

**Responsiveness of device-based and self-report measures of physical activity to detect behaviour change in men taking part in the Football Fans in Training (FFIT) programme**

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1 **Abstract**

2 The capacity of physical activity (PA) measures to detect *changes* in PA within interventions is crucial.  
3 This is the first study to examine responsiveness of *activPAL3™* and the International Physical Activity  
4 Questionnaire (IPAQ; Short Form) in detecting PA change during a 12 week group-based, men-only  
5 weight management programme - Football Fans in Training (FFIT). Participants wore an *activPAL3™* and  
6 completed the IPAQ pre- and post-programme (n=30). Relationships between change scores were  
7 assessed by Spearman's correlations. Mean or median changes in PA were measured using paired  
8 samples t-tests and Wilcoxon signed-rank tests. Responsiveness to change was assessed utilising  
9 Standardised Response Mean (SRM). Both device-based and self-report measures demonstrated  
10 significant changes pre-post intervention, although these changes were not significantly correlated. The  
11 SRM values for changes in *activPAL3™* metrics were: 0.54 (MET-mins/day); 0.53 (step counts/day); and  
12 0.44 (MVPA/day), indicating a small to medium responsiveness to change. SRM values for changes in  
13 IPAQ scores were: 0.59 (total PA mins/day); 0.54 (total MET-mins/day); 0.59 (walking MET-mins/day);  
14 0.38 (vigorous MET-mins/day); and 0.38 (moderate MET-mins/day), revealing a small to medium  
15 responsiveness to change. These findings reveal that two commonly used device-based and self-report  
16 measures demonstrated responsiveness to changes in PA. While inclusion of both device-based and  
17 self-report measures is desirable within interventions it is not always feasible. The results from this  
18 study support that self-reported measures can detect PA change within behavioural interventions,  
19 although may have a tendency to overestimate changes, compared with device-based measures.

20 **Keywords:** physical activity measurement, accelerometer, questionnaire, sensitivity, intervention, adults

21

22 There is strong evidence that physical activity (PA) provides substantial health benefits (Warburton &  
23 Bredin, 2017). However, at least a third of adults around the world do not meet current  
24 recommendations for moderate to vigorous activity (Guthold, Stevens, Riley, & Bull, 2018).

25 Many strategies have been suggested to increase PA globally (WHO, 2018), although there is limited  
26 evidence of successful implementation. Kelly and Barker (2016) recently outlined six common errors  
27 repeatedly made by public health researchers/practitioners with regards to implementing scientific  
28 evidence when attempting to change health behaviours, including PA. We would like to propose  
29 another reason for this perceived failure in implementation: the difficulty in assessing which strategies  
30 work and which do not, and in those that work, the difficulty in assessing the extent to which they  
31 change behaviour. We suggest that, because measurement of PA behaviour can be challenging, it is  
32 often difficult to detect evidence of behaviour change. If measures of PA are used or interpreted  
33 incorrectly, interventions that appear to be ineffective may be incorrectly judged as successful (Type-I  
34 error) and those that are effective might be rejected (Type-II error).

35 To understand whether strategies are effective in changing PA behaviour it is vital that appropriate  
36 measurement methods are incorporated within evaluations of behavioural interventions which aim to  
37 assess the extent of PA behaviour change. However, PA is a complex and multi-faceted behaviour often  
38 characterised across several domains (i.e. leisure, travel, housework/gardening, and occupation),  
39 dimensions and determinants/correlates (Kelly, Fitzsimons, & Baker, 2016). Consequently, assessment  
40 of PA offers considerable methodological options and challenges (Warren et al., 2010). Subjective (i.e.  
41 self-reported) PA measures are commonly employed in population and intervention studies as they are  
42 easy to use and cost less than objective (i.e. device-based) assessment. Wearable device-based  
43 technologies, such as accelerometers, have become increasingly popular in recent years as PA  
44 assessment tools that are not prone to recall bias, more valid and reliable compared with self-report

45 instruments and are often more practical compared with alternative more robust measures such as  
46 doubly labelled water (Silfee et al., 2018). Despite these benefits, there are limitations to relying solely  
47 on device-based forms of PA assessment (Pedišić & Bauman, 2015), particularly as outcomes in  
48 behavioural interventions. For instance, they are often unable to detect some forms of activity, and  
49 hence may underestimate overall PA levels (Silfee et al., 2018). They may also inadvertently influence  
50 PA when used as surveillance or measurement tools (e.g. measurement reactivity) and might enhance  
51 burden on participants (Baumann et al., 2018). Moreover, with the rise in the use of wearable device-  
52 based measures in recent years, there is substantial heterogeneity regarding the number of PA metrics  
53 being reported, limiting comparability between studies (Silfee et al., 2018).

54 Distinct forms of PA measurement can provide confusing or even contradictory findings (Thompson et  
55 al., 2009). Numerous studies have shown that correlations between device-based and self-report  
56 assessments of PA are low (Kowalski, Rhodes, Naylor, Tuokko, & MacDonald, 2012; Prince et al., 2008;  
57 Skender et al., 2016). It has been argued that although related, device-based and self-report measures  
58 assess distinct PA constructs and therefore not comparable (Fulton et al., 2016; Troiano, McClain,  
59 Brychta, & Chen, 2014).

60 Despite a growing number of intervention studies incorporating device-based and/or self-report  
61 measures of PA, there is a lack of research examining the (comparative) responsiveness of these  
62 measures to detect PA behaviour change over time as distinct PA constructs. For instance, there are  
63 only a small number of studies that have explicitly examined responsiveness to change of device-based  
64 and/or self-report measures in adults and children (e.g. Lee, Clark, Winkler, Eakin, & Reeves, 2015;  
65 Montoye, Pfeiffer, Sutton, & Trost, 2014; Swartz, Rote, Cho, Welch, & Strath, 2014). The term  
66 responsiveness (or sensitivity) is typically defined as an indicator of an instrument's sensitivity to change  
67 as well as being a gauge of the magnitude of intervention-related change over time (Beaton,

68 Bombardier, Katz, & Wright, 2001; Middel & van Sonderen, 2002). Although the validity and reliability  
69 of device-based and self-report PA instruments are often examined comprehensively (e.g. Lee,  
70 Macfarlane, Lam, & Stewart, 2011), responsiveness is comparatively under investigated, particularly  
71 within the context of behavioural interventions.

72 In order to understand whether PA interventions are effective in changing behaviour, it is vital to  
73 understand whether measures employed to evaluate changes in behaviour within intervention studies  
74 are capable of detecting changes in PA. In this study we aim to examine and compare the  
75 responsiveness of both device-based (*activPAL3™*) and self-report (International Physical Activity  
76 Questionnaire; IPAQ, Short Form) PA measures to detect changes in PA behaviour, using data collected  
77 before and after participation in the Football Fans in Training (FFIT) programme, a weight management  
78 and healthy lifestyle intervention for men classified as overweight or obese ( $BMI > 28 \text{ kg/m}^2$ ) and aged 35-  
79 65 years (see Gray et al., 2013a; Hunt et al., 2014b; Wyke et al., 2015).

## 80 **Methods**

### 81 *Participants and intervention setting*

82 Football Fans in Training (FFIT) is a 12 week gender-sensitised, group programme delivered free of  
83 charge by trained community coaches to men at Professional Football clubs in Scotland. The  
84 development of the FFIT programme is detailed elsewhere (Gray et al., 2013a). In brief, FFIT was  
85 designed in line with evidence of what was known to be effective for weight loss (National Institute for  
86 Health and Clinical Excellence, 2006; Scottish Intercollegiate Guidelines Network, 2010) and to work  
87 with rather than against prevailing notions of masculinity, appealing to men in: context (professional  
88 football clubs); content (e.g. information around the science of weight management presented simply  
89 and branded materials, such as club T-shirts); and style of delivery (e.g. coaches encourage peer-

90 support, participative learning and positive ‘banter’ to support discussion of more sensitive issues)  
91 (Wyke et al., 2015).

92 Funding was secured to undertake an evaluation of FFIT (a randomised controlled trial (RCT)  
93 incorporating an embedded process evaluation and cost-effectiveness); at that time funding was  
94 available for three deliveries of the programme in 13 professional football clubs (i.e. the 12 clubs in the  
95 top league in Scotland - then the Scottish Premier League (SPL) - and the most recently demoted club  
96 who had taken part in pilot deliveries in the previous season) in August-December 2011, February-April  
97 2012 and August-December 2012. Men taking part in the August-December deliveries in 2011 and 2012  
98 were participants in the FFIT RCT as outlined elsewhere (Hunt et al., 2014b; Wyke et al., 2015). During  
99 the baseline assessment period, the FFIT research team recruited adequate numbers of participants to  
100 fill *all* places then available on the three deliveries of FFIT (funded by the Football Pools and the Scottish  
101 Government). After recruitment of the intervention and control arms of the RCT had been achieved, the  
102 remaining 306 men were offered a place on ‘non-trial’ deliveries of FFIT in February-April, 2012. The  
103 RCT of FFIT demonstrated significant mean between-group difference in weight loss of 4.94kg (CI 3.95,  
104 5.94,  $p < 0.0001$ ) at 12 months after baseline (primary outcome), and in self-reported PA (International  
105 Physical Activity Questionnaire, Short Form), and other secondary outcomes, all in favour of the  
106 intervention group (Hunt et al., 2014a; Wyke et al., 2015). No device-based measures of PA were taken  
107 in men participating in the RCT.

108 The February 2012 delivery of FFIT provided an opportunity to examine factors not feasible to  
109 investigate within the FFIT RCT. This included the incorporation of measures of PA to assess pre- and  
110 post-programme activity levels, and changes in PA assessed both subjectively and objectively. All  
111 participants in the current study were sampled from men who took part in the ‘non-trial’ deliveries of

112 FFIT at 12 clubs, between February-April 2012 (Donnachie, Wyke, & Hunt, 2018; Donnachie, Wyke,  
113 Mutrie, & Hunt, 2017).

#### 114 *Procedure*

115 Data collection occurred between January 2012 and May 2012. Of the 306 men offered places on the  
116 February 2012 deliveries of FFIT, 203 men attended the pre-programme measurement sessions at each  
117 professional football club stadium and undertook a battery of objective physical (e.g. anthropometric  
118 measurements and blood pressure) and subjective (e.g. PA and diet) assessments pre-programme (T0)  
119 and post-programme (T1, 12 week follow-up). All of the assessments were performed by fieldwork staff  
120 trained to standard protocols concordant with the FFIT RCT (Hunt et al., 2014a; Hunt et al., 2014b).

121 Prior to attending pre-programme measurement sessions, men from four clubs (n=94) were sent a letter  
122 outlining research for a sub-study on objective PA assessment and inviting them to take part. This  
123 provided adequate time to decide if they were willing to take part in the sub-study before attending the  
124 pre-programme stadium-based measurement sessions. At T0 (week 0 of the FFIT programme),  
125 participants from these clubs were asked if they had received the information letter, given an additional  
126 copy of the study information to read and asked if they would be willing to wear an *activPAL3™* (PAL  
127 Technologies Ltd., Glasgow, Scotland, UK) device for seven consecutive days (i.e. providing six full days  
128 of activity monitoring) so that it could be retrieved when they attended for their first programme  
129 session (week 1 of the FFIT programme) the following week. They were also asked if they would be  
130 willing to wear the *activPAL3™* again between week 11 and week 12 of the programme (T1). Those who  
131 agreed to wear the device at week 11, provided data for a further seven days after the devices were  
132 collected at week 12, the final week of the programme.

133 During the pre-programme measurement session, participants gave written informed consent after they  
134 were fully briefed on the purpose of the *activPAL3™*, and given a demonstration on how to remove and

135 re-affix the device. The *activPAL3*<sup>™</sup> was placed inside a waterproof and protective nitrile sleeve,  
136 wrapped in a single layer of Hypafix<sup>®</sup> water resistant adhesive. Next, the device was affixed directly to  
137 the skin of the participants' right leg with one sheet of Hypafix<sup>®</sup> adhesive (10cm X 13cm) by the first  
138 author, following standardised protocols to protect privacy; participants were told the device need only  
139 be removed to prevent the device being immersed in water (i.e. during swimming or bathing) but could  
140 be worn while showering and sleeping. The men were each given additional Hypafix<sup>®</sup> strips to re-apply  
141 the device should it need to be removed for any reason throughout the week. When the monitors were  
142 removed and retrieved by the first author at each of the four clubs the following week, participants  
143 were asked to complete the IPAQ (short form) to obtain concurrent self-reported PA, recalled over the  
144 previous week. The same procedures were repeated again for FFIT programme weeks 11-12. Full  
145 ethical approval was granted by the University of Glasgow, College of Social Sciences Research Ethics  
146 Committee (CSS201020106).

#### 147 *Measures*

148 The device-based outcome measures in the current study were measured by the *activPAL3*<sup>™</sup> device and  
149 included: number of steps taken per day; minutes of moderate to vigorous intensity PA; and energy  
150 expenditure. The *activPAL3*<sup>™</sup> is a triaxial accelerometer/inclinometer which incorporates proprietary  
151 technology (Intelligent Activity Classification<sup>™</sup>) to measure three types of free-living activity: time spent  
152 sitting/lying; standing; and stepping. The *activPAL3*<sup>™</sup> quantifies the amount of steps performed, the  
153 intensity of steps taken (cadence) and estimates of energy expenditure (Lord et al., 2011). It is a small  
154 (35 X 53 X 7mm), lightweight device (15g), worn discreetly on the middle of the thigh between the hip  
155 and the knee, above the quadriceps muscle. The device has a battery life of around nine days, and thus  
156 can be worn continuously for 24 hour monitoring. The data are recorded in 15-second epochs and the  
157 output downloaded onto a Personal Computer (PC) via a USB interface. Previous studies have shown



158 the activity and posture functions of the *activPAL*<sup>™</sup> to be valid compared to direct observation and  
159 acceptable to participants in community-based research (e.g. Grant, Dall, Mitchell, & Granat, 2008).  
160 Prior to assessment, each of the *activPAL3*<sup>™</sup> monitors was fully charged and initialised to record six  
161 consecutive days. On retrieval of the monitors, data were uploaded to a PC using *activPAL*<sup>™</sup> proprietary  
162 software (PALtechnologies v5.9.1.1). Microsoft Office Excel was used for subsequent data processing  
163 and management. Custom software (HSC analysis software v2.19, Philippa Dall and Malcolm Granat,  
164 Glasgow Caledonian University) was used to extract information on individual participants' PA intensity  
165 using the *activPAL3*<sup>™</sup> time-stamped 'event' data files. Based on the conclusions of a systematic review  
166 (Tudor-Locke & Rowe, 2012), in the current study, time spent stepping at a cadence of at least 100  
167 steps/minute was deemed indicative of moderate intensity PA. Daily energy expenditure is classified by  
168 the *activPAL3*<sup>™</sup> software as metabolic equivalent (MET-hours) and expressed in this study as MET-  
169 minutes per day. Best practice guidelines for accelerometer use in PA measurement suggest that for  
170 adults a minimum of 3-5 days of monitoring is necessary to quantify free-living PA (Troost, McIver, &  
171 Pate, 2005; Ward, Evenson, Vaughn, Rodgers, & Troiano, 2005). Data files were inspected visually and  
172 individual cases excluded if less than three days of wear time were evident. Days with <500 steps were  
173 removed, consistent with previous studies which have incorporated similar cut-offs to classify non-wear  
174 days (Edwardson et al., 2017). Wake/sleep times were included as recorded by the *activPAL3*<sup>™</sup>,  
175 enabling capture of daily 24 hour activity (i.e. midnight to midnight). Self-report logs/diaries (e.g. to  
176 record sleep, wake or removal time) were not incorporated in the current study to reduce overall  
177 participant burden.

178 Self-reported PA outcomes were measured using the International Physical Activity Questionnaire  
179 (IPAQ, Short Form) (Craig et al., 2003), which included total PA minutes and total work done in PA per  
180 week (MET-minutes). The IPAQ is a well-established measure designed principally as a gold standard for

181 population surveillance of PA among adults (18-65 years) (Craig et al., 2003). According to the IPAQ  
182 scoring guidelines, data are reported as total metabolic equivalent of task (in MET-minutes) per week.  
183 Calculation of the total score involves summation of the duration (i.e. minutes) and frequency (i.e. days)  
184 of walking, moderate-intensity and vigorous-intensity activities, recalled over the past seven days. MET-  
185 minute scores are quantified by multiplying the MET score of an activity by the minutes performed. All  
186 reported activity (i.e. walking, moderate and vigorous activity) exceeding 'three hours' (or 180 minutes)  
187 were truncated to allow a maximum of 21 hours of activity per week for each category to minimise over  
188 reporting, consistent with the IPAQ scoring protocol ([https://sites.google.com/site/theipaq/scoring-  
189 protocol](https://sites.google.com/site/theipaq/scoring-protocol)). Changes in IPAQ and *activPAL3™* metrics are expressed in total minutes 'per day' to enable  
190 comparison between both measures. All IPAQ total scores ('per week') were divided by 7 for daily PA  
191 estimates.

## 192 *Statistical analysis*

193 Descriptive statistics are presented as means (standard deviation, SD), medians (interquartile range,  
194 IQR) and percentages (number). Exploratory analysis revealed that the majority of device-based PA  
195 metrics were approximately normally distributed, whereas the self-reported data were positively  
196 skewed. Paired samples t-tests or Wilcoxon signed-rank tests (for data that violated assumptions of  
197 normality) were used to examine differences pre- and post-intervention. Spearman's rank-order  
198 correlation coefficients ( $\rho$ ) were used to assess relationships between change scores for device-based  
199 (*activPAL3™*) and self-report (IPAQ) instruments, interpreted as weak ( $<0.3$ ), low (0.30–0.49), moderate  
200 (0.50–0.69), strong (0.70–0.89) or very strong ( $\geq 0.90$ ).

201 Responsiveness to change in device-based and self-report PA scores between T0 and T1 was assessed  
202 using the Standardised Response Mean (SRM) or Cohen's *d*<sub>z</sub> (Cohen, 1977; Dankel & Loenneke, 2018;  
203 Lakens, 2013; Liang, Fossel, & Larson, 1990), a type of effect size that has been used in previous studies

204 to assess responsiveness to change of device-based and self-report PA instruments in adults and  
205 children (e.g. Almeida et al., 2017; Clevenger et al., 2018; Swartz et al., 2014). SRM is calculated for each  
206 measure by dividing the absolute mean change score by the standard deviation of differences between  
207 the paired measurements and can be interpreted in line with Cohen's *d* as trivial, small, moderate or  
208 large (<0.20, ≥0.20 to <0.50, ≥0.50 to <0.80, and ≥0.80, respectively) (Cohen, 1977; Husted, Cook,  
209 Farewell, & Gladman, 2000; Stratford & Riddle, 2005). In addition to SRM values, non-parametric effect  
210 size (ES) values were calculated for each of the device-based and self-reported PA metrics using  
211 Wilcoxon's statistic and related Z-score divided by the square root of *n* ( $z/\sqrt{n}$ ), interpreted as small (*r* =  
212 <0.3), medium (*r* = ≥0.3 to <0.5) and large (*r* = ≥0.5) (Cohen, 1977; Field, 2009).

213 The Guyatt Responsiveness Index (GRI) is an alternative measure of responsiveness based on the  
214 variability of changes among stable participants (Guyatt, Walter, & Norman, 1987; Husted et al., 2000).  
215 When utilising this responsiveness statistic, participants are preferably assessed on several occasions to  
216 ascertain the level of variability across a 'stable' time period, ideally before taking part in an  
217 intervention, to detect minimally clinically important change exceeding any spurious changes in  
218 measurement which may occur over time (Guyatt et al., 1987). However, where only two observations  
219 are available (i.e. baseline and post-intervention), the GRI is calculated as the mean score of participants  
220 identified as improved, divided by the standard deviation of the change in participants identified as  
221 stable or showing no improvement pre- to post-intervention. In this analysis, the mean change of  
222 participants identified as having increased PA between T0 and T1, as indicated by each of the device-  
223 based and self-report PA metrics, were incorporated as the numerator, whereas the standard deviation  
224 of the change in participants identified as unchanged or having decreased PA were included as the  
225 denominator. Similarly to SRM, GRI values of 0.20, 0.50 and 0.80 or greater have been used to delineate  
226 low, moderate and high responsiveness, respectively (Husted et al., 2000). However, it is important to  
227 note that the GRI method is anticipated to yield higher coefficients than the SRM or other ES values as a

228 consequence of the removal of mean change values of unchanged participants (Stucki, Liang, Fossel, &  
229 Katz, 1995). Statistical analyses were undertaken using IBM SPSS 21.0 (Armonk, NY, USA). All tests were  
230 two-tailed with an alpha p-value of  $p < 0.05$  to assess statistical significance.

## 231 **Results**

### 232 *Demographic characteristics*

233 Descriptive characteristics of participants pre-programme are displayed in Table 1. The mean age of  
234 participants was 45.9 years ( $SD = 9.8$ ). Mean body weight was 111.8kg ( $SD = 14.3$ ), mean BMI was 35.9  
235  $\text{kg/m}^2$  ( $SD = 5.3$ ) and mean waist circumference was 118.5cm ( $SD = 11.1$ ), thus comparable with clinical  
236 characteristics of men taking part in other research deliveries of FFIT (Gray et al., 2013b; Hunt et al.,  
237 2014a). Participants in this study were from across the socioeconomic spectrum, consistent with  
238 previous research demonstrating that FFIT attracted men from a range of socioeconomic backgrounds  
239 (Hunt et al., 2014b).

### 240 *Changes in device-based and self-reported physical activity*

241 Changes in device-based and self-reported PA between T0 and T1 are presented in Table 2. Data are  
242 presented for  $n=30$  participants with concurrent PA data (i.e. device-based and self-report assessments)  
243 at both time points. Paired samples t-tests confirmed significant increases in *activPAL3*<sup>TM</sup>-assessed  
244 number of average daily 'steps' from 8315.5 ( $SD = 3063.3$ ) at T0 to 9834.4 ( $SD = 3855.9$ ) at T1 with an  
245 increase of 1518.8 steps, ( $t(29) = -2.9, p = 0.007$ ), time spent stepping at least at a moderate cadence  
246 increased from 28.3 ( $SD = 18.8$ ) minutes/day at T0 to 37.8 ( $SD = 27.3$ ) at T1 with an increase of 9.5  
247 minutes/day ( $t(29) = -2.4, p = 0.022$ ) and increased daily MET-minutes from 2040 ( $SD = 78$ ) at T0 to 2076  
248 ( $SD = 90$ ) at T1 with an increase of 36 MET-minutes/day, ( $t(29) = -2.9, p = 0.006$ ). Wilcoxon signed rank  
249 tests showed significant increases in self-reported PA (IPAQ) at T1 from T0 for total PA minutes ( $Z = -$

250 3.56,  $p = <0.001$ , median difference = 83 minutes/day), total MET-minutes ( $Z = -3.59$ ,  $p = <0.001$ , median  
251 difference = 341 MET-minutes/day), walking MET-minutes ( $Z = -2.86$ ,  $p = 0.004$ , median difference = 154  
252 MET-minutes/day), moderate MET-minutes ( $Z = -2.53$ ,  $p = 0.011$ , median difference = 56 MET-  
253 minutes/day) and vigorous MET-minutes ( $Z = -2.58$ ,  $p = 0.010$ , median difference = 80 MET-  
254 minutes/day).

255 The SRM and non-parametric effect size (ES) values for changes in device-based and self-reported PA  
256 between T0 and T1 are also displayed in Table 2. The SRM values for device-based (*activPAL3™*) time  
257 spent active stepping at least at a moderate cadence, average steps per day and daily MET-minutes  
258 were  $d = 0.44$ ,  $d = 0.53$  and  $d = 0.54$ , respectively, demonstrating a small to moderate responsiveness to  
259 change. The SRM values for total self-reported PA minutes/day, MET-minutes/day, walking MET-  
260 minutes/day, moderate MET-minutes/day and vigorous MET-minutes/day were,  $d = 0.59$ ,  $d = 0.54$ ,  $d =$   
261  $0.59$ ,  $d = 0.38$  and  $d = 0.38$ , respectively, revealing a small to moderate responsiveness to change  
262 between T0 and T1. The non-parametric ES values for changes in time spent active at least at a  
263 moderate stepping cadence, average steps per day and daily MET-minutes were  $r = 0.35$ ,  $r = 0.47$  and  $r =$   
264  $0.48$ , respectively, thus indicating a moderate effect size. The non-parametric ES values for changes in  
265 self-reported (IPAQ) total minutes/day, MET-minutes/day, walking MET-minutes/day, moderate MET-  
266 minutes/day and vigorous MET-minutes/day were  $r = 0.65$ ,  $r = 0.66$ ,  $r = 0.52$ ,  $r = 0.46$  and  $r = 0.47$   
267 respectively, indicating a moderate to large effect size.

268 The GRI values for changes in device-based and self-reported PA between T0 and T1 are depicted in  
269 Table 3. The GRI values for device-assessed daily MET-minutes, average steps per day and time spent  
270 active stepping at least at a moderate cadence (GRI = 2.24, GRI = 2.36, and GRI = 4.21, respectively)  
271 showed a large responsiveness to change. Self-reported total PA minutes/day and total MET-  
272 minutes/day were GRI = 0.66 and GRI = 0.64, respectively, demonstrating a moderate responsiveness to

273 change as a consequence of higher variability in changed total self-reported PA among participants.  
274 However, IPAQ sub-domains of walking, moderate and vigorous MET-minutes/day were GRI = 1.49, GRI  
275 = 1.05 and GRI = 11.83, respectively, revealing a large responsiveness to change between T0 and T1.

#### 276 *Comparison between device-based and self-reported physical activity*

277 The Spearman's correlation coefficients between device-based and self-reported activity scores at both  
278 T0 and T1 are displayed in Table 4. Generally, the highest correlations among device-based and self-  
279 report PA measures were observed at T0. The correlation coefficients between *activPAL3™*-assessed PA  
280 (number of steps, time spent stepping at least at a moderate intensity and total MET-minutes) and one  
281 of the five IPAQ metrics (walking MET-minutes), were positive but low ( $\rho = 0.42$ ,  $\rho = 0.49$  and  $\rho =$   
282  $0.37$ , respectively). The correlations between each of the *activPAL3™* metrics and IPAQ assessed total  
283 PA minutes, total MET-minutes, moderate MET-minutes and vigorous MET-minutes/day were all non-  
284 significant. All of the correlation coefficients between device-based and self-report PA measures at T1  
285 were not statistically significant, ranging from low to weak ( $\rho = 0.36$  to  $-0.11$ ).

286 The Spearman's correlation coefficients between the change scores for device-based and self-reported  
287 PA measures are displayed in Table 5 and ranged from  $-0.30$  to  $0.35$ ; none of these were statistically  
288 significant.

#### 289 **Discussion**

290 The capacity of self-report and device-based PA instruments to detect change in PA within intervention  
291 settings is crucial to determining which interventions work. To our knowledge, this is the only study that  
292 has compared responsiveness of both IPAQ (i.e. self-report) and *activPAL3™* (i.e. device-based)  
293 measures across a number of outcome metrics to assess changes in PA over time within the context of a  
294 behavioural intervention. This is also the first study to examine changes in both device-based and self-

295 reported PA within research deliveries of the FFIT programme, and extends previous research  
296 demonstrating significant increases in self-reported PA (i.e. IPAQ, Short Form) during pilot (Gray et al.,  
297 2013b) and full trial (Hunt et al., 2014b) deliveries of FFIT.

298 In this study, changes in all device-based and self-reported PA metrics were statistically significant.  
299 According to device-based assessment (*activPAL3™*) taking part in the 12 week FFIT programme resulted  
300 in an increase in an average of 1519 steps; 9.5 minutes spent stepping at least a moderate stepping  
301 intensity (i.e.  $\geq 100$  steps/minute); and an extra 36 MET-minutes per day. According to the self-reported  
302 PA measure (IPAQ), taking part in FFIT increased total PA by 83 minutes and 341 MET-minutes per day.  
303 IPAQ sub-domains of walking, moderate and vigorous intensity activity also showed an increase of 154,  
304 56, and 80 MET-minutes per day, respectively. The most salient finding from the current study is that  
305 we observed comparable responsiveness to change for both device-based and self-report instruments.  
306 SRM values for *activPAL3™* were greatest when measuring change in average MET-minutes (0.54) and  
307 steps per day (0.53), whereas IPAQ SRM values were highest when assessing change in total PA MET-  
308 minutes (0.54), walking MET-minutes (0.59) and total PA minutes (0.59), classified as moderate (i.e. SRM  
309 values  $\geq 0.50$ ). The SRM values for IPAQ sub-domains of moderate and vigorous PA intensity (both SRMs  
310 0.38) and *activPAL3™* assessed MVPA (time spent active at least a moderate intensity) (0.44), are  
311 considered small (i.e. SRM values  $< 0.50$ ). Similar trends were found for both non-parametric ES and GRI  
312 responsiveness values. Thus, our findings indicate that despite uncorrelated changes, both instruments  
313 were able to detect a comparable magnitude of change in PA. In contrast with previous research (Lee et  
314 al, 2015), self-reported PA demonstrated slightly greater responsiveness compared with device-based  
315 measures for total PA within the context of a 12 week, men-only behavioural intervention. However,  
316 total self-reported PA (i.e. IPAQ total PA minutes and total MET-minutes) demonstrated lower GRI  
317 values (GRI = 0.66 and GRI = 0.64, respectively) compared to each of the three device-assessed PA  
318 metrics: *activPAL3™* assessed MET-minutes (GRI = 2.24); number of steps (GRI = 2.36); and time

319 stepping at a moderate cadence (GRI = 4.21), thus demonstrating lower variability in changed device-  
320 based PA pre- to post-intervention. The findings suggest that both IPAQ and *activPAL3™* measures  
321 should be responsive to change when evaluating PA change in future intervention settings.  
322 Nonetheless, due to the substantial differences in self-reported PA scores compared with device-based  
323 assessment, caution is warranted when interpreting intervention change based solely on self-reported  
324 PA, as may overestimate change consistent with other research (Winkler et al., 2013).

325 There are a limited number of studies that have investigated responsiveness to change of both device-  
326 based and self-report PA measures in adults. A recent study investigated responsiveness to change of  
327 self-reported (Baecke Habitual Physical Activity Questionnaire) and device-based (ActiGraph GT3X-BT)  
328 PA measures in patients with chronic low back pain receiving physical therapy (Morelhão et al., 2018).  
329 The authors concluded that none of the PA measures were able to detect changes in PA over time,  
330 according to SRM values (<0.20). Similarly, Almeida et al (2017) examined the responsiveness of self-  
331 report (Community Health Activities Model Program for Older Adults Questionnaire) and two distinct  
332 device-based (Actigraph GT3X; Sensewear Armband) measures in detecting changes in PA in older adults  
333 with osteoarthritis during a rehabilitation programme following knee replacement surgery. The findings  
334 revealed that each PA measure exhibited low responsiveness to change (i.e. in light, moderate and  
335 vigorous intensity PA) as indicated by SRM values (<0.30). Nicaise and colleagues examined the  
336 sensitivity of the IPAQ (Long Form) for detecting changes in PA compared with device-based (Actigraph  
337 7164) assessment among Spanish-speaking Latina women during a 12 week pedometer-based  
338 intervention (Nicaise, Crespo, & Marshall, 2014). In this study, both IPAQ ( $r = 0.27$ ) and device-based ( $r$   
339  $= 0.40$ ) measures detected intervention-related changes in moderate intensity PA, indicating a small and  
340 moderate effect size of change. Consistent with our study findings, changes in self-report and device-  
341 based PA metrics were not correlated at 12 weeks.



342 Lee and colleagues reported significant changes in total PA minutes/week for two distinct self-report  
343 (Active Australia Survey; United States National Health Interview Survey) and device-based PA measures  
344 (Actigraph GT1M), longitudinally within the context of a weight loss intervention that were small in  
345 magnitude, although device-based PA was classed as slightly more responsive (Lee et al., 2015).

346 Research conducted by the same group of authors investigated responsiveness to changes in PA using  
347 three unique self-report instruments (Community Health Activities Model Program for Older Adults  
348 Questionnaire; Active Australia Survey; United States National Health Interview Survey) in adults  
349 following a four month behavioural intervention, demonstrating a small responsiveness to change  
350 (Reeves, Marshall, Owen, Winkler, & Eakin, 2010). The findings observed in the current study are similar  
351 to other research comparing responsiveness of device-based activity measures in adult populations  
352 (Swartz et al., 2014; van Nassau, Chau, Lakerveld, Bauman, & van der Ploeg, 2015). For instance, Swartz  
353 et al (2014) examined responsiveness to change in two different device-based PA measures (Actigraph  
354 GT3X; *activPAL™*) in sedentary adults during a behavioural intervention to reduce sitting time. They  
355 observed comparable SRM (0.44) values post-intervention for changes in *activPAL™* assessed PA  
356 (average daily steps) indicating a small responsiveness to change.

357 As noted by Lee et al (2015), the majority of studies have focused on assessing the validity of PA  
358 measures to examine behaviour change within interventions over time, usually relying on correlations  
359 between changes in self-report and device-based measures (e.g. Hoos, Espinoza, Marshall, & Arredondo,  
360 2012; Nicaise et al., 2014; Sloane, Snyder, Demark-Wahnefried, Lobach, & Kraus, 2009). However,  
361 research findings have indicated greater disagreement between device-based and self-reported PA at  
362 increased activity levels (e.g. Slootmaker, Schuit, Chinapaw, Seidell, & van Mechelen, 2009), hence  
363 agreement between instruments may be attenuated by intervention effects (Lee et al., 2015). Winkler  
364 et al (2013) observed that agreement between self-report and device-based measures deteriorated as  
365 levels of PA increased during a behavioural PA intervention, particularly among intervention group

366 participants compared to controls. The authors reported that intervention effects were greater when  
367 PA was assessed by self-report compared with device-based measures, despite both instruments  
368 yielding statistically significant differences. They suggest PA interventions might appear more effective  
369 when relying exclusively on self-report.

370 Device-based measures of PA are often heralded as the 'gold standard' for PA behaviour as they  
371 demonstrate somewhat stronger agreement with doubly labelled water (a precise measure of total  
372 energy expenditure) in comparison to self-report measures (Kelly et al., 2016). Device-based measures  
373 of PA quantify acceleration and movement, whereas self-reported methods provide an understanding of  
374 the purpose, domain and context of PA behaviour (Troiano, Gabriel, Welk, Owen, & Sternfeld, 2012).  
375 Both forms of PA assessment have distinct limitations and are susceptible to different forms of  
376 measurement error. For instance, self-report PA assessment is more prone to social desirability bias,  
377 poor recall, or misreading of questionnaires. Specifically, the IPAQ Short Form has been shown to  
378 overestimate PA by approximately 84 percent compared to objective assessments (Lee et al., 2011).  
379 Also, it is possible that some participants could have responded more favourably when completing self-  
380 reported PA assessments post-intervention as they may not have wanted to appear less physically active  
381 (Adams et al., 2005). Additionally, lifestyle interventions incorporating behaviour change techniques,  
382 such as self-monitoring of PA and goal setting, like the FFIT programme, may enhance participants'  
383 awareness of PA, hence potentially influencing PA reporting (Winkler et al., 2013).

384 In contrast, device-based measures may fail to accurately recognise certain forms of activity (e.g.  
385 swimming or resistance training) and therefore underestimate overall intervention effects. However,  
386 during the FFIT programme, participants were encouraged to increase their activity levels predominantly  
387 by increasing steps during the graduated walking component of the programme. It is therefore unlikely  
388 that many of the participants in this study would have been performing other forms of activity during

389 the intervention, such as swimming or strength-based exercises, thus the magnitude of error was likely  
390 small. Devices can be lost or malfunction, and only some participants may be willing to wear them.  
391 Further, data processing requires subjective decisions about thresholds and cut-offs that are much  
392 debated (Wijndaele et al., 2015). It has been advocated that due to the complexity in measuring PA, no  
393 single methodology is able to sufficiently capture all PA domains and subcomponents (Warren et al.,  
394 2010). We do not argue one or other method should be used; combining different methods of PA  
395 assessment may provide a more comprehensive reflection of individuals' amount of activity and its  
396 context, offering greater insights regarding evidence of behaviour change and efficacy of behavioural  
397 interventions targeting this complex behaviour. However, this study incorporated the IPAQ, Short Form  
398 which does not measure contextual information in the same way as the IPAQ, Long Form (e.g. leisure,  
399 transportation, housework/gardening, and occupation-related activity). Future studies investigating  
400 responsiveness of the IPAQ (Long Form) to changes in PA compared with device-based measures would  
401 be advantageous.

402 Previously noted low correlations between device-measured and self-reported PA have been used to  
403 criticise self-report measures. The results presented here suggest that if ability to detect *change* in PA  
404 behaviour is considered, self-reported PA can provide comparable sensitivity compared with device-  
405 based assessment. Importantly, it is frequently noted that the IPAQ should not be used to detect  
406 intervention effects as it was not designed for this purpose. The reality is that, due to its ubiquity, ease  
407 of use, and the lack of a viable alternative, it often is used. The results from this study based on a  
408 population of adult Scottish men add to arguments that the IPAQ can detect PA behaviour change.  
409 Nevertheless, it is important to note that higher responsiveness for self-reported PA may have occurred  
410 as a consequence of over reporting.

411 *Strengths and limitations*

412 This study has a number of strengths. First, the incorporation of device-based and self-report measures  
413 of PA enabled examination of the responsiveness of each measure to behaviour change longitudinally  
414 within the context of a 12 week intervention. The *activPAL*<sup>™</sup> monitor has been shown to be accurate in  
415 assessing step count in adults at normal walking speeds (Grant et al., 2008). The device is also able to  
416 assess MVPA utilising a threshold of cadence generally indicative of a moderate intensity (i.e. 100  
417 steps/minute). Additionally, inclusion of distinct indices of effect size and responsiveness is a further  
418 strength of this study as these calculations are simple to perform and easy to interpret, providing  
419 valuable information on the magnitude of behaviour change, thus enabling comparison of intervention  
420 efficacy across the field.

421 However, the study has some limitations. The assessment of responsiveness using SRM values is  
422 dependent to some degree on the extent to which data are normally distributed, although this is almost  
423 never the case with PA data (Lee et al., 2015). Also, the lack of a control condition restricted our use of  
424 alternative responsiveness methods used in other comparable studies. For example, the responsiveness  
425 statistic (Husted et al., 2000) also enables a comparison of the mean change in intervention scores  
426 compared to a control group condition. Hence, future research with a control condition would be  
427 advantageous. Future assessment regarding the degree of responsiveness to PA behaviour change  
428 (detected via self-report and device-based measures) compared to an established criterion (direct  
429 observation) would also be enlightening. Moreover, comparison of self-report and device-based  
430 methods in assessing responsiveness to long term behaviour change (beyond 12 weeks) would be of  
431 considerable value in understanding maintenance of PA behaviour change post-intervention. Another  
432 limitation of this study is the relatively small sample size which may have increased the chance of a type-  
433 II error, although a strength of using SRM as a measure of responsiveness is that it is independent of  
434 sample size (Prous, Salvanés, & Ortells, 2008). Additionally, the high degree of attrition may also  
435 indicate some bias towards participants who were successful in changing behaviour as indicated by both

436 self-report and device-based PA methods. Lastly, the findings are specific to adult men participating in a  
437 weight management and healthy lifestyle programme in Scotland (UK) and generalisability to wider  
438 population groups may be limited.

#### 439 **Conclusion**

440 In this study, two commonly used device-based (*activPAL3™*) and self-report (i.e. IPAQ, Short Form) PA  
441 measures were found to be responsive to behaviour change in men following participation in a 12 week  
442 weight loss and healthy living programme (FFIT), although there were non-significant correlations  
443 between these change scores. The magnitude of responsiveness to change was marginally higher for  
444 self-reported PA according to SRM values. While inclusion of both device-based and self-report  
445 measures is desirable, it is not always feasible, hence these findings provide support for the utility of  
446 self-reported PA instruments within the context of behavioural interventions promoting increased PA,  
447 although they may overestimate PA changes, relative to device-based measures.

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671 **Table 1 Pre-programme characteristics of study participants (n=30)**

<b>Physical measures</b>	<b>Mean (SD)</b>
Age (years)	45.9 (9.8)
Weight (kg)	111.8 (14.3)
BMI (kg/m <sup>2</sup> )	35.9 (5.3)
Waist (cm)	118.5 (11.1)
BP Systolic (mmHG)	139.8 (15.4)
BP Diastolic (mmHG)	86.8 (7.7)
<b>Socioeconomic status<sup>a</sup></b>	<b>% (n)</b>
1 (most deprived)	16.7 (5)
2	23.3 (7)
3	23.3 (7)
4	10 (3)
5 (least deprived)	26.7 (8)
<b>Marital Status</b>	<b>% (n)</b>
Single	3. (1)
Married	66.7 (20)
Separated	6.7 (2)
Living with someone	20 (6)
Divorced	3.3 (1)
Widowed	0 (0)

672 <sup>a</sup> Estimated using the Scottish Index of Multiple Deprivation based on home postcode  
673 (<http://www.gov.scot/Topics/Statistics/SIMD>).

674 **Table 2 Device-based (activPAL3™) and self-report (IPAQ) physical activity measurements at T0 and T1 and changes between T0 and T1 (n=30)**

	T0 Mean (SD)	Median (IQR)	T1 Mean (SD)	Median (IQR)	Change Mean (SD)	Change Median	Wilcoxo n (z)	<i>p</i>	SRM	ES
activPAL Number of steps (steps/day)	8315.5 (3063.3)	8167.2 (5874.7-9741.4)	9834.4 (3855.9)	9016.5 (6772.2-11667.5)	1518.8 (2891.1)	848.3	-2.58	0.007 <sup>a</sup>	0.53	0.47
activPAL Time stepping at a moderate cadence (min/day)	28.3 (18.8)	21.63 (12.7-43.5)	37.8 (27.3)	32.3 (15.6-46.6)	9.5 (21.6)	10.7	-1.90	0.022 <sup>a</sup>	0.44	0.35
activPAL MET-minutes (min/day)	2040 (78)	2031 (1976-2084)	2076 (90)	2056 (2025-2147)	36 (72)	24.6	-2.61	0.006 <sup>a</sup>	0.54	0.48
IPAQ Total PA minutes (min/day)	70.2 (78.4)	32.1 (23.8-112)	137.4 (86.3)	119.3 (62.7-181.1)	67.2 (113)	83	-3.56	<0.001 <sup>b</sup>	0.59	0.65
IPAQ Total MET-minutes (min/day)	304.5 (339.8)	166.5 (99-414.6)	622.1 (457.7)	507.9 (275.5-880.5)	317.7 (588.7)	341.4	-3.59	<0.001 <sup>b</sup>	0.54	0.66
IPAQ Walking MET-minutes (min/day)	134.7 (160.5)	75.4 (23.6-176.8)	254.4 (178.7)	229.9 (99-396)	119.7 (203.9)	154.4	-2.86	0.004 <sup>b</sup>	0.59	0.52
IPAQ Moderate MET-minutes (min/day)	65.4 (117.5)	0 (0-68.6)	115 (138.2)	55.7 (12.9-205.7)	49.5 (129.1)	55.7	-2.53	0.011 <sup>b</sup>	0.38	0.46

IPAQ Vigorous MET- minutes (min/day)	104.3 (170.2)	60 (0-137.1)	252.8 (348.1)	140 (0-291.4)	148.5 (388.6)	80	-2.58	0.010 <sup>b</sup>	0.38	0.47
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<sup>a</sup>Paired-samples t-test, <sup>b</sup>Wilcoxon signed-rank test, \*p < 0.05. \*\*p < 0.01. ES, effect size (non-parametric); SRM, standardised response mean.

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705 **Table 3 Responsiveness to change scores for participants demonstrating increased physical activity, no change or decreased physical activity**  
 706 **according to device-based (activPAL3™) and self-report (IPAQ) measurements between T0 and T1 (n=30)**

	% Increased PA (n) <sup>a</sup>	% Decreased PA (n)	% No change (n)	T0 and T1 mean change <sup>b</sup>	SD <sup>c</sup>	GRI
activPAL Number of steps (steps/day)	70 (21)	30 (9)	0 (0)	2913.1	1235.10	2.36
activPAL Time stepping at a moderate cadence (min/day)	56.7 (17)	43.3 (13)	0 (0)	23.5	5.58	4.21
activPAL MET-minutes (min/day)	73.3 (22)	26.7 (8)	0 (0)	72.7	32.4	2.24
IPAQ Total PA minutes (min/day)	86.7 (26)	10% (3)	3.3% (1)	95.5	145.18	0.66
IPAQ Total MET-minutes (min/day)	86.7 (26)	13.3% (4)	0 (0)	457.1	717.16	0.64
IPAQ Walking MET-minutes (min/day)	73.3 (22)	16.7% (5)	10% (3)	204.7	137.67	1.49
IPAQ Moderate MET-minutes (min/day)	60 (18)	17% (5)	23% (7)	119.0	113.83	1.05
IPAQ Vigorous MET-minutes (min/day)	60 (18)	10% (3)	30% (9)	321.71	27.19	11.83

707 <sup>a</sup>Percentage and number of participants demonstrating increased PA according to each measure, <sup>b</sup>Mean change in PA score for participants  
 708 identified as having increased PA from baseline to follow-up, <sup>c</sup>Standard deviation of change in PA score of participants indicating no change or  
 709 identified as having decreased PA from baseline to follow-up; GRI, Guyatt responsiveness index.

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717 **Table 4 Correlation coefficients between device-based (activPAL3™) and self-report (IPAQ) physical activity measurements**

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**T0 correlations (n=30)**

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<b>activPAL</b>	Total PA minutes (min/day)	Total MET-minutes (min/day)	<b>IPAQ</b>		
			Walking MET- minutes (min/day)	Moderate MET- minutes (min/day)	Vigorous MET-minutes (min/day)
Number of steps (steps/day)	0.34	0.29	0.42*	0.07	0.14
Time stepping at a moderate cadence (min/day)	0.26	0.18	0.49**	-0.15	-0.00
MET-minutes (min/day)	0.31	0.27	0.37*	0.08	0.14

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**T1 correlations (n=30)**

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<b>activPAL</b>	Total PA minutes (min/day)	Total MET-minutes (min/day)	<b>IPAQ</b>		
			Walking MET- minutes (min/day)	Moderate MET- minutes (min/day)	Vigorous MET-minutes (min/day)
Number of steps (steps/day)	0.36	0.30	0.34	0.14	0.15
Time stepping at a moderate cadence (min/day)	0.15	0.05	0.28	-0.10	-0.11
MET-minutes (min/day)	0.28	0.23	0.31	0.13	0.08

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718 Spearman's rank-order correlations, \*p < 0.05. \*\*p < 0.01.

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**Table 5 Correlation coefficients between device-based (activPAL3™) and self-report (IPAQ) physical activity changes**

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**T0-T1 correlations (n=30)**

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<b>activPAL</b>	Total PA minutes (min/day)	Total MET-minutes (min/day)	<b>IPAQ</b>		
			Walking MET- minutes (min/day)	Moderate MET- minutes (min/day)	Vigorous MET- minutes (min/day)
Number of steps (steps/day)	0.16	0.12	0.35	-0.20	-0.22
Time stepping at a moderate cadence (min/day)	0.07	0.04	0.18	-0.30	-0.19
MET-minutes (min/day)	0.13	0.10	0.31	-0.25	-0.21

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723 Spearman's rank-order correlations, \*p < 0.05. \*\*p < 0.01.