

# CALIBRATION OF WRIST- AND HIP-WORN ACCELEROMETERS IN OLDER ADULTS

1 Evaluation of wrist and hip sedentary behaviour and moderate-to-vigorous physical  
2 activity raw acceleration cutpoints in older adults

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45 **Evaluation of wrist and hip sedentary behaviour and moderate-to-vigorous**  
46 **physical activity raw acceleration cutpoints in older adults**

47

48 **Abstract**

49 Wrist-based accelerometers are now common in assessing physical activity (PA) and  
50 sedentary behaviour (SB) in population-based studies, but there is a scarcity of raw  
51 acceleration cutpoints in older adults. The study aimed to determine and evaluate  
52 wrist-based GENEActiv (GA) and hip-based ActiGraph GT3X+ (AG) raw  
53 acceleration cutpoints for SB and moderate-to-vigorous PA (MVPA) in older adults  
54  $\geq 60$  years of age. A laboratory-based calibration analyses of 34 healthy older adults  
55 involved receiver operator characteristic (ROC) curves to determine raw acceleration  
56 cutpoints for SB and MVPA. ROC analysis revealed an area under the curve (AUC)  
57 of 0.88 for GA SB and MVPA, and 0.90 for AG SB and 0.94 for AG MVPA.  
58 Sensitivity optimised SB and specificity optimised MVPA GA cutpoints of 57 mg  
59 and 104 mg, and AG cutpoints of 15 mg and 69 mg were also generated,  
60 respectively. Cross-validation analysis revealed moderate agreement for GA and AG  
61 SB cutpoints, and fair to substantial agreement for GA and AG MVPA cutpoints,  
62 respectively. The resultant cutpoints can classify older adults as engaging in SB or  
63 not engaging in MVPA but the sensitivity optimised SB cutpoints should be  
64 interpreted with a degree of caution due to their modest cross-validation results.

65

66 **Key Words:** *Accelerometry; Activity Monitors; Calibration; Cross-validation;*  
67 *Ageing*

68

## 69    **Introduction**

70    There is strong evidence supporting the benefits of reducing sedentary behaviour  
 71    (SB) and increasing physical activity (PA) in older adults (Devereux-Fitzgerald,  
 72    Powell, Dewhurst, & French, 2016; Greaney, Lees, Blissmer, Riebe, & Clark, 2016;  
 73    Kim, Im & Choi, 2016; Lewis, Napolitano, Buman, Williams, & Nigg, 2017).  
 74    Despite this, older adults (e.g., aged 60+ years; Heo et al., 2017) remain the most  
 75    sedentary and physically inactive segment of society (Chastin et al., 2017). Older  
 76    adults spend approximately 80% of their awake time engaged in SB which represents  
 77    eight to 12 hours/day (Chastin et al., 2017). Furthermore, compliance with  
 78    recommended PA guidelines is poor in the general population and even worse in  
 79    older adults (Troiano et al., 2008). Health Survey for England data indicate that only  
 80    20% of men and 17% of women aged 65 to 74 years meet recommended PA  
 81    guidelines (NHS, 2015). This contrasts with 49 % of men and 35 % of women aged  
 82    25 to 34 years (NHS, 2015). It is widely acknowledged that increasing age is  
 83    associated with decreased time spent in PA (Berkemeyer et al., 2016; Harvey,  
 84    Chastin & Skelton, 2014; Martinez-Gomez et al., 2017; Wullems, Verschueren,  
 85    Degens, Morse, & Onambélé, 2016) and this trend is apparent in older adults,  
 86    particularly after retirement age (Martinez-Gomez et al., 2017; Strain et al., 2016).  
 87    To exemplify this, Buman et al. (2010) reported that when comparing those between  
 88    66-69 years old with those aged 80 years and older, engagement in MVPA decreased  
 89    from 16.2 min·day<sup>-1</sup> to 10.7 min·day<sup>-1</sup>.

90

91    As described in the behavioural epidemiological framework (Sallis, Owen, &  
 92    Fotheringham, 2000), accurate measurements of SB and PA are needed to detect

93 potential correlates, identify relationships between such behaviours and associated  
94 health outcomes, and evaluate the efficacy of intervention strategies (Lewis et al.,  
95 2017). Accelerometry is now commonly adopted for monitoring older adults' SB  
96 and PA levels (Mañas et al., 2017; Oguma et al., 2017; Wullems, Verschueren,  
97 Degens, Morse, & Onambélé, 2017; Zhu et al., 2017), as it allows for valid, reliable,  
98 and accurate assessments of activity intensity, frequency, and duration (Mathie,  
99 Coster, Lovell, & Celler, 2004; Prince et al., 2008). Moreover, accelerometers are  
100 particularly appropriate for assessing PA in older adults as these devices require no  
101 input from the participant over the data collection period, and superior wearer  
102 compliance has been demonstrated when compared to younger age groups. For  
103 example, in the UK Biobank study of 103,578 adults and older adults, average wear  
104 time compliance of a wrist-worn triaxial accelerometers increased by an average of  
105 two hours 18 min·day<sup>-1</sup> (1.6%) for each decade from 40 to 79 years old (Doherty et  
106 al., 2017). Accelerometry also eliminates self-report questionnaire bias related to  
107 subjective recall of past events which is an ability that can decline with ageing  
108 (Barnett, van den Hoek, Barnett, & Cerin, 2016).

109

110 The hip has been the conventional attachment site for accelerometers because of its  
111 proximity to the centre of mass (Troiano, McClain, Brychta, & Chen, 2014; Van  
112 Hees et al., 2011). A limitation of hip-worn accelerometers in studies involving older  
113 adults (Copeland & Eslinger, 2009; Taylor et al., 2014) is that most commonly used  
114 cutpoints applied to data to classify PA intensity have been calibrated for younger  
115 adults (Falck, Davis, & Liu-Ambrose, 2016). As the energy expenditure associated  
116 with a given metabolic equivalent (MET) activity intensity threshold is lower in  
117 older adults compared to younger adults (Hall, Howe, Rana, Martin, & Morey,

118 2013), using accelerometer cutpoints developed in young adults would likely result  
119 in an underestimation of time spent in moderate-to-vigorous intensity PA (MVPA)  
120 (Barnett et al., 2016).

121

122 Recent accelerometer studies have suggested that the wrist may be a preferable  
123 attachment site as it can more accurately capture the arm motions of non-ambulatory  
124 based activities such as household chores (Evenson et al., 2015; Landry, Falck,  
125 Beets, & Liu-Ambrose, 2015), and is less influenced by atypical gait patterns and  
126 walking speed variability, which are both commonly observed in older adults (Ko,  
127 Jerome, Simonsick, Studenski, & Ferrucci, 2018). Wrist-worn accelerometers have  
128 demonstrated excellent validity against energy expenditure as the criterion measure,  
129 and in comparison to hip-worn monitors (Esliger et al., 2011). Furthermore, wrist-  
130 and hip-worn accelerometers have demonstrated comparable free-living MVPA  
131 classification accuracy (Hargens, et al., 2017). Superior wearer compliance has also  
132 been reported for accelerometers worn on the wrist versus the hip in large  
133 population-based studies including the National Health and Nutrition Examination  
134 Survey (NHANES), Dallas Heart Study, and the UK Biobank study adopting wrist-  
135 worn accelerometer protocols (Doherty et al., 2017; Lakoski & Kozlitina, 2014;  
136 Troiano et al., 2014). Specifically, wrist-worn data from the 2011 to 2012 cycle of  
137 NHANES showed that 70–80% of participants provided at least six days of data with  
138 at least 18 hours of wear. This contrasts with 40–70% of participants who provided  
139 at least six days of hip-worn accelerometer data with at least 10 hours of wear in the  
140 2003 to 2004 cycle of NHANES (Troiano et al., 2014).

141

142 A further development in accelerometer-based SB and PA research is the move  
 143 toward raw acceleration signal processing. This advance in accelerometer-based PA  
 144 monitoring, which has traditionally used accelerometer output reduced to  
 145 dimensionless activity “counts” per user-specified period of time or epoch  
 146 (Fairclough et al., 2016) is likely to provide greater methodological transparency in  
 147 post-data collection analytical processes and improve comparability of data between  
 148 different accelerometer models (Hildebrand, Van Hees, Hansen, & Ekelund, 2014).  
 149 Devices such as the GENEActiv (Activinsights, Cambs, United Kingdom) and  
 150 ActiGraph GT3X+ and GT9X (ActiGraph, Pensacola, FL) are capable of collecting  
 151 and recording raw unfiltered accelerations, which can then be subject to researcher-  
 152 driven data processing procedures (Welk, McClain, & Ainsworth, 2012). Interunit  
 153 reliability is acceptable for both brands (Esliger et al., 2011; Santos-Lozano et al.,  
 154 2012). Although time spent in SB and light, moderate and/or vigorous intensity PA  
 155 can be quantified from raw acceleration data (Matthew, 2005), currently, no raw  
 156 acceleration cutpoints for SB and MVPA exist for older adults. Consequently, the  
 157 aim of this study was to determine laboratory-based wrist-worn GENEActiv and hip-  
 158 worn ActiGraph GT3X+ raw acceleration cutpoints for SB and MVPA in older  
 159 adults.

160

## 161 **Methods**

### 162 *Study population*

163 A homogenous purposive sample of 34 community dwelling white, British older  
 164 adults (10 male), aged 60-86 years (mean age = 69.6, SD = 8.0 years) were recruited  
 165 through leaflets distributed at local fitness centres/gyms and community centres, and

166 through word of mouth referrals. A sample size of 30 participants was targeted so as  
167 to be comparable with recent calibration studies in older adults (Landry et al., 2015;  
168 Wullems et al., 2017). Individuals interested in participating in the study were pre-  
169 screened for inclusion criteria which set out that participants must be (1)  $\geq 60$  years  
170 of age, (2) be physically cleared for exercise using the modified Physical Activity  
171 Readiness Questionnaire (Modified PAR-Q; Cardinal, Esters, & Cardinal, 1996;  
172 Cardinal & Cardinal, 2000), (3) have the ability to walk briskly on a treadmill  
173 without assistance, and (4) not be taking any medications that would influence  
174 energy expenditure or their ability to perform ambulatory activity. Participants were  
175 excluded if they had a medical condition precluding them from exercise, were unable  
176 to wear a portable indirect calorimeter during testing, or had limited mobility such  
177 that they could not walk on a treadmill independently. Prior to the commencement of  
178 the study, institutional ethical approval was received (SPA-REC-2016-343) and all  
179 participants provided written informed consent prior to their inclusion.

180

### 181 *Anthropometrics*

182 Participants' body mass (Seca mechanical scales, Birmingham, UK) and standing  
183 height (Holtain Limited stadiometer, Crymych, UK) were measured in light clothing  
184 without shoes. Resting blood pressure was measured upon arrival and immediately  
185 prior to commencement of the accelerometer calibration protocol using a Boso  
186 Medicus Prestige blood pressure monitor (Boso Bosch + Sohn, Germany).

187

### 188 *Study protocol*



189 Participants completed two separate laboratory data collection visits (separated by  
190 one week) at the university site. Visit 1 was an initial familiarisation of the protocol  
191 structure, equipment, and laboratory. Participants also provided written informed  
192 consent and completed anthropometric measures, and a six-minute treadmill walk  
193 test (6MWT; ATS Committee on Proficiency Standards for Clinical Pulmonary  
194 Function Laboratories, 2002) to establish maximal walking speeds and to familiarise  
195 participants with treadmill walking at different speeds. Participants completed a  
196 laboratory-based protocol consisting of 16 activities (see Table 1 for protocol  
197 description). Older adults typically engage in SB and light intensity PA (LPA; Ku,  
198 Fox, Liao, Sun, & Chen, 2016) consisting of activities such as carrying light objects,  
199 walking slowly, and household chores (Public Health England, 2017). Thus, to  
200 represent these typical activity patterns and to make the distinction between sitting  
201 and standing, a range of sedentary, stationary, and LPA activities were included in  
202 the study protocol. MVPA activities reflected typical lifestyle behaviours of walking  
203 and stepping (e.g., stair climbing). All activities were performed in a standardised  
204 order as described in Table 1. Participants were provided with standardised  
205 instructions from a predetermined script delivered by the same researcher prior to  
206 beginning each activity. The activity protocol only was repeated at visit 2. Visit 1  
207 lasted ~80 minutes whilst visit 2 lasted ~60 minutes as participants did not need to  
208 repeat the familiarization components and 6MWT.

209

210 [INSERT TABLE 1 ABOUT HERE]

211

212 Sedentary, stationary and LPA activities were performed for 3-minutes each, whilst  
 213 the stepping and walking activities were performed for two minutes. Sedentary,  
 214 stationary, LPA, and stepping activities were separated by a 1-minute transition  
 215 period, whilst the treadmill walking activities were separated by 5-second transitions.  
 216 To ensure consistency across measurement sessions, the first author was trained and  
 217 led on all aspects of the measurement protocol. The start and end of each activity  
 218 was timed by the first author with a stopwatch (Fastime, Leicestershire, UK). All  
 219 instruments were synchronised to the same clock to ensure that criterion  
 220 measurements for a given period of activity were matched with time-stamped  
 221 accelerometer data for precisely the same duration of the activity. This allowed for  
 222 appropriate data comparisons to be made across all recording devices.

223

#### 224 *Accelerometers*

225 Participants wore GENEActiv (GA) (ActivInsights Ltd., Kimbolton,  
 226 Cambridgeshire, UK) and ActiGraph (AG) GT3X+ (ActiGraph, Pensacola, FL)  
 227 triaxial accelerometers on the non-dominant wrist and left hip, respectively. Both  
 228 monitors were set to collect raw triaxial accelerations at 60 Hz. Participants also  
 229 wore an activPAL (PAL Technologies Ltd., Glasgow, UK) accelerometer on the left  
 230 anterior thigh as the criterion measure for SB (Chastin, Culhane & Dall, 2014;  
 231 Varela Mato, Yates, Stensel, Biddle, & Clemes, 2017). The activPAL monitor has  
 232 been shown to accurately measure postural allocation when worn on the upper thigh  
 233 (Kozey-Keadle et al., 2011). It is valid for step counts, time spent sitting, lying,  
 234 standing, and walking, and is currently regarded as a gold standard for the objective  
 235 measurement of sedentary/sitting time and patterning of SB (Chastin et al., 2018;

236 Koster et al., 2016; Kozey-Keadle et al., 2011; Sellers, Dall, Grant, & Stansfield,  
 237 2016). The activPAL uses proprietary algorithms to classify activity into periods  
 238 spent sitting, standing, and stepping. activPAL data were collected at a sampling  
 239 frequency of 20 Hz. Participants wore the same monitors (matched by serial number)  
 240 for both visits. A total of six different GA and AG, and four different activPAL  
 241 monitors were used throughout the study. All devices were used and calibrated as per  
 242 manufacturers' instructions and initialised approximately 10 minutes before the start  
 243 of each data collection session.

244

245 Immediately after testing, the activity monitors were removed and the data  
 246 downloaded to a single, secured computer. The GA data were downloaded using  
 247 GENEActiv PC software version 2.9 (Activinsights, Cambs, United Kingdom) and  
 248 saved in raw format as .bin files, whilst the AG data were downloaded using  
 249 ActiLife version 3.13.3 (ActiGraph, Pensacola, FL), and saved in raw format as .gt3x  
 250 files and converted to time-stamped .csv files to facilitate raw data processing.  
 251 activPAL data were downloaded using activPAL3 software version 7.2.32 (PAL  
 252 Technologies Ltd., Glasgow, UK), saved as .datx files and converted to .csv "Event"  
 253 files for processing. Signal processing of raw GA .bin files and raw AG .csv files  
 254 was completed using R-package GGIR version 1.5 ([https://cran.r-](https://cran.r-project.org/web/packages/GGIR/)  
 255 [project.org/web/packages/GGIR/](https://cran.r-project.org/web/packages/GGIR/)) (van Hees et al., 2013b). GGIR facilitates data  
 256 cleaning and the extraction of user-defined acceleration levels, which can then be set  
 257 to reflect the intensity thresholds as derived in this study (Rowlands et al., 2016).  
 258 Concurrent with previous studies (Hildebrand et al., 2014; Fairclough et al., 2016;  
 259 Menai et al., 2017; Rowlands, Yates, Davies, Khunti, & Edwardson, 2016) and to  
 260 help promote comparability between studies, the Euclidean Norm Minus One

(ENMO) (van Hees et al., 2013b) was adopted to quantify acceleration relative to gravity ( $1 \text{ mg} = 0.00981 \text{ ms}^{-2}$ ), after which negative values were rounded to zero. The ENMO metric has proven competency and increasing use in the field (Vähä-Ypyä et al., 2015). ENMO has been shown to be comparable to other raw acceleration signal metrics such as MAD and HFEN in predicting PA energy expenditure (Bakrania et al., 2016; Van Hees et al., 2013b) and consequently, has been adopted in large scale studies for the analysis of raw acceleration data (Doherty et al., 2017; Menai et al., 2017). Furthermore, although there are differences in the design of the chosen GA and AG devices that may affect individual axis output, these differences affect the resultant ENMO values in a consistent manner with GA output approximately 10% higher than AG output (Rowlands et al., 2018).

272

Raw data were further reduced by averaging the ENMO values over 1-second epochs. All resulting values are expressed in milli ( $10^{-3}$ ) gravity-based acceleration units (mg), where  $1g = 9.81 \text{ m/s}^2$ . Although the ENMO metric can be sensitive to poor calibration (van Hees, et al., 2013b), GGIR autocalibrates the raw triaxial accelerometer signal in order to reduce such calibration error (van Hees et al., 2014). Where insufficient non-movement periods were available for auto-calibration (due to the relatively short duration of the protocol), back-up calibration coefficients derived from older adult males' and females' free-living data collected with the same accelerometer units were used (Hildebrand et al., 2016; Rowlands et al., 2018). Subsequently, no files were removed from the analytical sample as a result of calibration error. The activPAL "Event" files provided the exact time in seconds that posture changes occurred and each second was classified as sedentary, standing, or stepping. These files were then expanded using an Excel formula to obtain second-

by-second data, with each second subsequently classified as either sedentary or not sedentary. These second-by-second activPAL files were synchronised with the 1-second ENMO values from GA and AG. To exclude any transitional movements, the middle 2-minutes of data from each 3-minute activity were extracted and subsequently utilised for analysis. The full 2-minutes for each of the stepping and walking activities were used. This included the 5-second transition period between each walking speed.

293

#### 294 ***Energy Expenditure***

As the criterion measure for MVPA, oxygen consumption ( $\text{VO}_2$ ;  $\text{ml}\cdot\text{kg}\cdot\text{min}^{-1}$ ) was measured with a portable indirect calorimetry system (MetaMax 3B-R2, CORTEX Biophysik GmbH, Leipzig, Germany). The Metamax interface and breathing mask (7600 Series V2, Hans Rudolph, Kansas) were set up and fitted as per the manufacturer instructions.  $\text{VO}_2$  was measured using breath-by-breath mode and in order to match time periods across devices, data were stored in second-by-second intervals. These measurements were used to determine energy expenditure (EE), which was then used to classify activity intensity in METs. Resting energy expenditure was measured at visit 2 during the first three lying activities of the protocol. The observed mean resting energy expenditure was  $2.89 \text{ ml}\cdot\text{kg}\cdot\text{min}^{-1}$ , which was used to define 1 MET. This value is comparable with previous calibration studies in older adults (Barnett et al., 2016; Evenson et al., 2015; Sergi et al., 2010; Siervo et al., 2014), and is consistent with the expected decrease in RMR associated with ageing (Byrne, Hills, Hunter, Weinsier, & Schutz, 2005; Kwan, Woo, & Kwok,

2004). MVPA was defined as an intensity of 3 METs and above (e.g.,  $\geq 8.68$  ml·kg·min<sup>-1</sup>) (Shephard, 2011).

### ***Data Analysis***

*Cutpoint calibration.* A randomly counter-balanced sample of 17 participants (12 female, five male) from visit 1, and 17 participants (12 female, five male) from visit 2 provided the calibration data (N = 34). Descriptive statistics for all devices were calculated for each activity in the protocol. The activPAL sedentary events and 3 MET VO<sub>2</sub> values were used as the criterion reference standards for SB and MVPA, respectively. SB and MVPA were each coded as either 0 or 1, where 1 represented the behaviour occurring and 0 represented the behaviour not occurring. Receiver Operating Characteristic (ROC) curve analyses (Jago, Zakeri, Baranowski, & Watson, 2007) were used to determine SB and MVPA cutpoints. Area under the curve (AUC) was calculated for each analysis as a measure of diagnostic accuracy. AUC values of;  $\geq 0.90$  are considered excellent, 0.80–0.89 good, 0.70–0.79 fair, and  $< 0.70$  poor (Metz, 1978). For each device two different pairs of cutpoints were generated by analysing combinations of sensitivity (Se) and specificity (Sp) on the ROC curves. Our aim was to determine a cutpoint that accurately captured SB and MVPA (Se) whilst limiting misclassification of SB and MVPA (Sp). Two approaches were adopted to achieve this. Firstly, ENMO values that maximised both Se and Sp (Youden index) (Perkins & Schisterman, 2006) were identified as one set of cutpoints (SB<sub>Youden</sub> and MVPA<sub>Youden</sub>). The Youden index can however result in low positive predicted values (Evenson et al., 2015) and it is recommended that researchers consider the relative importance of Se and Sp (Welk, Laurson,

333 Eisenmann, & Cureton, 2011), and implications of the selected cutpoints on the  
 334 biobehavioural impact on the outcome variables (Mackintosh, Fairclough, Stratton,  
 335 & Ridgers, 2012). Secondly, cutpoints were determined that emphasised Se over Sp  
 336 for SB cutpoints ( $SB_{Se}$ ) to minimise the likelihood of classifying SB as PA, with Sp  
 337 emphasised over Se for MVPA cutpoints ( $MVPA_{Sp}$ ) to reduce the likelihood of  
 338 misclassifying light PA as MVPA. Both cutpoints reflected recommendations that  
 339 the lower Se or Sp values should be  $\geq 60\%$  (Lugade, Fortune, Morrow, & Kaufman,  
 340 2014). This prioritization approach minimises the risk of individuals being  
 341 misclassified in the target behaviour and is common in accelerometer calibration  
 342 (Landry et al., 2015; Mackintosh et al., 2012; Nero, Wallén, Franzén, Ståhle, &  
 343 Hagströmer, 2015) and fitness standards research (Welk et al., 2011). There was no *a*  
 344 *priori* preference for selecting either Youden or Se/Sp-based cutpoints, but instead  
 345 we wanted to examine the effect of both approaches and make an informed decision  
 346 as to which may be most suitable once the data were analysed.

347

348 *Cross-validation.* To be consistent with good practice guidelines suggested by Welk  
 349 (2005),  $SB_{Youden}$  and  $MVPA_{Youden}$ , and  $SB_{Se}$  and  $MVPA_{Sp}$  cutpoints were cross-  
 350 validated. Cross-validation analyses were performed with data from the 17  
 351 participants (12 female, five male) whose visit 1 data was not used in the calibration  
 352 analysis, and the 17 participants (12 female, five male) whose visit 2 data was not  
 353 used in the calibration analysis ( $N = 34$ ). Two-by-two ( $2 \times 2$ ) contingency tables were  
 354 used to check classification agreement. The criterion measure and ENMO data were  
 355 first categorised into sedentary/not sedentary and MVPA/not MVPA binary codes.  
 356 Computed Se and Sp, Cohen's kappa coefficients, and percentage agreement  
 357 between classifications were also assessed. Statistical analyses were performed using

358 IBM SPSS Statistics, version 24 (IBM, Armonk, NY), with the level of statistical  
359 significance set at  $p \leq 0.05$ .

360

## 361 **Results**

### 362 *Participant characteristics*

363 Of the 24 female and 10 male participants, 20 were classed as healthy (five male),  
364 seven were classed as overweight (three male), and five were classed as obese (two  
365 male) (NHS, 2016). Further descriptive characteristics of the sample are presented in  
366 Table 2. The mean (SD) energy expenditure and accelerometer output from GA and  
367 AG accelerometers are presented in Table 3 for each of phase of the laboratory  
368 protocol.

369

370 [INSERT TABLE 2 ABOUT HERE]

371

372 [INSERT TABLE 3 ABOUT HERE]

373

### 374 *ROC Curve Analysis*

375 ROC curve analysis revealed an AUC for the GA of 0.88 (95% CI: 0.87-0.88;  $P <$   
376 0.001) for SB (Figure 1) and 0.88 (95% CI: 0.87-0.88;  $P < 0.001$ ) for MVPA (Figure  
377 2). For the AG the AUC for SB was 0.90 (95% CI: 0.90-0.91;  $P < 0.001$ ) (Figure 3),  
378 and 0.94 (95% CI: 0.94-0.95;  $P < 0.001$ ) for MVPA (Figure 4).

379



380 [INSERT FIGURES 1, 2, 3, AND 4 ABOUT HERE]

381

### 382 *Cutpoint generation*

383 Table 4 displays all the generated cutpoints. The GA cutpoints which maximised  
 384 both Se and Sp using the Youden Index were SB<sub>Youden</sub>: 20 mg (Se = 94%, Sp = 72%)  
 385 and MVPA<sub>Youden</sub>: 32 mg (Se = 88%, Sp = 77%). AG cutpoints were 6 mg (Se = 85%,  
 386 Sp = 82%) for SB<sub>Youden</sub> and 19 mg (Se = 86%, Sp = 92%) for MVPA<sub>Youden</sub>. The  
 387 cutpoints optimising Se and Sp for GA were 57 mg (Se = 99%, Sp = 60%) for SB<sub>Se</sub>  
 388 and 104 mg (Se = 60%, Sp = 89%) for MVPA<sub>Sp</sub>. Respective AG cutpoints for SB<sub>Se</sub>  
 389 and MVPA<sub>Sp</sub> were 15 mg (Se = 98%, Sp = 60%) and 69 mg (Se = 60%, Sp = 99%).

390

### 391 *Cross-validation*

392 The classification agreement, sensitivity, specificity, and kappa coefficients between  
 393 calibration and cross-validation data for SB and MVPA cutpoints are shown in Table  
 394 4. GA SB<sub>Youden</sub> (Se = 47%, Sp = 92%) and MVPA<sub>Youden</sub> (Se = 76%, Sp = 76%)  
 395 cutpoints demonstrated moderate percentage agreement (73.1–76.2%) and moderate  
 396 kappa scores (0.42–0.52). AG SB<sub>Youden</sub> (Se = 62%, Sp = 93%) and MVPA<sub>Youden</sub> (Se =  
 397 86%, Sp = 89%) cutpoints demonstrated high percentage agreement (83.3–87.3%)  
 398 and moderate to substantial kappa scores (0.59–0.75). Comparatively, lower  
 399 percentage agreement and kappa scores were observed for both GA SB<sub>Se</sub> and  
 400 MVPA<sub>Sp</sub> (67.2–68.9%, k = 0.36–0.38), and AG SB<sub>Se</sub> and MVPA<sub>Sp</sub> (73.2–80.4%, k =  
 401 0.46–0.60) cutpoints, respectively.

402

403 [INSERT TABLE 4 ABOUT HERE]

404

## 405 **Discussion**

406 This is the first study to determine GA wrist- and AG hip-worn raw acceleration  
 407 cutpoints for SB and MVPA in older adults. ROC curve analyses revealed that wrist  
 408 GA and hip AG accelerometer raw acceleration cutpoints provide good and excellent  
 409 discriminations of SB and MVPA, respectively. The  $SB_{Se}$  and  $MVPA_{Sp}$  cutpoints  
 410 were comparable to those reported previously in younger adults (Hildebrand et al.,  
 411 2014; Hildebrand et al., 2016; Menai et al., 2017). The Se values of 99% for GA  
 412  $SB_{Se}$  and 98% for AG  $SB_{Se}$  cutpoints ensure that almost all older adults who are  
 413 sedentary have ENMO values below the established cutpoints, and therefore have a  
 414 very low risk of being misclassified as being physically active. The de-emphasis on  
 415 Sp (e.g., % of older adults correctly identified as not being sedentary) acknowledges  
 416 the risk that a proportion (up to 40%) of older adults who are physically active may  
 417 be classified as sedentary. However, SB is an identifiable risk factor affecting  
 418 physical (e.g., premature mortality, chronic diseases, and all-cause dementia risk)  
 419 and psychosocial (e.g., self-perceived quality of life, wellbeing, and self-efficacy)  
 420 determinants of health (Edwards & Loprinzi, 2016; Falck et al., 2016; Lewis et al.,  
 421 2017) independent of PA (Tremblay et al., 2017). Such misclassification is likely to  
 422 be beneficial if already physically active older adults were offered further  
 423 opportunities to take part in interventions to reduce SB and increase PA levels  
 424 (Chastin et al., 2017). Conversely, the higher Sp values for the GA  $MVPA_{Sp}$  cutpoint  
 425 (89%) and AG  $MVPA_{Sp}$  cutpoint (99%) ensures that older adults not engaged in  
 426 MVPA (e.g., ENMO values below the established cutpoints) are not falsely

classified as being in MVPA and are correctly identified and targeted for PA-promoting interventions (Lyons, Swartz, Lewis, Martinez, & Jennings, 2017). The de-emphasis on Se suggests that up to 40% of older adults who are not in MVPA could have ENMO values above this cutpoint (due to the lower true positive rate, relative to the true negative rate (Sp)), and therefore their behaviour could be misclassified as MVPA (Nero et al., 2015). However, it is more likely to be harmful for an older adult to be wrongly classified as active rather than asking active older adults to take part in additional MVPA. Hence, the goal of the MVPA cutpoint to identify older adults who may have increased health risks due to being below this cutpoint (by favouring Sp over Se) appears to be justified (Nero et al., 2015; Welk, Going, Morrow, & Meredith, 2011).

438

The  $SB_{\text{Youden}}$  and  $MVPA_{\text{Youden}}$  cutpoints yielded greater cross-validation classification accuracy. However, they are significantly lower than existing ENMO adult SB cutpoints for GA wrist-worn (46 mg) and AG hip-worn (47 mg) accelerometers (Hildebrand et al., 2016), and MVPA cutpoints for GA wrist-worn accelerometers in adults (93 mg; Hildebrand et al., 2014) and older adults (100 mg; Menai et al., 2017), and AG hip-worn accelerometers in adults (69.1 mg; Hildebrand et al., 2014). The mean age of the participants of 69.6 years was older than participants in both the Hildebrand et al. (2014) and Hildebrand et al. (2016) studies (34.2 years). Thus, the lower SB and MVPA cutpoints were anticipated given the lower RMR associated in older adults (Byrne et al., 2005; Kwan et al., 2004). Notwithstanding this, the  $SB_{\text{Youden}}$  and  $MVPA_{\text{Youden}}$  cutpoints were substantially lower than those previously reported. If these cutpoints were applied in free-living environments it is likely that they would significantly underestimate SB and

452 unrealistically overestimate MVPA, resulting in participants being falsely classified  
453 as being physically active when they are more likely to be sedentary.

454

455 Given that acceleration magnitudes are significantly lower for the AG GT3X+  
456 relative to the GA (John, Sasaki, Staudenmayer, Mavilia, & Freedson, 2013;  
457 Rowlands et al., 2015; Rowlands et al., 2016), the higher wrist-worn cutpoints  
458 relative to the hip-worn cutpoints were consistent with those observed previously  
459 (Rowlands et al., 2015; Stiles, Griew & Rowlands, 2013). Our protocol was  
460 comparable to previous calibration studies implemented in controlled settings (de  
461 Almeida Mendes, da Silva, Ramires Reichert, Martins, & Tomasi, 2017). However,  
462 laboratory calibration protocols rely on small deliberate increases in PA intensities  
463 and movement patterns within a limited period of time, compared to free-living  
464 activities over extended periods (van Hees, Golubic, Ekelund, & Brage, 2013a).  
465 Such protocols cannot fully reflect daily SB and PA patterns, and this may limit the  
466 accuracy of the SB and MVPA thresholds obtained for wrist- and hip-worn devices  
467 when they are applied in free-living environments (Van Hees et al., 2013a). This  
468 may have partially explained some of the modest results observed from the cross-  
469 validation phase, which repeated the laboratory protocol with the same participants.

470

471 One of the main decisions to be made by researchers using either raw acceleration or  
472 count-based outcomes is monitor placement location (de Almeida Mendes et al.,  
473 2017). After comparing SB and PA estimates from wrist- and hip-worn monitors  
474 with energy expenditure, Rosenberger et al. (2013) concluded that SB and MVPA  
475 classification accuracy was superior for the hip-worn devices. Our cross-validation

476 results support this due to the superior percent agreement and kappa scores for the  
477 hip-worn AG over the wrist-worn GA in classifying both SB and MVPA. However,  
478 our results also demonstrate that wrist-worn accelerometers can provide accurate  
479 estimates of SB and MVPA and the subsequent cutpoints performed reasonably well  
480 at discriminating both SB and MVPA (Troiano et al., 2014). Indeed, a recent  
481 systematic review of raw acceleration calibration studies reported no evidence of  
482 meaningful differences in the accuracy of wrist- and hip-worn accelerometers (de  
483 Almeida Mendes et al., 2017). Considering the superior wear compliance associated  
484 with wrist-worn devices (Doherty et al., 2017), this attachment site may be the most  
485 suitable location during free-living protocols.

486

487 Several strengths and limitations should be noted when interpreting the results of this  
488 study. A main strength was the use of raw acceleration data from two commonly  
489 used devices positioned at wrist and hip wear sites. These cutpoints will be of utility  
490 to researchers using the raw data capabilities of the GA and AG accelerometers to  
491 study SB and PA in older adults. We used best practice analytical procedures to  
492 calibrate and cross-validate the cutpoints (Welk, 2005), which were specific to adults  
493 aged 60 years and over. We also directly measured resting energy expenditure to  
494 allow a sample-specific interpretation of three METs as the MVPA threshold, and  
495 used a validated separate criterion measure for SB (Kim, Barry, & Kang, 2015).  
496 There were also a number of limitations. The sample may not have been  
497 representative of the wider older adult population in respect of their fitness status and  
498 motivation to engage in PA, as we recruited a convenience sample of healthy older  
499 adults who answered advertisements and showed an interest in the study representing  
500 a broad age range. Furthermore, specific older adult populations (e.g., those with

501 chronic diseases and impaired mobility) may require different SB and PA cutpoints  
 502 (Landry et al., 2015) that reflect differences in RMR and energy cost during  
 503 ambulatory PA across this age group (Miller, Strath, Swartz, & Cashin, 2010).  
 504 Moreover, we incorporated activities that replicate everyday movements and tasks  
 505 performed by older adults, but recognise that the laboratory setting limits the  
 506 ecological validity of the resultant data (Hildebrand et al., 2016). The duration of the  
 507 stepping and walking activities was relatively short and this may have limited the  
 508 amount of MVPA data available for use in the analysis. Lastly, cross-validation was  
 509 performed with the same participants using a repeated laboratory protocol rather than  
 510 with an independent sample using a free-living or a simulated free-living protocol  
 511 (Welk, 2005). It was felt that the challenges associated with having the participants  
 512 wear the gas analysis system for an extended period in free-living situations were too  
 513 great to warrant taking this approach. Consequently, the SB cutpoints which  
 514 performed modestly in the cross-validation, should be interpreted with caution. Both  
 515 sets of cutpoints should be further cross-validated in free-living environments (Welk,  
 516 2005) with independent samples over whole days using feasible criterion measures  
 517 such as activPALs and wrist-worn heart rate monitors (Brage et al., 2015).

518

519 In conclusion, cutpoints varied dependent upon attachment site, with the wrist-worn  
 520 GA cutpoints higher than those for the hip-worn AG. The identified GA and AG  
 521  $SB_{Se}$  and  $MVPA_{Sp}$  cutpoints can enable researchers to classify older adults as  
 522 engaging in SB or not engaging in MVPA, but the  $SB_{Se}$  cutpoints should be  
 523 interpreted with a degree of caution due to their modest cross-validation results.  
 524 More cross-validation research in independent samples within free-living  
 525 environments is needed to further test the utility of the  $SB_{Se}$  and  $MVPA_{Sp}$  cutpoints.

526

527 **Disclosure statement**

528 There are no conflicts of interest to report.

529

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