Instrumented Assessment of Physical Activity Is Associated With Muscle Function but Not With Muscle Mass in a General Population

Rojer, Anna G.M.; Reijnierse, Esmee M.; Trappenburg, Marijke C.; van Lummel, Rob C.; Niessen, Martijn; van Schooten, Kim S.; Pijnappels, Mirjam; Meskers, Carel G.M.; Maier, Andrea B.

published in
Journal of Aging and Health
2018

DOI (link to publisher)
10.1177/0898264317721554

document version
Publisher's PDF, also known as Version of record

citation for published version (APA)
Rojer, A. G. M., Reijnierse, E. M., Trappenburg, M. C., van Lummel, R. C., Niessen, M., van Schooten, K. S., Pijnappels, M., Meskers, C. G. M., & Maier, A. B. (2018). Instrumented Assessment of Physical Activity Is Associated With Muscle Function but Not With Muscle Mass in a General Population. *Journal of Aging and Health*, *30*(9), 1462-1481. https://doi.org/10.1177/0898264317721554

Article

Journal of Aging and Health
2018, Vol. 30(9) 1462–1481

DOI: 10.1177/0898264317721554
journals.sagepub.com/home/jah
SAGE

Instrumented Assessment of Physical Activity Is Associated With Muscle Function but Not With Muscle Mass in a General Population

Anna G. M. Rojer, BSc[1], Esmee M. Reijnierse, PhD[2], Marijke C. Trappenburg, MD, PhD[1,3], Rob C. van Lummel, PhD[4,5], Martijn Niessen, PhD[4], Kim S. van Schooten, PhD[6], Mirjam Pijnappels, PhD[5], Carel G. M. Meskers, MD, PhD[1], and Andrea B. Maier, MD, PhD[2,4]

Abstract

Objectives: Self-reported physical activity has shown to affect muscle-related parameters. As self-report is likely biased, this study aimed to assess

---

[1]VU University Medical Center Amsterdam, The Netherlands
[2]University of Melbourne, Australia
[3]Amstelland Hospital, Amstelveen, The Netherlands
[4]McRoberts B.V., The Hague, The Netherlands
[5]Vrije Universiteit Amsterdam, The Netherlands
[6]Simon Fraser University, Burnaby, British Columbia, Canada

Corresponding Author:
Andrea B. Maier, Department of Medicine and Aged Care, Royal Melbourne Hospital, University of Melbourne, Grattan Street, Parkville, Melbourne, Victoria 3052, Australia.
Email: andrea.maier@mh.org.au

the association between instrumented assessment of physical activity (I-PA) and muscle-related parameters in a general population. **Method:** Included were 156 young-to-middle-aged and 80 older community-dwelling adults. Seven days of trunk accelerometry (DynaPort MoveMonitor, McRoberts B.V.) quantified daily physical activity (i.e., active/inactive duration, number and mean duration of active/inactive periods, and number of steps per day). Muscle-related parameters included muscle mass, handgrip strength, and gait speed. **Results:** I-PA was associated with handgrip strength in young-to-middle-aged adults and with gait speed in older adults. I-PA was not associated with muscle mass in either age group. **Discussion:** The association between I-PA and muscle-related parameters was age dependent. The lack of an association between I-PA and muscle mass indicates the relevance of muscle function rather than muscle mass.

Keywords
motor activity, sarcopenia, muscle strength, aged, activity monitoring, physical performance

Introduction

Higher levels of physical activity and lower levels of sedentary behavior are important factors in human health and well-being (Penedo & Dahn, 2005). Particularly at higher age, physical activity is related to a lower risk of various major age-related diseases (Abioye, Odesanya, Abioye, & Ibrahim, 2015; Behrens et al., 2015; Behrens & Leitzmann, 2013; Castaneda et al., 2002; Manson et al., 2002), lower overall mortality (Hupin et al., 2015) and mobility disability in older adults (Leveille, Guralnik, Ferrucci, & Langlois, 1999; Pahor et al., 2014). Higher physical activity levels are associated with higher absolute muscle mass and higher handgrip strength in older males (Baumgartner, Waters, Gallagher, Morley, & Garry, 1999; Gomez-Cabello et al., 2014) and higher physical activity levels are associated with better physical performance in older females (Martin, Syddall, Dennison, Cooper, & Sayer, 2008). However, these studies measured physical activity using questionnaires while it has been shown that physical activity assessed by means of questionnaires is often over- as well as underestimated, as it is affected by recall and interpretation bias (Baranowski, 1988; Prince et al., 2008).

Muscle mass, muscle strength, and physical performance are important measures of the diagnostic process of sarcopenia (Cruz-Jentoft et al., 2010; Fielding et al., 2011; Studenski et al., 2014). The pathophysiology of sarcopenia is multifactorial, including physical inactivity (Rolland et al., 2008). In older males, higher levels of self-reported physical activity via questionnaires were found to be associated with a reduced risk of sarcopenia (Ryu et al., 2013). A major flaw of questionnaire-based physical activity measurements is that they often overlook short bouts of lower intensity leisure activity. As this level of physical activity comprises most of the activities of older adults (Tudor-Locke & Myers, 2001; Westerterp, 2008), instrumented assessment of physical activity (I-PA) provides a better assessment of actual physical activities (Harris et al., 2009). I-PA has been shown to reliably quantify various physical activity measures in older adults (van Schooten et al., 2015).

The aim of this study was to assess the association between I-PA and muscle-related parameters in young-to-middle-aged adults and older adults from a general population.

Method

Study Design

This cross-sectional cohort included 253 community-dwelling participants (169 young-to-middle-aged adults and 84 older adults being 70 years and older) recruited from the Grey Power debate events which took place in November 2014 at the VU University Medical Center Amsterdam, The Netherlands. The Grey Power debates were freely accessible lectures for the general population to promote healthy aging and attracted a predominantly vital and motivated group of socially active community-dwelling participants. No exclusion criteria were applied. This research was reviewed and approved by the medical ethical committee of the VU University Medical Center Amsterdam, The Netherlands. All participants gave written informed consent.

Characteristics

Questionnaires were used to determine age; sex; subjective fulfillment of the recommended Dutch physical activity guideline defined as 30 minutes of moderate physical activity for at least 5 days (Kemper, Ooijendijk, & Stiggelbout, 2000; Riebe et al., 2015); use of a walking aid; pain during movement; history of falls; current smoking; number of medications used; and multimorbidity. The question “Do you participate in 30 minutes of moderate physical activity for at least 5 days a week?” was used to assess the subjective fulfillment of the recommended Dutch physical activity guideline. Multimorbidity was defined as the presence of two or more chronic diseases including hypertension, myocardial infarction, stroke, chronic obstructive pulmonary disease, cancer, diabetes mellitus, osteoarthritis, and Parkinson’s disease. Body mass was assessed to the nearest 0.1 kg, and height was assessed to the nearest 0.1 cm using a height and weight measuring system (DS-102; Dong *S*ahn Jenix Co., Seoul, Korea). Body mass index (BMI) was calculated by body mass (kg) divided by height squared (m) and expressed in kg/m^2. Body mass was derived from direct segmental multifrequency bioelectrical impedance analysis (DSM-BIA; In-Body 230; Biospace Co., Ltd, Seoul, Korea), and height was derived from the height and weight measuring system (DS-102; Dong Sahn Jenix Co.).

Instrumented Physical Activity

Physical activity was assessed by use of a triaxial accelerometer (DynaPort MoveMonitor, McRoberts B.V., The Hague, The Netherlands) during seven consecutive days. The accelerometer was placed dorsally on the trunk at the level of L5 and attached with an elastic belt. Acceleration data were collected with a sampling frequency of 100 Hz and a range from −6 to +6 g. Participants were instructed to wear the accelerometer at all times except during aquatic activities such as showering and swimming. Periods of nonwearing, lying, sitting, standing, and locomotion were identified using commercially available software (MoveMonitor; McRoberts B.V., The Hague, The Netherlands). The duration of activity was defined as the sum of the total duration of standing and locomotion and expressed in minutes per day. The duration of inactivity was defined as the sum of the total duration of lying and sitting and expressed in hours per day. The used algorithm has demonstrated validity for physical activity classifications in healthy adults (de Groot & Nieuwenhuizen, 2013) and in community-dwelling older adults (Dijkstra, Kamsma, & Zijlstra, 2010). I-PA included the following measures: active duration (minutes/day), inactive duration (hours/day), number of active and inactive periods per day, mean duration of active periods (seconds/period), mean duration of inactive periods (minutes/period), and number of steps per day. Unclassified movements ("shuffling") were excluded from the analyses as the detection of shuffling in daily life conditions is inaccurate (Dijkstra et al., 2010). I-PA measures were averaged over valid days only, defined as a wearing time of the MoveMonitor for at least 75% (18 hours) of the day (Hart, Swartz, Cashin, & Strath, 2011; Matthews, Ainsworth, Thompson, & Bassett, 2002). If at least four valid days per participant were available, the participant was included in the analysis (van Schooten et al., 2015). Instrumentally assessed fulfillment of the Dutch physical activity guideline was done by use of algorithms provided by McRoberts B.V., The Hague, The Netherlands, thereby taking into account that the duration of bouts in moderate physical activity should endure for at least 5 minutes (Kemper et al., 2000). Of the 253 participants, data of

17 (6.7%) participants were excluded due to missing data on I-PA (*n* = 2) or having less than four valid measurement days (*n* = 15), leaving 236 participants for the present analysis.

Muscle-Related Parameters

Muscle-related parameters included absolute and relative muscle mass, handgrip strength, and gait speed. Body composition was assessed using direct segmental multi-frequency bioelectrical impedance analysis (DSM-BIA; In-Body 230; Biospace Co., Ltd). DSM-BIA is considered a valid tool to estimate muscle mass in healthy adults varying in age (Janssen, Heymsfield, Baumgartner, & Ross, 2000). The used DSM-BIA in the present study is considered a valid tool when validated against dual-energy X-ray absorptiometry (DEXA; Hurst et al., 2016; Karelis, Chamberland, Aubertin-Leheudre, & Duval, 2013; Ling et al., 2011). Measures of absolute muscle mass were skeletal muscle mass (SM) in kilograms and skeletal muscle mass index (SMI; SM divided by height^2; Janssen, Baumgartner, Ross, Rosenberg, & Roubenoff, 2004). The used measure of relative muscle mass was SM percentage (SM as a percentage of body mass; Janssen, Heymsfield, & Ross, 2002). Data on muscle mass were missing in seven participants (3.0%) due to the presence of a pacemaker. Handgrip strength was measured using a handheld dynamometry (JAMAR hand dynamometer; Sammons Preston, Inc., Bolingbrook, IL, USA) 3 times for each hand (Reijnierse et al., 2017). The maximum score was used for analyses and expressed in kilograms. Gait speed was assessed using a timed 4-m walking test at normal pace from a standing start using a stopwatch. Walking distance was longer than the required 4 m to prevent participants from slowing down before reaching the 4-m line. The fastest time of two trials was used for analyses, and gait speed was expressed in meters per second (m/s).

Statistical Analysis

Normally distributed continuous variables were presented as mean and standard deviation (*SD*). Skewed (non-Gaussian) distributed continuous variables were presented as median and interquartile range (IQR).

Muscle-related parameters were standardized into gender-specific *z* scores, to allow for direct comparison of effect sizes of I-PA with muscle-related parameters. For comparative interpretation between I-PA, number of steps per day was divided by 1,000 and numbers of active or inactive periods were divided by 100. The association between I-PA and muscle-related parameters was analyzed using multivariate linear regression models. First, analyses were performed in the total population; subsequently, to correct for possible nonlinearities in the associations, analyses were performed using a dichotomous stratification for age with a cutoff value of 70 years. The cutoff value for age was determined using the Jonckheere–Terpstra test. Analyses were adjusted for age and sex (Model 1) and additionally for specific muscle-related parameters as described elsewhere (Model 2; Reijnierse et al., 2015). Absolute muscle mass (SM in kg and SMI) was adjusted for absolute fat mass. Relative muscle mass (SM%) was adjusted for body mass. Handgrip strength was adjusted for body mass and height. Gait speed was adjusted for height. The following variables were checked for being confounders—pain during movement, multimorbidity, and number of medications used—but were not included in the adjustment models as they were not identified as confounders. The interpretations of the results of the multivariate linear regression analysis are as follows: One *SD* increase of I-PA is associated with the effect size times *SD* ($\beta \times$ SD) higher/lower of the muscle-related parameter.

Statistical Package for the Social Sciences (SPSS, version 22 for Windows) was used to perform the statistical analyses, and *p* values below .05 were considered statistically significant. Visualization was performed using GraphPad Prism version 6.3.

Results

Table 1 shows the participant characteristics. Median wearing time of the accelerometer was 6.9 days (IQR = 6.8-7.0) in both age groups. Active duration, number of active and inactive periods, and number of steps per day were higher in the young-to-middle-aged adults compared with the older adults. Inactive duration and mean duration of inactive periods were lower in the young-to-middle-aged adults compared with the older adults. Mean duration of active periods was comparable between groups. All muscle-related parameters were higher in young-to-middle-aged adults compared with older adults. A total of 119 (76%) young-to-middle-aged adults and 72 (90%) older adults reported to meet the recommended Dutch physical activity guideline, while I-PA indicated that, respectively, 37 (24%) and 13 (16%) participants objectively met these criteria.

Associations Between I-PA and Standardized Muscle-Related Parameters

In young-to-middle-aged adults, active duration and number of active periods were positively associated with handgrip strength, but not with the other muscle-related parameters (in Model 2). Mean duration of active periods, inactive duration, and number of inactive periods and mean duration of inactive periods were not associated with muscle-related parameters. The number of steps

Table 1. Participant Characteristics.

	Young-to-middle-aged adults	Older adults
	n = 156	*n* = 80
Age, median (IQR)	63.1 (53.7-66.9)	74.4 (72.4-78.0)
Male, *n* (%)	51 (32.7)	32 (40.0)
Walking aid, *n* (%)	1 (0.6)	1 (1.3)
Pain during movement, *n* (%)	43 (27.6)	24 (30.0)
History of falls,[a] *n* (%)	20 (12.8)	17 (21.3)
Current smoking, *n* (%)	7 (4.5)	4 (5.0)
Multimorbidity,[b] *n* (%)	15 (9.6)	18 (22.5)
Number of medication used, median (IQR)	0 (0-2)	1 (0-3)
Anthropometry		
Height (cm)	171.5 (9.2)	168.3 (8.3)
Body mass (kg)	74.4 (12.2)	75.0 (13.1)
BMI (kg/m^2)	25.3 (3.8)	26.3 (3.8)
Fat mass (kg)[c]	21.5 (8.8)	24.6 (8.2)
Instrumented physical activity		
Wearing time (days), median (IQR)	6.9 (6.8-7.0)	6.9 (6.8-7.0)
Active duration (minutes/day)	279.3 (61.9)	256.7 (67.2)
Number of active periods (per day)	1,553 (429)	1,407 (426)
Mean duration of active periods (seconds/period)	11.1 (2.0)	11.3 (2.2)
Number of steps (per day)	9,265 (2,969)	7,327 (2,507)
Inactive duration (hours/day)	18.6 (1.1)	19.0 (1.2)
Number of inactive periods (per day), median (IQR)	148 (128-178)	132 (111-160)
Mean duration of inactive periods (minutes/period)	7.5 (2.5)	8.9 (2.8)
Muscle-related parameters		
SM (kg)[c]	29.3 (5.8)	27.6 (5.8)
SM (%)[c]	39.5 (5.2)	36.6 (4.9)
SMI (kg/m^2)[c]	9.9 (1.1)	9.6 (1.3)
Handgrip strength (kg)	37.0 (11.2)	31.5 (9.5)
Gait speed (m/s)	1.46 (0.21)	1.38 (0.21)

Note. All variables are presented as mean (*SD*) unless indicated otherwise. IQR = interquartile range; BMI = body mass index; SM = skeletal muscle mass; SMI = skeletal muscle mass index.

[a] History of falls defined as the presence of at least one fall in the previous 12 months.

[b] Multimorbidity defined as ≥2 of the following diseases: hypertension, myocardial infarction, stroke, chronic obstructive pulmonary disease, cancer, diabetes mellitus, osteoarthritis, and Parkinson's disease.

[c] Data available in a subgroup of *n* = 153 young-to-middle-aged adults and *n* = 76 older adults.

per day was positively associated with SM% (association was lost after additional adjustment for body mass) and handgrip strength (in both models), but not with the other muscle-related parameters. Mean duration of inactive periods was positively associated with SM in kilograms (association was lost after additional adjustment for fat mass), but not with the other muscle-related parameters. Comparing the effect sizes, I-PA was most strongly associated with handgrip strength in young-to-middle-aged adults (Table 2).

In older adults, active duration, number of active periods, and number of steps were inversely associated with SMI (association was lost after additional adjustment for fat mass) and positively associated with gait speed (in both models), but not with the other muscle-related parameters. Mean duration of active periods was not associated with muscle-related parameters. Inactive duration was positively associated with SMI (association was lost after additional adjustment for fat mass) and inversely associated with gait speed (in both models), but not with the other muscle-related parameters. Number of inactive periods was positively associated with gait speed (in both models), but not with the other muscle-related parameters. Mean duration of inactive periods was inversely associated with gait speed (in both models), but not with the other muscle-related parameters. Comparing the effect sizes, I-PA was most strongly associated with gait speed in older adults (Table 3).

Figure 1 visualizes the associations between I-PA, expressed as number of steps and inactive duration, and the standardized muscle-related parameters in young-to-middle-aged and older adults.

Results of the association between I-PA and muscle-related parameters in the total population did not change the conclusions of the results in the age-stratified groups (Supplementary Table 1).

Discussion

In this study, the associations between I-PA and muscle-related parameters were found to be variable and highly dependent on chronological age. I-PA was most strongly associated with handgrip strength in young-to-middle-aged adults and with gait speed in older adults. I-PA was not associated with muscle mass.

The results indicate an age-related transition point at which associations between physical activity and muscle-related parameters change. Muscle-related parameters may have different age-related transition points; muscle mass was found to decline after the age of 50 years with 1% to 2% per year (Buford et al., 2010; Mitchell et al., 2012); handgrip strength was estimated to decline gradually with 0.06 kg per year between the ages of 20 and 50 years and to decline steeper after the age of 50 years with 0.37 kg per year (Beenakker et al., 2010), whereas gait speed was found to decline after the age of 70 years with 1% per year and declines steeper after the age of 80 years with 4% per year (Forrest, Zmuda, & Cauley, 2006; Hall et al., 2016; Himann, Cunningham, Rechnitzer, & Paterson, 1988). Transition points for physical activity are less clear; however, it is suggested that physical activity declines steeper around the age of 60 years (Hall et al., 2016; Schrack et al., 2014).

Table 2. Associations Between I-PA and Standardized Muscle-Related Parameters in Multivariate Linear Regression Models in Young-to-Middle-Aged Adults.

	SM (kg)			SM (%)			SMI (kg/m^2)			Handgrip strength (kg)			Gait speed (m/s)		
	n = 153			*n* = 153			*n* = 153			*n* = 156			*n* = 156		
	β	*SE*	*p*	β	*SE*	*p*	β	*SE*	*p*	β	*SE*	*p*	β	*SE*	*p*
Active duration (minutes/day)															
Model 1: age + sex	−.002	.001	.091	.000	.001	.709	−.001	.001	.674	.001	.001	.334	.001	.001	.537
Model 2: as 1 + outcome specific[a]	−.002	.001	.203	−.001	.001	.431	.000	.001	.792	.002	.001	**.043**	.001	.001	.264
Number of active periods (per day)															
Model 1: age + sex	−.015	.018	.395	.003	.017	.843	.004	.018	.803	.022	.017	.195	.019	.019	.305
Model 2: as 1 + outcome specific[a]	−.009	.017	.591	−.007	.014	.619	.013	.016	.432	.032	.016	**.043**	.025	.018	.169
Mean duration of active periods[b] (seconds/period)															
Model 1: age + sex	−.006	.039	.887	−.014	.036	.701	−.013	.038	.739	−.038	.035	.276	−.026	.039	.509
Model 2: as 1 + outcome specific[a]	−.017	.038	.658	−.004	.031	.886	−.028	.035	.429	−.041	.033	.212	−.025	.038	.520
Number of steps[c] (per day)															
Model 1: age + sex	−.007	.026	.781	.050	.024	**.036**	.002	.026	.929	.051	.024	**.037**	.026	.027	.332
Model 2: as 1 + outcome specific[a]	.013	.026	.613	.027	.021	.195	.030	.024	.209	.064	.023	**.006**	.029	.026	.280
Inactive duration (hours/day)															
Model 1: age + sex	.061	.069	.379	−.012	.064	.855	−.013	.068	.846	−.061	.064	.347	−.081	.071	.254
Model 2: as 1 + outcome specific[a]	.039	.067	.558	.028	.055	.613	−.044	.062	.484	−.101	.061	.099	−.107	.070	.129

(continued)

Table 2. (continued)

	SM (kg)			SM (%)			SMI (kg/m^2)			Handgrip strength (kg)			Gait speed (m/s)		
	n = 153			*n* = 153			*n* = 153			*n* = 156			*n* = 156		
	β	*SE*	*p*	β	*SE*	*p*	β	*SE*	*p*	β	*SE*	*p*	β	*SE*	*p*
Number of inactive periods (per day)															
Model 1: age + sex	−.176	.096	.070	.088	.089	.325	−.155	.095	.104	−.160	.089	.075	.101	.099	.311
Model 2: as 1 + outcome specific[a]	−.124	.094	.186	−.017	.078	.825	−.084	.088	.343	−.102	.086	.240	.125	.098	.201
Mean duration of inactive periods[b] (minutes/period)															
Model 1: age + sex	.066	.032	**.042**	−.045	.029	.131	.056	.032	.078	.028	.030	.352	−.050	.033	.129
Model 2: as 1 + outcome specific[a]	.044	.031	.163	−.002	.026	.927	.025	.030	.391	.004	.029	.891	−.060	.032	.068

Note. Muscle-related parameters were standardized into gender-specific *z* scores. Interpretation: One *SD* increase of I-PA is associated with an effect size times standard deviation (β × *SD*) higher/lower of the muscle-related parameters. The *p* values in bold are statistically significant. I-PA = instrumented assessment of physical activity; SM = skeletal muscle mass; SMI = skeletal muscle mass index (kg/m^2).

[a] Outcome-specific adjustments: SM (kg) for fat mass (kg), SM (%) for body mass (kg), SMI for fat mass (kg), handgrip strength for height + body mass (kg), and gait speed for height.

[b] Mean duration of active and inactive periods / 100.

[c] Number of steps per day / 1,000.

Table 3. Associations Between I-PA and Standardized Muscle-Related Parameters in Multivariate Linear Regression Models in Older Adults.

	SM (kg)			SM (%)			SMI (kg/m^2)			Handgrip strength (kg)			Gait speed (m/s)		
	n = 76			*n* = 76			*n* = 76			*n* = 80			*n* = 80		
	β	*SE*	*p*	β	*SE*	*p*	β	*SE*	*p*	β	*SE*	*p*	β	*SE*	*p*
Active duration (minutes/day)															
Model 1: age + sex	−.003	.002	.072	.001	.002	.455	−.004	.002	**.023**	.002	.001	.279	.005	.002	**.004**
Model 2: as 1 + outcome specific[a]	−.002	.002	.169	−.001	.001	.660	−.003	.002	.096	.002	.001	.108	.005	.002	**.004**
Number of active periods (per day)															
Model 1: age + sex	−.044	.026	.093	.012	.025	.645	−.060	.029	**.045**	.027	.022	.231	.072	.025	**.006**
Model 2: as 1 + outcome specific[a]	−.034	.026	.182	−.013	.023	.555	−.041	.027	.128	.036	.021	.089	.073	.025	**.005**
Mean duration of active periods[b] (seconds/period)															
Model 1: age + sex	.017	.052	.746	.017	.050	.738	.027	.059	.647	−.023	.043	.594	−.038	.052	.466
Model 2: as 1 + outcome specific[a]	.016	.051	.752	.018	.044	.678	.026	.053	.632	−.021	.040	.605	−.037	.051	.474
Number of steps[c] (per day)															
Model 1: age + sex	−.068	.044	.124	.044	.042	.303	−.100	.049	**.045**	.052	.038	.173	.182	.041	**<.001**
Model 2: as 1 + outcome specific[a]	−.052	.043	.237	−.001	.039	.987	−.069	.45	.133	.066	.036	.070	.182	.041	**<.001**
Inactive duration (hours/day)															
Model 1: age + sex	.166	.095	.084	−.051	.092	.581	.234	.107	**.031**	−.091	.081	.267	−.250	.093	**.009**
Model 2: as 1 + outcome specific[a]	.127	.094	.182	.047	.084	.576	.159	.099	.112	−.126	.077	.105	−.252	.093	**.008**

(continued)

Table 3. (continued)

	SM (kg)			SM (%)			SMI (kg/m^2)			Handgrip strength (kg)			Gait speed (m/s)		
	n = 76			*n* = 76			*n* = 76			*n* = 80			*n* = 80		
	β	*SE*	*p*	β	*SE*	*p*	β	*SE*	*p*	β	*SE*	*p*	β	*SE*	*p*
Number of inactive periods (per day)															
Model 1: age + sex	.153	.285	.593	.389	.268	.150	.000	.325	.999	.219	.243	.370	.622	.282	**.031**
Model 2: as 1 + outcome specific[a]	.283	.278	.312	.289	.238	.229	.230	.294	.436	.170	.227	.455	.589	.283	**.041**
Mean duration of inactive periods[b] (minutes/period)															
Model 1: age + sex	.019	.042	.654	−.059	.040	.142	.061	.047	.200	−.041	.035	.254	−.116	.041	**.005**
Model 2: as 1 + outcome specific[a]	−.007	.042	.876	−.027	.036	.458	.016	.044	.718	−.041	.034	.234	−.112	.041	**.007**

Note. Muscle-related parameters were standardized into gender-specific *z* scores. Interpretation: One *SD* increase of I-PA is associated with an effect size times standard deviation (β × *SD*) higher/lower of the muscle-related parameters. The *p* values in bold are statistically significant. I-PA = instrumented assessment of physical activity; SM = skeletal muscle mass; SMI = skeletal muscle mass index (kg/m^2).

[a] Outcome-specific adjustments: SM (kg) for fat mass (kg), SM (%) for body mass (kg), SMI for fat mass (kg), handgrip strength for height + body mass (kg), and gait speed for height.

[b] Mean duration of active and inactive periods / 100.

[c] Number of steps per day / 1000.

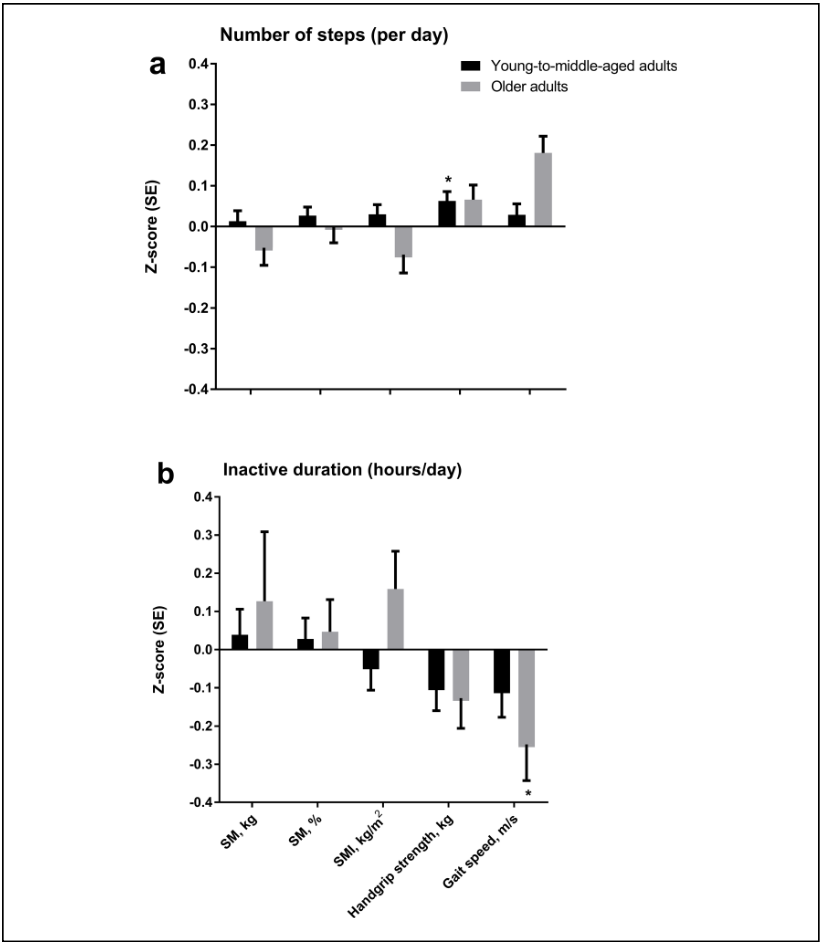

Figure 1. Associations between instrumented assessment of physical activity and standardized muscle-related parameters in young-to-middle-aged and older adults for (a) number of steps (per day) and (b) inactive duration (hours/day).

Note. Muscle-related parameters are presented as gender-specific z scores (*SE*). SM = skeletal muscle mass; SMI = skeletal muscle mass index. The *p* values were calculated with multivariate linear regression models including adjustments for age, sex, and outcome-specific adjustments. $^*p < .05$. $^{**}p < .001$.

Age-related changes in handgrip strength as suggested by Beenakker et al. (2010) may explain differences in association between I-PA and handgrip strength between the young-to-middle-aged and older adults. A previous study showed that questionnaire-based higher daily physical activity was associated with higher handgrip strength in community-dwelling adults aged 65 years and older (Hwang et al., 2016). The present study was not able to show this association, and this may be explained by the use of I-PA instead of a questionnaire when compared with the study by Hwang et al. (2016). Differences in association between the young-to-middle-aged adults and older adults may be driven by aforementioned age-related declines or may be attributable to handgrip strength because of the dissociation between handgrip strength and quadriceps strength in older adults (Chan, van Houwelingen, Gussekloo, Blom, & den Elzen, 2014).

I-PA was found to be associated with gait speed in older adults but not in young-to-middle-aged adults. A possible explanation is that gait speed remains relatively preserved until the age of 70 years (Forrest et al., 2006; Hall et al., 2016; Himann et al., 1988). Therefore, it is expected to find an association between I-PA and gait speed in older adults and not in young-to-middle-aged adults.

The muscle-related parameters in this study comprise both measures of muscle function (i.e., handgrip strength and gait speed), and muscle mass (i.e., absolute and relative muscle mass). No associations were found between I-PA and muscle mass. This is in contrast with other studies that showed that questionnaire-based daily physical activity and moderate-to-intense physical activity were positively associated with absolute muscle mass in older adults (Baumgartner et al., 1999; Mijnarends et al., 2016; Raguso et al., 2006). A potential explanation could be that not only being active but also the intensity of this activity (as more intense activities might be easier to recall) may play a role in retaining muscle mass. However, the lack of associations of I-PA with muscle mass and strong associations of I-PA with muscle function suggest that muscle function and not muscle mass might be more relevant for daily physical activities. This is in line with the finding that maintaining or gaining muscle mass did not prevent the loss of muscle strength in healthy older adults (Goodpaster et al., 2006). These findings suggest a role for other age-related factors affecting muscle function like increased levels of proinflammatory cytokines (Roubenoff, 2003), selective loss of type 2 muscle fibers (Lexell, Downham, & Sjostrom, 1986), myosteatosis (Goodpaster et al., 2001), and loss of motor units (Drey et al., 2016). Alternatively, the lack of associations between I-PA and muscle mass could be the selection of the predominantly vital and motivated group of socially active participants resulting in a ceiling effect. A previous study in community-dwelling older males has found an association between objectively measured moderate-to-vigorous physical activity and a reduced risk of sarcopenia defined by the European Working Group on Sarcopenia in Older People (EWGSOP) definition (Aggio et al., 2016).

Previous studies showed that self-reported physical activity both overestimates and underestimates actual physical activity (Prince et al., 2008). Recalling physical activity could be seen as a complex cognitive task, and many questionnaires are not validated for the full range of physical activity characteristics (Sallis & Saelens, 2000). The present study confirmed this by revealing a large discrepancy between self-reported and instrumentally assessed fulfillment of the Dutch physical activity guideline. Therefore, a valid estimation of daily physical activity requires the use of instruments as pedometers or accelerometers. Accelerometers provide more detailed information concerning the amount, types (i.e., walking, standing, sitting, and lying), and patterns of daily physical activity.

To the best of our knowledge, this study is the first to describe the association between I-PA and muscle mass, handgrip strength, and gait speed in young-to-middle-aged and older adults. A strength of this study is the use of accelerometry to objectively quantify actual amount and type of physical activity. As a consequence of recruiting participants from a lecture evening, a relative vital and motivated group of socially active young-to-middle-aged and older adults was included, which is also indicated by the high wearing time of the accelerometers. This resulted in a fairly homogeneous study population that could be seen as a limitation. Longitudinal studies are needed for better determination of transition points with age as the cross-sectional design of the present study does not allow to determine the associations between I-PA and muscle-related parameters change over time.

Conclusion

I-PA was most strongly associated with handgrip strength in young-to-middle-aged adults and with gait speed in older adults, but not with muscle mass in either age group. These results indicate the importance of muscle function and its dependency on chronological age. The lack of an association between I-PA and muscle mass might indicate the relevance of muscle function rather than muscle mass. The use of objectively measured physical activity is recommended as it provides objective and detailed information concerning daily physical activity. Future research should focus on unraveling the association between I-PA and the change of muscle mass, muscle strength, and gait speed in a longitudinal study design performed in heterogeneous study populations.

Acknowledgments

The authors thank the volunteers of the Grey Power debate events for their contribution to the study. McRoberts B.V. has provided the accelerometers and collected and analyzed the physical activity data with their software (MoveMonitor; McRoberts B.V., The Hague, The Netherlands)

Declaration of Conflicting Interests

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

The authors disclosed receipt of the following financial support for the research, authorship, and/or publication of this article: This study was supported by the PANINI program (Horizon 2020, Marie Curie, Sklodowska, Innovative Training Network, No. 675003) and PreventIT (European Union's Horizon 2020 Research and Innovation Program, No. 689238).

Supplemental Material

Supplemental material is available for this article online.

References

Abioye, A. I., Odesanya, M. O., Abioye, A. I., & Ibrahim, N. A. (2015). Physical activity and risk of gastric cancer: A meta-analysis of observational studies. *British Journal of Sports Medicine*, *49*, 224-229. doi:10.1136/bjsports-2013-092778

Aggio, D. A., Sartini, C., Papacosta, O., Lennon, L. T., Ash, S., Whincup, P. H., . . . Jefferis, B. J. (2016). Cross-sectional associations of objectively measured physical activity and sedentary time with sarcopenia and sarcopenic obesity in older men. *Preventive Medicine*, *91*, 264-272. doi:10.1016/j.ypmed.2016.08.040

Baranowski, T. (1988). Validity and reliability of self report measures of physical activity: An information-processing perspective. *Research Quarterly for Exercise and Sport*, *59*, 314-327.

Baumgartner, R. N., Waters, D. L., Gallagher, D., Morley, J. E., & Garry, P. J. (1999). Predictors of skeletal muscle mass in elderly men and women. *Mechanisms of Ageing and Development*, *107*, 123-136. doi:10.1016/s0047-6374(98)00130-4

Beenakker, K. G., Ling, C. H., Meskers, C. G., de Craen, A. J., Stijnen, T., Westendorp, R. G., & Maier, A. B. (2010). Patterns of muscle strength loss with age in the general population and patients with a chronic inflammatory state. *Ageing Research Reviews*, *9*, 431-436. doi:10.1016/j.arr.2010.05.005

Behrens, G., Jochem, C., Schmid, D., Keimling, M., Ricci, C., & Leitzmann, M. F. (2015). Physical activity and risk of pancreatic cancer: A systematic review and meta-analysis. *European Journal of Epidemiology*, *30*, 279-298. doi:10.1007/s10654-015-0014-9

Behrens, G., & Leitzmann, M. F. (2013). The association between physical activity and renal cancer: Systematic review and meta-analysis. *British Journal of Cancer*, *108*, 798-811. doi:10.1038/bjc.2013.37

Buford, T. W., Anton, S. D., Judge, A. R., Marzetti, E., Wohlgemuth, S. E., Carter, C. S., . . . Manini, T. M. (2010). Models of accelerated sarcopenia: Critical pieces for solving the puzzle of age-related muscle atrophy. *Ageing Research Reviews*, *9*, 369-383. doi:10.1016/j.arr.2010.04.004

Castaneda, C., Layne, J. E., Munoz-Orians, L., Gordon, P. L., Walsmith, J., Foldvari, M., . . . Nelson, M. E. (2002). A randomized controlled trial of resistance exercise training to improve glycemic control in older adults with type 2 diabetes. *Diabetes Care*, *25*, 2335-2341. doi:10.2337/diacare.25.12.2335

Chan, O. Y. A., van Houwelingen, A. H., Gussekloo, J., Blom, J. W., & den Elzen, W. P. (2014). Comparison of quadriceps strength and handgrip strength in their association with health outcomes in older adults in primary care. *Age*, *36*, 9714.

Cruz-Jentoft, A. J., Baeyens, J. P., Bauer, J. M., Boirie, Y., Cederholm, T., Landi, F., . . . Zamboni, M. (2010). Sarcopenia: European consensus on definition and diagnosis: Report of the European Working Group on Sarcopenia in Older People. *Age Ageing*, *39*, 412-423. doi:10.1093/ageing/afq034

de Groot, S., & Nieuwenhuizen, M. G. (2013). Validity and reliability of measuring activities, movement intensity and energy expenditure with the DynaPort MoveMonitor. *Medical Engineering & Physics*, *35*, 1499-1505.

Dijkstra, B., Kamsma, Y., & Zijlstra, W. (2010). Detection of gait and postures using a miniaturised triaxial accelerometer-based system: Accuracy in community-dwelling older adults. *Age Ageing*, *39*, 259-262. doi:10.1093/ageing/afp249

Drey, M., Sieber, C. C., Degens, H., McPhee, J., Korhonen, M. T., Muller, K., . . . Rittweger, J. (2016). Relation between muscle mass, motor units and type of training in master athletes. *Clinical Physiology and Functional Imaging*, *36*, 70-76. doi:10.1111/cpf.12195

Fielding, R. A., Vellas, B., Evans, W. J., Bhasin, S., Morley, J. E., Newman, A. B., . . . Zamboni, M. (2011). Sarcopenia: An undiagnosed condition in older adults. Current consensus definition: Prevalence, etiology, and consequences. International working group on sarcopenia. *Journal of the American Medical Directors Association*, *12*, 249-256. doi:10.1016/j.jamda.2011.01.003

Forrest, K. Y., Zmuda, J. M., & Cauley, J. A. (2006). Correlates of decline in lower extremity performance in older women: A 10-year follow-up study. *The Journals of Gerontology, Series A: Biological Sciences and Medical Sciences*, *61*, 1194-1200. doi:10.1093/gerona/61.11.1194

Gomez-Cabello, A., Carnicero, J. A., Alonso-Bouzon, C., Tresguerres, J. A., Alfaro-Acha, A., Ara, I., . . . Garcia-Garcia, F. J. (2014). Age and gender, two key factors in the associations between physical activity and strength during the ageing process. *Maturitas*, *78*, 106-112. doi:10.1016/j.maturitas.2014.03.007

Goodpaster, B. H., Carlson, C. L., Visser, M., Kelley, D. E., Scherzinger, A., Harris, T. B., . . . Newman, A. B. (2001). Attenuation of skeletal muscle and strength in the elderly: The health ABC study. *Journal of Applied Physiology (1985)*, *90*, 2157-2165.

Goodpaster, B. H., Park, S. W., Harris, T. B., Kritchevsky, S. B., Nevitt, M., Schwartz, A. V., . . . Newman, A. B. (2006). The loss of skeletal muscle strength, mass, and quality in older adults: The health, aging and body composition study. *The Journals of Gerontology, Series A: Biological Sciences and Medical Sciences*, *61*, 1059-1064. doi:10.1093/gerona/61.10.1059

Hall, K. S., Cohen, H. J., Pieper, C. F., Fillenbaum, G. G., Kraus, W. E., Huffman, K. M., . . . Morey, M. C. (2016). Physical performance across the adult life span: Correlates with age and physical activity. *The Journals of Gerontology, Series A: Biological Sciences and Medical Sciences*, *72*, 572-578. doi:10.1093/gerona/glw120

Harris, T. J., Owen, C. G., Victor, C. R., Adams, R., Ekelund, U., & Cook, D. G. (2009). A comparison of questionnaire, accelerometer, and pedometer: Measures in older people. *Medicine and Science in Sports and Exercise*, *41*, 1392-1402. doi:10.1249/MSS.0b013e31819b3533

Hart, T. L., Swartz, A. M., Cashin, S. E., & Strath, S. J. (2011). How many days of monitoring predict physical activity and sedentary behaviour in older adults? *The International Journal of Behavioral Nutrition and Physical Activity*, *8*, 62. doi:10.1186/1479-5868-8-62

Himann, J. E., Cunningham, D. A., Rechnitzer, P. A., & Paterson, D. H. (1988). Age-related changes in speed of walking. *Medicine & Science in Sports & Exercise*, *20*, 161-166. doi:10.1249/00005768-198804001-00010

Hupin, D., Roche, F., Gremeaux, V., Chatard, J. C., Oriol, M., Gaspoz, J. M., . . . Edouard, P. (2015). Even a low-dose of moderate-to-vigorous physical activity reduces mortality by 22% in adults aged >/=60 years: A systematic review and meta-analysis. *British Journal of Sports Medicine*, *49*, 1262-1267. doi:10.1136/bjsports-2014-094306

Hurst, P. R., Walsh, D. C., Conlon, C. A., Ingram, M., Kruger, R., & Stonehouse, W. (2016). Validity and reliability of bioelectrical impedance analysis to estimate body fat percentage against air displacement plethysmography and dual-energy X-ray absorptiometry. *Nutrition & Dietetics*, *73*, 197-204.

Hwang, A. C., Zhan, Y. R., Lee, W. J., Peng, L. N., Chen, L. Y., Lin, M. H., . . . Chen, L. K. (2016). Higher daily physical activities continue to preserve muscle strength after mid-life, but not muscle mass after age of 75. *Medicine*, *95*(22), e3809. doi:10.1097/MD.0000000000003809

Janssen, I., Baumgartner, R. N., Ross, R., Rosenberg, I. H., & Roubenoff, R. (2004). Skeletal muscle cutpoints associated with elevated physical disability risk in older men and women. *American Journal of Epidemiology*, *159*, 413-421. doi:10.1093/aje/kwh058

Janssen, I., Heymsfield, S. B., Baumgartner, R. N., & Ross, R. (2000). Estimation of skeletal muscle mass by bioelectrical impedance analysis. *Journal of Applied Physiology*, *89*, 465-471.

Janssen, I., Heymsfield, S. B., & Ross, R. (2002). Low relative skeletal muscle mass (sarcopenia) in older persons is associated with functional impairment and physical disability. *Journal of the American Geriatrics Society*, *50*, 889-896. doi:10.1046/j.1532-5415.2002.50216.x

Karelis, A. D., Chamberland, G., Aubertin-Leheudre, M., & Duval, C. (2013). Validation of a portable bioelectrical impedance analyzer for the assessment of body composition. *Applied Physiology, Nutrition, and Metabolism*, *38*(1), 27-32.

Kemper, H., Ooijendijk, W., & Stiggelbout, M. (2000). Consensus about the Dutch physical activity guideline [in Dutch]. *TSG*, *78*, 180-183.

Leveille, S. G., Guralnik, J. M., Ferrucci, L., & Langlois, J. A. (1999). Aging successfully until death in old age: Opportunities for increasing active life expectancy. *American Journal of Epidemiology*, *149*, 654-664. doi:10.1093/oxfordjournals.aje.a009866

Lexell, J., Downham, D., & Sjostrom, M. (1986). Distribution of different fibre types in human skeletal muscles: Fibre type arrangement in m. vastus lateralis from three groups of healthy men between 15 and 83 years. *Journal of the Neurological Sciences*, *72*, 211-222.

Ling, C. H., de Craen, A. J., Slagboom, P. E., Gunn, D. A., Stokkel, M. P., Westendorp, R. G., & Maier, A. B. (2011). Accuracy of direct segmental multi-frequency bioimpedance analysis in the assessment of total body and segmental body composition in middle-aged adult population. *Clinical Nutrition*, *30*, 610-615.

Manson, J. E., Greenland, P., LaCroix, A. Z., Stefanick, M. L., Mouton, C. P., Oberman, A., . . . Siscovick, D. S. (2002). Walking compared with vigorous exercise for the prevention of cardiovascular events in women. *The New England Journal of Medicine*, *347*, 716-725. doi:10.1056/NEJMoa021067

Martin, H. J., Syddall, H. E., Dennison, E. M., Cooper, C., & Sayer, A. A. (2008). Relationship between customary physical activity, muscle strength and physical performance in older men and women: Findings from the Hertfordshire Cohort Study. *Age Ageing*, *37*, 589-593. doi:10.1093/ageing/afn148

Matthews, C. E., Ainsworth, B. E., Thompson, R. W., & Bassett, D. R., Jr. (2002). Sources of variance in daily physical activity levels as measured by an accelerometer. *Medicine & Science in Sports & Exercise*, *34*, 1376-1381. doi:10.1097/00005768-200208000-00021

Mijnarends, D. M., Koster, A., Schols, J. M., Meijers, J. M., Halfens, R. J., Gudnason, V., . . . Harris, T. (2016). Physical activity and incidence of sarcopenia: The population-based AGES-Reykjavik study. *Age Ageing*, *45*, 614-620. doi:10.1093/ageing/afw090

Mitchell, W. K., Williams, J., Atherton, P., Larvin, M., Lund, J., & Narici, M. (2012). Sarcopenia, dynapenia, and the impact of advancing age on human skeletal muscle size and strength; a quantitative review. *Frontiers in Physiology*, *3*, 260. doi:10.3389/fphys.2012.00260

Pahor, M., Guralnik, J. M., Ambrosius, W. T., Blair, S., Bonds, D. E., Church, T. S., . . . Williamson, J. D. (2014). Effect of structured physical activity on prevention of major mobility disability in older adults: The LIFE study randomized clinical trial. *Journal of the American Medical Association*, *311*, 2387-2396. doi:10.1001/jama.2014.5616

Penedo, F. J., & Dahn, J. R. (2005). Exercise and well-being: A review of mental and physical health benefits associated with physical activity. *Current Opinion in Psychiatry*, *18*, 189-193. doi:10.1097/00001504-200503000-00013

Prince, S. A., Adamo, K. B., Hamel, M. E., Hardt, J., Connor, G. S., & Tremblay, M. (2008). A comparison of direct versus self-report measures for assessing physical activity in adults: A systematic review. *International Journal of Behavioral Nutrition and Physical Activity*, *5*, 56. doi:10.1186/1479-5868-5-56

Raguso, C. A., Kyle, U., Kossovsky, M. P., Roynette, C., Paoloni-Giacobino, A., Hans, D., . . . Pichard, C. (2006). A 3-year longitudinal study on body composition changes in the elderly: Role of physical exercise. *Clinical Nutrition*, *25*, 573-580. doi:10.1016/j.clnu.2005.10.013

Reijnierse, E. M., Jong, N., Trappenburg, M. C., Blauw, G. J., Butler-Browne, G., Gapeyeva, H., . . . Maier, A. B. (2017). Assessment of maximal handgrip strength: How many attempts are needed? *Journal of Cachexia, Sarcopenia and Muscle*, *8*, 466-474.

Reijnierse, E. M., Trappenburg, M. C., Leter, M. J., Blauw, G. J., de van der Schueren, M. A. E., . . . Maier, A. B. (2015). The association between parameters of malnutrition and diagnostic measures of sarcopenia in geriatric outpatients. *PLoS One*, *10*(8), e0135933. doi:10.1371/journal.pone.0135933

Riebe, D., Franklin, B. A., Thompson, P. D., Garber, C. E., Whitfield, G. P., Magal, M., & Pescatello, L. S. (2015). Updating ACSM's recommendations for exercise preparticipation health screening. *Medicine & Science in Sports & Exercise*, *47*, 2473-2479. doi:10.1249/MSS.0000000000000664

Rolland, Y., Czerwinski, S., Abellan van Kan, G., Morley, J. E., Cesari, M., Onder, G., . . . Vellas, B. (2008). Sarcopenia: Its assessment, etiology, pathogenesis, consequences and future perspectives. *The Journal of Nutrition, Health & Aging*, *12*, 433-450. doi:10.1007/bf02982704

Roubenoff, R. (2003). Catabolism of aging: Is it an inflammatory process? *Current Opinion in Clinical Nutrition & Metabolic Care*, *6*, 295-299. doi:10.1097/01.mco.0000068965.34812.62

Ryu, M., Jo, J., Lee, Y., Chung, Y. S., Kim, K. M., & Baek, W. C. (2013). Association of physical activity with sarcopenia and sarcopenic obesity in community-dwelling older adults: The Fourth Korea National Health and Nutrition Examination Survey. *Age Ageing*, *42*, 734-740. doi:10.1093/ageing/aft063

Sallis, J. F., & Saelens, B. E. (2000). Assessment of physical activity by self-report: Status, limitations, and future directions. *Research Quarterly for Exercise and Sport*, *71*(Suppl. 2), 1-14. doi:10.1080/02701367.2000.11082780

Schrack, J. A., Zipunnikov, V., Goldsmith, J., Bai, J., Simonsick, E. M., Crainiceanu, C., & Ferrucci, L. (2014). Assessing the "physical cliff": Detailed quantification of age-related differences in daily patterns of physical activity. *The Journals of Gerontology, Series A: Biological Sciences & Medical Sciences*, *69*, 973-979. doi:10.1093/gerona/glt199

Studenski, S. A., Peters, K. W., Alley, D. E., Cawthon, P. M., McLean, R. R., Harris, T. B., . . . Vassileva, M. T. (2014). The FNIH sarcopenia project: Rationale, study description, conference recommendations, and final estimates. *The Journals of Gerontology, Series A: Biological Sciences & Medical Sciences*, *69*, 547-558. doi:10.1093/gerona/glu010

Tudor-Locke, C. E., & Myers, A. M. (2001). Challenges and opportunities for measuring physical activity in sedentary adults. *Sports Medicine*, *31*, 91-100. doi:10.2165/00007256-200131020-00002

van Schooten, K. S., Rispens, S. M., Elders, P. J., Lips, P., van Dieen, J. H., & Pijnappels, M. (2015). Assessing physical activity in older adults: Required days of trunk accelerometer measurements for reliable estimation. *Journal of Aging and Physical Activity*, *23*, 9-17. doi:10.1123/japa.2013-0103

Westerterp, K. R. (2008). Physical activity as determinant of daily energy expenditure. *Physiology & Behavior*, *93*, 1039-1043. doi:10.1016/j.physbeh.2008.01.021