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ORIGINAL ARTICLE

Yearlong physical activity and sarcopenia in older adults: the Nakanojo Study

Hyuntae Park · Sungjin Park · Roy J. Shephard · Yukitoshi Aoyagi

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Abstract We tested the hypothesis that a low level of regular daily physical activity in elderly individuals would be associated with a clinically significant degree of sarcopenia. Subjects were 78 male and 97 female free-living Japanese, aged 65–84 years. A pedometer/accelerometer measured continuously the number of steps taken and the intensity of activity 24 h/day for 1 year. A whole-body dual X-ray absorptiometry scan assessed skeletal muscle mass in the upper and lower extremities at the end of the year. Sarcopenia was defined as a muscle mass/height^2 value >1 SD below the mean for healthy young Japanese. Linear and exponential regressions showed that after controlling data for age and/or sex, muscle mass was associated with physical activity, more closely for the legs than for the arms, and for duration of moderate activity (>3 METs) than for step count. Muscle mass increased progressively with daily activity, although when data were categorized into quartiles, muscle mass was not significantly greater in men and women who exceeded, respectively, 8,000 and 6,900 steps/day and/or 22 and 19 min/day at >3 METs. All participants meeting such criteria exceeded our sarcopenia threshold. Multivariate-adjusted logistic regressions predicted that individuals who walked <5,300 steps/day and/or spent <15 min/day at >3 METs were, respectively, 2.00–2.66 and/or 2.03–4.55 times more likely to show sarcopenia than those who walked >7,800 steps/day and/or spent >23 min/day at >3 METs. Our hypothesis was proven correct: seniors who walked at least 7,000–8,000 steps/day and/or spent 15–20 min/day at an intensity of >3 METs were likely to have a muscle mass above the sarcopenia threshold.

Keywords Aging · Exercise duration · Pedometer/accelerometer · Skeletal muscle mass · Step count

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H. Park · S. Park · Y. Aoyagi (✉)
Exercise Sciences Research Group,
Tokyo Metropolitan Institute of Gerontology,
35-2 Sakaecho, Itabashi-ku, Tokyo 173-0015, Japan
e-mail: aoyagi@tmig.or.jp

R. J. Shephard
Faculty of Physical Education and Health,
University of Toronto, Toronto, ON, Canada

Introduction

Sarcopenia is an age-related condition characterized by loss of muscle mass, with a concomitant decline of voluntary muscle strength and increase of fatigability (Evans 1995; Morley et al. 2001; Short and Nair 1999). It contributes to a decrease in physical abilities, a vicious cycle of diminishing physical activity and a deterioration in quality of life in those who are affected, to the point where assisted daily living is often required (Janssen et al. 2002; Visser et al. 2000).

A number of cross-sectional (Aubertin-Leheudre et al. 2006; Baumgartner et al. 1998; Melton et al. 2000; Rimbert et al. 2006; Starling et al. 1999; Szulc et al. 2004) and longitudinal studies (Hughes et al. 2001; Rantanen et al. 1997) have shown relationships between low levels of habitual physical activity and the presence or the development of sarcopenia. However, one limitation in most of these studies (Baumgartner et al. 1998; Hughes et al. 2001; Melton et al. 2000; Rantanen et al. 1997; Rimbert et al. 2006; Szulc et al. 2004) was that physical activity patterns were assessed by questionnaires; commonly, inquiry was made about the frequency and/or the duration of specific types of physical activity during a typical recent week. Unfortunately, such responses are subjective, and they provide only limited estimates of the yearlong volume and intensity of habitual physical activity in older adults, given that many in this age group have difficulties in recall and/or loss of cognition (Aoyagi and Shephard 2009, 2010; Stewart et al. 2001). Two previous studies (Aubertin-Leheudre et al. 2006; Starling et al. 1999) made objective accelerometer measurements, but these were limited to <10 days, despite evidence of substantial seasonal changes in the physical activity patterns of the elderly (Aoyagi and Shephard 2009, 2010; Shephard and Aoyagi 2009; Togo et al. 2005, 2008; Yasunaga et al. 2008). Thus, the quantity and quality of physical activity associated with the conservation of muscle mass have yet to be clearly defined.

Since walking is the main form of spontaneous physical activity for most older people, the average daily step count offers one promising objective indication of habitual physical activity. Such data can be collected relatively accurately by the latest designs of uniaxial pedometer/accelerometer. The duration of activity at a moderate-to-vigorous intensity also seems likely to be an important variable, and this can be ascertained by certain types of pedometer/accelerometer. The present study thus analyzed relationships between the skeletal muscle mass of older adults and yearlong assessments of step count and activity at a moderate-to-vigorous intensity, using an advanced design of pedometer/accelerometer (the modified Kenz Lifecorder). Our hypothesis was that there would be positive associations between our assessment of muscle mass and habitual physical activity (step count and duration of moderate-intensity physical activity).

Methods

Subjects

The subjects were a convenience sample of 78 male and 97 female Japanese volunteers aged 65–84 years, residents in the town of Nakanojo (population of about 18,000). Participants gave written informed consent to this institutionally approved investigation, after the protocol, stresses and possible risks had been fully explained to them. All had completed a detailed medical examination as a part of the overall Nakanojo Study (Aoyagi and Shephard 2009, 2010; Aoyagi et al. 2009; Park et al. 2007, 2008; Togo et al. 2005, 2008; Yasunaga et al. 2006, 2007, 2008; Yoshiuchi et al. 2006). They were ambulatory, without evidence of orthopedic problems, cognitive impairment, specific myopathies or chronic or terminal illness that could affect the variables under investigation.

Habitual physical activity measurements

The pedometer/accelerometer used in this study (modified Kenz Lifecorder, Suzuken Co., Ltd., Nagoya, Aichi, Japan) has been described previously (Aoyagi and Shephard 2009, 2010; Togo et al. 2005, 2008; Yasunaga et al. 2008). This instrument incorporates a proprietary algorithm that determines the daily step count (midnight to midnight) with an intramodel reliability of 0.998 and an absolute accuracy of ±<3% (Shephard and Aoyagi 2010). Eleven intensities of activity can also be identified, as described by Kumahara et al. (2004); in brief, absolute intensities of the step impulse (accelerations) were calibrated against the directly measured oxygen consumption in both experimental and free-living conditions. To minimize the effects of inter-individual differences in body mass, intensities of effort are expressed as metabolic equivalents (METs). For our present purpose, we determined the daily duration of activity at an intensity of >3 METs. This is a moderate, health-promoting intensity of activity for people in this age group (Aoyagi and Shephard 2009, 2010; Aoyagi et al. 2004) and is helpful in distinguishing deliberate exercise such as walking from incidental movements around the home. Subjects wore the recording device on their waist belts continuously for 1 year, between July 2002 and June 2003. The device has a storage capacity of up to 60 days, allowing data retrieval and battery replacement during a few minutes as part of regular monthly visits that subjects made to the Nakanojo Public Health Center. Data were reviewed and adjusted for very occasional recording problems, as previously described (Togo et al. 2005, 2008; Yasunaga et al. 2008).

Skeletal muscle mass measurements

Skeletal muscle mass was measured by whole-body dual X-ray absorptiometer (DXA; DPX-L, Lunar Radiation Corp., Madison, WI, USA). The scan followed the manufacture's default methodology (Heymsfield et al. 1990), analyzing data by the 3.4 version software. For the arm, estimates encompassed all soft tissue from the center of the humeral socket to the phalangeal tips, and for the leg, estimates included all soft tissue from an angled line through the femoral neck to the phalangeal tips. Contact with the ribs, pelvis and greater trochanter was avoided when making these measurements. The system software calculated the total mass, soft tissue attenuation ratios and the bone mineral mass for the selected regions. The soft tissue attenuation ratio was used to divide regional bone mineral-free tissue into fat and fat-free components. Total appendicular muscle mass was taken as the sum of arm and leg values; this estimate included a small and relatively constant amount of skin and connective tissue, together with any intramuscular fat infiltration. Sarcopenia (classes I + II) was defined as a value of muscle mass/height^2 falling more than 1 standard deviation (SD) below the mean for a young and healthy reference population (Janssen et al. 2002). The specific cutoff values for arm, leg and appendicular sarcopenia were, respectively, 1.54, 4.96 and 6.53 kg/m^2 in men and 1.16, 4.31 and 5.21 kg/m^2 in women.

Statistical analyses

All data were analyzed using the Statistical Package for the Social Sciences (SPSS) 14.0 (SPSS Inc., Chicago, IL, USA). Data are presented as mean ± SD. Non-paired *t* tests compared physical characteristics, muscle mass and habitual physical activity between men and women, between those aged 65–74 and 75–84 years, and between non-sarcopenic and sarcopenic individuals. Partial correlation analyses assessed independent associations between physical activity and muscle mass in all subjects (after controlling for age and sex), in each sex (after controlling for age), and in each age group (after controlling for sex). Linear and exponential regression analyses tested associations between habitual physical activity and muscle mass. We also divided subjects arbitrarily into increasing quartiles of habitual physical activity (Q1–Q4) to test the statistical significance of associations between levels of physical activity and muscle mass. Analyses of covariance (ANCOVA) assessed independent associations between the four categories of physical activity and muscle mass after controlling for age and/or sex. Logistic regressions assessed odds ratios and 95% confidence intervals adjusted for age, sex, smoking status (smoker/nonsmoker) and/or alcohol intake (drinker/nondrinker), and independent associations between habitual physical activity and the risk of sarcopenia. All statistical contrasts were made at the 0.05 level of significance, although the appropriate Bonferroni correction was applied when multiple comparisons were made.

Results

We saw the anticipated differences of height and body mass between men and women ($P < 0.05$), although the average age and body mass index (BMI) did not differ significantly between male and female subjects (Table 1). There were no significant differences in body mass, height or BMI between those aged 65–74 and 75–84 years. Non-sarcopenic subjects were significantly younger, heavier and taller than those classed as sarcopenic. Muscle mass for the arms, legs and all four limbs combined were significantly greater in men than in women. Average values for the legs and all four limbs, but not for the arms, were also significantly higher in 65- to 74- than in 75- to 84-year-old subjects. The prevalence of regional sarcopenia was for arm, leg and combined arm/leg data, respectively: 23, 25 and 25% in all subjects; 21, 23 and 23% in men; 24, 27 and 26% in women; 16, 18 and 19% in those aged 65–74 years; and 31, 36 and 38% in those aged 75–84 years. Men walked more steps per day than women. The year-averaged daily step count and daily duration of exercise >3 METs were significantly greater in those aged 65–74 years than in those aged 75–84 years and were also higher in non-sarcopenic than in sarcopenic subjects.

Table 1 Selected anthropometry, skeletal muscle mass and habitual physical activity of subjects

	All	Men	Women	Age 65–74 years	Age 75–84 years	Non-sarcopenia	Sarcopenia
Number of participants	175	78	97	118	57	132	43
Age (years)	72.5 ± 4.6	73.1 ± 4.8	72.1 ± 4.4	69.9 ± 2.5	77.9 ± 2.8†	71.9 ± 4.2	74.4 ± 5.1‡
Body mass (kg)	55.3 ± 8.2	59.1 ± 7.5	52.3 ± 7.6*	55.9 ± 8.7	54.3 ± 7.2	56.7 ± 7.9	51.0 ± 7.7‡
Height (m)	1.53 ± 0.08	1.60 ± 0.06	1.48 ± 0.05*	1.54 ± 0.08	1.52 ± 0.08	1.54 ± 0.83	1.51 ± 0.79‡
Body mass index (kg/m^2)	23.6 ± 3.0	23.2 ± 2.7	23.9 ± 3.2	23.7 ± 3.0	23.4 ± 3.1	24.1 ± 2.8	21.9 ± 3.1‡
Appendicular muscle mass (kg/m^2)	6.77 ± 1.03	7.61 ± 0.73	6.32 ± 0.60*	7.03 ± 1.03	6.37 ± 1.02†	7.79 ± 0.92	5.86 ± 0.81‡
Arm muscle mass (kg/m^2)	1.54 ± 0.27	1.76 ± 0.20	1.36 ± 0.17*	1.65 ± 0.28	1.33 ± 0.25	1.84 ± 0.26	1.22 ± 0.22‡
Leg muscle mass (kg/m^2)	5.51 ± 0.60	5.85 ± 0.57	5.25 ± 0.49*	5.55 ± 0.60	5.32 ± 0.61†	5.88 ± 0.52	4.90 ± 0.54‡
Year-averaged step count (steps/day)	6,535 ± 2,726	7,021 ± 2,696	6,144 ± 2,701*	7,096 ± 2,513	5,402 ± 2,807†	7,009 ± 2,594	5,081 ± 2,633‡
Year-averaged duration of physical activity >3 METs (min/day)	17.4 ± 12.0	18.9 ± 13.0	16.2 ± 11.1	19.7 ± 11.6	12.6 ± 11.4†	19.2 ± 12.1	11.7 ± 9.8‡

Values are mean ± SD

*Versus men ($P < 0.05$), †versus age 65–74 years ($P < 0.05$), ‡versus non-sarcopenia ($P < 0.05$)

Table 2 Partial correlation coefficients (r) between daily physical activity and skeletal muscle mass

	All	Men	Women	Age 65–74 years	Age 75–84 years
Year-averaged step count versus:					
Appendicular muscle mass	0.28*	0.18	0.36*	0.23*	0.39*
Arm muscle mass	0.13	0.13	0.03	0.11	0.17
Leg muscle mass	0.21	0.19	0.15	0.20	0.24*
Year-averaged duration of physical activity >3 METs versus:					
Appendicular muscle mass	0.34*	0.28*	0.38*	0.26*	0.46*
Arm muscle mass	0.14	0.23	0.10	0.15	0.22
Leg muscle mass	0.24*	0.27*	0.15	0.22	0.28*

*$P < 0.05$

Correlation coefficients were adjusted as appropriate for age and/or sex

Partial correlation analyses controlling for age and/or sex showed significant positive associations between physical activity and combined arm/leg muscle mass (Table 2). Associations were stronger for daily duration of activity of >3 METs than for daily step count, and in men the association for step count was not statistically significant. Leg muscle mass, when considered individually, tended to be associated with habitual physical activity, significantly so for step count in 75- to 84-year-old subjects and for the year-averaged daily duration of activity >3 METs in all subjects, male subjects and 75- to 84-year-old subjects. In contrast, arm muscle mass, when considered individually, showed no significant associations with habitual physical activity.

Linear and exponential regressions demonstrated significant positive associations between combined arm/leg muscle mass and both the daily step count and the daily duration of activity >3 METs (Fig. 1). Three of the four regression coefficients of determination (r^2) tended to be greater for exponential than for linear relationships, although in no case did the differences in r^2 attain statistical significance ($P = 0.13$–0.41). Both linear and exponential regression analyses showed a continuing trend for muscle mass to increase with habitual physical activity, at least to values where the two types of regression intercepted each other, at values of 9,000–10,000 steps/day and 25–30 min/day at an intensity of >3 METs. However, those men and women who walked, respectively, >8,000 and >7,000 steps/day and/or spent >20 and >15 min/day of physical activity at >3 METs were likely to exceed the proposed thresholds of muscle mass for a clinical diagnosis of sarcopenia.

When subjects were categorized into quartiles of physical activity scores (Table 3), ANCOVA controlling for age showed trends toward inter-quartile differences in combined arm/leg muscle mass. In men, this was statistically significant for daily step count Q1 versus Q4 and for daily duration at an intensity of >3 METs Q1 versus Q3 and Q4, and Q2 versus Q4. In women, this was significant for step count Q1 versus Q3 and Q4 and for moderate-effort duration Q1 versus Q3 and Q4, and Q2 versus Q4.

Logistic regression analyses controlling for age, current smoking and alcohol intake confirmed that both with and without lifestyle adjustment, the risk of appendicular sarcopenia was related to both measures of physical activity in both men and women (Table 4). Again, relationships were stronger for the duration of moderate-intensity exercise than for step count. After adjusting data for physical and lifestyle factors, men and women in the lowest quartile (Q1) of step count and in the two lowest quartiles (Q1 and Q2) of moderate-exercise duration showed, respectively, 2.00 and 2.66, and 2.03–3.39 and 3.15–4.55 times greater risk of sarcopenia than those in the highest quartile (Q4).

Discussion

In keeping with our initial hypothesis, after adjustments for physical and/or lifestyle-related factors, the skeletal muscle mass of older people showed weak but statistically significant positive associations with rhythmic habitual activity, both in the daily duration of exercise at an intensity of >3 METs and in the daily step count. These relationships were stronger for the legs than for the arms, and for activity at an intensity of >3 METs than for step count. In the present sample, all men and women who exceeded, respectively, counts of around 8,000 and 6,900 steps/day and/or durations of around 22 and 19 min/day at intensities of >3 METs demonstrated a muscle mass above our sarcopenia threshold, and the combined arm/leg muscle mass was only slightly greater in those exceeding these levels of activity.

Since our data were cross-sectional, we could not affirm whether lack of activity led to sarcopenia, or sarcopenia restricted activity; the two factors are plainly closely intertwined. Previous reports (Aoyagi and Shephard 1992; Roubenoff and Castaneda 2001) have underlined that sarcopenia is associated with an age-related reduction in physical activity, especially a lack of muscle overload. If habitual activity lacks sufficient intensity and duration to recruit type II (fast-twitch, FT) muscle fibers, then the individual becomes prone to a risk of selective

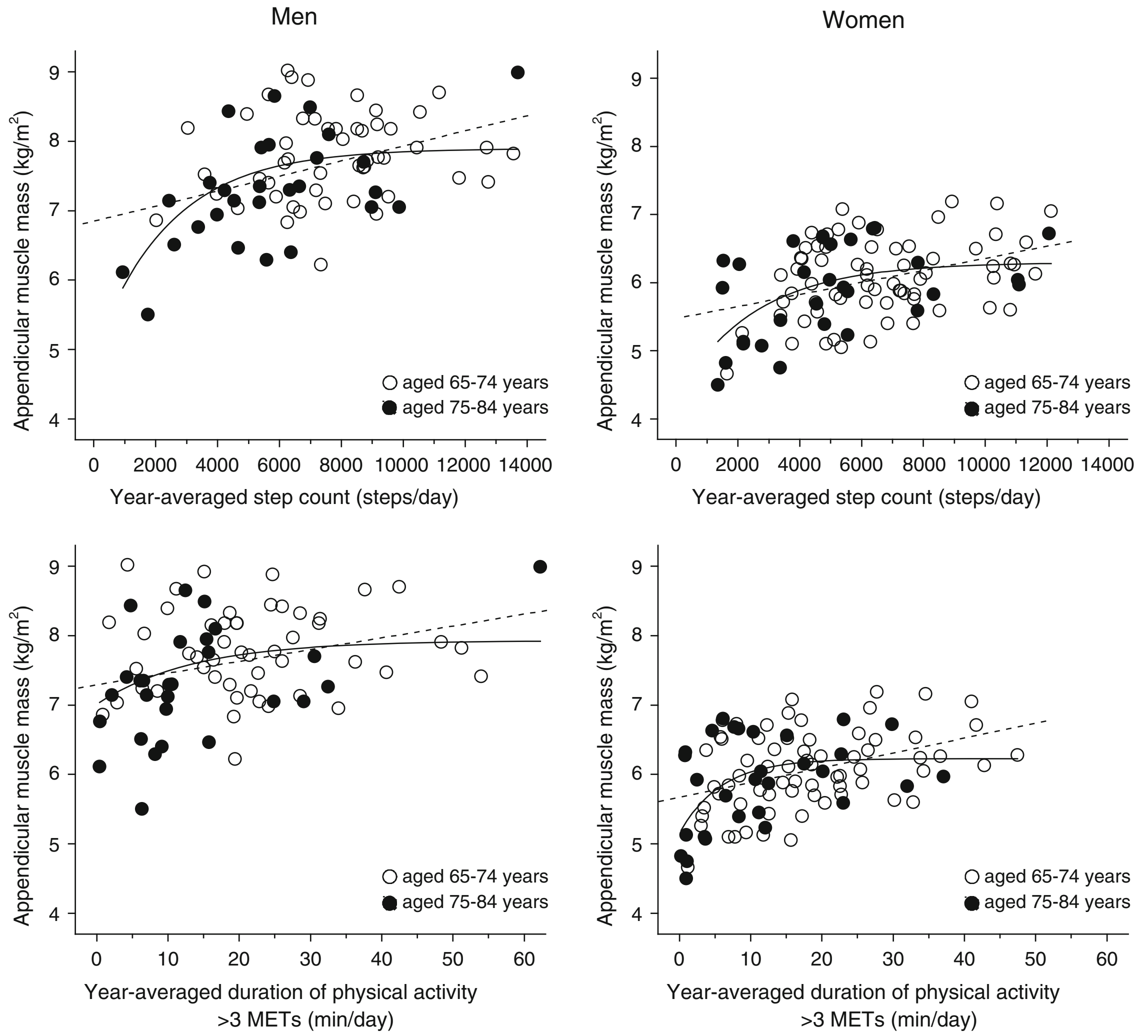

Fig. 1 Relationships between appendicular skeletal muscle mass and the year-averaged daily step count or daily duration of physical activity >3 metabolic equivalents (METs). The linear and exponential fits are statistically significant ($P < 0.05$): in men, for step count $y = 6.85 + (1.08 \times 10^{-4})x$ ($r^2 = 0.17$) and $y = 7.90 - 2.96e^{-x/2,423}$ ($r^2 = 0.23$), and for moderate-exercise duration $y = 7.29 + (1.70 \times 10^{-2})x$ ($r^2 = 0.15$) and $y = 7.93 - 0.92e^{-x/13.5}$ ($r^2 = 0.13$); in women, for step count $y = 5.47 + (8.83 \times 10^{-5})x$ ($r^2 = 0.16$) and $y = 6.27 - 1.99e^{-x/2,522}$ ($r^2 = 0.20$), and for moderate-exercise duration $y = 5.67 + (2.13 \times 10^{-2})x$ ($r^2 = 0.16$) and $y = 6.23 - 1.08e^{-x/5.9}$ ($r^2 = 0.21$). $n = 78$ and 97 for men and women, respectively

FT fiber atrophy and sarcopenia (Aoyagi and Shephard 1992; Roubenoff and Castaneda 2001). Older adults are thus encouraged to engage regularly in specific muscle-strengthening exercises and/or higher-impact weight-bearing activity to maintain and, in particular, to restore muscle health. None of our subjects were participating in any deliberate strength training programs, and one might question how far rhythmic activities such as walking are helpful in sustaining muscle mass. Nevertheless, the present DXA data show that many of our independently living seniors avoided clinical sarcopenia to quite an advanced age and that maintenance of muscle mass was associated with rhythmic habitual activity (more closely with the daily duration of activity >3 METs than with the daily step count). There are several possible explanations of our observations. It could be that the onset of sarcopenia limits physical activity, although we were not dealing with frail institutionalized individuals, and the positive association of the two variables continued to quite high levels of daily activity, tending to argue against this explanation. It also remains arguable that individuals in our sample who had a low skeletal muscle score were inactive because of poor general health, but again this seems unlikely as the main explanation of our findings, since most of our subjects had maintained a relatively consistent pattern of both physical activity and health over the past 10 years. Alternatively, moderate-to-vigorous aerobic activity such as brisk walking may have provided sufficient muscular exercise to slow the loss of muscle mass, or it may be serving as a marker of those individuals who were

Table 3 Appendicular skeletal muscle mass in quartiles (Q1–Q4) of habitual physical activity

	n	Men				*n*	Women		
		Year-averaged step count (steps/day)		Muscle mass (kg/m^2)			Year-averaged step count (steps/day)		Muscle mass (kg/m^2)
Q1	19	3,427 ± 1,247	(936–5,336)	7.19 ± 0.15	Q1	25	3,048 ± 1,028	(1,356–4,391)	5.99 ± 0.11
Q2	20	6,171 ± 430	(5,413–6,924)	7.60 ± 0.15	Q2	24	4,999 ± 371	(4,498–5,658)	6.26 ± 0.12
Q3	19	7,972 ± 661	(6,999–8,834)	7.64 ± 0.15	Q3	24	6,942 ± 629	(5,874–7,819)	6.36 ± 0.11[a]
Q4	20	10,545 ± 1,657	(8,985–13,712)	7.91 ± 0.16[a]	Q4	24	9,974 ± 1,386	(7,828–12,133)	6.47 ± 0.12[a]
	n	Men				*n*	Women		
		Year-averaged duration of physical activity >3 METs (min/day)		Muscle mass (kg/m^2)			Year-averaged duration of physical activity >3 METs (min/day)		Muscle mass (kg/m^2)
Q1	19	6.7 ± 5.4	(0.4–9.1)	7.25 ± 0.15	Q1	25	5.9 ± 4.8	(0.3–7.7)	5.94 ± 0.11
Q2	20	14.7 ± 6.5	(9.8–15.4)	7.52 ± 0.15	Q2	24	10.1 ± 3.6	(7.8–14.5)	6.22 ± 0.12
Q3	19	21.6 ± 8.0	(15.6–26.1)	7.71 ± 0.16[a]	Q3	24	18.5 ± 6.0	(15.1–22.8)	6.39 ± 0.11[a]
Q4	20	33.5 ± 10.0	(26.2–62.3)	7.86 ± 0.16[a,b]	Q4	24	31.1 ± 7.7	(23.0–47.6)	6.48 ± 0.12[a,b]

Values are mean ± SD, with ranges in parentheses

[a] Versus Q1 ($P < 0.05$) after adjustment for age

[b] Versus Q2 ($P < 0.05$) after adjustment for age

Table 4 Multifactor-adjusted odds ratios (OR) and 95% confidence intervals (CI) for having appendicular sarcopenia in quartiles (Q1–Q4) of habitual physical activity

	n	Men				*n*	Women		
		Year-averaged step count (steps/day)		OR (95% CI)			Year-averaged step count (steps/day)		OR (95% CI)
Q1	19	3,427 ± 1,247	(936-5,336)	2.00 (1.01–5.03)	Q1	25	3,048 ± 1,028	(1,356–4,391)	2.66 (1.21–4.99)
Q2	20	6,171 ± 430	(5,413–6,924)	1.20 (0.20–3.22)	Q2	24	4,999 ± 371	(4,498–5,658)	1.57 (0.96–4.04)
Q3	19	7,972 ± 661	(6,999–8,834)	0.79 (0.19–1.96)	Q3	24	6,942 ± 629	(5,874–7,819)	1.02 (0.31–2.36)
Q4	20	10,545 ± 1,657	(8,985–13,712)	1	Q4	24	9,974 ± 1,386	(7,828–12,133)	1
	n	Men				*n*	Women		
		Year-averaged duration of physical activity >3 METs (min/day)		OR (95% CI)			Year-averaged duration of physical activity >3 METs (min/day)		OR (95% CI)
Q1	19	6.7 ± 5.4	(0.4–9.1)	3.39 (1.21–7.10)	Q1	25	5.9 ± 4.8	(0.3–7.7)	4.55 (1.12–7.12)
Q2	20	14.7 ± 6.5	(9.8–15.4)	2.03 (1.00–4.31)	Q2	24	10.1 ± 3.6	(7.8–14.5)	3.15 (1.02–4.91)
Q3	19	21.6 ± 8.0	(15.6–26.1)	1.05 (0.28–3.14)	Q3	24	18.5 ± 6.0	(15.1–22.8)	1.23 (0.29–3.25)
Q4	20	33.5 ± 10.0	(26.2–62.3)	1	Q4	24	31.1 ± 7.7	(23.0–47.6)	1

Activity data are mean ± SD, with ranges in parentheses

OR and 95% CI were adjusted for age, current smoking and alcohol intake

undertaking sufficient resistance activity to conserve their muscle mass.

To our knowledge, this is the first study that has examined relationships between measures of yearlong habitual physical activity and the muscle mass of the arms and legs in elderly men and women. Studies in other populations are in apparent conflict with our findings. Thus, Starling et al. (1999) reported that the physical activity captured by 9 days of uniaxial accelerometer recording was unrelated to the appendicular muscle mass of older men. Likewise, Aubertin-Leheudre et al. (2006) concluded that there were no differences of energy expenditure between sarcopenic and non-sarcopenic subjects after collecting just 3 days of accelerometer data on obese post-menopausal women. However, these previous observations seem counter-intuitive, and the problem in both of these studies may be that the short observation periods failed to give an accurate picture because of seasonal variations in physical activity (Aoyagi and Shephard 2009, 2010; Shephard and Aoyagi 2009; Togo et al. 2005, 2008; Yasunaga et al. 2008). Togo et al. (2008) have emphasized that >1 month of consecutive observation days are required to achieve >90% reliability when estimating the yearly physical activity of an older individual.

Our exponential regression models suggest a positive association between yearlong activity and muscle mass up to counts as high as 9,000–10,000 steps/day and up to durations of 25–30 min/day at an intensity of >3 METs. Further tests are needed to examine whether indeed the association reaches a ceiling, but the present data suggest that the combined arm/leg muscle mass was greatest in those reaching the highest activity levels. The threshold of habitual physical activity associated with freedom from sarcopenia seems similar to that associated with other aspects of good physical health (Aoyagi and Shephard 2009, 2010; Aoyagi et al. 2009; Park et al. 2007): in men and women, approximately >8,000 and >7,000 steps/day and/or >20 and >15 min/day at an intensity of >3 METs, respectively.

Our logistic regressions confirmed significant relationships between sarcopenia and physical activity patterns (closer for activity >3 METs than for step count). The likelihood of sarcopenia for individuals falling into the lower two quartiles (respective mean counts of 3,000–3,400 and 5,000–6,200 steps/day and durations at >3 METs of 6–7 and 10–15 min/day) was 2.00–4.55 times higher than that for individuals in the top quartile (those walking 10,000–10,500 steps/day and spending 31–34 min/day at an intensity of >3 METs).

Our observations suggest that the positive associations between objective pedometer/accelerometer assessments of yearly habitual physical activity and DXA indices of skeletal muscle mass are stronger for leg than for arm muscle mass. This is in accordance with our previous study (Aoyagi et al. 2009) which showed significant positive relationships of walking speed and knee extension torque with both daily step count and daily duration of activity >3 METs. There are several possible reasons for the apparent regional specificity of associations between physical activity and muscle mass. There may be a faster age-related deterioration of muscle function in the lower than in the upper limbs (Aoyagi and Shephard 1992). However, the greater statistical significance of changes in the legs reflects, in part, the greater precision of these measurements. When compared with non-sarcopenic subjects, those of our sample with sarcopenia had 34% less muscle in the arms, but only 17% less in the legs; likewise, when comparing younger and older age groups, the trend was to a loss of 19% in the arms, but only 4% in the legs. The larger muscle mass of the legs and thus a greater precision of muscle mass measurements may be making associations more evident. These observations may also point toward a causal relationship, since walking (the primary component of our indices of habitual activity) is more likely to maintain muscle function in the legs than in the arms (Aoyagi and Katsuta 1990).

As with most epidemiological studies, there are important limitations to our data. The uniaxial pedometer/accelerometer that we used to monitor physical activity provides a relatively accurate assessment of level walking, the principal activity of the elderly. When climbing or descending hills, the step count remains accurate, but there may be some small changes of pace length and thus the distance walked. Also, changes in energy expenditure related to positive and negative work against gravity are signaled only to the extent that there is a change in the force of impact at each stride. Fortunately, few of the streets in Nakanojo have steep inclines. Another issue with activity assessment is that the pedometer/accelerometer has only a limited response to resisted movements, which will be of particular significance for maintaining muscle mass. Although these several factors limit estimates of absolute energy expenditure, their main impact on any associations with muscle mass would be to weaken the strength of associations. The measurement of DXA before and after the sampling year would have been helpful in strengthening the analysis of relationships between sarcopenia and physical activity, but unfortunately our subjects were only able to attend for assessments of muscle mass at the end of the year when physical activity had been assessed. Our methodology was also unable to allow for the effects of any intramuscular infiltration of fat, as commonly seen in the elderly. This was probably a less important issue in Nakanojo than elsewhere, because our subjects were on average thinner than most North American samples. Nevertheless, this factor would again weaken the strength of any observed associations with physical activity. Our observations were based on a convenience sample of the Nakanojo population, but their average daily level of habitual physical activity matched that of a large and representative sample of the Japanese population (Japan Ministry of Health, Labour and Welfare 2006). Associations between sarcopenia and physical activity may well differ in other populations and in other environments; our findings apply specifically to a medium-sized town where a substantial proportion of the population live in single-family dwellings with gardens or vegetable plots that they cultivate on a regular basis.

In summary, our cross-sectional study indicates that after appropriate adjustments for physical and/or lifestyle-related factors, the skeletal muscle mass of an older person shows a weak, but statistically significant, positive association with his or her habitual aerobic activity, both in the daily duration of exercise at an intensity of >3 METs and in the daily step count. These relationships are stronger for the legs than for the arms, and for activity at an intensity of >3 METs than for step count. In the present sample, all men and women who exceeded, respectively, counts of around 8,000 and 6,900 steps/day and/or durations of around 22 and 19 min/day at intensities of >3 METs demonstrated a muscle mass above our sarcopenia threshold. The combined arm/leg muscle mass was only slightly greater in those who exceeded these levels of activity, although the positive association with muscle mass continued to quite high levels of exercise. Relationships were stronger for the walking than for the arm muscles. Prospective observations are needed to examine causal relationships, but we can affirm that elderly individuals, who maintain a pedometer count of at least 7,000–8,000 steps/day, including a minimum of 15–20 min/day at an intensity >3 METs, do not demonstrate sarcopenia. If we assume that some 4,000 steps/day are accumulated in incidental movements around the home (Aoyagi and Shephard 2009, 2010; Togo et al. 2005), and the pace length is 0.65 m, then the non-sarcopenic individuals engage in 2.0–2.6 km of deliberate walking per day, or at a speed of 4 km/h, 30–39 min of walking. In terms of the maintenance of muscle mass, the proposed volume of activity supports the exercise guidelines for older adults proposed by the Public Health Agency of Canada and the Canadian Society for Exercise Physiology (Public Health Agency of Canada and the Canadian Society for Exercise Physiology 1998) and the American College of Sports Medicine and the American Heart Association (Nelson et al. 2007).

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