Published in final edited form as:

Med Sci Sports Exerc. 2016 November ; 48(11): 2216–2221. doi:10.1249/MSS.0000000000001018.

Evaluating Walking Intensity with Hip-Worn Accelerometers in Elders

Duane B Corbett, Vincenzo Valiani, Jeffrey D Knaggs, and Todd M Manini

University of Florida, Department of Aging and Geriatric Research, Institute on Aging, Gainesville, FL

Abstract

Purpose—Accelerometer activity counts are used to objectively categorize physical activity levels. We examined the association between accelerometer activity counts and metabolic effort in older adults.

Methods—Forty-five older adults (76.3 ± 5.1 yr) completed a 400-m walk at both a usual and rapid pace. A portable metabolic unit measured pulmonary gas exchange while a hip-worn accelerometer measured activity counts. Participants were categorized as either a “slow walker” or “fast walker” based on the threshold of $1.0 \text{ m} \cdot \text{s}^{-1}$ during usual-pace walking.

Results—Activity counts during rapid- ($r = 0.62$, $P < 0.01$), but not usual-pace ($r = 0.24$, $P = 0.11$) walking were significantly associated with metabolic equivalents (METs). Slow walkers attained only half the activity counts of fast walkers during each walk condition ($p < 0.01$) while at the same time achieving between 82-90% of their MET level.

Conclusion—Accelerometers may misclassify the activity level of functionally impaired older adults with slow walking speed.

Keywords

Aging; physical activity; energy expenditure; pedometer

INTRODUCTION

Activity monitors that use accelerometers are a pervasive and rapidly growing technology that is expected to shed significant light on the health effects of daily physical activity (PA) and sedentary patterns (29). These devices are extremely popular in both research and public settings because of their convenience, portability, and ease of use. However, there remain challenges with interpreting the output of the accelerometer in connection to metabolic intensity of movement (12). The accelerometer signal is often pre-processed and converted into units that are attributable to human movement. These units, called activity counts or counts $\cdot\text{min}^{-1}$, represent a quantitative measurement of movement that equates to a magnitude of acceleration over a specific unit of time (29). Therefore, the output from an

Corresponding author: Todd Manini, Ph.D., PO Box 112610, 210 East Mowry Rd., Gainesville, FL 32611-0107; Phone: 352-273-5914; Fax: 352-273-5920; tmanini@ufl.edu.

There are no conflicts of interest to disclose.

activity monitor is directly proportional to movement velocity as faster and more forceful footfalls register higher counts when a monitor is worn on the hip. Since movement velocity is often associated with increased metabolic rate, the activity monitor has been conveniently used to estimate the intensity of physical activities that require ambulation such as running or walking.

The intensity of PA is an important concept to fully capture as it used to provide the public a guide for performing moderate and vigorous intensity for meeting the US Department of Health and Human Services' 2008 Physical Activity Guidelines for Americans (PAGA) (12). The 2003-2004 National Health and Nutrition Examination Survey (NHANES) used activity counts from accelerometers to objectively categorize the population's PA level and engagement in moderate to vigorous physical activity (MVPA) (28). While these efforts are noteworthy, the output from the accelerometer and cut points used to define categories of PA level might misclassify people who move more slowly yet achieve a metabolic rate that is consistent with the recommended intensity of PA. This is particularly true for older adults who ambulate at a slower pace than younger adults yet have a sufficient metabolic rate to categorize that activity as being moderate to vigorous intensity (13,16). In fact, there is growing literature demonstrating that aging is associated with a general increase in the metabolic costs of physical activities, particularly those involving ambulation (13,15,16,25,32). In addition, the sensitivity of some accelerometers may be compromised at slower walking speeds and thus further compounding the problem (1).

This study sought to understand the association between habitual walking speed and metabolic rate of ambulation in relation to activity count output from a hip-worn accelerometer. We hypothesized that older adults with slow habitual walking speed are misclassified as not performing moderate to vigorous physical activity (MVPA) according to traditional count cut points from a hip-worn activity monitor. This knowledge is expected to create a better understanding of how to apply traditional cut point values to hip-worn activity monitors in older adults and those with functional impairments for estimating MVPA.

METHODS

Older adults between the ages of 70 and 90 yr were targeted through local mailings, flyers, and advertisements to participate in this study. Prior to participation, all participants underwent telephone and in-person screening. Exclusions included significant head injury with loss of consciousness exceeding 5 min, severe Parkinson's disease or other neurological disorder affecting physical function, history of stroke with mobility impairment, severe uncorrected vision or hearing impairment, extensive alcohol abuse, current use of anabolic hormones, active cancer, a heart or pulmonary condition diagnosed within the last 6 mos, shortness of breath during daily activities, and contraindications to MVPA (e.g. cardiac pacemaker, implanted cardiac defibrillator). Individuals with dementia or active cognitive impairment, assessed using the Mini-Mental State Exam (MMSE) with a cut point score of 23 or less, were also excluded. This study was approved by the University of Florida Institutional Review Board and written informed consent was obtained from all participants.

Measurements and design

Forty-five participants were asked to perform a 400-m walk test at both a usual and rapid pace under direct supervision of a clinical research assistant. The test was performed in a long corridor using two cones set 20 m apart (40 m per lap). We chose walking because it is the preferred and the most popular exercise mode among this age group with a 70% prevalence rate for those who report performing exercise (7,14). Testing was performed in a laboratory setting in a controlled temperature environment. Prior to the start of each walk, participants received standardized instructions to perform the activity at their usual or rapid pace without overexertion. The two tasks were performed on separate testing days to minimize fatigue and contamination between tests. Individuals with a usual-pace walking speed $< 1.0 \text{ m}\cdot\text{s}^{-1}$ were categorized as slow walkers. This level is considered a clinically meaningful slow walking speed in community-dwelling older adults, identifying individuals at a high risk of health related outcomes (3,26).

During the walk tasks, an Actigraph GT1M activity monitor (Actigraph Inc., Pensacola, FL) was worn on the right hip in line with the anterior axillary line. This monitor is small ($3.8 \times 3.7 \times 1.8 \text{ cm}$), lightweight (27 g), and includes a uniaxial accelerometer that measures accelerations in the range of 0.05-2 G with a band-limited frequency of 0.25-2.5 Hz. Prior to the start of and immediately after each testing session, each monitor was initialized and data downloaded using the ActiLife software (version 3.3.0) provided by the manufacturer. The monitors ran firmware version 3.2.0 with data collection set at 10-s epochs. Counts were subsequently summated over 1-min epochs and averaged over 2 min of walking during the middle phase of the walking test. The cut points of $2020 \text{ counts}\cdot\text{min}^{-1}$ and $1041 \text{ counts}\cdot\text{min}^{-1}$ that have each been previously designated as movements that meet a moderate to vigorous intensity were used for comparison to metabolic data collected using indirect calorimetry (5,28).

Participants wore a portable Cosmed K4b2 portable gas analysis system during the walking tasks. The K4b2 system weighs 1.5 kg, including the battery and specially designed harness and has been validated against Douglas bags during steady-state exercise (19). The low weight and adjustable harness was positioned to minimize any interference to walking. Prior to data collection, the oxygen and carbon dioxide sensors were calibrated according to the manufacturer's instructions. Reference gas calibration, using a gas mixture sample of 16.0% oxygen and 5.0% carbon dioxide, and a room air calibration were performed to calibrate the gas sensors before each participant. The turbine flowmeter was calibrated using a 3.0-liter syringe. A gas delay calibration was also performed on a weekly basis to account for the lag time occurring between the expiratory measurements of the flowmeter and analysis of the gas sensors. A flexible face mask was positioned over the participant's mouth and nose and attached to the flowmeter. Facemasks were fitted to prevent leaking of expired gases. Oxygen consumption ($\text{VO}_2 = \text{mL}\cdot\text{min}^{-1}\cdot\text{kg}^{-1}$) was measured breath-by-breath. Respiratory exchange ratio's (RER) were continuously monitored to ensure appropriate oxygen and carbon dioxide collection. The breath-by-breath data were reduced to an average walking VO_2 when steady state metabolic rate was reached. Steady state was defined as a plateau in oxygen consumption, which typically occurred after 2 min of walking. Data were expressed as METs after dividing the VO_2 values by the traditional standard of $3.5 \text{ mL}\cdot\text{min}^{-1}\cdot\text{kg}^{-1}$.

A series of questionnaires were administered to characterize the participants in the study. First, the Functional Assessment of Chronic Illness Therapy (FACIT) Fatigue Scale (version 4) was completed by self-administration (2). This 13-item scale assesses how fatigue affects activity over the previous seven days. Composite scores range from 0-52, with higher scores indicating less fatigue. The SF-12 Version 2 (SF-12v2) Health Survey was also completed through interview-based administration. This shorter version of the SF-36v2 Health Survey is a valid and reliable measure of self-perceived functional health and well-being and has been used in over 1,900 randomized clinical trials (24). The SF-12v2 provides psychometrically-based physical component summary (PCS) and mental component summary (MCS) scores that are normalized according to established algorithms (33). A disability questionnaire used in the Established Populations for Epidemiologic Studies of the Elderly (6) along with a 7-day recall PA questionnaire modeled on the Yale Physical Activity Survey (8) were also assessed through interview-based administration. The duration of walking for exercise, aerobic calisthenics, moderate intensity activities (e.g. golf, bowling, dancing), and recreational athletics (e.g. bicycling, swimming, jogging) were pooled into a variable for the total $\text{min} \cdot \text{d}^{-1}$ of PA.

Data analysis

Analysis of baseline characteristics and comparisons across walk speed groups were performed using analysis of variance (ANOVA) for continuous variables and chi-square tests for categorical variables. Pearson correlations were used to evaluate the association between activity counts and MET values during each walking test. Sensitivity and specificity was used to evaluate the classification of MVPA by indirect calorimetry (> 3 METs) and by the activity monitor (> 2020 and $> 1041 \text{ counts} \cdot \text{min}^{-1}$).

RESULTS

Table 1 shows the descriptive characteristics of the overall study population and among participants grouped by walking pace ≥ 1.0 or $< 1.0 \text{ m} \cdot \text{s}^{-1}$. These groups were similar in gender, BMI, MMSE score, FACIT composite score, SF-12v2 mental composite summary score, disease prevalence, total number of disease conditions, and perceived effort during both usual and rapid pace walking. Slow walkers were older (79.0 ± 4.7 vs 75.0 ± 4.7 yr; $P = 0.01$), had a lower SF-12v2 physical composite summary score (43.2 ± 8.3 vs 51.8 ± 5.6 ; $P < 0.01$) than faster walkers.

Figure 1 shows the correlation between activity counts and metabolic rate in usual- and rapid-pace walking. Activity counts during rapid ($r = 0.62$, $P < 0.01$), but not usual-pace ($r = 0.24$, $P = 0.11$) walking were significantly associated with METs. Figure 2 summarizes the oxygen consumption and average activity counts $\cdot \text{min}^{-1}$ during rapid- and usual-pace 400-m walks, respectively. The data are categorized by individuals who walked greater than or less than $1.0 \text{ m} \cdot \text{s}^{-1}$ at a usual pace; a pace that designates older individuals as “slow walkers” with potential functional impairments (2). Slow walkers attained only half the amount of activity counts during each walk condition (usual: 1125 ± 132 vs. 2242 ± 121 ; rapid: 1534 ± 214 vs. $3117 \pm 219 \text{ counts} \cdot \text{min}^{-1}$, $P < 0.01$) while at the same time achieving between 82-90% of MET level of individuals who walked $\geq 1.0 \text{ m} \cdot \text{s}^{-1}$.

Table 2 shows classification of MVPA by indirect calorimetry (≥ 3 METs) and by the activity monitor (≥ 2020 and ≥ 1041 counts $\cdot\text{min}^{-1}$). For all walk tests, sensitivity and specificity of the NHANES cut point of 2020 counts $\cdot\text{min}^{-1}$ was 59.2% and 64.3%, respectively. The sensitivity improved to 88.2% using the 1041 counts $\cdot\text{min}^{-1}$ cut point with a reduction of specificity to 7.1%. The improvements in sensitivity were similar in fast and slow walkers.

DISCUSSION

Accelerometry is an increasingly utilized method for objectively measuring PA in both research and applied settings for older adults. However, established activity count thresholds do not account for slower walking speeds common among older adults (26) and are thereby likely to underestimate the amount of time that older adults engage in MVPA (12). Our results show that the metabolic demand during ambulation among older adults is significantly associated with hip-worn accelerometer derived activity counts during rapid-pace walking. However, the association was significantly attenuated with usual-pace walking despite having sufficient variability in the data. Interestingly, only the participants who walked at a usual pace ≥ 1.0 m $\cdot\text{s}^{-1}$ were able to achieve the 2020 counts $\cdot\text{min}^{-1}$ threshold and meet the suggested 3.0 MET level. Participants walking at a usual pace < 1.0 m $\cdot\text{s}^{-1}$ were unable to achieve the 2020 counts $\cdot\text{min}^{-1}$ threshold, but were able to meet the 1041 counts $\cdot\text{min}^{-1}$ threshold while achieving the 3.0 MET level. This study validates our hypothesis that older adults with slow habitual walking speed may be misclassified as not performing MVPA according to the traditional 2020 count $\cdot\text{min}^{-1}$ cut point for hip-worn activity monitors.

With regard to the observed discrepancy between accelerometer based activity counts and metabolic rate, our findings show important implications to research and practice. The primary implication of this discrepancy is that epidemiological studies investigating older adult compliance with the PAGA may be underestimating the amount of time older adults engage in MVPA. For example, data from NHANES may be misinterpreting this subpopulation as not achieving the PAGA. According to recent estimates using NHANES 2005-2006 data, while 46.9% of adults aged ≥ 70 yr self-report to be meeting the PAGA, only 6.3% of individuals within this subpopulation are meeting the PAGA when objectively assessed through accelerometry measures using the 2020 counts $\cdot\text{min}^{-1}$ threshold for MVPA (30). This equates to an alarming difference between perception of meeting the guidelines and objective assessment of doing so.

Looking at reported average walk speeds using NHANES 1988-1994 data reveals that 92% of older adults would fall into the category of slow walkers (< 1.0 m $\cdot\text{s}^{-1}$) (26). Additionally, the prevalence of slow walking reported in other large cohort studies of community-dwelling older adults include: 80% in the Cardiovascular Health Study (11), 93% in the Established Populations for the Epidemiological Study of the Elderly (17), 96% in the Hispanic Established Populations for the Epidemiological Study of the Elderly (18), 69% in the Predicting Elderly Performance Study (25), and 46% in the Invecchiare in Chianti Study (9). Generalizing this to the population would mean that a large number of older adults with

lower habitual waking speed are performing more MVPA than estimated using higher thresholds such as 2020 counts•min⁻¹.

Others have used individually tailored accelerometer cut points for older adults. These studies that have accounted for walk speed have shown promising results for correctly estimating the amount of time performing MVPA. For example, in an ancillary study to the LIFE-P trial (21), Pruitt et al. showed that using an individually tailored counts•min⁻¹ threshold based on walk speed was useful in identifying health benefiting activity among older adults in a PA intervention (21). When they compared their range of individually tailored cut points to previously defined moderate-intensity cut points used in prior studies they found that application of traditional cut points compromised the detection of important group differences in meaningful activity. Notably, the threshold of 2020 counts•min⁻¹ was found to disregard 63% of the sample in achieving MVPA. Taking things a step further, Rejeski et al. identified relevant factors for predicting counts•min⁻¹ achieved during structured exercise (23). The results showed that three variables (age, age², and 400-m walk speed) accounted for 61% of the variability in counts•min⁻¹. Of these three, walk speed alone accounted for the 53% of variability. Interestingly, they found that 1041 counts•min⁻¹ was the best approximation of their individually tailored cut points. So although individually tailored cut points would be optimal for measuring MVPA, it appears that a lower cut point such as 1041 counts•min⁻¹ may be the ideal option when considering a universal approach.

The second implication from our results is the concern that epidemiological studies would incorrectly estimate PA levels of older adults and their association with various health outcomes. One such example would be a recent secondary analysis of the KORA-Age Study (20). In this analysis, a relatively similar threshold criterion of 1952 counts•min⁻¹ for MVPA was used to detect associations between intensity levels and related activity patterns with multimorbidity and disability among older adults. Results of the analysis showed that overall participants spent approximately 2% of their day in MVPA, which is likely underestimated according to the current study's results. As such, epidemiological analyses could suffer differential misclassification causing an attenuation of risk estimations.

Another implication is that older adults who use activity monitors in their personal lives may become discouraged with their perceived inability to achieve the recommended amount of PA. This may also transfer to lower self-efficacy ultimately affecting adherence to a PA regimen. This is most disturbing when considering that our analysis was exclusive to walking, which for older adults is the most commonly preferred mode of exercise (7,14).

These results suggest that practitioners should be cautious of interpreting and applying information provided by activity monitors for prescribing PA to older adults with slower walking speeds. For example, the sensitivity of detecting true MVPA using a cut point of 2020 for slow walkers was only 25%. This improved to 70% using a lower cut point of 1041. Although using this lower cut point reduced the classification specificity, a practitioner's major goal is to detect true positive cases as opposed to true negative cases. Therefore, to improve classification, older adults with slower walking speeds should receive a lower counts•min⁻¹ threshold for quantifying MVPA that would better reflect the actual metabolic cost. A threshold of 1041 counts•min⁻¹—originally proposed by Copeland and colleagues—

captures a majority of ambulatory MVPA and appears to be a reasonable solution. Alternatively, an individualized cut point—similar to the approach by Rejeski and colleagues—could be applied. However, the drawback to this approach is that a measurement of walking speed would need to be included to appropriately set the threshold. This is currently not standard practice, but should be considered in the future.

The major strength of this study is the evaluation of hip-worn accelerometers in older adults with variable walking speeds while also collecting expiratory gases to estimate metabolic demand. However, the results are balanced with some notable weaknesses. First, this study had a relatively small sample size that is not sufficient for establishing new accelerometer activity count thresholds for older adults. Additionally, we used activity count thresholds to assess monitor intensity levels and this approach is becoming less common with new technology that samples the raw accelerations at high resolutions. Despite this limitation, results from this study suggest that even the new methods would likely require population specific algorithms. It may also be considered a weakness that our methods included the use of a hip-worn monitor during a period of rapidly growing popularity in wrist-worn monitors. In fact, alternative body placements may improve detection of MVPA (thigh, ankle etc.) in this population. However, the use of hip-worn monitors is most common placement used in the literature and has considerable validation work in detecting MVPA, which provided the rationale for the current study (4). Another important weakness of the study is that only walking was assessed and therefore these data do not apply to the entire continuum of activities recommended for MVPA. Future studies should aim to encompass a variety of activities to better understand the relationship between metabolic demand and hip-worn accelerometer derived activity counts during MVPA for older adults.

In conclusion, the results of this study demonstrated a clear distinction between the measured activity counts and metabolic demands of higher and lower functioning older adults performing usual- and rapid-paced walking tasks. In fact, lower functioning older adults who achieved the PAGA recommended level of MVPA based on metabolic rate did not achieve it using an accelerometer cut point of 2020 counts•min⁻¹. Moreover, lower functioning older adults might not be able to achieve such a high accelerometer count threshold because they are often limited by health conditions that impair their mobility. It is clear that we need to consider a lower accelerometer activity count threshold for assessing MVPA among the older adult population—particularly those with slower walking speeds. Establishing a threshold dependent on walk speed would seem most appropriate considering the prevalence of walking in this subpopulation (7,14) and the relative ease of assessment through other simple preexisting clinical tests that use walking as a modality to assess mobility disability (10).

Acknowledgments

This research was supported by the Paffenbarger-Blair Fund for Epidemiological Research on Physical Activity from the American College of Sports Medicine Foundation. This research was also partially supported by grants: NIH HL121023, AG042525 and P30AG028740. The results of this study do not constitute endorsement by the American College of Sports Medicine.

References

1. Abel MG, Hannon JC, Sell K, Lillie T, Conlin G, Anderson D. Validation of the Kenz Lifecorder EX and ActiGraph GT1M accelerometers for walking and running in adults. *Appl Physiol Nutr Metab.* 2008; 33(6):1155–64. [PubMed: 19088773]
2. Bonomi AE, Cella DF, Hahn EA, et al. Multilingual translation of the Functional Assessment of Cancer Therapy (FACT) quality of life measurement system. *Qual Life Res.* 1996; 5(3):309–20. [PubMed: 8763799]
3. Cesari M, Kritchevsky SB, Penninx BW, et al. Prognostic value of usual gait speed in well-functioning older people – results from the Health, Aging and Body Composition Study. *J Am Geriatr Soc.* 2005; 53(10):1675–80. [PubMed: 16181165]
4. Cheung VH, Gray L, Karunanithi M. Review of accelerometry for determining daily activity among elderly patients. *Arch Phys Med Rehabil.* 2011; 92(6):998–1014. [PubMed: 21621676]
5. Copeland JL, Eslinger DW. Accelerometer assessment of physical activity in active, healthy older adults. *J Aging Phys Act.* 2009; 17(1):17–30. [PubMed: 19299836]
6. Cornoni-Huntley J, Ostfeld AM, Taylor JO, et al. Established populations for epidemiologic studies of the elderly: study design and methodology. *Aging Clin Exp Res.* 1993; 5(1):27–37.
7. Crespo CJ, Keteyian SJ, Heath GW, Sempos CT. Leisure-time physical activity among US adults. Results from the Third National Health and Nutrition Examination Survey. *Arch Intern Med.* 1996; 156(1):93–8. [PubMed: 8526703]
8. Di Pietro L, Caspersen CJ, Ostfeld AM, Nadel ER. A survey for assessing physical activity among older adults. *Med Sci Sports Exerc.* 1993; 25(5):628–42. [PubMed: 8492692]
9. Ferrucci L, Bandinelli S, Benvenuti E, et al. Subsystems contributing to the decline in ability to walk. *J Am Geriatr Soc.* 2000; 48(12):1618–25. [PubMed: 11129752]
10. Fielding RA, Rejeski WJ, Blair S, et al. The Lifestyle Interventions and Independence for Elders Study: design and methods. *J Gerontol A Biol Sci Med Sci.* 2011; 66(11):1226–37. [PubMed: 21825283]
11. Fried LP, Borhani NO, Enright P, et al. The Cardiovascular Health Study. *Ann Epidemiol.* 1991; 1(3):263–76. [PubMed: 1669507]
12. Hall KS, Howe CA, Rana SR, Martin CL, Morey MC. METs and accelerometry of walking in older adults: standard versus measured energy cost. *Med Sci Sports Exerc.* 2013; 45(3):574–82. [PubMed: 23059862]
13. Hall KS, Morey MC, Dutta C, et al. Activity-related energy expenditure in older adults: a call for more research. *Med Sci Sports Exerc.* 2014; 46(12):2335–40. [PubMed: 24714651]
14. Ham SA, Kruger J, Tudor-Locke C. Participation by US adults in sports, exercise, and recreational physical activities. *J Phys Act Health.* 2009; 6(1):6–14. [PubMed: 19211953]
15. Jones LM, Waters DL, Legge M. Walking speed at self-selected exercise pace is lower but energy cost higher in older versus younger women. *J Phys Act Health.* 2009; 6:327–32. [PubMed: 19564661]
16. Knaggs JD, Larkin KA, Manini TM. Metabolic cost of daily activities and effect of mobility impairment in older adults. *J Am Geriatr Soc.* 2011; 59(11):2118–23. [PubMed: 22091979]
17. Lavsky-Shulan M, Wallace RB, Kohout FJ, Lemke JH, Morris MC, Smith IM. Prevalence and functional correlates of low back pain in the elderly: the Iowa 65+ Rural Health Study. *J Am Geriatr Soc.* 1985; 33(1):23–8. [PubMed: 3155530]
18. Markides, KS.; Stroup-Benham, C.; Black, S.; Satis, S.; Perkowski, L.; Ostir, G. The health of Mexican American elderly: Selected findings from the Hispanic EPESE. In: Wykle, ML.; Ford, A., editors. *Serving Minority Elders in the 21st Century.* New York, NY: Springer; 1999. p. 72-90.
19. McLaughlin JE, King GA, Howley ET, Bassett DR Jr, Ainsworth BE. Validation of the COSMED K4 b2 portable metabolic system. *Int J Sports Med.* 2001; 22(4):280–4. [PubMed: 11414671]
20. Ortlieb S, Gorzelniak L, Nowak D, et al. Associations between multiple accelerometry-assessed physical activity parameters and selected health outcomes in elderly people—results from the KORA-age study. *PLoS One.* 2014; 9(11):e111206. [2015 December 23] [Internet] Available from <http://www.ncbi.nlm.nih.gov/pubmed/25372399>. doi: 10.1371/journal.pone.0111206 [PubMed: 25372399]

21. Pahor M, Blair SN, Espeland M, et al. Effects of a physical activity intervention on measures of physical performance: Results of the Lifestyle Interventions and Independence for Elders Pilot (LIFE-P) study. *J Gerontol A Biol Sci Med Sci*. 2006; 61(11):1157–65. [PubMed: 17167156]
22. Pruitt LA, Glynn NW, King AC, et al. Use of accelerometry to measure physical activity in older adults at risk for mobility disability. *J Aging Phys Act*. 2008; 16(4):416–34. [PubMed: 19033603]
23. Rejeski WJ, Marsh AP, Brubaker PH, et al. Analysis and interpretation of accelerometry data in older adults: The LIFE Study. *J Gerontol A Biol Sci Med Sci*. 2015 Epub ahead of print.
24. Resnick B, Nahm ES. Reliability and validity testing of the revised 12-item Short-Form Health Survey in older adults. *J Nurs Meas*. 2001; 9(2):151–61. [PubMed: 11696939]
25. Richardson CA, Glynn NW, Ferrucci LG, Mackey DC. Walking energetics, fatigability, and fatigue in older adults: the study of energy and aging pilot. *J Gerontol A Biol Sci Med Sci*. 2015; 70(4): 487–94. [PubMed: 25190069]
26. Studenski S, Perera S, Patel K, et al. Gait speed and survival in older adults. *JAMA*. 2011; 305(1): 50–8. [PubMed: 21205966]
27. Studenski S, Perera S, Wallace D, et al. Physical performance measures in the clinical setting. *J Am Geriatr Soc*. 2003; 51(3):314–22. [PubMed: 12588574]
28. Troiano RP, Berrigan D, Dodd KW, Masse LC, Tilert T, McDowell M. Physical activity in the United States measured by accelerometer. *Med Sci Sports Exerc*. 2008; 40(1):181–8. [PubMed: 18091006]
29. Troiano RP, McClain JJ1, Brychta RJ, Chen KY. Evolution of accelerometer methods for physical activity research. *Br J Sports Med*. 2014; 48(13):1019–23. [PubMed: 24782483]
30. Tucker JM, Welk GJ, Beyler NK. Physical activity in U.S. adults compliance with the Physical Activity Guidelines for Americans. *Am J Prev Med*. 2011; 40(4):454–61. [PubMed: 21406280]
31. U.S. Department of Health and Human Services. The 2008 Physical Activity Guidelines for Americans. Rockville, MD: U.S Department of Health and Human Services, Office of the Surgeon General; 2008. Available from: <http://www.health.gov/paguidelines> [2015 December 23]
32. Voorrips LE, van Acker TM, Deurenberg P, van Staveren WA. Energy expenditure at rest and during standardized activities: a comparison between elderly and middle-aged women. *Am J Clin Nutr*. 1993; 58:15–20. [PubMed: 8317383]
33. Ware, JE.; Kosinski, M.; Turner-Bowker, DM.; Gandek, B.; Keller, SD. How to score version 2 of the SF-12 Health Survey (With a Supplement Documenting Version 1). Lincoln, RI: Quality Metric Incorporated; 2002. p. 1-267.

FIGURE 1. Scatter plot and lines of best fit predicting metabolic rate with vertical axis activity counts recorded with a hip-worn accelerometer.

FIGURE 2.

Oxygen consumption and average activity counts $\cdot \text{min}^{-1}$ during 400-m walk at A. usual and B. rapid pace. The data are categorized by individuals who walked greater than or less than $1.0 \text{ m} \cdot \text{s}^{-1}$ at a usual pace – a pace that designates older individuals as “slow walkers” with potential functional impairments. Dotted lines represent cut points for metabolic rate (3.0 METs) or accelerometer counts (2020 counts $\cdot \text{min}^{-1}$ and 1041 counts $\cdot \text{min}^{-1}$) that designate the walking intensity equal to or greater than moderate. Significant differences occurred in accelerometer counts between slow and fast walkers ($P < 0.05$).

TABLE 1

Participant descriptive characteristics

	Total (n = 45)	Fast Walkers (n = 30)	Slow Walkers (n = 15)
Age (yr)	76.3 (5.1)	75.0 (4.7)	79.0 (4.7)*
Female, % (n)	55.5 (25)	53.3 (16)	60.0 (9)
BMI (kg•m ⁻²)	26.7 (3.8)	26.5 (3.7)	27.1 (4.3)
MMSE score	28.5 (1.4)	28.6 (1.4)	28.3 (1.5)
Education (yr)	14.4 (4.9)	14.9 (4.6)	13.5 (5.6)
FACIT composite score	45.7 (6.3)	45.7 (6.7)	45.7 (5.5)
SF-12v2 physical composite score	48.9 (7.7)	51.8 (5.6)	43.2 (8.3)*
SF-12v2 mental composite score	56.3 (6.8)	55.5 (5.5)	58.0 (8.9)
Rapid-pace walk – speed (m•s ⁻¹)	1.1 (0.25)	1.3 (0.17)	0.93 (0.18)*
Usual-pace walk – speed (m•s ⁻¹)	1.0 (0.18)	1.1 (0.09)	0.83 (0.13)*
Usual-pace walk – RPE	2.2 (2.0)	1.9 (1.8)	2.7 (2.3)
Rapid-pace walk – RPE	2.5 (1.9)	2.6 (1.9)	2.2 (1.9)
Total PA (min•d ⁻¹)	34.1 (29.9)	31.2 (42)	19.6 (18.3)
History of cardiovascular disease, % (n)	17.4 (8)	13.3 (4)	26.6 (4)
Diabetes, % (n)	6.6 (3)	3.3 (1)	13.3 (2)
Osteoarthritis, % (n)	32.6 (15)	36.7 (11)	26.7 (4)
History of cancer, % (n)	15.2 (7)	16.7 (5)	13.3 (2)
Hypertension, % (n)	23.9 (11)	23.3 (7)	26.7 (4)
Osteoporosis, % (n)	6.5 (3)	6.7 (2)	6.7 (1)
Total disease conditions, % (n)	1.0 (0.80)	1.0 (0.78)	1.1 (0.83)

Data are means and SD unless otherwise noted.

* Significance at $P < 0.05$

BMI, Body Mass Index; MMSE, Mini-Mental State Exam; FACIT, Functional Assessment of Chronic Illness Therapy
 Fatigue Scale; SF-12v2, SF-12 Version 2 Health Survey; RPE, rating of perceived exertion; PA, physical activity.

TABLE 2

Measured metabolic cost vs. accelerometer-based estimate of MVPA frequency distribution, sensitivity, and specificity.

	counts•min ⁻¹	< 2020	2020	< 1041	1041
All walk tests					
< 3 METs	9	5	1	13	
3 METs	31	45	9	67	
Sensitivity		59.2%		88.2%	
Specificity		64.3%		7.1%	
Fast Walkers					
< 3 METs	3	5	0	8	
3 METs	13	39	2	50	
Sensitivity		75%		96.2%	
Specificity		37.5%		0%	
Slow Walkers					
< 3 METs	6	0	1	5	
3 METs	18	6	7	17	
Sensitivity		25%		70.8%	
Specificity		100%		16.7%	