Accelerometry analysis of physical activity and sedentary behavior in older adults: a systematic review and data analysis

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Abstract Accelerometers objectively monitor physical activity and sedentary patterns and are increasingly used in the research setting. It is important to maintain consistency in data analysis and reporting, therefore, we: (1) systematically identified studies using accelerometry (ActiGraph, Pensacola, FL, USA) to measure moderate-to-vigorous physical activity (MVPA) and sedentary time in older adults, and (2) based on the review findings, we used different cut-points obtained to analyze accelerometry data from a sample of community-dwelling older women. We identified 59 articles with cut-points ranging between 574 and 3,250 counts/min for MVPA and 50 and 500 counts/min for sedentary time. Using these cut-points and data from women (mean age, 70 years), the median MVPA minutes per day ranged between 4 and 80 min while percentage of sedentary time per day ranged between 62 % and 86 %. These data highlight (1) the importance of reporting detailed information on the analysis assumptions and (2) that results can differ greatly depending on analysis parameters.

Keywords Accelerometer · Measurement · Analysis assumptions · Physical activity · Sedentary behavior

Introduction

Physical activity contributes to healthy aging, while it is increasingly recognized that sedentary behavior is also an independent determinant of health. The American College of Sports Medicine provides physical activity guidelines specific to older adults for functional ability, mortality, falls, mental and cognitive health, and the prevention and treatment of many chronic conditions [60]. They recommend that older adults accumulate 30 min of aerobic activity at a moderate level for at least 5 days/week [60], although more recent guidelines recommend 150 min/week [86, 90]. In contrast, sedentary behavior describes activities that are low in energy expenditure [≤1.5 metabolic equivalent of task (METs)]. These activities are done in a sitting or reclining position [76] and are associated with adverse health outcomes [85]. Accurately measuring time spent in both physical and sedentary activities is important for (1) investigating their dose–response influence on specific health outcomes, (2) informing appropriate interventions, and (3) testing the effectiveness of interventions aimed at increasing physical activity and/or decreasing sedentary time.
Physical activity and sedentary time are frequently assessed using self-report questionnaires, however, potential limitations include recall bias, socially desirable responses [74], and the influence of mood, depression, anxiety, cognition, and disability on responses [72]. This is especially important with questionnaires developed for younger adults but administered to older adults, as they may underestimate the physical activity level of older adults as they engage in different types of activities [92]. More recently, accelerometers are used to objectively describe activity patterns. They provide an objective measure that eliminates many of the challenges associated with self-report questionnaires and are appropriate for use in older adults [59].

The ActiGraph (Pensacola, FL, USA) accelerometer is a commonly used accelerometer for physical activity research. The monitor is usually worn at the waist. Early versions of the monitor used (cantilever beam) piezoelectric sensors to measure raw acceleration that is processed into activity counts with frequency filters. Since the introduction of the GT1M monitor, the sensor is a Micro Electro Mechanical Systems (MEMS) capacitative accelerometer [11]. Thresholds for the activity counts (cut-points) are determined from validation studies to classify activity intensity [11]. The monitors provide time and date-stamped information on activity intensity, categorized as sedentary (≤1.5 METs), light (1.6–2.9 METs) [64], or moderate-to-vigorous (≥3 METs) [23].

Accelerometry assumptions for the choice of cut-points and data analysis are not standardized across research protocols [52]. The majority of peer-reviewed literature informing accelerometry data analysis methods are from studies that included children and young adults [52, 53, 70, 88]. Literature on accelerometry in older adults is limited and many previous studies used validity studies completed on younger adults to determine cut-points for activity intensity. Taraldsen and colleagues [83] reviewed the use of accelerometers for physical activity monitoring in older adults and highlighted the wide variety of physical activity measures and called for the development of a consensus.

Therefore, our purpose was to: (1) undertake a systematic review of the literature to identify studies that used ActiGraph accelerometers to assess moderate-to-vigorous physical activity (MVPA) and sedentary behavior in older adults and (2) determine the effect of changing physical activity and sedentary cut-points on the results for older adults. The results of this study will provide an overview of literature objectively measuring physical activity and sedentary behavior patterns in older adults and will highlight current practice for accelerometry analysis for this age group.

Methods

In this two-part study, first, we completed a systematic search of the published peer-reviewed literature that used accelerometry to assess physical activity and sedentary behavior patterns of older adults and identified cut-points used to classify intensity of activities. Second, we used this information to analyze an accelerometry sample of older women’s activity patterns over 7 days to illustrate the effect of changing the different reported cut-points.

Phase 1: systematic review

Data sources and search strategy. We completed an electronic search of the peer-reviewed literature for publications related to accelerometers, physical activity or sedentary behavior, and older adults. We reviewed published peer-reviewed literature from 1950 to July 4, 2012 from the following databases: AgeLine, CINAHL, EMBASE, OVID Medline, PubMed, and SPORTDiscus. We limited our search to adults aged 65 years and older using relevant Medical Subject Heading and keywords but included articles with older adults with a group mean age ≥60 years if they were found with our search strategy (Fig. 1). We completed the review in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-analyses guidelines [45].

Study selection. We included studies that used ActiGraph accelerometer (Pensacola, FL, USA) models CSA, MTI, 7164, GT1M, GT3X, and GT3X+ at the waist to objectively measure physical activity and sedentary behavior in free-living conditions. Specifically, we included studies with defined cut-points to determine activity intensity in community dwelling older adults (mean age of 60 years or older). We excluded studies that were targeted for special populations (e.g., older adults with stroke). Two of three reviewers (EG, HH, PY) independently reviewed each retrieved article based on title and abstract for relevance, and the additional reviewer resolved any discrepancies. Two of three reviewers (EG, HH, PY) then independently reviewed each full text article for inclusion and documented reasons for exclusion from the review. The final decision to include studies was decided by consensus with the third reviewer resolving any discrepancies. We did not rate the quality of the studies included in this review.

Data extraction. We extracted the following information from the included studies: study population; accelerometry data collection methods and accelerometry analysis assumptions including valid day criteria; cut-points; and any other relevant assumptions reported. Two reviewers independently extracted data, and a third reviewer (EG, HH, PY) checked this information for accuracy.

Phase 2: accelerometry data analysis

Based on the cut-points reported in published literature identified and reviewed in Phase 1, we analyzed accelerometry
data from active community-dwelling older women (65–75 years). Data were from a sample from a randomized controlled trial testing the effect of frequency of resistance training on cognition in older women [46]. This study was approved by the local university and hospital ethics review boards, and all eligible participants provided written informed consent. Participants wore the accelerometer (ActiGraph GT1M) at the waist during waking hours for 1 week in the winter. We set the accelerometers to collect data with 1-min epochs. To be included in the analysis, participants wore the accelerometer for at least 4 days and at least 10 h/day of valid wear time. We did not adjust for wear time. We analyzed the accelerometry data with the reported cut-points that we obtained from the systematic review. We used MeterPlus (Santech, Inc., La Jolla, CA) to analyze the accelerometer data files and excluded non-wear time (60 min or more of continuous zeros, based on the NHANES (National Health and Nutritional Examination Survey) criteria [87] and determined the time spent in sedentary, MVPA, and bouted MVPA (≥10 min of continuous MVPA with 1 to 2 min tolerance). For descriptive purposes, we included participants’ age, body mass index (BMI), 6-min walk test time (6MWT) [7] and Physical Activity Scale for the Elderly (PASE) self-reported physical activity score [93].

Statistical analysis

We used percent agreement to report consistency between reviewers for study inclusion in the systematic review. For data analysis, we summarized participants’ descriptive information with mean/standard deviation (SD) or median/interquartile range (IQR) (if data were skewed). We calculated the mean and SD, or median and IQR for the average daily time spent in sedentary and MVPA for each cut-point determined from the literature. For each cut-point, we calculated the percentage of participants who met 30 min of physical activity per day and the average percentage of the day spent in sedentary time. These values were compared with the most commonly used cut-point (1,952 counts/min for MVPA and 100 counts/min for sedentary time) following Bland-Altman’s method for assessing agreement between two measures [4]. To investigate differences between the most commonly used cut-point and other cut-points when used to measure group differences, we used logistic regression to calculate odds ratios for meeting 30 min of MVPA based on participant age and 6MWT result. For the 6MWT, we used a cut-point ≤490 m to indicate lower physical capacity [69]. For the Bland-Altman methods, we presented values of the mean differences, standard deviation (SD) of the differences, and the upper and lower limit of the Bland-Altman agreement levels (SD ± 1.96). We used R (Foundation for Statistical Computing, Vienna, Austria) for the statistical analyses [18].

Results

Phase 1

In this review, we identified 59 publications for inclusion (Fig. 2), and this represented 45 unique study data sets. Our two independent reviewers had 92 % agreement on the inclusion of articles in the study. The details of the 59 included publications, in particular, the activity monitor model, their accelerometry data collection, and analysis protocols are listed in Table 1. Within the 59 publications, there were: 34 papers that used the models 7164, 71256, MTI (7162); 23 that used the GT1M accelerometer; and only one study that used the GT3X monitor. A total of 53 publications included cut-points for MVPA and 36 for sedentary time. We located nine publications with the National Health and Nutritional Examination...
Survey (NHANES) 2003–2004 data and three that used the NHANES 2005–2006 data. The majority of studies (48 out of 59) included men and women, and the ActiGraph accelerometers were set at a 1-min epoch (40 of 59) for ≥7 days (52 of 59). Most publications (33 of 59) required participants to have at least four valid days with ≥10 wear hours/day to be included in their analysis.

We identified many cut-points for MVPA and sedentary time in the included studies. Eight different cut-points were identified for MVPA ranging from a median of 4 to 80 min/day and between 0 and 24 min of MVPA accumulated in bouts of 10 min or greater/day (Table 3). Using Bland-Altman methods and the most common cut-point (≥1,952) as the reference, the observed differences ranged from −15 to 64 min/day. Between 4 and 95 % of participants met 30 min/day of MVPA depending on the cut-point (Table 3). Compared with the most common cut-point (≥1,952), the observed differences for accumulated bouts of MVPA ranged from −9 to 16 min/day (Table 3).

Using logistic regression and age 65 to 68 years as the reference group, the odds ratios for not meeting 30 min/day of MVPA were highest for the 73 to 76 years participants and ranged from 4.32 to 5.88 depending on the cut-point used. For the 6MWT and >490 m as the reference group, the odds ratios for not meeting 30 min/day of MVPA depending on the cut-point (Table 3). Compared with the most common cut-point (≥1,952), the observed differences for accumulated bouts of MVPA ranged from −9 to 16 min/day (Table 3).

For sedentary time, the amount of time determined from cut-points ranged from 475 to 665 min/day (Table 5). Using the reported cut-points, participants from the sample group averaged 62 % to 86 % of their day in sedentary behavior, and the most common cut-point (100 counts/min)
| Study (data source) | Model | Population, amount of physical activity | Data collection | Data cleaning | Data inclusion | Cut-points (counts/min) |
|--------------------|-------|-----------------------------------------|----------------|--------------|---------------|------------------------|
|                    |       |                                         |                |              |               | Moderate to vigorous | Sedentary              |
| Pre-2007 (N=2)     |       |                                         |                |              |               |                        |                        |
| Morse et al. [58]  | 7164  | N=21, 73.7 (3.6) years; men/women=21/0; moderate PA (3–5.99 METs)=33.47 (21.07)min/day | At least 7 days, 1 min epoch | Removed unusually low counts (no moderate activity with all counts ≤1,952), or unusually high counts (all activity vigorous with all counts >5,724), and continuous data with the same value). Manually checked missing and incomplete data and compared with logs. | 7 days ≥10 h/day | ≥1,952 |
| Kolbe-Alexander et al. [43], South Africa | MTI (7162) | N=122, median (IQR) 66 years (62 to 70); men/women=52/70; MVPA, not reported | 7 days, 1-min epoch | Removed unusually low counts (no moderate activity with all counts ≤1,952), or unusually high counts (all activity vigorous with all counts >5,724), and continuous data with the same value). Manually checked missing and incomplete data and compared with logs. | >10 h/day | >1,952 |
| 2007 (N=5)         |       |                                         |                |              |               |                        |                        |
| Aznar-Lain et al. [2], Spain | 7164 | N=163, 76.1 years (3.9); men/women =70/91; MVPA/day=19.9 (16.3) | 7 days, 1-min epoch | Removed unusually low counts (no moderate activity with all counts ≤1,952), or unusually high counts (all activity vigorous with all counts >5,724), and continuous data with the same value). Manually checked missing and incomplete data and compared with logs. | 5 days ≥10 h/day | >1,999 |
| Davis and Fox [15], UK (Better Ageing) | 7164 | N=176; men, 75.8 years (4.0); men/women =78/98, MVPA not reported | 7 days, 1-min epoch | Referenced to Davis and Fox [15]. Removed unusually low counts (no moderate activity with all counts ≤1,952), or unusually high counts (all activity vigorous with all counts >5,724), and continuous data with the same value). Manually checked missing and incomplete data and compared with logs. | Referenced to Davis and Fox [15] five consecutive days ≥10 h/day | ≥1,999 |
| Fox et al. [22], UK (Better Ageing) | 7164 | N=122; men and women 65–79 years, median MVPA/day=21 (8–43) | 7 days, 1-min epoch | Referenced to Davis and Fox [15]. Removed unusually low counts (no moderate activity with all counts ≤1,952), or unusually high counts (all activity vigorous with all counts >5,724), and continuous data with the same value). Manually checked missing and incomplete data and compared with logs. | Referenced to Davis and Fox [15] f i v e consecutive days ≥10 h/day | >1,999 |
| Hagströmer et al. [30], Sweden (ABC) | 7164 | N=91, 74 years (9.5); men/women=29/60, MVPA only 17.2 % of 489 days had ≥30 min | 7 days, 1-min epoch | Removed ≥20 min of consecutive zero counts and periods of monitor malfunction (counts >20,000). Removed overnight accelerometer data identified from logs. Visual inspected data and confirmed the pedometer and self-reported physical activity of participants with over 60 min of MVPA. | 4 days with at least one weekend day ≥10 h/day | ≥1,952 |
| Rowe et al. [73], USA | 7164 | N=97, 68.8 years (3); men/women=0/73, mean MVPA=156 (90) min/day | 1-min epoch | Removed ≥10 min of consecutive zero counts and periods of monitor malfunction (counts >20,000). Removed overnight accelerometer data identified from logs. Visual inspected data and confirmed the pedometer and self-reported physical activity of participants with over 60 min of MVPA. | 4 days (including 1 weekend day) ≥10 h/day | ≥574 |
| 2008 (N=11)        |       |                                         |                |              |               |                        |                        |
| Ashe et al. [1], Canada | GT1M | N=73, 68.8 years (3); men/women=0/73, mean MVPA=156 (90) min/day | 4 days (including 1 weekend day) ≥10 h/day | Removed ≥10 min of consecutive zero counts and periods of monitor malfunction (counts >20,000). Removed overnight accelerometer data identified from logs. Visual inspected data and confirmed the pedometer and self-reported physical activity of participants with over 60 min of MVPA. | 4 days (including 1 weekend day) ≥10 h/day | ≥574 |
| Gerhdam et al. [27], Sweden | 71526 | N=70, 81 years (0.1); men/women=0/57, median MVPA=13 (6–23) min/day | 7 days, 10-s epoch | Removed ≥10 min of consecutive zero counts and periods of monitor malfunction (counts >20,000). Removed overnight accelerometer data identified from logs. Visual inspected data and confirmed the pedometer and self-reported physical activity of participants with over 60 min of MVPA. | 5 days ≥28 h/day | >1,952 |
| Johanssen et al. [39], USA | ActiGraph (model number not provided) | N=153, Aged group (N=58): 69 years (1); nonagenarian (N=95): 92 years (0.3)Men/Women 46/49 | 14 days, 1 minute epoch | Removed ≥10 min of consecutive zero counts and periods of monitor malfunction (counts >20,000). Removed overnight accelerometer data identified from logs. Visual inspected data and confirmed the pedometer and self-reported physical activity of participants with over 60 min of MVPA. | 7 days ≥22.9 hours/day | ≥574 |
| Study (data source) | Model | Population, amount of physical activity | Data collection | Data cleaning | Data inclusion | Cut-points (counts/min) |
|---------------------|-------|----------------------------------------|----------------|--------------|---------------|------------------------|
| Matthews et al. [54], USA (NHANES 2003–2004) | 7164 | \(N=1,437, 60–85\) years; men/women = 710/727; MVPA not reported | 7 days, 1-min epoch | Removal of ≥60 min of consecutive zero counts with allowance for up to 2 min of counts between 1 and 100 and data from monitors that were not in calibration when returned. | 1 day ≥10 h/day | Moderate to vigorous <100 Sedentary |
| Metzger et al. [56], USA (NHANES 2003–2004) | 7164 | \(N=1,901\); men and women ≥60 years, MVPA reported by days of the week | 7 days, 1-min epoch | Removed ≥60 min of consecutive zero counts and monitor malfunction (10 min of identical consecutive nonzero count values). Missing data were imputed for files with at least 1 day. | 1 day | ≥2,020 |
| Orsini et al. [61], Sweden (Swedish mammography) | 7164 | \(N=116\); 64.4 years (5.6); men/women = 59/57; MVPA not reported | 7 days, 1-min epoch | Removal of ≥60 min of consecutive zero counts and periods of monitor malfunction (counts >20,000). | 4 days ≥10 h/day | 760 ≥259 |
| Orsini et al. [62], Sweden (Swedish mammography) | 7164 | \(N=133\); 64.2 years (5.7); men/women = 69/64; MVPA not reported | 7 days, 1-min epoch | Removal of ≥60 min of consecutive zero counts and periods of monitor malfunction (counts >20,000). | 4 days ≥10 h/day | 760 ≥259 |
| Parker et al. [63], USA | 7164 | \(N=84\); 71.3 years (8.4); men/women = 28/56; MVPA not reported | 7 days, 1-min epoch | Removal of data resulting from monitor malfunctions identified with visual inspection. On and off times provided from participant logs. | 5 days ≥10 h/day | Individualized (based on 400 m walk) |
| Pruitt et al. [68], USA | 7164 | \(N=259\); Men and women ≥60 years, MVPA 79.7 (46.7) min/day | 7 days, 1-min epoch | Removal of ≥60 min of consecutive zero counts. | 4 days ≥10 h/day | 760 ≥2020 |
| Strath et al. [81], USA (NHANES 2003–2004) | 7164 | Men and women ≥60 years, MVPA (non-bouted) 54.5 (37.3) min/day | 7 days, 1-min epoch | Removal of ≥60 min of consecutive zero counts. | 4 days ≥10 h/day | 760 ≥2020 |
| Troiano et al. [87], USA (NHANES 2003–2004) | 7164 | \(N=1,260\); men = 71.1 (0.4) years; women = 70.4 (0.2) years; men/women = 54/46; MVPA not reported | 7 days, 1-min epoch | Removal of ≥60 min of consecutive zero counts with allowance for 1–2 min between 0 and 100, ≥60 min if monitor did not return to zero; and data from monitors that were not in calibration when returned. | 4 days ≥10 h/day | 760 ≥2020 |
| Brandon et al. [5], Canada GT1M | 7164 | \(N=48\); 77.4 years (4.7); men/women = 12/36; MVPA 16.5 (44.5) min/day | 7 days, 1-min epoch | Removal of zero counts when the accelerometer was not worn by verifying the data with the log book. | 7 days | ≥3,250 (based on 4 METs) |
| Copeland and Esliger [14], Canada GT1M | 7164 | \(N=38\); 69.7 years (3.5); men/women = 18/20; MVPA 68.2 (32.5) min/day | 7 days, 1-min epoch | Referenced to Esliger et al. [19]. | 5 days ≥10 h/day | 1,041 ≤50 |
| Harris [35], UK GT1M | 7164 | \(N=238\); ≥65 years; men/women = 124/114; moderate PA 2.5% of study participants met the recommended level of 150 min/week | 7 days, 5-s epoch | Removal of non-wear time verified with activity logs in individuals with average daily step counts less than 2,500. | 5 days | ≥2,000 ≤200 |
| Kang et al. [41], USA | 7164 | \(N=91\); Men and women ≥60 years, MVPA not reported | 7 days | Missing data imputed using a semi-simulation design. | Three weekdays and one weekend | 1,951 |
| 2010 (\(N=6\)) | 7164 or 71256 | \(N=862\); 75.4 years (6.8); men/women = 380/482; MVPA 12.3 min/day | 7 days, 1-min epoch | Visually identified and removed malfunctioning accelerometer units (maximum recordable value or periods of repeated non-zeros). Valid hours had <30 consecutive zeros. | 5 days ≥10 h/day or ≥66 valid hours over 7 days | 1,952 ≤100 |
| Study (data source) | Model | Population, amount of physical activity | Data collection | Data cleaning | Data inclusion | Cut-points (counts/min) |
|---------------------|-------|----------------------------------------|----------------|--------------|---------------|-----------------------|
| Hagström et al. [31], Sweden, USA (ABC and NHANES 2003–2004) | 7164 | 60–75 years; men/women, accumulated time, US N = 486; moderate PA, men 15 [13, 17] and women; 10 [9, 12] min/day; Sweden, N = 218, moderate PA men 29 [25, 34] and women 23 [20, 28] min/day | 7 days, 1-min epoch | Removed ≥60 min of consecutive zero counts with allowance for 1–2 min of counts between 0 and 100. | 4 days ≥10 h/day | ≥2,020 <100 |
| Ham and Ainsworth [32], USA (NHANES 2003–2004) | 7164 | N = 939; men and women 65–74 years = 495, ≥75 years = 444, MVPA not reported | 7 days, 1-min epoch | Removed ≥60 min of consecutive zero counts with allowance for 1–2 min of counts between 1 and 100 and invalid recordings due to monitor malfunction. Implausible data were replaced with imputed data. | 4 days with at least one weekend day ≥10 h/day | ≥760 |
| Hurtig-Wennlöf et al. [38], Sweden | GT1M | Men/women=23/31, N=54, median (IQR): men 71 years (68 to 76); moderate PA men 29 [25, 34] and women 23 [20, 28] min/day | 7 days, 15-s epoch | Removal of >20 min of consecutive zero epoch counts with interruptions of up to two counts of >250 activity counts/min; 2) steps/min >200; and 3) 32,767 activity counts/min (maximum value) or if the ActiGraph were not in calibration when returned. | 5 days | ≥1,952 <260 |
| Jürimäe et al. [40], Estonia | 7164 | N = 49, 73.6 years (4.2); men/women=0/49, median (IQR): men 74 years (69 to 74); moderate PA 85 (65–99) min/day | 7 days, 5-s epoch | Visual inspection to remove unusually low/high activity counts and the continuous data with the same values. Compared data to log. | 1 day ≥10 h/day | ≥2,020 |
| Peters et al. [66], China (N=18) | 7164 | Men and women ≥60 years, MVPA 79.5 (57.2–105.7) min/day | 7 days, 1-min epoch | Removed ≥60 min with a modified threshold of ≥50 counts/min. | 2 days ≥10 h/day | ≥760 <100 |
| Camhi et al. [9], USA (NHANES 2005–2006) | 7164 | N =1,196, ≥60 years; men/women= 611/585, MVPA 10.4 (9.1–11.7) min/day | 7 days, 1-min epoch | Removal of outliers and unreasonable values: data with ≥10 min of 1) 0 steps and ≥250 activity counts/min; 2) steps/min ≥200; and 3) 32,767 activity counts/min (maximum value) or if the ActiGraph were not in calibration when returned. | 1 day ≥10 h/day | ≥1,952 <100 |
| Cerin et al. [10], Hong Kong | GT1M | N=96, 65–74 years, 62 % 75–84 years, 36 % 85+ years; 2 % men/women=40/56, MVPA 161 (145) min/week | 7 days, 1-min epoch | Removed ≥100 min of consecutive zero counts | 5 days (including one weekend day) ≥10 h/day | ≥1,952 <100 |
| Clark et al. [13], USA (NHANES 2003–2004 and 2005–2006) | 7164 | N = 2,303; men and women 70 years (7.6), MVPA not reported | 7 days, 1-min epoch | Removed ≥60 min of consecutive zero counts with interruptions of up to two counts of 550 activity counts/min. Epoch reduced to 1 min. Removed ≥100 consecutive zero counts. | 4 days (including one weekend day) ≥10 h/day | ≥1,952 <100 |
| Davis et al. [17], UK (OPAL) | GT1M | N = 230, 78.1 years, men/women=117/113, MVPA 3.6 (3.4–27.9) min/day | 7 days, 10-s epoch | Removed ≥100 min of consecutive zero counts with interruptions of up to one count of ≥50 activity counts/min. Epoch reduced to 1 min. Removed ≥100 consecutive zero counts. | 5 days ≥10 h/day | ≥1,952 <100 |
| Davis et al. [16], UK (OPAL) | GT1M | N = 214, 78.1 (5.7) years; men/women= 169/105; MVPA ranged from 14.3 (22.4–19.8) (22.6) min/day depending on the day of the week | 7 days, 10-s epoch | Removed ≥100 min of consecutive zero counts | 5 days ≥10 h/day | ≥1,952 |
| Fox et al. [21], UK (OPAL) | GT1M | N = 240; men 77.5 years (5.6); women 78.6 years (8.6); men/women=125/115, MVPA not reported | 7 days, 10-s epoch | Removed ≥100 min of consecutive zero counts | 5 days ≥10 h/day | ≥1,952 |
| Gardiner et al. [25], Australia (Gardiner) | GT1M | N=48, 72.8 (8.1) years; men/women= 13/35, MVPA not reported | 7 days, 11-min epoch | Removed ≥100 min of consecutive zero counts | 5 days ≥10 h/day | ≥1,952 |
| Gardiner et al. [26], Australia (Gardiner) | GT1M | N=59, 74.3 (9.3) years; men/women= 15/44, MVPA not reported | 7 days, 11-min epoch | Removed ≥100 min of consecutive zero counts | 4 days ≥10 h/day | ≥1,952 <100 |
| Study (data source)          | Model | Population, amount of physical activity | Data collection | Data cleaning                         | Data inclusion                                                                 | Cut-points (counts/min)                  |
|-----------------------------|-------|------------------------------------------|-----------------|---------------------------------------|--------------------------------------------------------------------------------|------------------------------------------|
| Gonzales et al. [28], USA   | GT1M  | N = 40; range, 60–78 years; men/women = 19/21; MVPA men 109 (49) min/day; women 85 (36) min/day | 4 days, 10 s epoch | Removed ≥ 60 min of consecutive zero counts | ≥ 1,041                                                                            |
| Hart et al. [36], USA       | 7164  | N = 52, 69.3 years (7.4); men/women = 13/39, 12.0 (5.2–30.0) to 15.7 (6.5–39.0) min/day | 21 days, 1-min epoch | Removed ≥ 60 min of consecutive zero counts | ≤ 50, moderate lifestyle activity 760–1,951; moderate-to-vigorous ≥ 1,952 |
| King et al. [42], USA (SNQLS) | 7164 or 71256  | N = 719, 74.4 (6.3) years; men/women = 338/381; MVPA (median) 48.5 (18.7) to 83.6 (18.9) min/week | 7 days, 1-min epoch | Removed ≥ 60 min of consecutive zero counts | 5 days ≥ 10 h/day OR ≥ 60 valid hours across 7 days ≤ 1,952 |
| Marquez et al. [50], USA  | GT1M  | N = 60; 69.9 (5.8) years; men/women = 0/60; MVPA (baseline exercise group, 83.6 (35.2); control group, 79.6 (37.8) min/day | 7 days, 15-s epoch | Removed ≥ 60 min of consecutive zero counts | 3 days ≥ 10 h/day ≤ 1,566 |
| Marques et al. [48], Portugal (Marques) | GT1M  | N = 60; 69.9 (5.8) years; men/women = 0/60; MVPA (baseline exercise group, 83.6 (35.2); control group, 79.6 (37.8) min/day | 7 days, 15-s epoch | Removed ≥ 60 min of consecutive zero counts | 4 days ≥ 1,041 |
| Marques et al. [49], Portugal (Marques) | GT1M  | N = 60; 69.0 years (5.3); men/women = 0/71; MVPA (baseline resistance exercise group, 93.2 (26.3); aerobic exercise group, 86.2 (32.1); control group, 78.8 (40.5) min/day | 7 days, 15-s epoch | Removed ≥ 60 min of consecutive zero counts | 4 days ≥ 1,041 |
| Peclova et al. [65], Czech Republic | GT1M  | N = 92; men/women = 0/92; MVPA (median) control group, 62.61 (6.8) years; median 200 (242) min/week; women with osteopenia 65.76 (5.21) years, 160 (202) min/week | 8 days, 1-min epoch | Referenced to Esliger et al. (2005) [19]. | ≤ 2,020 |
| Silva et al. [77], Portugal | GT1M  | N = 123, ≥ 60 years; men/women = 40/83; MVPA (median (SEM)) men, 33.2 (3.6) min of MVPA, women 27.8 (2.5) min | 7 days, 15-s epoch | Removed ≥ 60 min of consecutive zero counts | 4 days ≥ 10 h/day ≤ 1,566 |
| Tucker et al. [89], USA (NHANES 2005–2006) | 7164  | Men and women ≥ 60 years; moderate PA 33–45 min/week for 60 years+ | 7 days, 1 min epoch | Removed ≥ 60 min of consecutive zero counts | 4 days ≥ 10 h/day ≤ 2,020 |
| Zhang et al. [96], USA  | GT1M  | N = 32, ≥ 60 years; men/women = 10/22; moderate PA men 23 min/day; women 7.7 min/day | 4 days, 1-min epoch | Removed ≥ 60 min of consecutive zero counts with allowance for 1–2 min of counts between 0 and 100 | 2 days ≥ 10 h/day ≤ 2,020 |
| 2012 (N = 13)              |       |                                          |                 |                                       |                                                                                     |
| Baptista et al. [3], Portugal | GT1M  | N = 679, men/women = 268/411; moderate PA men 74.4 (6.8) years, 30.8 (1.3) min/day; women 74.3 (7.0) years; 22.9 (1.0) min/day | 4 days, 15-s epoch | Removed ≥ 60 min of zero activity intensity counts and non-wear time identified from participant logs | 3 days (including one weekend day) ≥ 10 h/ day ≤ 2,020 |
| Gába et al. [24], Czech Republic | GT1M  | N = 97, 63.6 (5.23) years; men/women = 0.97; moderate PA 225 (152) min/week | 7 days, 15-s epoch | Removed ≥ 60 min of consecutive zero counts | ≥ 10 h/day ≤ 1,952 |
| Grimm et al. [29], USA      | 7164  | N = 127, 63.9 (7.7) years; men/women = 31/96; moderate PA 103.1 (45.6) min/day | 7 days, 1-min epoch | Removed ≥ 60 min of consecutive zero counts | 5 days ≥ 10 h/day ≤ 760 |
| Hamer et al. [33], UK (Whitehall II Study 2009/2010) | GT3X  | N = 443, 66 (6) years; men/women = 223/220; MVPA 59.8 % of men and 49.3 % of women recorded at least 30 min/day | 7 days | Removed first and last days of data, removed ≥ 60 consecutive minutes of zero count | 6 days ≥ 10 h/day ≤ 1,999 |

Table 1 (continued)
Table 1 (continued)

| Study (data source)          | Model | Population, amount of physical activity | Data collection | Data cleaning | Data inclusion | Cut-points (counts/min) |
|-----------------------------|-------|------------------------------------------|-----------------|---------------|---------------|--------------------------|
| Hansen et al. [34], Norway  | GT1M  | $N = 591$, men 71.8 (5.3) y, women 71.9 (5.7) y; men/women=296/295, MVPA 27.9 (1.0 SEM)min/day | 7 days, 10-s epoch | Removed ≥60 consecutive minutes of zero counts with allowance for 1 min with counts >0. Excluded 12AM–6AM as overnight non-wear time. | 4 days ≥10 h/day | Moderate activity, ≥2,020; moderate lifestyle activity: >760 ≥2,019 ≤100 |
| Hekler et al. [37], USA (SNQLS) | 7164 and 71256 | $N = 870$, 75.3 (6.8) y; men/women=377/493; MVPA not reported | 7 days (×2 phases), 1-min epoch | Removed ≥45 consecutive minutes of zero counts | 5 valid days (30 consecutive “zero” and ten valid hours per day rule) OR ≥66 valid hours across 7 days day ≥10 h/day | >1952 ≤100 |
| Koster et al. [44], USA (NHANES 2003–2004) | 7164 | $N = 1,906$, 63.8 (10.5) y; men/women=46.0 %/54.0 %, MVPA 14.2 (17.4) min/day | 7 days | Removed ≥60 consecutive minutes of zero counts (allowance for up to two minutes of counts between 1 and 100) | 1 day ≥10 h/day | ≥2,020 <100 |
| Santos et al. [75], Portugal | GT1M | $N = 296$, 74.42 ±6.72) y; men/women=112/184, MVPA 25.5 (25.8) min/day | 4 days, 15-s epoch | Removed ≥60 consecutive minutes of zero counts | 3 days (including 1 weekend day) ≥10 h/ day | ≥2,020 <100 |
| Stamatakis et al. [78], UK (Health Survey for England) | GT1M | $N = 649$, ≥60 years, men/women=292/357, MVPA not reported | 7 days, 1-min epoch | Removed ≥60 consecutive minutes of zero counts (allowance for up to two consecutive minutes of 1–100) | 1 day ≥10 h/day | ≥2,020 <100 |
| Strath et al. [80], USA | 7164 | $N = 148$, 64.3 (8.4) y; men/women=20.4 %/79.6 %, MVPA not reported | 7 days, 1-min epoch | Removed ≥60 consecutive minutes of zero counts | 4 days ≥10 h/day | >760 ≤50 |
| Swartz et al. [82], USA | 7164 | $N = 232$, 64.3 (6.9) y; men/women=56/176, MVPA 22.9 (22.0) min/day | 7 days | Removed ≥60 consecutive minutes where count was zero; removed values >20,000 | 4 days (including 1 weekend day) ≥10 h/ day | ≥1,952 <100 |
| Theou et al. [84], Greece | GT1M | $N = 50$, range, 63–90 y; men/women=50 | 1 day, 1-min epoch | Compared various data cleaning protocols | | |
| Winkler et al. [95], Australia (AusDiab 2004–2005, NHANES 2003–2004) | 7164 (not available) | $N = 44$, men and women ≥60 years, MVPA not reported | 7 days, 1-min epoch | | | ≥1,952 <100 |

ABC Attitude Behaviour Change, NHANES National Health and Nutrition Examination Survey, OPAL Older People and Active Living, SNQLS Senior Neighbourhood Quality of Life Study, MVPA moderate to vigorous physical activity, MET metabolic equivalent of task
resulted in an average of 68% sedentary time per day. Using Bland-Altman methods and the most common cut-point (>100) as the reference, the observed differences ranged from −47 to 143 min/day (Table 5).

**Table 2** Participant characteristics for the accelerometer data sample of older women (N=114)

| Measure                          | Mean (SD)/median (IQR) |
|---------------------------------|------------------------|
| Age, years                      | 69.6 (2.9)             |
| Body mass index, kg/m²          | 26.6 (5.0)             |
| Six-minute walk test, m         | 541.5 (75.03)          |
| Physical Activity Scale for the Elderly (PASE) | 120.5 (75.3 to 158.6) |
| Valid accelerometry days, days  | 6 (5 to 6)             |

**Table 3** Minutes per day of moderate to vigorous physical activity (MVPA) based on accelerometry, for the sample data of 114 older women analyzed with the different cut-points identified by a review of the available literature

| MVPA cut-point (counts/minute) | Median minutes/day (IQR) | % (95% CI) who met criteria | Mean Difference (SD) | +/- 1.96 | Median bouted min/day (IQR) | Mean Difference (SD) | +/- 1.96 |
|--------------------------------|--------------------------|----------------------------|--------------------|----------|-----------------------------|----------------------|----------|
| ≥574                           | 80.1 (56.9 to 117.3)     | 94.7 (91.6 to 98.8)        | 63.75 (29.18)     | 57.19    | 24.3 (6.6 to 46.4)          | 15.59 (14.69)        | 28.80    |
| ≥760                           | 61.8 (39.9 to 88.6)      | 85.1 (78.5 to 91.6)        | 42.35 (21.26)     | 41.66    | 17.7 (5.1 to 36.9)          | 9.92 (9.64)          | 18.90    |
| ≥1041                          | 43.1 (25.5 to 62.0)      | 64.0 (55.2 to 72.8)        | 23.37 (12.88)     | 25.25    | 13.9 (2.7 to 31.3)          | 5.84 (6.27)          | 12.29    |
| ≥1566                          | 27.3 (11.7 to 44.8)      | 44.7 (35.6 to 53.9)        | 6.50 (4.00)       | 7.85     | 10.5 (0 to 26.4)            | 2.28 (3.02)          | 5.92     |
| ≥1952                          | 19.7 (6.9 to 35.8)       | 33.3 (24.7 to 41.9)        | Reference         | Reference | 7.4 (0 to 23.5)             | Reference            | Reference |
| ≥2000                          | 19.4 (6.6 to 34.8)       | 31.6 (23.05 to 40.1)      | −0.59 (0.48)      | 0.94     | 7.1 (0 to 22.9)             | −0.29 (0.76)         | 1.49     |
| ≥2020                          | 19.1 (6.6 to 34.6)       | 31.6 (23.05 to 40.1)      | −0.88 (0.69)      | 1.35     | 7.1 (0 to 22.9)             | −0.40 (0.90)         | 1.77     |
| ≥3250                          | 3.6 (0.4 to 12.9)        | 4.4 (0.6 to 8.1)           | −15.47 (14.09)    | 27.61    | 0 (0 to 7.1)                | −9.35 (13.38)        | 26.22    |

The table includes median minutes of MVPA/day and mean difference (SD +/- 1.96) of different cut-points compared with the mostly frequently used cut-point (≥1,952 counts/min) based on the results from Bland-Altman methods

*a Recommended minimum of 30 min average MVPA per day

**Discussion**

In this systematic review, we identified 59 publications that used ActiGraph accelerometers at the wrist to classify the activity patterns of older adults. Although the field is moving toward pattern recognition [67], accelerometry data analysis using cut-points remains the most common method used. We found eight cut-points used for classifying MVPA, ranging from 574 to 3,250 counts/min. We also identified five cut-points used for classifying sedentary time, ranging from 50 to 500 counts/min. This wide range of cut-points resulted in a correspondingly large range of minutes of MVPA (4 to 500 counts/min. This wide range of cut-points led to a substantial range of observed differences across age groups and potential physical capacity (6MWT). Therefore, different cut-points can substantially impact the classification of meeting recommended guidelines and the proportion of time spent in sedentary behaviors for a sample of healthy community-dwelling older adults.

Within our review of available evidence, we noted that more than half of the publications reported using the previous models [7164, 71256, and MTI (7162)] to acquire data. More recent evidence reports that the previous accelerometer models were more sensitive to movement. For example, in a 2013 article by Cain and colleagues [8], the authors noted significant differences between the older ActiGraph models and the more recent one (GT3X+). Specifically, the newer model (GT3X+) had significantly less daily step counts, more minutes of sedentary time and less light activity compared with the 7164. However, these differences were attenuated with the application of the low-frequency extension filter to the results from the newer models. Other recent studies support these findings [71, 91], and the understanding is that thresholds of the newer models were raised to overcome “noise” resulting from daily environmental vibrations. However, this higher threshold may be a limitation when measuring activity patterns of older adults who have slower gait speed and low activity patterns.
Although there is currently no consensus on the optimal cut-points for older adults, the majority of studies use the same cut-points for MVPA (1,952 counts/min) and sedentary time (100 counts/min), and this allows for comparison between the studies. However, these cut-points are not specific to older adults; the most commonly reported cut-point of 1,952 counts/min was validated in young adults [23]. Older adults may have a different capacity for activity, and their walking patterns may be altered [55] with increased energy expenditure [47, 51]. That is, for the same activity, older adults may expend more energy to complete a task compared with a fitter, younger adult. Therefore, a lower cut-point for MVPA than what is used in adult research may be appropriate due to the age-related decline in fitness, if present. Ideally, individualized cut-points, which were used in one of the studies included in the review [68], would allow for the most accurate assessment of an individual’s activity level and reduce the risk of overestimating or underestimating physical activity. Individualized cut-points are not always feasible, and age-specific cut-points may be an appropriate compromise for older adults, but the results will also depend on the physical capacity of the participants. For example, Copeland and colleagues’ [14] cut-point of 1,041 counts/min was developed specifically for older adults, and using this cut-point resulted in 64 % of the older women in our dataset meeting physical activity guidelines compared with 33 % meeting guidelines using the most commonly reported cut-point of 1,952 counts/min. Other investigations showed that different cut-point values result in statistically significant changes in the amount of MVPA [20] while Miller and colleagues [57] investigated the impact of age on the validity of ActiGraph accelerometers using a lab-based treadmill protocol. They found that there was no statistically significant difference across age groups for the absolute physical activity intensity. However, there was a significant difference in the relative physical activity intensity due to individual differences in cardiorespiratory and muscular fitness as a result of the aging process or physical inactivity.

The results from our analyses highlight that approximately one third of study participants were active for ≥30 min/day. This may reflect the fact that the study participants were active, community-dwelling older women and not representative of all older adults. In our review of the literature, we noted a range of physical activity results, including: a number of other studies that also reported high levels of MVPA for their study participants [30, 38] and population-based studies reporting very low values for MVPA [31]. Thus, the selection of cut-points may depend on target group and the purpose of the investigation. Using the same cut-points across all age groups may be appropriate for large epidemiological studies (that are interested in the absolute physical activity intensity), but age-specific cut-points may be necessary for physical activity prescription or when investigating the dose–response and effectiveness of interventions (where relative physical activity intensity is of interest). In addition, many recent studies have divided the MVPA category into two categories representing moderate lifestyle activity and moderate intensity physical activity. This allows for the comparison to studies using other cut-points.

We found that, for sedentary time, the range of cut-points resulted in a difference of 25 %, or over 3 h/day, which is important as older adults could spend a large proportion of their day in sedentary activities. It is promising that the majority of studies are using the same cut-points for sedentary time. However, to our knowledge, there are no studies that validated sedentary cut-points for older adults. This is an emerging area of research, and older adult specific validation is needed.

Another issue that can affect the accuracy of reported sedentary time is the ability to differentiate between non-wear time and sedentary time [94]. This is of particular concern for older adults’ accelerometer data because the large amount of time they spend in sedentary behaviors can potentially lead to the misclassification of sedentary time as non-wear time [94]. Of the included publications, 50 reported

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**Table 4** Odds ratios of not meeting 30 min/day of MVPA using accelerometry and different cut-points, based on age and six-minute walk test (6MWT)

| MVPA cut-point (counts/min) | ≥574 | ≥760 | ≥1,041 | ≥1,566 | ≥1,952 | ≥2,000 | ≥2,020 | ≥3,250 |
|----------------------------|------|------|--------|--------|--------|--------|--------|--------|
| Age groups                 |      |      |        |        |        |        |        |        |
| 65 to 68 years (reference) | 1.00 | 1.00 | 1.00   | 1.00   | 1.00   | 1.00   | 1.00   | 1.00   |
| 69 to 72 (N=44)            | b    | 1.66 | 1.65   | 1.56   | 1.80   | 1.83   | 1.83   | 1.83   |
| 73 to 76 (N=24)            | b    | 4.32 | 5.30   | 4.94   | 5.88   | 5.38   | 5.38   | 5.38   |
| 6MWT scores (N=104) a      |      |      |        |        |        |        |        |        |
| >490 m (N=81) (reference)  | 1.00 | 1.00 | 1.00   | 1.00   | 1.00   | 1.00   | 1.00   | 1.00   |
| ≤490 (N=23)                | 1.80 | 6.67 | 9.92   | 13.80  | 15.92  | 14.37  | 14.37  | 14.37  |

Relative odds of not meeting 30 minutes of moderate to vigorous physical activity (MVPA) by age and by MVPA cut-points

a Relative odds of not meeting 30 min of MVPA by age and by MVPA cut-points

b No valid estimates calculated
some assumptions for their data cleaning procedure to identify spurious data or non-wear time (Table 1). The most common criteria for non-wear time (24 of 50) was based on the NHANES recommended protocol for the removal of 60 min or more of continuous zeros with allowance of 1–2 min with counts between 1 and 100 [87]. More recent literature suggests 90 min may be more appropriate for some older adults [12], and by limiting the sedentary time to 60 min at a given time, we may be underestimating sitting time. These are both important points and should be considered during the analysis process for the current way of data analysis. Finally, we acknowledge that we did not have a criterion measure of participants’ activity level to compare the results with and ultimately determine the optimal cut-points. However, we used the results from the 6MWT to calculate odds of not meeting 30 min/day of MVPA.

Future research in this area is promising as there are increasingly more studies being published using ActiGraph accelerometers in older adults. All of the publications identified in this review were published since 2004. Despite this growth in research utilizing accelerometers, many researchers are using a variety of different cut-points. Accelerometry is not only being used in healthy community dwelling older adults, as in the current study, but also in a variety of other specific populations (e.g., adults, older adults after stroke, or in hospital), and appropriate assumptions for these groups may need to be condition-specific. Furthermore, technological advances in device hardware and analysis software continue to evolve. With respect to analysis of data, this includes using artificial intelligence to identify activity types [67, 79]. Many of these advances are still under development, thus current practice remains in favor of using the manufacturer-provided software that allows for cut-point analysis. The monitors themselves continue to increase in memory capacity and battery life to allow for the collection of data in shorter epochs or in raw form for longer time periods as well as the addition of multiple axes.

### Conclusion

In summary, our review highlights that there is not a standardized method to quantifying accelerometry-based physical activity and sedentary time in older adults. The assumptions used in data analysis of accelerometer data can produce markedly different results, and using too low or too high cut-points may obscure important group or treatment differences. For future studies, standard reporting should include specific data assumptions for analysis. Further research is needed to determine which assumptions are most appropriate for older adults, taking into account their physical capacity.

### Disclosures

**Conflict of interest statement** All authors declare that they have no conflict of interest.
Informed consent All procedures followed were in accordance with the ethical standards of the responsible committee on human experimentation (institutional and national) and with the Helsinki Declaration of 1975, as revised in 2000 (5). Informed consent was obtained from all participants for being included in the study.

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