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Accelerometer-determined physical activity, muscle mass, and leg strength in community-dwelling older adults

Yi Chao Foong[1,2], Nabil Chherawala[1], Dawn Aitken[1], David Scott[3,4]*, Tania Winzenberg[1,5] & Graeme Jones[1]

[1]*Menzies Institute for Medical Research, University of Tasmania, Private Bag 23, Hobart, Tasmania 7000, Australia;* [2]*North West Regional Hospital, Burnie, Tasmania 7250, Australia;* [3]*Department of Medicine, School of Clinical Sciences, Faculty of Medicine, Nursing and Health Sciences, Monash University, Clayton, Victoria 3146, Australia;* [4]*NorthWest Academic Centre, The University of Melbourne, St Albans, Victoria 3021, Australia;* [5]*Faculty of Health, University of Tasmania, Hobart, Tasmania 7000, Australia*

Abstract

Introduction The aim of this study was to describe the relationship between accelerometer-determined physical activity (PA), muscle mass, and lower-limb strength in community-dwelling older adults.

Methods Six hundred thirty-six community-dwelling older adults (66 ± 7 years) were studied. Muscle mass was measured using dual-energy x-ray absorptiometry, whilst lower limb strength was measured via dynamometry. We measured minutes/day spent in sedentary, light, moderate, and vigorous intensity activity using Actigraph GT1M accelerometers.

Results Participants spent a median of 583(Interquartile ratio (IQR) 522–646), 225(176–271), 27(12–45) and 0(0–0) min in sedentary, light, moderate, and vigorous activity, respectively. PA intensity was positively associated with both lean mass percentage and lower limb strength in a dose–response fashion. Sedentary activity was negatively associated with lean mass percentage, but not lower-limb strength. There was a positive association between PA and appendicular lean mass in men only. There was an interaction between age and activity; as age increased, the magnitude of the association of PA with lean mass percentage decreased. Those who adhered to the Australian Department of Health PA guidelines (moderate/vigorous PA >/=150 min/week) had greater lean mass percentage, appendicular lean mass, and lower limb strength.

Conclusions Using accelerometer technology, both the amount and intensity of accelerometer-determined PA had an independent, dose–response relationship with lean mass percentage and lower limb strength, with the largest effect for vigorous activity. Time spent in sedentary activity was negatively associated with lean mass percentage, but was not associated with lower limb strength. The magnitude of the association between PA and lean mass percentage decreased with age, suggesting that PA programmes may need to be modified with increasing age.

Keywords Physical activity; Accelerometer; Muscle mass; Strength

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**Correspondence to: Dawn Aitken, Menzies Institute for Medical Research, University of Tasmania, Private Bag 23, Hobart, Tasmania, 7000, Australia, Tel: +61 3 6226 7769, Fax: +61 3 6226 7704, Email: dawn.aitken@utas.edu.au*

Introduction

The age-related decline in skeletal muscle mass and strength, known as sarcopenia, is a normal physiological process that is associated with impaired physical function.[1–6] Several studies have explored methods to prevent or reduce the progression of sarcopenia in the elderly, with resistance training and increased physical activity proving to be a consistent recommendation.[7–11]

Physical activity (PA) is commonly measured using pedometers.[12,13] Pedometers record vertical accelerations of the hips during ambulation and have good accuracy in counting steps.[14] It would be expected that increased levels of pedometer-determined PA would result in positive effects on muscle mass and strength; however, studies examining this in older adults have shown inconsistent results. Bassey *et al.*[15]found that walking was positively correlated with increases in leg strength in men only. In contrast, we have

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shown that walking was positively associated with leg strength and muscle quality in women only, and surprisingly, leg lean mass was negatively associated with walking in women.[12,15]

Whilst pedometers are a convenient method to measure PA, they are limited by the inability to assess intensity of activity or sedentary time. Accelerometers are able to provide this information; however, it is uncertain whether the additional information gives greater insights into the association between PA and sarcopenia. The few studies that have employed accelerometers as a measurement tool have focused on elderly Japanese participants.[16–18] Abe *et al.* found that moderate and vigorous PA was associated with greater muscle mass in the lower leg but not the upper leg, whilst Park *et al.* found that moderate and vigorous PA was associated with greater leg muscle mass in men only.[17,18] These inconsistencies may be due to the small participant numbers (ranging from 48 to 175 participants). Furthermore, because only elderly Japanese participants were studied, these results may not be generalizable to other populations.

Thus, the aim of this study was to examine the cross-sectional associations between accelerometer-determined PA, muscle mass, and leg strength in a large sample of Caucasian community-dwelling older adults.

Methods

Participants

This study was conducted as part of the Tasmanian Older Adult Cohort study, an ongoing, prospective, population-based study of community-dwelling older adults.[19]

An equal number of men and women between the ages of 50 and 80 years were randomly selected from the electoral roll in Southern Tasmania (population 229 000), with a response rate of 57%. Electoral rolls represent the most complete population information available in Australia because voting in federal and state elections is compulsory. The sample was stratified by sex to provide equal numbers of men and women, and equal distribution was drawn from urban and rural areas in Southern Tasmania. Exclusion criteria included contraindication for magnetic resonance imaging (MRI) (as MRI tests were required to examine osteoarthritis progression) and institutionalization. One thousand one hundred were enrolled in the study, and 1099 attended a baseline clinic between March 2002 and September 2004. Phase 2 follow-up data were collected for 875 participants approximately 2.7 years later, and phase 3 follow-up data were collected for 767 participants approximately 5 years after baseline. The current study consists of a sample of participants ($n = 636$) who had complete accelerometer, dual-energy x-ray absorptiometry (DXA) assessment of body composition, and muscle strength measures across Phase 2 ($n = 210$) and Phase 3 ($n = 426$). The study was approved by the Southern Tasmanian Health and Medical Human Research Ethics committee, and written informed consent was obtained from all participants.

Anthropometrics

Height was measured to the nearest 0.1 cm (with shoes, socks, and headwear removed) using a Leicester stadiometer (Invicta, Leicester, UK). Weight was measured to the nearest 0.1 kg (with shoes, socks, and bulky clothing removed) using electronic scales (Heine, Dover, New Hampshire, USA). Body mass index (BMI; kg/m2) was calculated from these measurements.

Body composition was determined from a whole body scan by DXA using a Hologic Delphi densitometer (Hologic, Waltham, Ma, Apex v2.0). The analysis provided regional estimates for lean muscle mass and fat in grammes. Calculations were then made to determine appendicular lean mass (ALM) (sum of lean mass in the right and left arms and legs) and appendicular fat mass (AFM) (sum of fat mass in the right and left arms and legs). Lean muscle mass percentile was calculated as total body lean mass relative to its total mass. Participants were excluded from DXA scanning if their weight exceeded 130 kg as their bodies were too wide for the scan field ($n = 3$), if they were unable to remain supine for the duration of the scanning procedure ($n = 2$), or if they had an artificial limb ($n = 2$). Self-report of smoking status and disease status (such as the presence of hypertension and diabetes) was recorded by questionnaire.

Strength

Knee extension strength was measured by isometric contraction of knee extensors with a 100 kg Pocket Balance dynamometer. Participants were seated with hips and knees at a 90° angle, and were instructed to keep their backs straight and grip their chair throughout the test. A strap was positioned 10 cm superior to the lateral malleolus of the dominant leg and attached to the dynamometer that recorded maximum contractile force whilst participants attempted to extend their leg.

Leg strength was assessed in both legs simultaneously, using a dynamometer (TTM Muscular Metre, Tokyo, Japan). Participants were positioned on the back of a dynamometer platform standing with knee flexed to 115°, with their backs against a wall. A bar was attached to the dynamometer, and participants were instructed to lift the bar to maximum contractile force, using their legs only whilst maintaining proper head and neck posture.[14]

Physical activity

Accelerometer-determined PA was assessed once in every participant, either at Phase 2 or Phase 3 as counts/day using an ActiGraph GT1M. Accelerometers were added to this study halfway through Phase 2, which explains why some participants were assessed at Phase 2 and the remainder were assessed at Phase 3. Each participant was instructed to wear an accelerometer for 7 consecutive days following their clinic visit. Participants were provided with a diary where they recorded the start and finish times each day, as well as the duration and reason for any periods where they took the accelerometer off. They also reported any circumstances that may have affected the accelerometer reading (such as driving on uneven ground). During the cleaning process, we took these into account and omitted any obvious accelerometer activity that was not a result of PA. Participants were included in data analysis if they wore the accelerometer for at least 5 valid days, where a valid day was defined as having worn the device for more than 10 h.

Absolute time spent engaged in sedentary (<1.5 Metabolic equivalents (METS)), light (1.5–2.9 METS), moderate (3–5.9 METS), and vigorous (> = 6METS) intensity activity was calculated. We employed the sedentary activity cut-off proposed by Matthews[20] and cut-offs for other categories as per the Freedson equation.[21] We have also performed an analysis based on the raw accelerometer counts. This is because older adults tend to spend more time performing PA at a lower intensity but with less intervals between bouts of activity, resulting in an underestimation of total PA with categorical data.[22]

Cognitive function

The Trail Maker Test (TMT), a widely used neuropsychological assessment, was used to assess executive functioning and speed of cognitive processing.[23] The TMT is a two-part (TMT A and TMT B) assessment of general brain function, with TMT A requiring participants to connect numbers scattered over an 8.5" x 11" sheet of paper, and connecting letters and numbers in the more challenging TMT B. TMT A primarily requires visuo-perceptual abilities, whilst TMT B requires working memory and task-switching skills, although processing speed and general intelligence are other cognitive constructs thought to be involved in the TMT.[23] Participants were administered the TMT according to the established guidelines[24] in a laboratory-based setting, and scores were determined by time, with faster completion of the test indicative of higher speed of cognitive processing (TMT A) and enhanced executive function (TMT B).

We used a revised version of the Hopkins Verbal Learning Test (HVLT)[25]to assess neuropsychological impairment in episodic verbal memory. Three learning trials are conducted, whereby the examiner reads 12 words aloud to the participant, who is then asked to freely recall the words immediately. Trial 4, a delayed recall trial, occurs after a 20–25 min delay. The total number of words recalled for each of the three learning trials (HVLT total recall; range 0–36) and the total number of words recalled in the delayed trial (HVLT delayed recall; range 0–12) were recorded. Further administration and scoring details can be found in the HVLT revision paper.[25]

Statistical analyses

Linear regression was used to examine the associations between PA and muscle mass (lean mass percentage and ALM) and muscle strength (knee extension strength and leg strength). The exposure for all regression analyses was minutes of PA per day (sedentary, light, moderate, and vigorous) and raw accelerometer counts. Interactions were present between PA and sex for ALM; therefore, the analysis was stratified by sex. We also found a significant PA–age interaction on muscle mass and muscle strength measures, and further analyses were modelled with interactions and presented across tertiles of age. Univariable analysis was performed with a range of lifestyle and demographic factors (smoking, calorie intake, diabetes, hypertension, and alcohol intake), and those that were significantly associated were included in the multivariable model along with age and sex.

In further analysis, participants who achieved at least 150 min of moderate activity (minutes engaged in vigorous activity was weighted by a factor of two) per week were dichotomized as having met the Australian Department of Health recommendations for physical activity. Linear regression was then performed for the same outcomes.

All analyses were adjusted for age residuals instead of age because of a strong correlation between age and PA. Given that as we age, we do less PA, it was necessary to adjust for the component of age, which was not explained by PA. In order to do this, four separate simple linear regressions were performed where age was regressed on the four levels of PA (sedentary, light, moderate, and vigorous), and the residuals were predicted, which represent the component of age not explained by the four PA levels. The residual factor was added to each model: sedentary, light, moderate, and vigorous, respectively. Models were also adjusted for AFM, calculated as the sum of the fat mass of each limb.

Standard diagnostic checks of model adequacy and unusual observations were performed on all models. A *P*-value less than 0.05 (two-tailed) was considered statistically significant. All statistical analyses were performed on Intercooled StataV.12.0 for Windows (StataCorp LP).

Results

Table 1 presents the baseline characteristics of the participants. Mean BMI was 28.0 and 28.1 for men and women, respectively, and a majority (73.4%) of our participants were overweight or obese (BMI ≥ 25). There was no significant difference between the sexes in terms of comorbidities. Raw accelerometer counts were significantly greater in men. As

Table 1 Characteristics of participants ($n = 636$)

	Women (n = 323)	Men (n = 313)	P-value
Age (years)	66.0 (6.7)	66.6 (7.4)	0.25
Body mass index (kg/m^2)	28.1 (5.3)	28.0 (4.0)	0.69
Caloric intake (kJ)	**6177.6 (1970.1)**	**8459.6 (2641.0)**	**<0.01**
Alcohol intake (standard drinks/week)	**9.4 (12.0)**	**19.9 (20.3)**	**<0.01**
Diabetes (%)	0.9	2.2	0.19
Hypertension (%)	7.4	9.3	0.40
Current smokers (%)	8.4	9.6	0.59
Raw accelerometer count (per 10 000 counts)	**27.7 (12.5)**	**31.5 (14.3)**	**<0.01**
Muscle mass measures			
Lean percentage (%)	**57.3 (4.7)**	**69.1 (4.9)**	**<0.01**
Appendicular lean mass (kg)	**20.2 (2.8)**	**28.8 (3.2)**	**<0.01**
Strength			
Leg strength (kg)	**56.4 (27.1)**	**129.0 (39.5)**	**<0.01**
Knee extension strength (kg)	**28.2 (9.1)**	**39.3 (8.1)**	**<0.01**
Accelerometer			
Sedentary (minutes/day)	582.6 (89.0)	585.1 (99.5)	0.74
Light (minutes/day)	226.7 (7.1)	227.1 (73.0)	0.95
Moderate (minutes/day)	**27.9 (22.5)**	**36.3 (26.7)**	**<0.01**
Vigorous (minutes/day)[a]	**0.5 (0.3)**	**1.2 (0.4)**	**<0.01**
Cognitive function			
HVLT total recall (range 7–36)	24.8 ± 5.4	27.1 ± 4.8	**<0.01**
HVLT delayed recall (range 0–12)	9.2 ± 2.4	10.0 ± 1.9	**<0.01**
Cognitive speed functioning (TMT A) (sec)	39.1 ± 14.1	39.7 ± 24.7	0.83
Executive functioning (TMT B) (sec)	96.8 ± 41.9	98.7 ± 60.0	0.85

HVLT, Hopkins Verbal Learning Test; TMT, Trail Maker Test. Mean (SD) except for diabetes, hypertension, and current smokers (%).
[a] Only 24.4% of study participants recorded any vigorous activity.

expected, all measures of muscle strength and muscle mass were greater in men. There was also a significant difference in terms of the amount of moderate and vigorous PA—men performed significantly greater amounts of Moderate and Vigorous Physical Activity (MVPA) compared with women. In terms of cognitive function, there was a significant difference favouring men for HLVT total and delayed recall; however, there was no difference for executive and cognitive speed functioning.

Table 2 presents the associations between muscle mass, leg strength, and PA. In both univariable and multivariable analysis, time spent in sedentary activity was negatively associated with lean mass percentage. This association persisted after further adjusting for time spent in other levels of physical activity (data not shown). On the other hand, light, moderate, and vigorous activity was positively associated with lean mass percentage in a dose–response fashion with the largest effect for vigorous activity. The association between ALM and PA differed by sex. In multivariable analysis adjusting for age residuals and AFM, we found that for men, time spent in sedentary activity was negatively associated with ALM, whilst light and moderate PA was positively associated with ALM. There was a dose–response trend with regard to the intensity of activity, but vigorous activity was not significantly associated with ALM. However, there was no significant association between ALM and PA in women. There was no age interaction.

There was no significant association between time spent in sedentary activity and leg and knee extension strength, even after adjusting for time spent at other levels of PA (data not shown). However, there was a dose–response relationship between PA and lower limb strength, where the greater the intensity of activity, the greater the effect on lower limb strength. This remained significant in multivariable analysis adjusting for age residuals and sex. There was no age or sex interaction. In all of the aforementioned analysis, adjusting for other potential confounders (smoking, calorie intake, diabetes, hypertension, measures of cognitive function, and alcohol intake) did not result in a significant change in the beta coefficient (defined as greater than 10%). The aforementioned analyses were repeated with raw accelerometer counts as reflected in *Table* 3. In both univariable and multivariable analyses, raw accelerometer counts were positively associated with lean mass percentage. The association between ALM and raw accelerometer counts differed by sex. In univariable analysis, only men were found to have a significant association between ALM and raw accelerometer counts; however, upon adjusting for age residuals and AFM, this association became significant in both sexes. Finally, both knee extension and leg strength were positively correlated with raw accelerometer counts.

There was a significant PA–age interaction for lean mass percentage, indicating that the effect for each level of PA activity was modified by age. As shown in *Figure* 1, with increasing age, the magnitude of the association between lean mass percentage and time spent in sedentary, light, and moderate activity diminishes. The results with time spent in vigorous activity are not shown, as very few participants engaged in meaningful levels of vigorous activity when data were stratified by age. This interaction was also significant ($P = < 0.01$) when age was analysed continuously, but we chose to display

Table 2 Regression coefficients expressing cross-sectional differences in muscle mass and strength measures per 10 min of activity per day

	Univariate		Multivariable[b]	
	β (95% CI)	*P*-value	β (95% CI)	*P*-value
Lean mass (%)				
Sedentary	**−0.1 (−0.1, −0.01)**	**0.032**	**−0.1 (−0.1, −0.03)**	**0.001**
Light	**0.2 (+0.1, +0.3)**	**<0.001**	**0.2 (+0.1, +0.2)**	**<0.001**
Moderate	**1.1 (+0.9, +1.3)**	**<0.001**	**0.7 (+0.5, +0.8)**	**<0.001**
Vigorous	**3.6 (+2.0, +5.1)**	**<0.001**	**1.9 (+0.9, +2.9)**	**<0.001**
Appendicular lean mass (kg)[a]				
Men				
Sedentary	−0.03 (−0.1, +0.01)	0.108	**−0.03 (−0.1, −0.01)**	**0.021**
Light	**0.08 (+0.03, +0.1)**	**0.001**	**0.08 (+0.04, +0.1)**	**<0.001**
Moderate	**0.2 (+0.04, +0.3)**	**0.009**	**0.2 (+0.1, +0.3)**	**<0.001**
Vigorous	0.4 (−0.3, +1.2)	0.268	0.5 (−0.2, +1.2)	0.148
Women				
Sedentary	0.02 (−0.01, +0.06)	0.223	0.02 (−0.02, +0.05)	0.320
Light	0.001 (−0.04, +0.05)	0.973	0.02 (−0.02, +0.06)	0.262
Moderate	−0.04 (−0.2, +0.1)	0.565	0.07 (−0.01, +0.2)	0.281
Vigorous	0.3 (−0.8, +1.4)	0.566	0.4 (−0.5, +1.4)	0.353
Leg strength (kg)				
Sedentary	−0.3 (−0.7, +0.1)	0.162	−0.1 (−0.4, +0.2)	0.438
Light	**0.8 (+0.2, +1.3)**	**0.005**	**0.4 (+0.1, +0.8)**	**0.023**
Moderate	**5.2 (+3.7, +6.8)**	**<0.001**	**1.6 (+0.6, +2.7)**	**0.002**
Vigorous	**21 (+11, +31)**	**<0.001**	**7.5 (+0.9, +14.1)**	**0.026**
Knee extension strength (kg)				
Sedentary	−0.1 (−0.2, +0.01)	0.072	−0.03 (−0.1, +0.04)	0.415
Light	**0.2 (+0.1, +0.3)**	**<0.001**	**0.1 (+0.02, +0.2)**	**0.019**
Moderate	**1.2 (+0.9, +1.5)**	**<0.001**	**0.6 (+0.3, +0.8)**	**<0.001**
Vigorous	**5.1 (+3.0, +7.2)**	**<0.001**	**2.7 (+1.0, +4.5)**	**0.002**

[a] A sex interaction existed for appendicular lean mass; therefore, the analysis is displayed separately by men and women.
[b] Adjusted for age residuals and sex, apart from appendicular lean mass, which is adjusted for age residuals and appendicular fat mass.
Boldface denotes statistically significant result, where *P*-value < 0.05; 95% CI, 95% confidence interval; β, beta coefficients

Table 3 Regression coefficients expressing cross-sectional differences in muscle mass and strength measures per 10 000 raw accelerometer counts

	Univariate		Multivariable[b]	
	β (95% CI)	*P*-value	β (95% CI)	*P*-value
Lean mass (%)	**0.20 (0.16, 0.24)**	**<0.001**	**0.14 (0.12, 0.17)**	**<0.001**
Appendicular lean mass (kg)[a]				
Men	**0.04 (0.02, 0.07)**	**0.001**	**0.06 (0.04, 0.09)**	**<0.001**
Women	0 (−0.03, 0.02)	0.855	**0.04 (0.02, 0.06)**	**<0.001**
Leg strength (kg)	**0.99 (0.70, 1.27)**	**<0.001**	**0.65 (0.46, 0.83)**	**<0.001**
Knee extension strength (kg)	**0.23 (0.17, 0.29)**	**<0.001**	**0.17 (0.12, 0.22)**	**<0.001**

[a] A sex interaction existed for appendicular lean mass; therefore, the analysis is displayed separately by men and women.
[b] Adjusted for age residuals and sex, apart from appendicular lean mass, which is adjusted for age residuals and appendicular fat mass.
Boldface denotes statistically significant result, where *P*-value < 0.05; 95% CI, 95% confidence interval; β, beta coefficients

age tertiles for clearer presentation. The interaction was further verified by regressing each outcome measure on raw accelerometer counts by age interaction (all interaction *P*-values <0.05).

Table 4 displays the relationship between meeting the Australian Department of Health physical activity recommendations and lean mass percentage, ALM, and leg and knee extension strength, stratified by men and women. About 59.1% (376/636) of our participants met the PA guidelines (data not shown). Participants who achieved the PA recommendations had significantly higher total lean muscle percentage. Interestingly, our results also demonstrated that ALM was positively associated with meeting the guidelines in men, whilst an inverse relationship was observed for women. Knee extension strength was shown to be strongly positively associated with meeting the guidelines for both sexes. Leg strength also showed a strong positive relationship with meeting the guidelines, but the association was borderline significant in women.

Discussion

This large cross-sectional study of community-dwelling older adults demonstrated a dose–response relationship between

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Figure 1 Interaction between sedentary, light, and moderate activity and age on lean mass percentage. As age increases, the association between each activity level and lean mass percentage diminishes. Beta coefficient represents the change in lean mass percentage for every 10 min increase in activity level. All interaction *P*-values < 0.05.

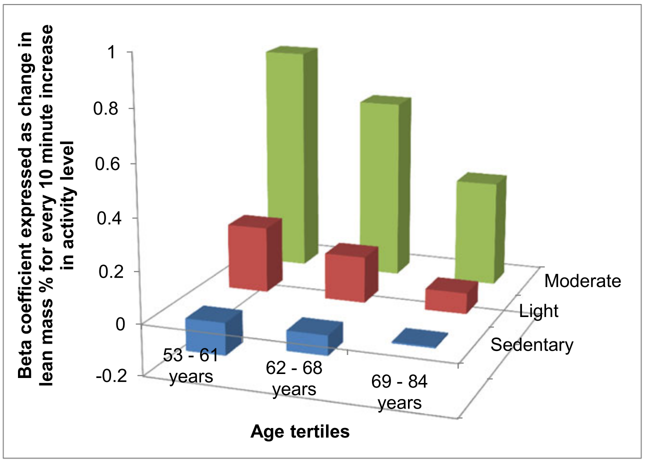

Table 4 Relationship between muscle mass and strength and meeting the Australian Department of Health recommendations

	β (95% CI)	*P*-value
Lean percentile (%)		
Men	**2.6 (1.5, 3.7)**	**$<$0.001**
Women	**2.7 (1.7, 3.8)**	**$<$0.001**
Appendicular lean mass (kg)[a]		
Men	**0.1 (0.1, 0.2)**	**$<$0.001**
Women	**−0.1 (−0.1, −0.07)!**	**$<$0.001**
Knee extension strength (kg)		
Men	**3.9 (2.0, 5.8)**	**$<$0.001**
Women	**3.3 (1.5, 5.1)**	**$<$0.001**
Leg strength (kg)		
Men	**16.2 (8.6, 23.9)**	**$<$0.001**
Women	6.9 (−0.4, 14.3)	0.063

[a]Adjusted for appendicular lean mass which is adjusted for age residuals and appendicular fat mass. Boldface denotes statistically significant result; 95% CI, 95% confidence interval; β, beta coefficients

intensity of PA and lean mass percentage and lower limb strength. Sedentary activity was negatively associated with lean mass percentage but not lower limb strength. There was a significant association between PA intensity and ALM for men only. Interestingly, the magnitude of the association between PA and lean mass percentage decreased with age. These results have significant implications for PA recommendations with regard to maintaining muscle strength and muscle mass in older adults.

Few studies have examined associations of accelerometer-determined PA with lean mass percentage as determined by DXA in an elderly, community-dwelling population. In our study, PA was positively associated with lean mass percentage with greater effect sizes seen at higher levels of PA intensity, whilst sedentary activity was negatively associated with lean mass percentage. This is consistent with other studies that have shown that sedentary activity is associated with lower lean mass[26] and that physical activity is associated with a lower risk of developing sarcopenia.[17,27] However, in the Park *et al.* study, this association was only present for moderate and vigorous activity, whilst we have demonstrated that even light activity is positively associated with lean mass percentage.[17] This may be due to their smaller study sample and the smaller effect size of light PA (as compared with moderate and vigorous PA) on lean mass percentage.

We also found a significant age–PA interaction on lean mass percentage, where the magnitude of association between lean mass percentage and PA decreased with age. We believe that this is one of the first studies documenting a decreased association between PA and lean mass percentage with age. Our results imply that greater amounts and intensities of PA would be necessary to maintain or increase muscle mass with ageing. However, older adults may have a limited ability to tolerate large amounts of PA, given the increased prevalence of other comorbidities. In fact, in our study population, only 11.3% (24/212) of our participants in the oldest age tertile reported doing any vigorous activity. There is also emerging evidence that vigorous ambulatory activity may be detrimental to older adults in certain respects, such as causing structural changes in weight-bearing joints.[28]Future studies could explore modalities of vigorous PA that is safe for older adults (such as swimming or high-intensity progressive resistance training).[29,30]Furthermore, it may be that other factors play a greater role in influencing lean mass percentage in older adults. There is emerging evidence pointing towards the role of diet, vitamin D intake, and comorbidities such as heart disease and depression in modulating muscle mass.[11,31,32]

Appendicular lean mass was positively associated with PA, with greater effect sizes seen with higher PA intensity in men.

Previous studies by our group in the same cohort showed a strong association between fat mass and PA—however, adjusting for age residuals and AFM did not significantly affect our results.[33]These findings are consistent with previous pedometer-based studies, which also found ALM in men increased with steps taken per day.[12,34] A likely explanation for the difference in findings between the sexes may be due to the underestimation of PA because of analysing our data as categorical variables. In an analysis using raw accelerometer counts, there was a significant association between ALM and PA in both men and women, after adjusting for AFM and age residuals.

In both men and women, intensity of PA was positively associated with knee extension strength and leg strength in a non-linear dose–response fashion; however, there was no association between sedentary activity and strength. Previous studies have reported differences between sexes, with one study reporting that PA resulted in dose–response strength increases in women only[12] and another a sex interaction where PA was associated with muscle strength to a greater extent in women.[35] However, our methodology differs significantly—Gomez-Cabello *et al.* employed a questionnaire (Physical Activity Scale for the Elderly) to assess PA, whilst Scott *et al.* utilized pedometers, which do not allow for examination of activity intensity. Leg strength is particularly important in elderly adults and has been shown to be associated with a range of key outcomes, including falls, decreased mobility, and mortality.[36–39]Thus, increasing PA intensity and duration may translate into improved morbidity and mortality for older adults. The landmark Pedometer Accelerometer Consultation Evaluation (PACE) Lift cluster trial has shown that objective PA assessment via accelerometry combined with personalized, primary care support can significantly increase MVPA in older adults.[40] Future studies should explore innovative ways of increasing MVPA in the elderly, such as commercial electronic accelerometers (such as Fitbit),[41] and exploring potential barriers to MVPA, such as a fear of falling or a lack of interest.[42,43]Previous pilot studies have shown that a resistance-training programme in line with American Heart Association guidelines (which at the time of study was identical to the Australian Department of Health guidelines) resulted in increased muscle strength.[44] Our study shows that adhering to the Australian PA guidelines was positively associated with lower limb muscle strength, lean mass percentage, and ALM. The effect size is sizable; for example, there was a difference in knee extension strength between those adhering to Australian guidelines and those who did not (3.9 kg for men and 3.3 kg for women). In the Newman *et al.* landmark study, knee extension strength was inversely related to mortality, with a hazard ratio of 1.51 for men and 1.65 for women.[36] Given that few older adults comply with PA guidelines,[45] future studies should explore the underlying factors impeding adherence. Current Australian guidelines make no mention regarding time spent in sedentary activity for older adults. Whilst this study demonstrates that PA plays a greater role in influencing muscle mass and leg strength, sedentary activity was still independently associated with lean mass percentage. This is consistent with the results of a smaller study using self-reported measures of PA and sedentary behaviour by Gianoudis *et al.*[26]

This study has several limitations. The cross-sectional design of the study indicates that we are unable to comment on causality, and it may be possible that those with greater muscle mass and strength were able to perform higher-intensity PA. A longitudinal study would clarify this issue. This study was also conducted in community-dwelling older adults, and thus may not be generalizable to the institutionalized elderly. In terms of our measures of cognitive function, we did not obtain data on the prevalence of dementia in our participants. Whilst the rate of dementia is likely to be under-represented in this community-based cohort, future studies should consider this potential confounder. As with all waist-mounted monitors, non-ambulatory activity (such as swimming and weight training) will be underestimated. However, only a small proportion of our participants reported being involved in these activities. Finally, we used a categorical variable in our analysis. This has the potential for underestimating total PA in older adults as they are likely to perform more PA at lower intensity with less intervals between bouts of activity. To address this, we have also performed an analysis using the raw accelerometer count data as shown earlier.

In conclusion, our findings demonstrate an independent dose–response relationship between duration and intensity of PA and lean mass percentage, ALM in men and lower limb strength with the largest effect for vigorous activity. Time spent in sedentary activity was negatively associated with lean mass percentage, but was not associated with lower limb strength. The magnitude of the association between PA and lean mass percentage decreased with age, suggesting that PA programmes may need to be modified with increasing age. Future studies could explore well-tolerated forms of vigorous activity in the elderly and the efficacy of unique interventions to encourage PA in older adults.

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Conflict of interest

None declared.

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