ethics Committee, Concord Repatriation General Hospital, Sydney, Australia.

Physical Activity

The Physical Activity Scale for the Elderly (PASE) questionnaire, previously validated with objective measures of physical activity,(28) was self-administered at each time point to determine leisure, household and occupational activity. Participants reported the frequency
and duration of, and listed in written form, activities they performed over the past 7 days under five categories: walking outside of home, light, moderate and strenuous sport and recreational activities, and targeted exercise. PASE scores were computed by summing the multiplied frequency and metabolic equivalent task (MET) weighting of each activity category.\(^{(29)}\) The written answers were used to classify participation according to activity type rather than the participants’ perceived intensity of the activity. Given two or more activities can be reported in response to the same question (e.g. golf and bowling both listed under light activity), the specific time spent on each activity could not be ascertained. Instead, each activity was assigned an effective load rating (ELR). For each activity, the ELR was determined following the principles of estimating intensity and frequency of ground reaction forces used in the Bone-specific Physical Activity Questionnaire (BPAQ).\(^{(19)}\) Briefly, the BPAQ estimates peak vertical ground reaction force and the rate of force application of the fundamental actions of an activity using a force platform. The ELR of a physical activity is the product of the peak force and rate of the fundamental actions composing the activity, in multiples of an individual’s body weight.

In addition to questions about intentional physical activities, the PASE questionnaire included yes/no questions on whether individuals walked or performed housework, gardening, or volunteer work with lifting over the past 7 days. These are hereafter referred to as “lifestyle” activities and are popular among older adults. These types of activities are likely to provide loading and therefore potentially contribute to bone changes,\(^{(30,31)}\) and thus were included in the analysis. The summed and peak (highest) ELR of all activities performed by each participant over the past 7 days were obtained. Daly and Bass had previously modified and adapted the Historical Leisure Activity Questionnaire, which originally calculates METs, to obtain osteogenic index scores which similarly reflect older men’s participation in weight-bearing activities.\(^{(32)}\)

Table 1 displays examples of how ELRs were calculated from the PASE questionnaire. Every category in the PASE questionnaire had both a multiple-choice checkbox for the participant’s frequency of activity and an open-ended response for the type of activity engaged. However, some physical activity modalities were self-reported as having been performed in the open-ended response, despite the participant marking the “Never (having been performed over the past 7 days)” option. These conflicting responses were not included in either the PASE or ELR calculations.
To determine the maximal loading intensity experienced in the past 7 days, *peak force* (kg) was calculated as the product of body mass and peak ELR. This represents the maximum mechanical strain magnitude and rate performed by an individual for the initiation of skeletal adaptation, based on Turner and Robling’s osteogenic index, according to the mechanostat model.\(^{(18,33,34)}\)

**Anthropometric and Bone Mineral Density Measurement**

Body mass index (BMI, kg/m\(^2\)) was calculated from height, measured with a Harpenden stadiometer, and weight, measured with Wedderburn digital scales. Total hip and anteroposterior lumbar spine (L1-L4) dual-energy X-ray absorptiometry (DXA) scans were performed with a Hologic Discovery-W scanner (Hologic Inc., Bedford, MA, USA) to estimate total hip, femoral neck and lumbar spine areal BMD (g/cm\(^2\)). Participants removed jewellery and wore light cotton gowns free of metal. The same DXA scanner was used for all scans. Quality-control scans were performed daily with the Hologic whole-body phantom and indicated no shifts or drifts. The coefficient of variation for scans duplicated on 30 men from the study cohort was 1.6% for the total hip, 2.1% for the femoral neck and 1.6% for the lumbar spine.

**Ascertainment of Incident Falls and Fractures**

Men were contacted by telephone every 4 months following their baseline assessment until January 2014 to ascertain incident falls and fractures. The following questions were asked: “Have you fallen in the past 4 months? If yes, how many times have you fallen?” and “Have you broken or fractured a bone in the past 4 months?”. For self-reported fractures, radiology reports were obtained either from the participant, hospital medical records or radiology practices. Additional manual searching for fractures was conducted by accessing medical records within the study health district. Only fractures with radiographic evidence were recorded. Pathological fractures and fractures of the hands, fingers, feet, toes and skull were excluded. The first incident fracture that met the inclusion criteria was included in this analysis, dated as the date on the radiology report, regardless of trauma level or subsequent fractures reported.\(^{(35)}\) Fractures were classified as any, vertebral or non-vertebral. Time to censorship was either date of death, date of official withdrawal from the study, or date of the last telephone contact.

Additional prospective hip fracture data was obtained from the Centre for Health Record Linkage (CHeReL), a dedicated data linkage unit by the NSW Ministry of Health. The associated NSW Admitted Patient Data Collection (APDC) collated inpatient separations (discharges, transfers and deaths) from all NSW public, private, psychiatric and repatriation hospitals. The International Classification of Diseases 10\(^{th}\) revision Australian Modification
(ICD-10-AM) (36) and the Australian Classification of Health Interventions (ACHI) procedure codes (37) were used to identify hip fractures. CHAMP participants’ hospitalisations and diagnoses for hip fractures up to April 2019 were obtained.

Sociodemographic and Lifestyle Measures

Sociodemographic variables including age, income (pension only or other sources), living arrangements (live alone or lives with others) and smoking status (never smoker, ex-smoker or current smoker) were self-reported.

Blood Tests

Blood tests were performed at the Diagnostic Pathology Unit of Concord RG Hospital, which is a National Australian Testing Authority accredited pathology service, using a MODULAR Analytics system (Roche Diagnostics, Castle Hill, Australia). Fasting serum 25-hydroxyvitamin D (25OHD) levels were measured by RIA (DiaSorin Inc., Stillwater, MN, USA), as described previously. (38) The 25OHD assay has a sensitivity of <3.75 nmol/L with an intra-assay precision of 7.6% and interassay precision of 9.0%.

Medication Assessment

Trained personnel conducted a medication inventory of each participant during the baseline clinic visit. Participants were instructed to bring current prescription and over-the-counter medications to the clinic visit for review. They were also asked if they had taken any other medications during the past month. Reported medicines were coded using the Iowa Drug Information Service code numbers. (39) The medications included in the analysis were grouped into classes: psychotropic medications, bisphosphonates and corticosteroids because these are known to influence BMD and fractures. Polypharmacy was defined as the regular use of ≥5 medicines. (40)

Health Status and Measures

Participants were asked if they were ever told by a health professional if they had the following conditions: diabetes, thyroid dysfunction, osteoporosis, Paget’s disease, stroke, Parkinson’s disease, epilepsy, hypertension, heart attack, angina, congestive heart failure, intermittent claudication, chronic obstructive lung disease, liver disease, cancer (excluding nonmelanoma skin cancers), osteoarthritis, and gout. The number of reported comorbidities was summed, excluding Parkinson’s disease and stroke, which were examined separately. A fall and fracture history were also obtained at the baseline assessment. Participants were asked if they had fallen in the past 12 months.
The short version of the Geriatric Depression Scale (41) was used to assess depressive symptoms, where possible depression was defined as having 5 or more depressive symptoms. Physical disability was assessed by seven items from a modified version of the Katz activities of daily living (ADL) scale, including walking across a small room, bathing, grooming, dressing, eating, transferring from a bed to a chair, and using the toilet. ADL disability was defined as needing help with one or more activities. Self-rated general health was assessed using the 12-Item Short Form Health Survey (SF-12) (43). Men were asked to rate their health, compared to other people their own age, on a five-point scale as excellent, good, fair, poor, or very poor. Health status was categorized as poor if health was rated as poor or very poor.

Corrected visual acuity was assessed with a Bailey-Lovie chart. Men with visual acuity of $\leq 20/40$ were considered to have poor visual acuity. All participants were screened for cognitive impairment using the Mini-Mental State Examination (MMSE) and a short form of the Informant Questionnaire on Cognitive Decline in the Elderly (IQCODE) (45,46). Participants who scored $\leq 26$ on the MMSE or $\geq 3.6$ on the IQCODE were clinically assessed by a geriatrician. Two geriatricians, a neurologist and a neuropsychologist met weekly to review all relevant information and reach a consensus diagnosis of dementia, mild cognitive impairment or normal cognition.

**Statistical analyses**

All statistical analyses were performed using SPSS software version 25 (IBM, Chicago, IL, USA) and R (R Foundation for Statistical Computing, Vienna, Austria). Baseline descriptive characteristics were compared between men with low (sum ELR $\leq 3.8$) versus moderate to high total impact activity (sum ELR $>3.8$). The cut-off of 3.8 was selected as it represented the sample median. Comparisons were made using independent t-tests for continuous variables and chi-square tests for categorical variables. Repeated measures ANOVA with Greenhouse-Geisser correction was used to study the longitudinal change in sum ELR, peak force and PASE scores in participants with physical activity data over the three time points (baseline, 2 and 5 years). Bonferroni post hoc tests were then performed to compare differences in sum ELR, peak force and PASE scores between time-points.

Linear regression initially analysed the associations between sum ELR, peak force and PASE scores and spine, total hip and femoral neck BMD at baseline. Analyses were unadjusted, then adjusted for baseline age, education, income, living arrangement, smoking status, self-rated health, number of comorbidities, Parkinson’s disease, dementia, depression, disability, stroke, serum 25OHD levels, psychotropics use, corticosteroids use, bisphosphonates use, visual acuity, history of prior fractures, history of prior falls and
polypharmacy. This model additionally adjusted for BMI for sum ELR and PASE scores, and height for peak force as weight was factored in the peak force variable. A second model adjusted for the above factors with the addition of the individual domain scores of PASE for walking; light; moderate; or strenuous sports and recreational activities; targeted exercise; and lifestyle physical activities to determine whether observed associations of sum ELRs and peak force were independent of perceived intensity levels of physical activity. Generalised estimating equation (GEE) analyses were used to determine the longitudinal association between change in sum ELR, peak force and PASE scores and change in spine, total hip and femoral neck BMD. GEE considers the time-varying nature over multiple time points of both the outcome and exposure and provides an estimated population average model by using all longitudinal data. With GEE analysis, the association between two longitudinally measured variables can be studied simultaneously while adjusting for within-person correlations caused by repeated measurement on each participant using robust estimation of the variances of the regression coefficients. The GEE is known to be also robust when treating data missing at random. GEE analyses were initially unadjusted, then adjusted for the covariates in the above models.

As falls are relatively common in older age and physical activity levels are likely to have immediate to short-term effects on falls risk, only falls occurring up to 2 years after baseline were included in falls analyses, while the entire follow-up period was included for fractures. Unadjusted and multivariable negative binomial regression examined 2-year incident falls rates associated with baseline sum ELR, peak force and PASE scores. This analysis adjusted for covariates in the aforementioned models with the exception of history of prior fractures and bisphosphonates use.

Unadjusted and adjusted Cox proportional hazards regression models examined associations of baseline sum ELR, peak force and PASE scores with incident any, vertebral and non-vertebral self-reported fractures that were confirmed by radiographic evidence during 4-monthly follow ups, and hip fractures confirmed by data-linkage. Fine and Gray competing risk regression models were additionally performed using the same models to account for the competing risk of mortality. To detect non-linear associations, quartiles of sum ELR, peak force and PASE scores with the lowest physical activity quartile as the referent group were also examined in all analyses.
Results

After excluding participants who did not attend the baseline appointment (n=32), did not complete the PASE questionnaire (n=19) or had incomplete DXA (n=41) and anthropometric data (n=14) a total of 1,599 participants were included in the analysis. Table 2 reports baseline characteristics of the sample and participants engaged in low versus moderate to high total loading of self-reported physical activity. Compared to men with low sum ELRs, men with moderate to high sum ELRs were significantly younger, had fewer self-reported comorbidities, and were less likely to smoke, be on a pension, rate their health as poor or very poor, or report ADL disabilities. They were also less likely to be on psychotropic drugs, have dementia, Parkinson’s disease, stroke, possible depression, poor visual acuity or low serum 25OHD levels. However, men with moderate to high sum ELRs were less likely to have a history of falls. As expected, PASE scores were significantly higher in men with higher sum ELR. Total hip and femoral neck BMD were significantly higher in men with moderate to high sum ELR.

A total of 905 physical activity modalities were self-reported by 1,599 men at baseline. Figure 1 displays the distribution of all reported activities. The most common activities were golf (n=159), followed by lawn bowling (n=125). The most common moderate- to high-impact activities of >2 ELR (in number of bodyweights) were dancing (n=49), tennis (n=36) and running (n=13). Participation in gymnastics (n=3 at baseline, n=1 at 2- and 5-year follow-up) accounted for a maximal peak ELR of 55.0 over the three time points. For lifestyle activities at baseline, 94.4% (n=1,509) of men participated in housework and gardening, 83.9% (n=1,342) participated in walking, 64.7% (n=1,034) participated in heavy gardening, and 6.9% (n=110) performed lifting in volunteer work.

Table 3 reports baseline and follow-up values for sum ELR, peak force and PASE scores. Repeated measures ANOVA for participants with complete data at all time points (n=902) showed that sum ELR, peak force and PASE scores differed significantly between time points \[F(1.7, 1529.6)=13.7, p<0.001\] for sum ELR; \[F(1.7, 1468.2)=14.7, p<0.001\] for peak force; \[F(1.7, 1264.2)=29.4, p<0.001\] for PASE scores]. Post hoc tests revealed that sum ELR, peak force and PASE scores at 5-year follow-up were significantly lower to that at baseline and 2-year follow-up. There was an additional significant difference between baseline and 2-year follow-up for PASE scores, but not for sum ELR and peak force (Table 3).
Linear regression analyses determined cross-sectional associations between physical activity measures and spine, total hip and femoral neck BMD (Supplementary Table 1). In unadjusted analyses, peak force was significantly positively associated with BMD at all sites while sum ELR and PASE scores were only significantly positively associated with total hip and femoral neck BMD. Following adjustment for covariates, PASE scores were not associated with BMD at any site, while sum ELR and peak force were significantly positively associated with BMD at all sites in the fully adjusted Model 2 (Supplementary Table 1).

GEE analyses determined longitudinal population average associations between self-reported physical activity measures and spine, total hip and femoral neck BMD (Table 4). In unadjusted analyses, all physical activity measures were significantly positively associated with maintenance in spine, total hip and femoral neck BMD over time, except for PASE scores and spine BMD. Peak force demonstrated the greatest standardised effect size of BMD maintenance at each site compared to sum ELR and PASE scores. After adjustment for potential confounders (Model 1 and 2), the associations of both sum ELR and peak force with spine, total hip and femoral neck BMD remained significant (Table 4). PASE scores only remained significantly associated with total hip BMD.

Thirty percent of men (n=450) reported at least one fall, and fifteen percent (n=216) reported two or more falls up to 2 years after baseline. Unadjusted negative binomial regression models demonstrated that every standard deviation increase in sum ELR, peak force and PASE scores significantly decreased the rate of falls by 8.4%, 6.7% and 37.4% respectively (Table 5). Only PASE scores were associated with a 10.3% reduction in falls rate in the fully adjusted model (95% confidence interval (CI)=19.4%, 0.3%, \( p=0.044 \)).

Self-reported radiographically confirmed fractures were followed up over a mean period of 6.0±2.2 years. Table 6 displays Cox proportional hazards regression models for incident fractures across self-reported physical activity measures. In unadjusted models, each standard deviation increase in sum ELR and peak force were significantly associated with decreases in hazard for any incident self-reported radiographically confirmed fracture of 30.5% and 27.0% respectively, which was higher than that of the PASE scores (22.3% decreased hazard) (Table 6). After adjustments for potential confounders, all physical activity measures treated as continuous variables did not remain significantly associated with fracture risk at any site. However, when physical activity measures were analysed as quartiles (Supplementary Table 2C), the highest quartile of peak force (>253.95kg) was associated with significantly reduced risk of any self-reported fractures by 40.4% in the fully adjusted Model 2 (95% CI=0.1%, 64.5%, \( p<0.050 \)), and vertebral fractures by 80.4% in Model 1 (95% CI=4.4%, 96.0%, \( p=0.044 \)) compared to the lowest quartile of peak force.
(<36.75kg). No significant associations were observed between physical activity measures and self-reported non-vertebral fracture in any model. Adjusting for the competing risk of mortality attenuated the associations between peak force and any self-reported fracture when unadjusted (Supplementary Table 3). Additionally, following competing risk regression, the highest quartile of peak force only remained significantly different to the lowest quartile for the risk of vertebral fractures in Model 1 [relative risk=0.20 (0.04, 0.89) \( p=0.035 \), but not any fracture in Model 2 [relative risk=0.66 (0.40, 1.10) \( p=0.110 \)].

Over a mean follow-up period of 8.8±3.6 years, 6.6% men had a hip fracture identified by data-linkage. When unadjusted, peak force showed the greatest standardised effect size of a 41.3% decreased hazard risk (Table 6). When adjusted for potential confounders, all physical activity measures, whether treated as continuous or categorical variables, were not significantly associated with hip fracture risk. Competing risk regression did not considerably vary these associations (Supplementary Table 3).
Discussion

This study investigated a novel approach to estimating measures of bone loading from an energy expenditure-based physical activity questionnaire, and its associations with bone outcomes, incident falls and fractures, in community-dwelling older men. We found that increases in physical activity loading were associated with BMD maintenance over five years, while recent energy expenditure measured by the PASE questionnaire was associated with falls risk reduction. However, none of the physical activity measures were significantly associated with fracture risk following multivariable adjustments.

Increases in sum ELR and peak force were significantly associated with BMD maintenance at the lumbar spine and proximal femur in longitudinal analyses over 5 years, whilst PASE scores were only significantly associated with total hip BMD following multivariable adjustment. Previous studies have reported equivocal associations between energy expenditure assessed by physical activity questionnaires and bone mass and microarchitecture,\(^\text{12,21,50-55}\) supporting development of bone loading questionnaires like the BPAQ.\(^\text{19,32,56}\) Despite this, there is a paucity of evidence favouring bone loading scores over energy expenditure estimates when assessing bone outcomes. The extraction of bone loading scores from traditional physical activity questionnaires has previously been performed in older men \(^\text{32}\) and young adults,\(^\text{57}\) revealing positive associations between physical activity with loading and bone microarchitecture, but no overt comparisons with original questionnaire scores were made. One comparative study in 24 young adult females demonstrated that higher historical BPAQ scores were associated with increased lumbar spine and femoral BMD, but not energy expenditure estimated by a 7-day physical activity recall questionnaire.\(^\text{58}\) A previous study in the CHAMP population also compared the contributions of PASE scores with engagement in high bone loading activity (dancing, jogging or tennis), and found stronger associations between BMD and the latter binary variable.\(^\text{59}\) Our study adds to previous findings by demonstrating that bone loading scores were more robust physical activity measures than PASE scores in predicting BMD at clinically relevant sites after adjustment for known confounders in a population of older men. In addition, men who had increases in BMD had smaller decreases in sum ELR (difference of 0.1 to 0.4) and peak force (difference of 4kg to 25kg) over time compared to those who had decreases in BMD (data not shown). This suggests that the addition of intentional activity, even if low impact such as golf or walking, may maintain BMD at clinically relevant sites.

Similar to our findings, the Osteoporotic Fractures in Men Study (MrOS) reported weak positive relationships between PASE scores and hip BMD (<1% variation) and non-significant associations with lumbar spine BMD in multivariate models.\(^\text{53}\) However, this
differential association regarding hip and lumbar spine BMD was also observed in other studies employing the use of the BPAQ in older men and women aged ≥50 years old.\(^{60-62}\) Reasons attributed to the lack of relationship between skeletal loading and lumbar spine BMD include lumbar osteophytes resulting in spuriously high BMD,\(^{63}\) or an upward dissipation of forces from physical activity with loading,\(^{66}\) resulting in associations only being observed more distally. In contrast, the positive relationship between bone loading parameters and spine BMD in the current study may be explained by a high engagement in activities such as golf and bowling, which create bone-stressing muscle contractions at both spine and hip.\(^{56,64}\) Also, physical activity and BMD were longitudinally analysed over five years, which may more accurately capture the long-term osteogenic effects of physical activity on multiple skeletal sites even in later life.\(^{20,21}\)

We observed that peak force displayed a greater standardised effect compared to sum ELR and PASE scores on BMD at all sites, which may be due to the factoring of body weight in its calculation. Indeed, BMD has been shown to be 3-7% greater for every 10kg increase in body weight in older men.\(^{12}\) However, it was difficult to isolate the effect of the maximal loading intensity and rate of a physical activity performed by an individual as the majority were attributed a maximum ELR of either 0.4 or 3 times their body weight (data not shown), given many physical activity modalities reflect these values.\(^{19}\) Nonetheless, men who experienced high peak force had a 40% decreased risk of any self-reported fracture compared to low peak force in categorical analyses after adjustment for confounders. For an individual with an average body mass of 70kg, this protection is conferred for participation in activities of ELR>3.6 such as running, dancing and tennis\(^{19}\) which, however, were observed to be uncommon in our cohort. However, this finding should be interpreted with caution due to the large confidence interval of hazard ratio (0.1%, 64.5%). Also, the role of body mass on the protective effect of skeletal loading in physical activity from fractures in older men is unclear, as the complex interplay with BMD and physical function may have confounded these findings.\(^{65}\) This association was also attenuated after accounting for the competing risk of death, which is especially high in long-term studies of older populations.\(^{66}\) However, utilising competing risk analyses for non-fatal outcomes like fractures has been met with contention in making misleading inferences about clinically relevant risks.\(^{67}\)

This study addressed the knowledge gap of the relationship between estimated bone loading of physical activity and falls and fractures. Previous prospective cohort studies in older men investigating metabolically intense physical activity and fracture risk have reported inconsistent associations,\(^{68}\) and similar to our findings, many significant associations were attenuated following adjustment of important confounders including BMI and history of fractures.\(^{69-72}\) This may have been attributed to a small number of fractures recorded
despite a follow-up period of more than 6 years (10.3% self-reported any fracture and 6.5% had data-linkage confirmed hip fractures). Likewise, determining the optimal load and frequency of physical activities to confer protection from fractures in controlled trials are met with impracticalities of large sample sizes and long follow-up durations. A 30-month high-impact exercise trial in 160 elderly women reported significantly less fall-related fractures in the exercise group despite no difference in falling rates between groups, but was not adequately powered to conclude that impact exercise can prevent fractures. Indeed, physical activity with skeletal loading may be insufficient to reduce falls risk, and exercise with balance and strength training components are more likely to be protective from falls, and thus minimal-trauma fractures in older adults. Only PASE scores were associated with falls risk reduction over two years in multivariate analyses, and in the same population, swimming was previously cited to be significantly associated with improvements in balance, resulting in reduced falls risk. When calculating ELRs, swimming was scored poorly as it only generates forces of 0.07 times the body weight, but swimmers in this study may have performed activities at a high aerobic intensity and attained high PASE scores. Despite the observed decreased falls risk and improved BMD associated with physical activity measures in the current study, these findings may have limited statistical and clinical significance in preventing osteoporotic fractures.

This study has limitations. Self-reported intensity levels of physical activity are subject to recall bias, individual interpretation and physical function. We were also unable to factor in the duration of participation of these activities in the computation of sum ELR and peak force. However, only a few loading cycles are required to stimulate osteogenesis in bone, and accounting for exercise modality may have been sufficient in estimating bone loading of physical activity. Due to the nature of the questionnaire, exercise type was not accounted for in PASE score calculations, and perceived intensity of activity was not factored into ELR estimates. Additionally, long-term physical activity habits and historical physical activity over the entire lifetime were not collected. It is known that peak bone mass accrued during the critical peri-adolescent growth period has great implications on bone outcomes, and the skeleton responds slowly to physical activity. Men who had high sum ELR or peak force in this population may have similarly been highly active during adolescence, and it may be that loading activity at younger age is more important than contemporary activity for predicting bone health. Indeed, physical activity behaviours tend to track throughout the lifetime as suggested by our cohort where there were positive associations between all baseline and follow-up physical activity measures (data not shown) resulting in the observed associations. With the exception of data-linkage determined hip fractures, incident fractures were obtained
through self-report, and despite being radiographically-confirmed, false-negative ascertainment of true fracture events may have introduced bias in this study.\textsuperscript{(77)}

In future, utilising the BPAQ as a physical activity measure in cohort studies may be recommended given that BPAQ scores were previously shown to be associated with total cholesterol, waist-to-hip ratio and mean arterial pressure,\textsuperscript{(78)} and historical physical activity may also provide insight into the risk of major cardiovascular events in older adults.\textsuperscript{(79)} Nonetheless, our approach may support retrospective re-analyses of existing datasets where bone health and fracture outcomes are of interest. In conclusion, our study in community-dwelling older men has revealed a longitudinal relationship between physical activity with loading and BMD at clinically relevant sites, falls risk reduction associated with PASE scores, but limited associations between physical activity measures and fracture risk.

References


32. Daly RM, Bass SL. Lifetime sport and leisure activity participation is associated with greater bone size, quality and strength in older men. Osteoporos Int. 2006;17(8):1258-67. Epub 2006/05/09.
39. IDIS drug vocabulary and thesaurus description. Coralville, IA: Division of Drug Information Service, College of Pharmacy, University of Iowa; 2012.


### Table 1 Calculation of Sum and Peak Effective Load Ratings (ELRs) from the Physical Activity Scale for the Elderly (PASE) Questionnaire

<table>
<thead>
<tr>
<th>Activity performed over past 7 days</th>
<th>Assigned ELR value(^a)</th>
<th>Sample response 1</th>
<th>Sample response 2</th>
<th>Sample response 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Written Sport/Recreational Activity</td>
<td>Previously obtained from ground reaction force measures</td>
<td>Tennis (7.84)</td>
<td>Running (4.88); Resistance Training (0.51)</td>
<td>Golf (0.4); Lawn Bowls (0.4)</td>
</tr>
<tr>
<td>Walking</td>
<td>0.4 ✓ x x x x x x</td>
<td>✓ x x x x x x</td>
<td>✓ x x x x x x</td>
<td>✓ x x x x x x</td>
</tr>
<tr>
<td>Housework or Gardening</td>
<td>0.4 ✓ x x x x x</td>
<td>✓ x x x x x x</td>
<td>✓ x x x x x x</td>
<td>✓ x x x x x x</td>
</tr>
<tr>
<td>Lifting &lt;50kg in Volunteer Work</td>
<td>0.51 x x ✓ x x x</td>
<td>✓ x x x x x x</td>
<td>✓ x x x x x x</td>
<td>✓ x x x x x x</td>
</tr>
<tr>
<td>Lifting &gt;50kg in Volunteer Work</td>
<td>1.68 ✓ x x x x x</td>
<td>✓ x x x x x x</td>
<td>✓ x x x x x x</td>
<td>✓ x x x x x x</td>
</tr>
<tr>
<td>Heavy Gardening (Lawn/Yard work)</td>
<td>3 ✓</td>
<td>✓ x</td>
<td>✓ x x x x</td>
<td>✓ x x x x x x</td>
</tr>
<tr>
<td>Sum ELR (# of bodyweights)</td>
<td>9.92 ✓ x</td>
<td>✓ x x x x x x</td>
<td>✓ x x x x x x</td>
<td>✓ x x x x x x</td>
</tr>
<tr>
<td>Peak ELR (# of bodyweights)</td>
<td>7.84 ✓ x</td>
<td>✓ x x x x x x</td>
<td>✓ x x x x x x</td>
<td>✓ x x x x x x</td>
</tr>
</tbody>
</table>

\(^a\) Values previously obtained from ground reaction force measures by Weeks and Beck, 2008.\(^{19}\)

### Table 2 Baseline Characteristics of Study Participants According to Low [Sum Effective Load Rating (Sum ELR) ≤ 3.8] and Moderate to High (Sum ELR > 3.8) Total Loading of Self-reported Physical Activity

<table>
<thead>
<tr>
<th></th>
<th>Total Population (n=1599)</th>
<th>Sum ELR ≤ 3.8 (n=1137)</th>
<th>Sum ELR &gt; 3.8 (n=462)</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>76.8 ± 5.4</td>
<td>77.3 ± 5.5</td>
<td>75.5 ± 4.9</td>
<td>&lt;0.001**</td>
</tr>
<tr>
<td>BMI (kg/m(^2))</td>
<td>27.8 ± 3.9</td>
<td>27.9 ± 4.0</td>
<td>27.5 ± 3.78</td>
<td>0.053</td>
</tr>
<tr>
<td>Lives alone (%)</td>
<td>18.5</td>
<td>18.1</td>
<td>19.5</td>
<td>0.513</td>
</tr>
<tr>
<td>Pension (%)</td>
<td>45.6</td>
<td>49.1</td>
<td>37.0</td>
<td>&lt;0.001**</td>
</tr>
<tr>
<td>Current smoker (%)</td>
<td>6.1</td>
<td>7.6</td>
<td>2.4</td>
<td>&lt;0.001**</td>
</tr>
<tr>
<td>Total number of comorbidities</td>
<td>2.5 ± 1.7</td>
<td>2.6 ± 1.8</td>
<td>2.3 ± 1.6</td>
<td>&lt;0.001**</td>
</tr>
<tr>
<td>Self-rated health</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Excellent/good/fair (%)</td>
<td>70.9</td>
<td>68.5</td>
<td>76.8</td>
<td>&lt;0.001**</td>
</tr>
<tr>
<td>ADL disability (%)</td>
<td>40.1</td>
<td>45.8</td>
<td>26.0</td>
<td>&lt;0.001**</td>
</tr>
<tr>
<td>Medication</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Psychotropics (%)</td>
<td>12.2</td>
<td>13.4</td>
<td>9.2</td>
<td>0.018*</td>
</tr>
<tr>
<td>Bisphosphonates (%)</td>
<td>4.2</td>
<td>4.6</td>
<td>3.2</td>
<td>0.230</td>
</tr>
<tr>
<td>Corticosteroids (%)</td>
<td>9.6</td>
<td>9.9</td>
<td>8.9</td>
<td>0.513</td>
</tr>
<tr>
<td>History of fracture (%)</td>
<td>43.4</td>
<td>42.1</td>
<td>46.8</td>
<td>0.086</td>
</tr>
<tr>
<td>History of falls (%)</td>
<td>18.7</td>
<td>21.4</td>
<td>12.1</td>
<td>&lt;0.001**</td>
</tr>
<tr>
<td>Dementia (%)</td>
<td>5.1</td>
<td>6.0</td>
<td>3.0</td>
<td>0.015*</td>
</tr>
<tr>
<td>Parkinson’s disease or stroke (%)</td>
<td>9.6</td>
<td>11.1</td>
<td>5.8</td>
<td>0.001**</td>
</tr>
<tr>
<td>≥5 depressive symptoms(^a) (%)</td>
<td>13.8</td>
<td>16.5</td>
<td>7.1</td>
<td>&lt;0.001**</td>
</tr>
<tr>
<td>Poor visual acuity(^b) (%)</td>
<td>20.1</td>
<td>22.9</td>
<td>13.5</td>
<td>&lt;0.001**</td>
</tr>
<tr>
<td>25OHD (nmol/L)</td>
<td>56.4 ± 22.2</td>
<td>54.1 ± 21.1</td>
<td>62.1 ± 23.5</td>
<td>&lt;0.001**</td>
</tr>
<tr>
<td>PASE score</td>
<td>125.4 ± 61.8</td>
<td>109.1 ± 57.9</td>
<td>167.5 ± 51.8</td>
<td>&lt;0.001**</td>
</tr>
<tr>
<td>BMD (g/cm(^2))</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total hip</td>
<td>0.940 ± 0.141</td>
<td>0.931 ± 0.142</td>
<td>0.960 ± 0.134</td>
<td>&lt;0.001**</td>
</tr>
<tr>
<td>Femoral Neck</td>
<td>0.763 ± 0.129</td>
<td>0.755 ± 0.129</td>
<td>0.784 ± 0.128</td>
<td>&lt;0.001**</td>
</tr>
<tr>
<td>Lumbar Spine</td>
<td>1.105 ± 0.199</td>
<td>1.099 ± 0.200</td>
<td>1.120 ± 0.195</td>
<td>0.055</td>
</tr>
</tbody>
</table>

Values are mean ± standard deviation or n (%) as indicated; all tests are independent t-tests for continuous variables or chi-square tests for categorical variables; Bolded values are significant at p<0.05* or p<0.01**.
\(^a\) Depressive symptoms were assessed with the short version of the Geriatric Depression Scale.\(^{41}\)
\(^b\) Poor visual acuity was ≤20/40 assessed with a Bailey-Lovie chart.\(^{44}\)

Abbreviations: ELR, effective load rating; BMI, body mass index; ADL, activities of daily living; 25OHD, 25-hydroxyvitamin D; PASE, physical activity scale for the elderly; BMD, bone mineral density.
Table 3 *Sum Effective Load Rating, Peak Force and PASE Score at Each Time Point*

<table>
<thead>
<tr>
<th></th>
<th>n</th>
<th>Sum ELR (# of bodyweights)</th>
<th>Peak Force (kg)</th>
<th>PASE Score</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean ± SD</td>
<td>Range</td>
<td>Mean ± SD</td>
<td>Range</td>
</tr>
<tr>
<td>Total population</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Baseline</td>
<td>1599</td>
<td>3.47 ± 3.5</td>
<td>0.00, 60.68</td>
<td>195.2 ± 227.8</td>
</tr>
<tr>
<td>2-year follow-up</td>
<td>1311</td>
<td>3.36 ± 2.97</td>
<td>0.00, 59.20</td>
<td>189.5 ± 192.3</td>
</tr>
<tr>
<td>5-year follow-up</td>
<td>924</td>
<td>3.31 ± 3.14</td>
<td>0.00, 59.20</td>
<td>185.7 ± 220.3</td>
</tr>
<tr>
<td>Population with complete data at all time points</td>
<td>902</td>
<td>3.80 ± 3.69b</td>
<td>0.00, 60.68</td>
<td>213.7 ± 241.1b</td>
</tr>
<tr>
<td>2-year follow-up</td>
<td>902</td>
<td>3.68 ± 3.21b</td>
<td>0.00, 59.20</td>
<td>208.3 ± 213.6b</td>
</tr>
<tr>
<td>5-year follow-up</td>
<td>902</td>
<td>3.33 ± 3.15</td>
<td>0.00, 59.20</td>
<td>186.6 ± 221.7</td>
</tr>
</tbody>
</table>

*a* Significant difference to 2-year follow-up.

*b* Significant difference to 5-year follow-up.

Abbreviations: ELR, effective load rating; PASE, physical activity scale for the elderly.

---

Table 4 *Longitudinal Associations Between Change in BMD per Standard Deviation Increase in Sum Effective Load Rating (ELR), Peak Force and PASE Scores Over 5 Years*

<table>
<thead>
<tr>
<th></th>
<th>Spine BMD (mg/cm²)</th>
<th>Peak Force</th>
<th>PASE Score</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Unadjusted</td>
<td>Adjusted Model 1</td>
<td>Adjusted Model 2</td>
</tr>
<tr>
<td></td>
<td>11.06** (3.19, 18.93)</td>
<td>11.29** (3.93, 18.65)</td>
<td>9.77* (2.33, 17.21)</td>
</tr>
<tr>
<td></td>
<td>18.00** (8.45, 27.56)</td>
<td>15.46** (6.42, 24.49)</td>
<td>14.92** (6.70, 23.14)</td>
</tr>
<tr>
<td></td>
<td>3.59 (-4.10, 11.27)</td>
<td>4.44 (-3.21, 12.08)</td>
<td>---------------</td>
</tr>
<tr>
<td>Total Hip BMD (mg/cm²)</td>
<td>16.41** (9.67, 23.16)</td>
<td>22.25** (7.82, 36.69)</td>
<td>11.27** (5.97, 16.58)</td>
</tr>
<tr>
<td></td>
<td>10.95** (5.57, 16.33)</td>
<td>14.14** (3.99, 24.29)</td>
<td>5.59* (0.72, 10.47)</td>
</tr>
<tr>
<td></td>
<td>10.05** (4.72, 15.38)</td>
<td>14.14** (3.65, 24.63)</td>
<td>---------------</td>
</tr>
<tr>
<td>Femoral Neck BMD (mg/cm²)</td>
<td>17.20** (11.14, 23.27)</td>
<td>21.26** (9.85, 32.67)</td>
<td>9.83** (4.93, 14.74)</td>
</tr>
<tr>
<td></td>
<td>12.52** (7.28, 17.75)</td>
<td>14.48** (6.27, 22.70)</td>
<td>4.66 (-0.19, 9.34)</td>
</tr>
<tr>
<td></td>
<td>10.76** (5.68, 15.85)</td>
<td>13.72** (5.82, 21.62)</td>
<td>---------------</td>
</tr>
</tbody>
</table>

Data presented as β coefficients (95% confidence interval). Bolded values are significant at p<0.05* or p<0.01**.

*a* Adjusted for baseline age, BMI, education, income, living arrangement, smoking, self-rated health, number of comorbidities, Parkinson's disease, dementia, depression, disability, stroke, serum 25OHD levels, psychotropics use, corticosteroid use, bisphosphonate use, visual acuity, history of prior fractures, history of prior falls and polypharmacy. Height instead of BMI was used for peak force as weight was factored in peak force calculation.

*b* Adjusted for the above factors with the addition of individual domains of PASE.

Abbreviations: ELR, effective load rating; PASE, physical activity scale for the elderly; BMD, bone mineral density; BMI, body mass index; 25OHD, 25-hydroxyvitamin D.
### Table 5: Incident Rate Ratios (95% Confidence Interval) for Incident Self-reported Falls Over 2 Years per Standard Deviation Increase in Baseline Sum Effective Load Rating (ELR), Peak Force and PASE Scores

<table>
<thead>
<tr>
<th>Sum ELR</th>
<th>Peak Force</th>
<th>PASE Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Incident Self-reported Falls Over 2 Years</td>
<td>Unadjusted</td>
<td>Adjusted Model 1&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>0.92* (0.86, 0.98)</td>
<td>1.04 (0.97, 1.11)</td>
</tr>
<tr>
<td></td>
<td>0.93* (0.87, 1.00)</td>
<td>1.05 (0.98, 1.12)</td>
</tr>
<tr>
<td></td>
<td>0.63** (0.58, 0.68)</td>
<td></td>
</tr>
</tbody>
</table>

Data presented as standardised incident rate ratios (95% confidence interval). Bolded values are significant at p<0.05* or p<0.01**.

<sup>a</sup> Adjusted for baseline age, BMI, education, income, living arrangement, smoking, self-rated health, number of comorbidities, Parkinson’s disease, dementia, depression, disability, stroke, serum 25OHD levels, psychotropics use, corticosteroids use, visual acuity, history of prior falls and polypharmacy. Height instead of BMI was used in the adjusted model for peak force as weight was factored in peak force calculation.

<sup>b</sup> Adjusted for the above factors with the addition of individual domains of PASE at baseline.

Abbreviations: ELR, effective load rating; PASE, physical activity scale for the elderly; BMI, body mass index; 25OHD, 25-hydroxyvitamin D.

### Table 6: Hazard Ratios (95% Confidence Interval) for Incident Fractures per Standard Deviation Increase in Baseline Sum Effective Load Ratings (ELR), Peak Force and PASE Scores

<table>
<thead>
<tr>
<th>Sum ELR</th>
<th>Peak Force</th>
<th>PASE Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Incident Self-reported Fractures Over 6 Years with Radiographic Evidence</td>
<td>Unadjusted</td>
<td>Adjusted Model 1&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Any fracture (n=165)</td>
<td>0.70** (0.54, 0.90)</td>
<td>0.85 (0.66, 1.08)</td>
</tr>
<tr>
<td></td>
<td>0.73* (0.55, 0.97)</td>
<td>0.90 (0.69, 1.17)</td>
</tr>
<tr>
<td></td>
<td>0.78** (0.66, 0.91)</td>
<td>0.92 (0.76, 1.12)</td>
</tr>
</tbody>
</table>

Vertebral fracture (n=32)

|                  | Unadjusted | Adjusted Model 1 | Adjusted Model 2 |
|                  | 0.46* (0.23, 0.90) | 0.56 (0.24, 1.26) | 0.62 (0.25, 1.51) |
|                  | 0.50* (0.25, 0.99) | 0.62 (0.27, 1.41) | 0.68 (0.29, 1.63) |
|                  | 0.62* (0.43, 0.91) | 0.64 (0.39, 1.07) |                     |

Non-vertebral fracture (n=133)

|                  | Unadjusted | Adjusted Model 1 | Adjusted Model 2 |
|                  | 0.78 (0.59, 1.02) | 0.82 (0.61, 1.10) | 0.84 (0.70, 1.00) |
|                  | 0.91 (0.71, 1.17) | 0.95 (0.75, 1.21) | 1.00 (0.81, 1.23) |
|                  | 0.86 (0.64, 1.15) | 0.91 (0.68, 1.21) |                     |

Incident Fractures Over 9 Years Confirmed by Data-linkage

|                  | Unadjusted | Adjusted Model 1 | Adjusted Model 2 |
|                  | 0.70* (0.51, 0.97) | 0.98 (0.77, 1.27) | 0.98 (0.75, 1.27) |
|                  | 0.59** (0.41, 0.85) | 0.90 (0.64, 1.26) | 0.87 (0.60, 1.27) |
|                  | 0.61** (0.49, 0.75) | 0.88 (0.69, 1.13) |                     |

Data presented as standardised hazard ratios (95% confidence interval). Bolded values are significant at p<0.05* or p<0.01**.

<sup>a</sup> Adjusted for baseline age, BMI, education, income, living arrangement, smoking, self-rated health, number of comorbidities, Parkinson’s disease, dementia, depression, disability, stroke, serum 25OHD levels, psychotropics use, corticosteroids use, visual acuity, history of prior falls and polypharmacy. Height instead of BMI was used in the adjusted model for peak force as weight was factored in peak force calculation.

<sup>b</sup> Adjusted for the above factors with the addition of individual domains of PASE at baseline.

Abbreviations: ELR, effective load rating; PASE, physical activity scale for the elderly; BMI, body mass index; 25OHD, 25-hydroxyvitamin D.
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Date:
2021-04

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