

Disentangling the relationship between sedentariness and obesity: Activity intensity, but not sitting posture, is associated with adiposity in women

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1 **Disentangling the relationship between sedentariness and obesity: Activity**
2 **intensity, but not sitting posture, is associated with adiposity in women**

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44 **ABSTRACT**

45 **Background**

46 The relationship between free-living sedentary behaviour (SB) and obesity is unclear.
47 Studies may arrive at disparate conclusions because of inconsistencies and limitations
48 when defining and measuring free-living SB. The aim of this cross-sectional study was
49 to examine whether the relationship between SB and adiposity differed depending on
50 the way SB was operationally defined and objectively measured.

51 **Methods**

52 Sixty-three female participants aged 37.1 years (SD=13.6) with a body mass index
53 (BMI) of 29.6 kg/m² (SD=4.7) had their body composition measured (BodPod,
54 Concord, CA) then were continuously monitored for 5-7 days with the SenseWear
55 Armband (SWA; sleep and activity intensity) and the activPAL (AP; posture). Data
56 from both activity monitors were analysed separately and integrated resulting in a third
57 measure of SB (activity intensity and posture; SED^{INT}). SB outputs were compared
58 according to week or weekend day averages then correlated against body composition
59 parameters after adjusting for moderate-to-vigorous physical activity (MVPA).

60 **Results**

61 SED^{SWA} resulted in the most sedentary time 11.74 hours/day (SD=1.60), followed by
62 SED^{AP} 10.16 hours/day (SD=1.75) and SED^{INT} 9.10 hours/day (SD=1.67). There was a
63 significant positive association between SED^{SWA} and body mass [r(61)=.29, p=.02],
64 BMI [r (61)=.33, p=.009] and fat mass [r(61) = .32, p = .01]. SED^{AP} and SED^{INT} were
65 not associated with any of the indices of adiposity. When the correlations between
66 SED^{SWA} and body mass [r(60) = -.01, p = .927], BMI [r(60) = .05, p = .678] and fat
67 mass [r(60) = .01, p = .936] were controlled for MVPA, the correlations were no longer
68 significant.

69 **Conclusions**

70 The relationship between SB and adiposity differed depending on how SB was
71 operationally defined and measured, and was confounded by MVPA. The definition of
72 SB based on a sitting posture (SED^{AP}) was not strongly related to body fat, whereas the
73 accumulation of any behaviour (sitting or standing) with an intensity of <1.5 METs
74 (SED^{SWA}) (offset by the presence of MVPA) was positively associated with indices of
75 adiposity. These data suggest that the postural element of SB (sitting) is not sufficient
76 for the accumulation of adiposity, rather activities requiring low EE (<1.5 METs) and
77 the absence of MVPA, regardless of posture, are associated with higher fat mass.

78

79 **Keywords**

80 Sedentary behaviour, sitting, posture, activity intensity, adiposity, measurement

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83 Key findings:

- 84 • The amount of time spent sedentary differs depending on the measurement
85 technique used to quantify sedentary behaviour.
- 86 • Only the activity intensity (<1.5 METs) measure of sedentary behaviour was
87 associated with measures of adiposity.
- 88 • Sitting posture alone is not sufficient to account for the accumulation of fat
89 mass.

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93 **1.1 BACKGROUND**

94 There is growing evidence linking sedentary behaviour (SB) with a number of negative
95 health outcomes including all-cause mortality, metabolic syndrome, cardiovascular
96 disease, type 2 diabetes and obesity [1-3]. An inherent limitation with the majority of
97 SB research are the methods by which SB is measured. Studies often use self-reported
98 TV viewing as a proxy measure of total sedentary time [4-6], however TV viewing may
99 not be representative of total sedentary time [7, 8] and is also associated with other
100 health related behaviours such as snacking on energy-dense foods [9, 10]. Due to
101 advancements in technology, objective measurement devices are increasingly being
102 used and these overcome some of the limitations of self-report measures of SB [11-13].
103 However, objective measurement devices are not without limitations and different
104 devices capture different facets of SB. For example, the activPAL (AP) measures SB
105 by distinguishing between sitting/lying and standing postures [14], whereas the
106 SenseWear armband (SWA) measures SB based on the accumulation of activities with
107 an intensity <1.5 metabolic equivalents (METs) [15]. The inconsistencies between
108 studies in the way SB is defined and measured make it difficult to deduce which
109 components of SB are driving the negative association with health outcomes reported
110 in the literature and may also contribute to the inconsistent relationship reported
111 between SB and adiposity [4, 16-24]. A standardized definition of SB has obvious
112 benefits for clarifying the impact of SB on health outcomes such as obesity. Indeed,
113 different facets of SB may be associated with some health outcomes and not others.

114 The most widely used definition of SB refers to “any waking behaviour characterised
115 by an energy expenditure ≤ 1.5 METs while in a sitting or reclining posture” [25].
116 Despite the Sedentary Behaviour Research Network’s attempt to consolidate the two
117 ways in which SB has previously been reported in scientific literature (posture alone [3]
118 and activity intensity alone [26]), there remains no consensus definition of SB [27]. The

119 word 'sedentary' originates from the Latin word 'sedere', which means to sit, and
120 implies posture is a fundamental facet of SB. However, it is unclear whether the
121 postural element of SB is important from a public health perspective or whether non-
122 sitting behaviours with an activity intensity of <1.5 METs also contribute to health
123 related outcomes such as adiposity. Thus, it is important to evaluate whether posture
124 should be included in the SB definition [27]. Indeed, it has been acknowledged that the
125 specific properties of SB that contribute to diminished health outcomes needs further
126 investigation and the inclusion of different SB definitions in studies to identify
127 differences in health outcomes has been encouraged [27, 28]. Furthermore, if SB is
128 defined by both activity intensity and posture, it is yet to be determined what activities
129 performed in a standing posture with an intensity of <1.5 METs should be categorised
130 as. The newly published SB terminology consensus suggests these activities should be
131 categorised as passive standing, but how such activities relate to health end points is not
132 clear.

133 The available tools to objectively quantify free-living SB limit researchers' ability to
134 address these questions. It has been noted that there is no single measurement device
135 that provides an accurate measure of both posture and activity intensity simultaneously
136 [14, 27]. To address this measurement limitation a method to integrate data from the
137 SWA mini and AP micro was developed [29]. We demonstrated that it is possible to
138 integrate time-stamped data from the SWA and the AP to measure SB defined by any
139 waking behaviour with an activity intensity of <1.5 METs whilst in a seated or
140 reclining posture. Furthermore, our previous work identified a negative association
141 between SB and adiposity when SB was defined by activity intensity alone, but not
142 when moderate-to-vigorous physical activity (MVPA) was controlled for [15]. This
143 relationship has previously been reported in cross-sectional studies using objective
144 measurement devices to quantify SB based on activity intensity [11, 30, 31], however

145 some studies have reported no association [22-24]. The aim of this study was to explore
146 whether the relationship between SB and adiposity differed depending on the way in
147 which SB was measured and defined. The three measures of SB were defined by i)
148 activity intensity, ii) posture and iii) activity intensity and posture, during waking
149 hours.

150

151 **1.2 METHODS**

152 **1.2.1 Participants**

153 Participants in the current study were initially recruited from a series of three studies
154 conducted at the University of Leeds between December 2014 and June 2016. General
155 recruitment strategies included emails circulated on University mailing lists and poster
156 advertisements. General inclusion criteria were: women, aged between 18 and 70 years,
157 body mass index (BMI) between 18.5 and 45.0 kg/m², premenopausal status, reporting
158 good health, no contraindications to exercise and not taking medication known to effect
159 metabolism or appetite. In the present analysis, each study's baseline data was used
160 from participants who had body composition data and ≥ 5 days (including ≥ 1 weekend
161 day) of valid SWA and AP data. Written informed consent was obtained before any
162 study procedures were carried out and all studies were approved by either the School of
163 Psychology (University of Leeds) or NHS (NRES Yorkshire and the Humber) Ethics
164 Committees (14-0099, 14-0090 and 09/H1307/7).

165 **1.2.2 Study Design**

166 The three studies included in this cross-sectional analysis followed the same systematic
167 protocol according to laboratory standardised operating procedures. Participants
168 attended the research unit twice over the course of one week. Free-living SB was

169 measured continuously for a minimum of 5 days for >22 hours/day with the SWA and
170 AP simultaneously.

171 On the morning of day one, participants were provided with a physical activity (PA)
172 diary and fitted with a SWA mini (BodyMedia, Inc., Pittsburgh, PA) and AP micro
173 (PAL Technologies Ltd, Glasgow, UK) and instructed to continue their normal daily
174 living activities during the measurement period. Participants returned to the lab on day
175 7 or 8 after an overnight fast (no food or drink except water from 9:00 pm the evening
176 before) to return the activity monitors and completed PA diary and have their body
177 composition and anthropometric measurements taken (height, weight, waist
178 circumference).

179 **1.2.3 Free-living Sedentary Behaviour**

180 Participants wore the SWA on the posterior surface of their upper non-dominant arm
181 for a minimum of 22 hours per day for ≥ 6 days (except for the time spent showering,
182 bathing or swimming). For the SWA data to be valid ≥ 22 hours of data per day had to
183 be recorded on at least five days (midnight to midnight) including at least one weekend
184 day. The SWA measures motion (triaxial accelerometer), galvanic skin response, skin
185 temperature and heat flux. Proprietary algorithms available in the accompanying
186 software (SenseWear Professional 8.0, algorithm v5.2) calculate energy expenditure
187 and classify the intensity of activity. SB using the SWA only was classified as time
188 spent in activities <1.5 METs excluding sleep [26, 32]. The SWA has been shown to
189 perform better than accelerometer-only activity monitors when classifying activity into
190 minutes of SB, light, moderate and vigorous PA [33]. The SWA only records data
191 when it is in contact with the skin and therefore provides a direct measure of
192 compliance.

193 The AP is a small, light, thigh-mounted triaxial accelerometer which directly measures
194 the postural element of SB. Accelerometer-derived information about thigh position
195 and acceleration are used to determine body posture (sitting or lying (it is unable to
196 distinguish between sitting and lying), standing and stepping), transitions between
197 different postures, and number of steps using proprietary algorithms within the
198 accompanying software (activPAL software version 7.2.32, Intelligent Activity
199 Classification). SB using the AP posture measure (and removing sleep using the SWA
200 data) was classified as time spent sitting or lying excluding sleep. The AP was placed
201 in a nitrile sleeve and attached to the midline anterior aspect of the upper thigh on the
202 non-dominant leg with a hypafix waterproof dressing. Participants were instructed to
203 wear the AP at all times. If they removed the device they were asked to record the day,
204 time and reason for removing in the activity diary provided. Compliance with the AP
205 wear protocol was determined by cross-checking any prolonged periods of sitting/lying
206 (>2 hours) with SWA data from the same period. If the SWA recorded movement (i.e.
207 stepping) and an activity >1.5 METs during this period it would indicate the AP had
208 been removed and that days data would be removed. No data was removed for this
209 reason in the current study. The AP has almost perfect correlation and excellent
210 agreement with direct observation for sitting/lying time, upright time, sitting/lying to
211 upright transitions and for detecting reductions in sitting [34-36].

212 Information on sleep and activity intensity (<1.5 METs) from the SWA and posture
213 (sitting/lying) from the AP were integrated to generate a measure of SB defined by both
214 activity intensity and posture during waking hours. The procedure for integrating data
215 from the SWA and AP has been described in detail previously [29]. This procedure
216 resulted in three SB outputs that were represented by SED^{SWA} , SED^{AP} and SED^{INT} ,
217 when referring to data from the SWA, AP and integrated data from both activity

218 monitors, respectively. Table 1 shows the criteria for defining SB based on each of the
219 SB outputs. By subtracting SED^{INT} from SED^{SWA} it was also possible to identify time
220 spent standing at an intensity of <1.5 METs (SED^{STAND}).

221 Table 1. Classification of sedentary behaviour based on the three sedentary behaviour
222 measurement techniques.

Variable	Awake	<1.5 METs	Sitting/lying
SED^{SWA}	✓	✓	-
SED^{AP}	✓	-	✓
SED^{INT}	✓	✓	✓

SED, sedentary time; SWA, SenseWear Armband; AP, activPAL; INT, integrated data; METs, metabolic equivalents.

223

224 1.2.4 Body Composition and Anthropometrics

225 Body composition was measured using air displacement plethysmography (BodPod,
226 Life Measurement Incorporated, Concord, CA). Waist circumference was measured
227 horizontally in line with the umbilicus. Three measures were taken and averaged.

228 Where possible the same researcher completed all measurements. Height was measured
229 using a stadiometer (Leicester height measure, SECA). Measurements were recorded to
230 the nearest 0.1 cm. Body weight was obtained from the BodPod whilst participants
231 were wearing minimal clothing and BMI was calculated as weight in kg/height in m^2 .

232 1.2.5 Statistical Analysis

233 Data are reported as mean (SD) throughout. Statistical analysis was performed using
234 IBM SPSS for Windows (Chicago, Illinois, Version 21). Relationships were regarded
235 as statistically significant with a p value $< .05$. All variables were checked for

236 normality using the Shapiro-Wilk test and indicating that the data was normally
237 distributed [$p > .05$]. Characteristics of the study population were summarised using
238 descriptive statistics. Differences in SED^{SWA} , SED^{AP} and SED^{INT} methods were
239 examined using repeated measures ANOVA with Bonferroni post-hoc tests. To identify
240 differences in SED on weekdays compared with weekend days paired sample t-tests
241 were performed. Pearson correlations were performed to examine the associations
242 between SB (whole week, weekday and weekend day), MVPA and body composition.
243 Partial correlations were performed to control for the potential confounding influence
244 of MVPA in the association between SED^{SWA} / SED^{STAND} and body composition.
245 Independent sample t-tests were conducted to examine differences in time spent in
246 different intensities of PA between those who registered more SED^{SWA} than SED^{AP}
247 (sedentary standers) and those who performed more SED^{AP} than SED^{SWA} (active
248 sitters).

249

250 **1.3 RESULTS**

251 **1.3.1 Participant Characteristics**

252 Study sample characteristics are displayed in table 2. Sixty-three participants (women)
253 had ≥ 5 days (including ≥ 1 weekend day) of valid SWA and AP data and body
254 composition data. Average wear time for the SWA was 23.61 hours/day ($SD = 0.27$) or
255 98.38% ($SD = 1.13$) and the average wear period was 6.48 days ($SD = 0.67$).

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261 Table 2. Descriptive statistics of study sample.

Variable	Mean (SD)	Range
Age (years)	37.08 (13.58)	19.00 – 69.00
Height (m)	1.64 (0.06)	1.49 – 1.79
Body mass (kg)	79.51 (13.81)	44.90 – 115.80
BMI (kg/m²)	29.57 (4.67)	19.00 – 42.50
Fat mass (kg)	33.29 (11.23)	11.90 – 62.90
Fat-free mass (kg)	46.22 (5.19)	32.10 – 57.40
Waist circumference (cm)	98.28 (13.58)	69.00 – 139.00
Wear time^{SWA} (hours/day)	23.61 (0.27)	22.70 – 24.00
Sleep^{SWA} (hours/day)	7.38 (0.99)	5.50 – 9.90
SED^{SWA} (hours/day)	11.74 (1.60)	8.27 – 14.72
SED^{AP} (hours/day)	10.16 (1.75)	6.40 – 14.40
SED^{INT} (hours/day)	9.10 (1.67)	5.02 – 12.97
SED^{STAND} (hours/day)	2.64 (1.51)	0.80 - 7.45
MVPA (hours/day)	1.54 (0.86)	0.25 – 3.47

BMI, body mass index; SED, sedentary time; SWA, SenseWear Armband; AP, activPAL; INT, integrated data; MVPA, moderate-to-vigorous physical activity.

262

263 **1.3.2 Differences between the three sedentary behaviour measurement methods**

264 There was a significant difference between average daily sedentary time determined by
 265 the different measurement methods; participants were sedentary (excluding sleep) for
 266 an average of 11.74 hours/day (SD = 1.60), 10.16 hours/day (SD = 1.75) and 9.10
 267 hours/day (SD = 1.67) determined by the SED^{SWA}, SED^{AP} and SED^{INT} methods,
 268 respectively [F(1.18, 73.15) = 104.70, p < .001]. Post-hoc comparisons with Bonferroni
 269 corrections revealed all three methods were significantly different from each other [p <
 270 .001].

271 **1.3.3 Weekday versus weekend day sedentary time**

272 Paired sample t-tests revealed that the amount of sedentary time accumulated on
273 weekdays ($M = 11.93$ hours/day, $SD = 1.74$) compared with weekend days ($M = 11.36$
274 hours/day, $SD = 2.17$) was significantly different when measured using SED^{SWA} [$t(62)$
275 $= 2.11$, $p = .04$], but not SED^{AP} [$p = .11$] or SED^{INT} [$p = .25$]. The amount of time spent
276 sleeping on weekdays ($M = 7.23$ hours/day, $SD = 1.08$) compared with weekend days
277 ($M = 7.74$ hours/day, $SD = 1.38$) was significantly different [$t(62) = 2.88$, $p = .005$].

278 **1.3.4 Associations between free-living sedentary behaviour and body composition**

279 Before adjusting for MVPA, there was a positive correlation between SED^{SWA} and
280 body mass [$p = .02$], BMI [$p = .009$] and fat mass [$p = .01$]. However, there were no
281 correlations between SED^{AP} and SED^{INT} and any of the measures of body composition
282 (see table 3). Panels A, B and C of Figure 1 are visual representations of the
283 relationship between sedentary time and body fat when SB is defined by either an
284 activity intensity of <1.5 METs, a sitting or lying posture or a combination of both.
285 After adjusting for MVPA, there were no significant correlations between SED^{SWA} and
286 indices of adiposity [$p > .05$] (see table 3). MVPA and indices of adiposity were
287 inversely associated with body mass [$r(61) = -.50$, $p < .001$], BMI [$r(61) = -.48$, $p <$
288 $.001$] and fat mass [$r(61) = -.53$, $p < .001$], see panel D of figure 1.

289 **Figure 1 around here**

290 It was also possible to examine the relationship between SED^{STAND} and body
291 composition. Before controlling for MVPA, there was a positive correlation between
292 SED^{STAND} and BMI [$r(61) = .32$, $p = .012$] and fat mass [$r(61) = .26$, $p = .039$].
293 However, when partial correlations were performed to control for the amount of
294 MVPA, the correlations between SED^{STAND} and BMI [$r(60) = .16$, $p = .214$] and
295 SED^{STAND} and fat mass [$r(60) = .07$, $p = .577$] were no longer significant.

296 Participants were categorised based on whether they performed more SED^{SWA} than
 297 SED^{AP} (sedentary standers; n = 52) or those who performed more SED^{AP} than SED^{SWA}
 298 (active sitters; n = 11). Independent sample t-tests revealed that sedentary standers
 299 performed less total PA [t(61) = 4.18, p < .001], light PA [t(61) = 3.78, p < .001] and
 300 MVPA [t(61) = 2.51, p = .015] than active sitters.

301 When total sedentary time was divided in to weekday and weekend day sedentary time
 302 only weekday SED^{SWA} was associated with body mass [p = .02], BMI [p = .01] and fat
 303 mass [p = .01], see table 3.

304

305 Table 3. Correlation between the different measures of free-living sedentary time and
 306 body composition for the whole week, weekdays and weekend days separately.

		BM (kg)	BMI (kg/m ²)	FM (kg)	WC (cm)	FFM (kg)
Whole week	SED^{SWA} (min/day)	.29*	.33**	.32**	.23	.08
	SED^{AP} (min/day)	.05	-.02	.02	-.05	.10
	SED^{INT} (min/day)	.09	.03	.08	.01	.08
Weekday	SED^{SWA} (min/day)	.28*	.31*	.31*	.21	.08
	SED^{AP} (min/day)	.17	.20	.18	.16	.06
	SED^{INT} (min/day)	-.001	-.09	-.04	-.12	.09
Weekend day	SED^{SWA} (min/day)	.11	.08	.09	.10	.10
	SED^{AP} (min/day)	.04	-.03	0.2	-.06	.07
	SED^{INT} (min/day)	.13	.09	.12	.13	.08
Whole week	SED^{SWA} (min/day)†	-.01	.05	.01	-.02	-.05
	SED^{AP} (min/day)†	.04	-.04	-.00	-.06	.10
	SED^{INT} (min/day)†	-.03	-.09	-.05	-.09	.04
Weekday	SED^{SWA} (min/day)†	.03	.08	.05	.01	-.01
	SED^{AP} (min/day)†	-.01	-.10	-.05	-.14	.09

	SED^{INT} (min/day)†	-0.07	-0.14	-0.10	-0.15	.04
Weekend day	SED^{SWA} (min/day)†	-0.17	-0.10	-0.17	-0.14	-0.10
	SED^{AP} (min/day)†	-0.04	-0.07	-0.07	-0.04	.04
	SED^{INT} (min/day)†	-0.10	-0.13	-0.11	-0.07	-0.01

n=63; Data in the upper panel are zero-order Pearson correlations and the lower panel are partial correlations controlling for MVPA (†). ** p < .01. BMI; * p < .05; BM, body mass; BMI, body mass index; FM, fat mass; WC, waist circumference; FFM, fat-free mass; SED, sedentary time; SWA, SenseWear Armband; AP, activPAL; INT, integrated data.

307

308 **1.4 DISCUSSION**

309 The aim of the current study was to examine whether the way in which SB is
310 operationally defined and objectively measured impacts on the estimation of sedentary
311 time and its association with health related outcomes. More specifically, whether the
312 addition of posture to low intensity behaviour (<1.5 METs) is a stronger predictor of
313 indices of adiposity than measures of low intensity behaviour and posture alone.
314 Furthermore, we tested whether any relationships between the different measures of SB
315 and adiposity were independent of MVPA. Utilising the methodological platform
316 described previously [29] to combine information from two validated activity monitors
317 using a novel integrative procedure, three measures of SB were defined by i) activity
318 intensity (<1.5 METs), ii) posture (sitting/lying) and iii) activity intensity and posture.
319 This study is the first to report the relationship between SB and adiposity when SB is
320 defined and objectively measured in multiple ways, simultaneously in the same study
321 participant. Our study demonstrates that the method used to measure SB impacts on the
322 observed relationship with adiposity. Furthermore, the relationship between SB (when
323 defined by an EE <1.5 METs) and adiposity is not independent of MVPA. Only when
324 SB was defined by low intensity behaviour (<1.5 METs), and not adjusted for MVPA,
325 was an association with adiposity apparent. Participants who performed more SED^{SWA}
326 had more fat mass, a higher BMI and overall body mass, however the presence or lack

327 of MVPA appears to be a stronger determinant of obesity than SB. These relationships
328 are consistent with our previous work [15]. Previous studies have examined the
329 relationship between objectively measured free-living SB and body fatness and have
330 produced mixed findings [11, 22-24, 30, 31, 37]. The inconsistencies between studies
331 regarding the relationship between SB and adiposity could be explained by the different
332 measurement methods used to quantify SB or whether MVPA is accounted for.

333 Interestingly, SED^{AP} and SED^{INT} were not significantly associated with any measures
334 of adiposity even without adjusting for MVPA. The absence of an association between
335 measures of sitting/lying and sitting/lying plus low intensity behaviour and adiposity in
336 our data suggests that the postural element (sitting) of SB is not sufficient for fat mass
337 accumulation. However, it is important to note that the amount of time spent in a seated
338 posture is an important risk factor for adiposity because it contributes approximately
339 80% of the time spent with an activity intensity <1.5 METs. Given that SED^{SWA}
340 recorded significantly more sedentary time than SED^{AP} and SED^{INT} it is possible that
341 the measures which include posture are too restrictive and exclude behaviour that is
342 negatively impacting on health outcomes. SED^{SWA} is likely to capture some standing
343 with an activity intensity of <1.5 METs as well as sitting/lying; only when both of these
344 postures are included (sitting and standing at <1.5 METs) does an association with
345 adiposity become apparent. A recent study found that compared to sitting, standing did
346 not cause a sustained increase in energy expenditure in the majority (81%) of the study
347 sample and energy expenditure did not exceed 1.5 METs in any of the participants [38].
348 In light of this, recommendations to reduce sitting by increasing standing [39] may not
349 cause a significant enough increase in energy expenditure to produce health benefits -
350 even in those who do very little MVPA, although other metabolic and psychosocial
351 benefits are possible. The relationship between activities of low energy expenditure
352 (<1.5 METs) in a standing posture with health related outcomes needs exploring. It was

353 possible to calculate SED^{STAND} by subtracting SED^{INT} from SED^{SWA} and correlation
354 analysis revealed there was a positive relationship between BMI, fat mass and
355 SED^{STAND} , which was not apparent after controlling for MVPA.

356 The absence of an association between activity of <1.5 METs in a sitting posture
357 (SED^{INT}), but the presence of a relationship between activity of <1.5 METs in a
358 standing posture (SED^{STAND}) seems counter intuitive. Further analysis revealed that
359 those who performed more SED^{SWA} than SED^{AP} (accumulated time standing with an
360 energy expenditure of <1.5 METs) performed less total PA, light PA and MVPA than
361 those who performed more SED^{AP} than SED^{SWA} (accumulated time sitting with an
362 energy expenditure of >1.5 METs). Therefore, the positive association between
363 SED^{STAND} and BMI and fat mass could be confounded by lower levels of MVPA rather
364 than standing at an energy expenditure of <1.5 METs. When relating SB to adiposity,
365 the definition of SB by Pate et al. seems most appropriate; "sedentary behaviour
366 includes activities that involve energy expenditure at the level of 1.0-1.5 METs." [26].

367 It is important to note that the relationships between SED^{SWA} and SED^{STAND} and
368 indices of adiposity were no longer significant after controlling for MVPA. This is in
369 agreement with previous research that demonstrated the relationship between SB and
370 indices of adiposity is nullified after controlling for MVPA [13, 15, 24, 31]. This
371 suggests that the relationship between low intensity behaviour (<1.5 METs) and indices
372 of adiposity depends on the amount of MVPA an individual performs.

373 Importantly, the lack of association between posture and adiposity does not rule out the
374 role of sitting in the development of other cardio metabolic health outcomes [40].

375 Laboratory studies examining the mechanisms underlying negative health outcomes
376 associated with SB indicate that prolonged sitting may trigger a chain of unhealthy
377 molecular responses, including down regulation of lipoprotein lipase activity, which

378 could impact on physiological outcomes such as insulin sensitivity [41], whether
379 engaging in MVPA might ameliorate these relationships is unclear. It also remains
380 unclear whether a change in posture is sufficient to induce improvements in biological
381 markers of metabolic health or whether a change in posture must be accompanied with
382 an increase in energy expenditure before any benefit is accrued. Pulsford et al. [42]
383 recently found that interrupting sitting with repeated short bouts of light intensity
384 walking improved insulin sensitivity, whereas repeated short bouts of standing did not.
385 As with the results of the present study, these findings indicate that the postural element
386 of SB (sitting) is not driving the relationship between SB and negative health outcomes
387 reported in the literature and in fact it is the accumulation of low intensity behaviours
388 (whilst sitting or standing) and/or the absence of MVPA.

389 Participants slept longer on the weekend days (30 min/day) which appeared to displace
390 SB as SED^{SWA} was significantly less on the weekend (34 min/day). A similar difference
391 in sleep and sedentary time between weekdays and weekend days has previously been
392 reported [43, 44]. When the relationship between weekday and weekend day SB and
393 body composition was examined, only weekday SED^{SWA} was associated with indices
394 of adiposity before controlling for MVPA. This is in keeping with previous research
395 that demonstrated the relationship is stronger between weekday sedentary time and
396 adiposity compared with weekend sedentary time using the same measurement
397 technique to quantify SB as in the current study (SED^{SWA}) [44]. A possible explanation
398 for the difference in association between weekday and weekend day SED^{SWA} is that
399 participants have less choice over how they spend their time on weekdays due to
400 sedentary occupations whereas participants may choose to be more active during the
401 weekend. As there are more weekdays (~70% of whole week) than weekend days,
402 weekdays are more representative of usual behaviour and could explain the relationship
403 with adiposity.

404 The current study demonstrates the associations between SB and body composition
405 differ depending on the measurement technique used to quantify and define SB, and are
406 secondary to MVPA. This is a pertinent issue as research in this area employs a
407 plethora of measurement techniques to measure SB; from self-report questionnaires
408 focusing on screen-based activities such as TV viewing [19, 20], to objective measures
409 of activity intensity or posture [15, 31, 45]. The present study suggests that before
410 accounting for MVPA, low energy expenditure, as a result of accumulating a high
411 volume of behaviours expending <1.5 METs (either sitting or standing), is associated
412 with greater fat mass, whereas posture is not. There are certain limitations to the
413 present study that should be taken into account with our interpretation. Firstly, the
414 limited sample size and unknown contribution of measurement error in our
415 methodologies may have influenced our findings and further studies are required to
416 examine the relationship between different measures of SB and obesity and other health
417 related endpoints. It is also important to address the possibility of reverse causality. Our
418 interpretation of the data suggests that in the absence of MVPA, high volumes of low
419 intensity behaviour will lead to a positive energy balance and promote weight gain.
420 Alternatively, weight gain, as a result of high energy intake, may promote sedentariness
421 (an energy expenditure of <1.5 METs, but not sitting) or discourage engagement in
422 MVPA. Indeed, bidirectional or reciprocal causality may exist with a cycle of increased
423 fat mass as a result of high volumes of sedentary behaviour, which leads to further
424 increases in sedentary time. Further longitudinal research is required to better
425 understand the causal relationships between SB, MVPA and adiposity.

426 **1.4.1 Conclusions**

427 Of the three measures of SB included in this study, only low intensity behaviour (<1.5
428 METs) was associated with adiposity. This relationship was not apparent after
429 correcting for MVPA. The present research indicates that the relationship between SB

430 and adiposity depends on the measurement device used to measure behaviour and
431 therefore which aspects of SB the device captures, as well as the amount of MVPA that
432 is accumulated. These data suggest that the postural element of SB (sitting) is not
433 sufficient for the accumulation of adiposity. Rather low EE, as a result of high volumes
434 of low intensity behaviour (<1.5 METs) regardless of posture, and a lack of moderate-
435 to-high intensity activity, is associated with higher fat mass.

436

437

438 **LIST OF ABBREVIATIONS**

439 AP, activPAL micro; BMI, body mass index; METs, metabolic equivalents; MVPA,
440 moderate-to-vigorous physical activity; PA, physical activity; SB, sedentary behaviour;
441 SED^{SWA} , sedentary time measured using the SenseWear armband; SED^{AP} , sedentary
442 time measured using the activPAL; SED^{INT} , sedentary time measured using the
443 integrated data; SED^{STAND} , time spent standing with an energy expenditure <1.5 METs;
444 SWA, SenseWear Armband mini.

445 **DECLARATIONS**

446 **Ethics approval and consent to participate**

447 All participants provided their written informed consent and all studies were approved
448 by either the School of Psychology (University of Leeds) or NHS (NRES Yorkshire
449 and the Humber) Ethics Committees (14-0099, 14-0090 and 09/H1307/7).

450 **Consent for publication**

451 Not applicable

452 **Availability of data and material**

453 The datasets used and/or analysed during the current study are available from the
454 corresponding author on reasonable request.

455 **Competing interests**

456 The authors declare that they have no competing interests and there are no conflicts
457 regarding Edward Butler's corporate affiliation with Endava Ltd.

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461

462 **Authors' contributions**

463 AM, MD, NB, CG, GF and JB designed research; AM, MD, NB and CG conducted
464 research; EB developed the integration program for sedentary behaviour data from the
465 SenseWear Armband and activPAL; AM integrated and processed activity monitor
466 data; AM analysed data; AM wrote the manuscript and GF, CG and JB provided
467 feedback. All authors discussed results/interpretation and approved the final
468 manuscript.

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471 **Twitter**

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473

474 **1.5 REFERENCES**

- 475 1. Edwardson CL, Gorely T, Davies MJ, Gray LJ, Khunti K, Wilmot EG,
476 Yates T, Biddle SJ: **Association of sedentary behaviour with**
477 **metabolic syndrome: a meta-analysis.** *PLoS One* 2012, **7**:e34916.
- 478 2. Biswas A, Oh PI, Faulkner GE, Bajaj RR, Silver MA, Mitchell MS, Alter
479 DA: **Sedentary Time and Its Association With Risk for Disease**
480 **Incidence, Mortality, and Hospitalization in Adults: A Systematic**
481 **Review and Meta-analysis.** *Ann Intern Med* 2015, **162**:123-132.
- 482 3. Biddle S, Cavill N, Ekelund U, Gorely T, Griffiths M, Jago R, Oppert J,
483 Raats M, Salmon J, Stratton G: **Sedentary behaviour and obesity:**
484 **review of the current scientific evidence.** *United Kingdom-*
485 *Department of Health: Department for Children SaF* 2010.
- 486 4. Dunstan D, Salmon J, Owen N, Armstrong T, Zimmet P, Welborn T,
487 Cameron A, Dwyer T, Jolley D, Shaw J: **Associations of TV viewing**
488 **and physical activity with the metabolic syndrome in Australian**
489 **adults.** *Diabetologia* 2005, **48**:2254-2261.
- 490 5. Ford ES, Caspersen CJ: **Sedentary behaviour and cardiovascular**
491 **disease: a review of prospective studies.** *Int J Epidemiol* 2012,
492 **41**:1338-1353.
- 493 6. Atkin AJ, Gorely T, Clemes SA, Yates T, Edwardson C, Brage S,
494 Salmon J, Marshall SJ, Biddle SJ: **Methods of measurement in**
495 **epidemiology: sedentary behaviour.** *Int J Epidemiol* 2012, **41**:1460-
496 1471.
- 497 7. Biddle SJ, Gorely T, Marshall SJ: **Is television viewing a suitable**
498 **marker of sedentary behavior in young people?** *Ann Behav Med*
499 2009, **38**:147.
- 500 8. Sugiyama T, Healy GN, Dunstan DW, Salmon J, Owen N: **Is television**
501 **viewing time a marker of a broader pattern of sedentary behavior?**
502 *Ann Behav Med* 2008, **35**:245-250.
- 503 9. Gore SA, Foster JA, DiLillo VG, Kirk K, Smith West D: **Television**
504 **viewing and snacking.** *Eating Behaviors* 2003, **4**:399-405.
- 505 10. Thomson M, Spence JC, Raine K, Laing L: **The association of**
506 **television viewing with snacking behavior and body weight of**
507 **young adults.** *Am J Health Promot* 2008, **22**:329-335.
- 508 11. Healy GN, Wijndaele K, Dunstan DW, Shaw JE, Salmon J, Zimmet PZ,
509 Owen N: **Objectively measured sedentary time, physical activity,**
510 **and metabolic risk the Australian Diabetes, Obesity and Lifestyle**
511 **Study (AusDiab).** *Diabetes Care* 2008, **31**:369-371.
- 512 12. Healy GN, Dunstan DW, Salmon J, Cerin E, Shaw JE, Zimmet PZ,
513 Owen N: **Breaks in sedentary time beneficial associations with**
514 **metabolic risk.** *Diabetes Care* 2008, **31**:661-666.
- 515 13. Henson J, Yates T, Biddle SJ, Edwardson CL, Khunti K, Wilmot EG,
516 Gray LJ, Gorely T, Nimmo MA, Davies MJ: **Associations of objectively**
517 **measured sedentary behaviour and physical activity with markers**
518 **of cardiometabolic health.** *Diabetologia* 2013, **56**:1012-1020.
- 519 14. Edwardson CL, Winkler EA, Bodicoat DH, Yates T, Davies MJ, Dunstan
520 DW, Healy GN: **Considerations when using the activPAL monitor in**
521 **field-based research with adult populations.** *Journal of Sport and*
522 *Health Science* 2016.
- 523 15. Myers A, Gibbons C, Finlayson G, Blundell J: **Associations among**
524 **sedentary and active behaviours, body fat and appetite**

- 525 **dysregulation: investigating the myth of physical inactivity and**
526 **obesity.** *Br J Sports Med* 2016:bjsports-2015-095640.
- 527 16. Heinonen I, Helajärvi H, Pahkala K, Heinonen O, Hirvensalo M, Pälve K,
528 Tammelin T, Yang X, Juonala M, Mikkilä V: **Sedentary behaviours and**
529 **obesity in adults: the Cardiovascular Risk in Young Finns Study.**
530 *BMJ open* 2013, **3**.
- 531 17. Bell JA, Hamer M, Batty GD, Singh-Manoux A, Sabia S, Kivimaki M:
532 **Combined effect of physical activity and leisure time sitting on**
533 **long-term risk of incident obesity and metabolic risk factor**
534 **clustering.** *Diabetologia* 2014, **57**:2048-2056.
- 535 18. Hu FB, Li TY, Colditz GA, Willett WC, Manson JE: **Television watching**
536 **and other sedentary behaviors in relation to risk of obesity and**
537 **type 2 diabetes mellitus in women.** *JAMA* 2003, **289**:1785-1791.
- 538 19. Healy GN, Dunstan DW, Salmon J, Shaw JE, Zimmet PZ, Owen N:
539 **Television time and continuous metabolic risk in physically active**
540 **adults.** *Med Sci Sports Exerc* 2008, **40**:639-645.
- 541 20. Healy GN, Matthews CE, Dunstan DW, Winkler EA, Owen N: **Sedentary**
542 **time and cardio-metabolic biomarkers in US adults: NHANES 2003–**
543 **06.** *Eur Heart J* 2011, **32**:590-597.
- 544 21. Pulsford RM, Stamatakis E, Britton AR, Brunner EJ, Hillsdon MM:
545 **Sitting behavior and obesity: evidence from the Whitehall II study.**
546 *Am J Prev Med* 2013, **44**:132-138.
- 547 22. Murabito JM, Pedley A, Massaro JM, Vasani RS, Esliger D, Blease SJ,
548 Hoffman U, Fox CS: **Moderate-to-Vigorous Physical Activity With**
549 **Accelerometry is Associated With Visceral Adipose Tissue in**
550 **Adults.** *Journal of the American Heart Association* 2015, **4**:e001379.
- 551 23. McGuire KA, Ross R: **Incidental physical activity and sedentary**
552 **behavior are not associated with abdominal adipose tissue in**
553 **inactive adults.** *Obesity* 2012, **20**:576-582.
- 554 24. Van Dyck D, Cerin E, De Bourdeaudhuij I, Hinckson E, Reis RS, Davey
555 R, Sarmiento OL, Mitas J, Troelsen J, MacFarlane D: **International**
556 **study of objectively measured physical activity and sedentary time**
557 **with body mass index and obesity: IPEN adult study.** *Int J Obes*
558 2015, **39**:199-207.
- 559 25. Sedentary Behaviour Research Network: **Letter to the editor:**
560 **standardized use of the terms “sedentary” and “sedentary**
561 **behaviours”.** *Applied Physiology, Nutrition, and Metabolism* 2012,
562 **37**:540-542.
- 563 26. Pate RR, O'Neill JR, Lobelo F: **The evolving definition of " sedentary".**
564 *Exerc Sport Sci Rev* 2008, **36**:173-178.
- 565 27. Gibbs BB, Hergenroeder AL, Katzmarzyk PT, Lee I-M, Jakicic JM:
566 **Definition, measurement, and health risks associated with**
567 **sedentary behavior.** *Med Sci Sports Exerc* 2015, **47**:1295-1300.
- 568 28. Byrom B, Stratton G, Mc Carthy M, Muehlhausen W: **Objective**
569 **measurement of sedentary behaviour using accelerometers.** *Int J*
570 *Obes* 2016, **40**:1809-1812.
- 571 29. Myers A, Gibbons C, Butler E, Dalton M, Buckland N, Blundell J,
572 Finlayson G: **A novel integrative procedure for identifying and**
573 **integrating three-dimensions of objectively measured free-living**
574 **sedentary behaviour.** *BMC Public Health* 2017, **17**:979.

- 575 30. Hamer M, Venuraju SM, Urbanova L, Lahiri A, Steptoe A: **Physical**
576 **activity, sedentary time, and pericardial fat in healthy older adults.**
577 *Obesity* 2012, **20**:2113-2117.
- 578 31. Lynch BM, Dunstan DW, Healy GN, Winkler E, Eakin E, Owen N:
579 **Objectively measured physical activity and sedentary time of**
580 **breast cancer survivors, and associations with adiposity: findings**
581 **from NHANES (2003–2006).** *Cancer Causes Control* 2010, **21**:283-288.
- 582 32. Ainsworth BE, Haskell WL, Herrmann SD, Meckes N, Bassett Jr DR,
583 Tudor-Locke C, Greer JL, Vezina J, Whitt-Glover MC, Leon AS: **2011**
584 **Compendium of Physical Activities: a second update of codes and**
585 **MET values.** *Med Sci Sports Exerc* 2011, **43**:1575-1581.
- 586 33. Calabró MA, Lee J-M, Saint-Maurice PF, Yoo H, Welk GJ: **Validity of**
587 **physical activity monitors for assessing lower intensity activity in**
588 **adults.** *International Journal of Behavioral Nutrition and Physical Activity*
589 2014, **11**:119-128.
- 590 34. Kozey-Keadle S, Libertine A, Lyden K, Staudenmayer J, Freedson PS:
591 **Validation of wearable monitors for assessing sedentary behavior.**
592 *Med Sci Sports Exerc* 2011, **43**:1561-1567.
- 593 35. Kozey-Keadle S, Libertine A, Staudenmayer J, Freedson P: **The**
594 **feasibility of reducing and measuring sedentary time among**
595 **overweight, non-exercising office workers.** *J Obes* 2012, **2012**.
- 596 36. Lyden K, Kozey-Keadle SL, Staudenmayer JW, Freedson PS: **Validity**
597 **of two wearable monitors to estimate breaks from sedentary time.**
598 *Med Sci Sports Exerc* 2012, **44**:2243.
- 599 37. Thorp AA, Owen N, Neuhaus M, Dunstan DW: **Sedentary behaviors**
600 **and subsequent health outcomes in adults: a systematic review of**
601 **longitudinal studies, 1996–2011.** *Am J Prev Med* 2011, **41**:207-215.
- 602 38. Miles-Chan JL, Fares EJ, Berkachy R, Jacquet P, Isacco L, Schutz Y,
603 Montani JP, Dulloo AG: **Standing economy: does the heterogeneity**
604 **in the energy cost of posture maintenance reside in differential**
605 **patterns of spontaneous weight-shifting?** *Eur J Appl Physiol* 2017,
606 **117**:795-807.
- 607 39. Buckley JP, Hedge A, Yates T, Copeland RJ, Loosemore M, Hamer M,
608 Bradley G, Dunstan DW: **The sedentary office: an expert statement**
609 **on the growing case for change towards better health and**
610 **productivity.** *Br J Sports Med* 2015:bjsports-2015-094618.
- 611 40. Young DR, Hivert M-F, Alhassan S, Camhi SM, Ferguson JF,
612 Katzmarzyk PT, Lewis CE, Owen N, Perry CK, Siddique J: **Sedentary**
613 **Behavior and Cardiovascular Morbidity and Mortality.** *Circulation*
614 2016, **134**:e262-e279.
- 615 41. Hamilton MT, Hamilton DG, Zderic TW: **Role of low energy**
616 **expenditure and sitting in obesity, metabolic syndrome, type 2**
617 **diabetes, and cardiovascular disease.** *Diabetes* 2007, **56**:2655-2667.
- 618 42. Pulsford RM, Blackwell J, Hillsdon M, Kos K: **Intermittent walking, but**
619 **not standing, improves postprandial insulin and glucose relative to**
620 **sustained sitting: A randomised cross-over study in inactive**
621 **middle-aged men.** *J Sci Med Sport* 2016, **20**:278-283.
- 622 43. Ruiz JR, Segura-Jiménez V, Ortega FB, Álvarez-Gallardo IC, Camiletti-
623 Moirón D, Aparicio VA, Carbonell-Baeza A, Femia P, Munguía-Izquierdo
624 D, Delgado-Fernández M: **Objectively measured sedentary time and**

- 625 **physical activity in women with fibromyalgia: a cross-sectional**
626 **study.** *BMJ open* 2013, **3**:e002722.
- 627 44. Drenowatz C, Gribben N, Wirth MD, Hand GA, Shook RP, Burgess S,
628 Blair SN: **The Association of Physical Activity during Weekdays and**
629 **Weekend with Body Composition in Young Adults.** *J Obes* 2016,
630 **2016.**
- 631 45. Smith L, Thomas EL, Bell JD, Hamer M: **The association between**
632 **objectively measured sitting and standing with body composition:**
633 **a pilot study using MRI.** *BMJ open* 2014, **4**:e005476.

634

635

636 Figure 1. The association between SED^{SWA} (awake and <1.5 METs) and fat mass (A),
637 SED^{AP} (awake and sitting/lying posture) and fat mass (B), SED^{INT} (awake, <1.5 METs
638 and sitting/lying posture) and fat mass (C) and MVPA (moderate-to-vigorous physical
639 activity) and fat mass (D).