

Associations among sedentary and active behaviours, body fat and appetite dysregulation: investigating the myth of physical inactivity and obesity

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1 Associations amongst sedentary and active behaviours, body fat and appetite
2 dysregulation: investigating the myth of physical inactivity and obesity.

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22 **ABSTRACT**

23 **Background**

24 There is considerable disagreement about the association between free-living
25 physical activity and sedentary behaviour and obesity. Moreover studies frequently
26 do not include measures that could mediate between physical activity and adiposity.
27 The present study used a validated instrument for continuous tracking of sedentary
28 and active behaviours as part of habitual daily living, together with measures of
29 energy expenditure, body composition and appetite dysregulation. This cross-
30 sectional study tested the relationship between inactivity and obesity.

31 **Methods**

32 Seventy-one participants (81.7% women) aged 37.4 years (± 14) with a body mass
33 index (BMI) of 29.9 kg/m² (± 5.2) were continuously monitored for 6-7 days to track
34 free-living physical activity (light 1.5-3 METs; moderate 3-6 METs; and vigorous
35 >6 METs) and sedentary behaviour (<1.5 METs) with the SenseWear Armband.
36 Additional measures included body composition, waist circumference, cardiovascular
37 fitness, total and resting energy expenditure, and various health markers. Appetite
38 control was assessed by validated eating behaviour questionnaires.

39 **Results**

40 Sedentary behaviour (11.06 \pm 1.72 hours/day) was positively correlated with fat mass
41 ($r=0.50$, $p<0.001$) and waist circumference ($r=-0.65$, $p<0.001$). Moderate-to-vigorous
42 physical activity was negatively associated with fat mass ($r=-0.72$, $p<0.001$) and
43 remained significantly correlated with adiposity after controlling for sedentary
44 behaviour. Activity energy expenditure was positively associated with the level of PA
45 and negatively associated with fat mass. Disinhibition and Binge Eating behaviours
46 were positively associated with fat mass ($r=0.58$ and 0.47 , respectively, $p<0.001$).

47 **Conclusion**

48 This study demonstrated clear associations among objective measures of physical
49 activity (and sedentary behaviour), energy expenditure, adiposity and appetite
50 control. The data indicate strong links between physical inactivity and obesity. This
51 relationship is likely to be bi-directional.

52

What are the new findings

- Habitual sedentary time was associated with higher adiposity.
- Moderate-to-vigorous physical activity (MVPA) was associated with lower adiposity.
- The strongest relationship was with MVPA.
- The relationship between physical (in)activity and adiposity is likely to be bidirectional and depends mainly on MVPA.

Impact on clinical practice

- Patients/clients should be encouraged to replace some sedentary and light activity with at least moderate PA such as brisk walking in order to optimise benefits.

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59 **BACKGROUND**

60 In recent years the relative contributions of overconsumption of food and the under-
61 expenditure of energy (physical inactivity) to obesity have been vigorously debated.
62 On one side it has been claimed that an increase in food availability (energy flux)
63 was more than sufficient to account for the increase in average body weight of US
64 citizens over a 20 year period.[1] This argument has recently been extended to a
65 global level.[2] In contrast it has been argued that the decline in work-related
66 physical activity (and therefore energy expenditure) over several decades has been
67 sufficient to account for a positive energy balance and the rise in obesity in the
68 US.[3] In general it seems that the excess food notion of obesity is more favourably
69 received than the low activity idea. This view has been promoted by the print media
70 with headlines such as 'Why exercise makes you fat'.[4] These headlines have
71 appeared despite evidence from controlled trials demonstrating dose related effects
72 of physical activity on weight loss;[5] the more you do (duration or energy expended)
73 the more weight is lost. Additionally, although Cochrane systematic reviews have
74 also reported beneficial effects of exercise on weight loss independent of any dietary
75 effect,[6] the view persists that being active does not contribute to weight control. In
76 a recent editorial commentary in this journal, a headline title referred to '...the myth of
77 physical inactivity and obesity' and the text categorically stated that 'physical activity
78 does not promote weight loss'.[7] Strongly argued articles refuting these claims [8 9]
79 have attempted to prevent further damaging perceptions emanating from these
80 claims.

81 For over two decades we have investigated the interactions between energy
82 expenditure and energy intake.[10] We have demonstrated in several published
83 studies that a programme of supervised and measured exercise in obese individuals
84 leads to a significant reduction in body fat and a maintenance or increase in lean
85 mass (fat-free mass) in both men and women.[11-13] These studies indicate that
86 physical activity has the capacity to influence body fat in obese people. Recently we
87 have used a sensitive validated wearable device (BodyMedia SenseWear armband
88 (SWA)) to directly measure the amount of time people spend in sedentary behaviour

89 and in light, moderate and vigorous activity.[14] We have quantified the amount of
90 time (and energy expended) in sedentary and active behaviours, and related this to
91 measures of body adiposity and validated traits reflecting dysregulated appetite
92 control. We have used this methodology to directly test the myth of physical inactivity
93 and body fatness (obesity). The study was designed to provide accurate and
94 objective measures of the quantity of sedentary and active behaviours in habitual
95 daily life, and to examine the relationships with measures of adiposity, energy
96 expenditure, fitness and markers of health; and with psychological measures of the
97 loss of control over appetite.

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111 **METHODS**

112 **Participants**

113 Seventy-one participants (81.7% women) aged 37.4 years (± 14) with a body mass
114 index (BMI) of 29.9 kg/m² (± 5.2) were recruited from the University of Leeds, UK,
115 and surrounding area for this cross-sectional study. Sixty-eight of the 71 participants
116 had valid SWA data (95.8% compliance) and all participants had valid body
117 composition and appetite dysregulation data. Participants were males and females
118 aged >18 years with no contraindications to exercise and not taking medication
119 known to effect metabolism or appetite. All participants provided written informed
120 consent before taking part in the study, and ethical approval was granted by the
121 School of Psychology Ethics Board (14-0091).

122 **Study design**

123 Participants attended the research unit twice over the course of one week. Free-
124 living PA and sedentary behaviour were measured continuously for a minimum of 7
125 days for >22 hours/day. Participants were fasted for a minimum of 12 hours and had
126 abstained from exercise and alcohol for at least 24 hours before both laboratory
127 visits.

128 On the morning of day one the following measures were taken: height, weight, waist
129 and hip circumference, body composition and resting metabolism. Health markers
130 including, fasting blood glucose diastolic and systolic blood pressure (BP) and
131 resting heart rate (HR) were taken, along with measures of appetite dysregulation
132 (Three-Factor Eating Questionnaire, Binge Eating Scale). Participants were provided
133 with a PA diary and fitted with a SenseWear Mini Armband (BodyMedia, Inc.,
134 Pittsburgh, PA).

135 *Anthropometrics*

136 Height was measured using a stadiometer (Leicester height measure, SECA) and
137 body composition was measured using air plethysmography (Bodpod, Concord, CA).
138 Body weight was obtained from the BodPod whilst participants were wearing minimal
139 clothing. BMI was calculated as weight in kg / height in m². Waist circumference was
140 measured horizontally in line with the umbilicus and hip circumference was
141 measured horizontally at the maximum circumference of the hip. Three measures
142 were taken for each and averaged. The same researcher completed all
143 measurements.

144 *Resting metabolic rate and health markers*

145 Resting metabolic rate (RMR) was measured using indirect calorimetry (GEM,
146 NutrEn Technology Ltd, Cheshire, UK). Participants were instructed to remain awake
147 but motionless in a supine position for 40 minutes, with RMR calculated from
148 respiratory data averaged during the last 30 minutes of assessment. BP and resting
149 HR were measured using an automatic sphygmomanometer (Omron) immediately
150 after completion of the RMR procedure. Fasting glucose was obtained from a finger
151 prick blood sample analyzed using a blood glucose analyzer (YSI 2300 STAT PLUS
152 Glucose and Lactate Analyzer).

153 *Appetite dysregulation*

154 Participants completed the Three Factor Eating Questionnaire, a 51 item
155 questionnaire measuring restraint, disinhibition and hunger[15] and the Binge Eating
156 Scale, a 16 item questionnaire measuring binge eating behaviour and cognitions
157 indicative of eating disorders.[16]

158 *Free living PA and EE*

159 Free-living physical activity and sedentary behaviour was measured objectively using
160 the SWA. Participants wore the armband on the posterior surface of their upper non-
161 dominant arm for a minimum of 22 hours per day for 7-8 days (except for the time

162 spent showering, bathing or swimming). This data collection allowed for the
163 calculation of daily averages for each activity category. The SWA measures motion
164 (triaxial accelerometer), galvanic skin response, skin temperature and heat flux.
165 Proprietary algorithms available in the accompanying software calculate energy
166 expenditure (EE) and classify the intensity of activity. Sedentary behaviour was
167 classified as <1.5 METs, light 1.6-2.9 METs, moderate 3-5.9 METs and vigorous >6
168 METs.[17] Sedentary behaviour and PA variables were calculated as a percentage
169 of total awake time over the wear period of 6-7 days, for example, total sedentary
170 minutes were divided by total awake minutes to give the proportion of awake time
171 spent sedentary over the total wear period. Moderate and vigorous PA was grouped
172 together to form one MVPA category to correspond with the guidelines for PA.[18]
173 The SWA has been shown to accurately estimate time in MVPA and EE at rest and
174 during free-living light and moderate intensity PA.[19-22] For the SWA data to be
175 valid >22 hours of data per day had to be recorded and at least six 24 hour periods
176 (midnight to midnight) including 2 weekend days. Participants completed a physical
177 activity diary to coincide with the PA monitoring period detailing the intensity,
178 duration and type of activity performed along with details on removal of the SWA

179 Participants returned to the lab on day 7 or 8 to return the activity monitors and
180 completed PA diary. Cardiovascular fitness was also measured.

181 *Maximal aerobic capacity*

182 Maximal aerobic capacity ($\dot{V}O_2\text{max}$) was measured during an incremental treadmill
183 test with expired air (SensorMedics Vmax29, Yorba Linda, USA) and heart rate
184 (Polar RS400, Polar, Kempele, Finland) measured continuously. Attainment of true
185 $\dot{V}O_2\text{max}$ was determined by a plateau in $\dot{V}O_2$ with an increase in workload, a
186 respiratory quotient (RQ) of >1 and a HR within 20 beats of age predicted maximum
187 HR (220-age).

188 **Statistical analysis**

189 Data are reported as mean \pm SD throughout. Statistical analysis was performed
190 using IBM SPSS for Windows (Chicago, Illinois, Version 21). For reasons of

191 scientific rigour and to reduce the likelihood of false positives, we only regarded
192 relationship as meaningful with a p value < 0.01. Characteristics of the study
193 population were summarised using descriptive statistics. Pearson correlations were
194 performed to examine the associations amongst sedentary and active behaviour,
195 body composition and appetite dysregulation. In addition partial correlations were
196 also carried out to separate the effects of a third variable acting concurrently on two
197 variables; this involved controlling for body fat percentage, sedentary behaviour and
198 MVPA in different analyses.

199

200 **RESULTS**

201 **Participant Characteristics**

202 Study sample characteristics are displayed in table 1. Of the 71 participants who
203 took part in the study 68 provided ≥ 6 days of valid armband data. Average wear time
204 of the armband was 23.55 ± 0.26 hours/day ($98 \pm 1.2\%$). Participants were sedentary
205 for an average of 11.06 ± 1.72 hours/day (excluding sleep) and recorded 3.26 ± 1.03
206 hours/day in light PA and 2.10 ± 1.40 hours/day in MVPA (see figure 1). Participants
207 mean age was 37.35 ± 14.01 and their average total energy expenditure was
208 2708.07 ± 421.81 kcal/d.

Table 1. Descriptive statistics of study sample

| Variable | Mean (SD) | Range |
|------------------------|------------------|----------------|
| Age (years)* | 37.35 (14.01) | 18.00 – 72.00 |
| Height (m)* | 1.66 (0.09) | 1.49 – 1.91 |
| Body mass (kg)* | 82.24 (15.26) | 44.90 – 113.90 |

| | | |
|--|------------------|-------------------|
| BMI (kg/m²)* | 29.94 (5.24) | 19.10 – 39.90 |
| Fat mass (kg)* | 31.79 (13.37) | 5.00 – 60.40 |
| Lean mass (kg)* | 50.44 (9.28) | 32.10 – 81.40 |
| Waist circumference (cm)* | 100.23 (12.83) | 69.00 – 133.70 |
| Systolic blood pressure (mm Hg)* | 118.17 (14.12) | 87.00 – 162.00 |
| Diastolic blood pressure (mm Hg)* | 77.80 (10.25) | 61.00 – 77.80 |
| Resting heart rate (bpm)* | 58.56 (9.71) | 37.00 – 84.00 |
| Blood glucose (mmol/L)** | 4.73 (0.69) | 1.98 – 6.70 |
| Resting metabolic rate (kcal/d)† | 1698.54 (296.86) | 1070.90 – 2451.90 |
| Total energy expenditure (kcal/d)^ | 2708.07 (421.81) | 1827.30 – 4256.60 |
| Cardiovascular fitness (ml/kg/min)^ | 40.99 (7.88) | 29.60 – 54.93 |
| SWA wear time (hours/d)^ | 23.55 (0.26) | 22.47 – 23.95 |
| Sedentary behaviour (hours/d)^ | 11.06 (1.72) | 6.01 – 15.40 |
| Light PA (hours/d)^ | 3.26 (1.03) | 1.35 – 6.05 |
| MVPA (hours/d)^ | 2.10 (1.40) | 0.48 – 6.74 |
| Restraint* | 8.21 (3.82) | 0.00 – 17.00 |
| Disinhibition* | 8.85 (3.88) | 0.00 – 15.00 |
| Hunger* | 6.00 (3.16) | 0.00 – 13.00 |
| Binge Eating* | 13.23 (7.31) | 1.00 – 34.00 |

SWA, SenseWear armband; MVPA, moderate-to-vigorous physical activity; * n=71; ** n=69; † n=70; ^ n=68

209

Figure 1 near here

210

211 **Association between sedentary behaviour and different categories of physical**
 212 **activity**

213 Sedentary behaviour was negatively associated with light ($r(66)=-0.39$, $p=0.001$),
214 moderate ($r(66)=-0.76$, $p<0.001$) and vigorous ($r(66)=-0.44$, $p<0.001$) PA. Light PA
215 was also negatively associated with vigorous PA ($r(66)=-0.33$, $p<0.01$). Moderate
216 and vigorous PA were positively correlated ($r(66)=0.65$, $p<0.001$).

217 **Associations between sedentary behaviour, physical activity and body** 218 **composition**

219 Sedentary behaviour was positively correlated with multiple indices of adiposity
220 including body mass ($r(66)=0.44$, $p<0.001$), BMI ($r(66)=0.50$, $p<0.001$), fat mass
221 ($r(66)=0.50$, $p<0.001$) and waist circumference ($r(66)=0.45$, $p<0.001$) as shown in
222 Table 2. On the other hand, MVPA was negatively associated with body mass
223 ($r(66)=-0.55$, $p<0.001$), BMI ($r(66)=-0.71$, $p<0.001$), fat mass ($r(66)=-0.72$, $p<0.001$)
224 and waist circumference ($r(66)=0.45$, $p<0.001$).

225 Partial correlations were performed to identify the independent effects of sedentary
226 behaviour (controlled for MVPA), light PA (controlled for MVPA and sedentary
227 behaviour, separately) and MVPA (controlled for sedentary behaviour) on body
228 composition. After controlling for MVPA the magnitude of the correlation between
229 sedentary behaviour and adiposity were markedly weakened. However, when the
230 correlations between MVPA and adiposity were adjusted for sedentary behaviour all
231 correlations remained significant (body mass ($r(65)=-0.38$, $p=0.001$), BMI ($r(65)=-$
232 0.57 , $p<0.001$) fat mass ($r(65)=-0.63$, $p<0.001$) and waist circumference ($r(65)=-0.55$,
233 $p<0.001$)). Controlling the correlation between body composition and light PA for
234 sedentary behaviour resulted in significant positive correlation for body mass, BMI,
235 fat mass, body fat percentage and waist circumference.

236 The graphical relationships between fat mass and the percentage time spent
237 sedentary and in MVPA categories are shown in Figure 2.

238

239

Figure 2 near here

240

241 It is noticeable in Figure 2a that four participants have low amounts of sedentary
242 behaviour and it was possible that these values were unduly influencing the

243 correlation. When the statistical test was repeated excluding these subjects the
 244 correlation remained positive and significant ($r(62)=0.31$, $p=0.01$).

Table 2. Correlation between sedentary and active behaviours and body composition

| | Body mass | BMI | Fat mass | Waist circumference | Lean mass |
|--|----------------|----------------|----------------|---------------------|-----------|
| Sedentary behaviour | 0.44** | 0.50** | 0.50** | 0.45** | -0.01 |
| Light PA | 0.06 | 0.18 | 0.19 | 0.17 | -0.18 |
| MVPA | -0.55** | -0.71** | -0.72** | -0.65** | 0.14 |
| Sedentary behaviour¹ | -0.001 | -0.14 | -0.16 | -0.13 | 0.18 |
| Light PA¹ | 0.01 | 0.16 | 0.18 | 0.15 | -0.16 |
| Light PA² | 0.32† | 0.54** | 0.52** | 0.45** | -0.19 |
| MVPA² | -0.38** | -0.57** | -0.63** | -0.55** | 0.24 |

n=68; Data are Pearson correlation (r). ¹ Controlled for MVPA (minutes); ² Controlled for sedentary behaviour (minutes). ** $p<0.001$; † $p<0.01$. BMI, body mass index.

245

246 **Associations between sedentary behaviour, physical activity and markers of**
 247 **appetite dysregulation**

248 There were no significant correlations between sedentary behaviour and any of the
 249 indices of appetite dysregulation; Restraint ($r(66)=-0.13$, $p=0.30$), Disinhibition
 250 ($r(66)=0.16$, $p=0.19$), Hunger ($r(66)=-0.02$, $p=0.88$), and Binge Eating ($r(66)=0.14$,
 251 $p=0.25$).

252 However, light PA and MVPA showed some relationship to the questionnaire scores,
 253 but these were no longer apparent when partial correlations were performed
 254 controlling for the amount of body fat (see Table 3).

255

Table 3. Correlations between sedentary and active behaviours and appetite dysregulation

| | Sedentary behaviour | Light PA | MVPA | Sedentary behaviour ¹ | Light PA ¹ | MVPA ¹ |
|----------------------|------------------------|--------------|----------------|-------------------------------------|--------------------------|-------------------|
| Restraint | -0.13 | 0.14 | 0.05 | -0.15 | 0.15 | 0.08 |
| Disinhibition | 0.16 | 0.36† | -0.44** | -0.13 | 0.25 | -0.06 |
| Hunger | -0.02 | 0.24 | -0.15 | -0.05 | 0.23 | -0.16 |
| Binge Eating | 0.14 | 0.24* | -0.34† | -0.05 | 0.15 | -0.07 |

n=68; Data are Pearson correlation (r). ¹ Controlled for body fat percentage. ** p<0.001; † p<0.01. MVPA, moderate-to-vigorous physical activity.

256 **Associations among physical activity, sedentary behaviour and energy**
 257 **expenditure**

258 In order to investigate whether the relationship between behaviour and adiposity was
 259 accounted for by energy expenditure, Activity Energy Expenditure (AEE) was
 260 calculated as the difference between Total EE (Armband) and RMR (directly
 261 measured by indirect calorimetry). The AEE was positively correlated with MVPA
 262 ($r(66)=0.48$, $p<0.0001$) and negatively related to time spent in sedentary behaviour
 263 ($r(66)=-0.57$, $p<0.0001$).

264 **Associations between markers of appetite dysregulation and body**
 265 **composition**

266 TFEQ Disinhibition and Binge Eating were positively associated with body mass
 267 ($r(69)=0.51$ and $r(69)=0.49$, respectively, $p<0.001$), BMI ($r(69)=0.59$ and $r(69)=0.45$,
 268 respectively, $p<0.001$), fat mass ($r(69)=0.58$ and $r(69)=0.47$, respectively, $p<0.001$)
 269 and waist circumference ($r(69)=0.56$ and $r(69)=0.48$, respectively, $p<0.001$). Fat free
 270 mass was not significantly associated with any of the measures of appetite
 271 dysregulation nor were there any associations between any of the measures of body
 272 composition and Restraint or Hunger (see table 4).

273

Table 4. Correlations between body composition and appetite dysregulation

| | Body mass | BMI | Fat mass | Waist circumference | Lean mass |
|----------------------|---------------|---------------|---------------|---------------------|-----------|
| Restraint | -0.20 | -0.05 | -0.07 | -0.14 | -0.23 |
| Disinhibition | 0.51** | 0.59** | 0.58** | 0.56** | 0.00 |
| Hunger | 0.18 | 0.12 | 0.10 | 0.12 | 0.15 |
| Binge Eating | 0.49** | 0.45** | 0.47** | 0.48** | 0.12 |

n=71; Data are Pearson correlation (r). ** p<0.001. BMI, body mass index.

274

275

276 **DISCUSSION**

277

278 The aim of the present study was to examine the associations amongst objectively
 279 measured free-living sedentary and active behaviours, body composition and
 280 appetite dysregulation, and to throw light upon the potential link between physical
 281 (in)activity and obesity.

282

283 **Free-living sedentary and active behaviour and adiposity**

284 Our data show sedentary behaviour and light PA was associated with higher
 285 adiposity. However, after controlling for MVPA the magnitude of the correlation
 286 between sedentary behaviour and body fat percentage was weakened and the
 287 correlation between light PA and body fat percentage was strengthened. Previous
 288 research assessing the relationship between sedentary behaviour and adiposity has
 289 yielded mixed results. Lynch et al,[23] reported an association between sedentary
 290 time and waist circumference and BMI in breast cancer survivors, furthermore after
 291 controlling for MVPA the associations were attenuated. Similarly, when lean and
 292 obese individuals were compared the obese group spent around 2 hours/day longer
 293 in sedentary behaviours.[24 25] Longitudinal studies have also demonstrated an
 294 association between sedentary behaviour and adiposity. Ekelund et al.[26] found that

295 those who gained weight over a 5 to 6 year period performed significantly more
296 sedentary behaviour than those who lost weight at follow-up.

297 The relationship between sedentary behaviour, light PA and adiposity has important
298 implications given that sedentary behaviour and light PA accounts for the majority of
299 the waking day.[27] In the current sample participants spent just over 11 hours of
300 their waking day in sedentary activities and over 3 hours in light PA. Similar values
301 have been observed in previous studies,[28 29] however, some studies report less
302 sedentary time and more light intensity PA perhaps due to variations in
303 measurement techniques.[30 31] Important to note are the correlations between light
304 intensity PA and all markers of adiposity after controlling for sedentary behaviour.
305 Under these circumstances light PA is associated with increased body mass, BMI,
306 fat mass, body fat percentage and waist circumference and becomes a marker for
307 sedentary behaviour. We have noted the inverse association between light and
308 vigorous PA this means that the protective effect of exercise on adiposity is threshold
309 based, and needs to be at least moderate intensity to produce any benefit.

310 Our data confirm the association between MVPA and adiposity previously
311 demonstrated.[23 31-34] MVPA was inversely associated with body mass, BMI, fat
312 mass, body fat percentage and waist circumference independent of sedentary
313 behaviour. The positive association between MVPA and total energy expenditure
314 observed in our data (data not presented) provides one possible explanation for the
315 relationship with adiposity; PA results in increased energy expenditure. Healy et
316 al,[34] also demonstrated an inverse association between MVPA and adiposity
317 independent of sedentary behaviour. After controlling for MVPA only body fat
318 percentage remained significantly correlated with sedentary behaviour but all
319 correlations remained significant between MVPA and indices of adiposity when
320 controlled for sedentary behaviour. This suggests that the absence of MVPA could
321 be more important than the presence of sedentary behaviour in the accumulation of
322 fat mass. Recommendation to displace sedentary time with light PA may not be
323 sufficient for weight management and to accrue any benefit PA must be at least
324 moderate intensity in line with current PA guidelines.[35]

325

326 **Free-living sedentary and active behaviour, appetite dysregulation and**
327 **adiposity**

328 There were no correlations between sedentary behaviour and any of the measures
329 of appetite dysregulation. MVPA was associated with higher Disinhibition and Binge
330 Eating but these relationships were no longer significant after controlling for body fat
331 percentage. Our analysis has shown a strong relationship between measures of
332 adiposity and questionnaire measures of eating that imply a loss of control over
333 appetite in the environment. This association is supported by many studies in the
334 literature.[36 37] This outcome suggests that any observed relationship between
335 sedentary behaviour and trait measures of poor appetite control may be mediated
336 indirectly via mechanisms involved in adipose tissue dynamics.

337

338 **Conclusion**

339 This study has examined the relationship between objective measures of physical
340 activity (from sedentary to vigorous) and measures of adiposity under conditions of
341 daily habitual living. The outcome has shown that the level of physical activity is
342 associated with body fatness and is likely to be relevant for obesity.

343 The outcome measures were based on systematic measures taken under natural
344 conditions without any specific intervention. The analysis was derived from
345 correlations (and partial correlations) and the interpretation informed by logic and
346 plausibility. We are aware that correlations are not proof of causation, but they
347 certainly do not rule out the possibility of causal relationships. This study has shown
348 strong and statistically significant links between bodily activity and adiposity; this
349 provides presumptive evidence that sedentary behaviour itself and a low level of
350 physical activity is relevant for obesity. Our interpretation is that bidirectional
351 causality can account for this link. Therefore, low levels of physical activity involving
352 low energy expenditure will lead to a positive energy balance and favour the gain of
353 body fat. In turn a greater degree of adiposity (caused by low activity or by high
354 energy intake) will serve as a disincentive to perform physical activity and will favour
355 a positive energy balance. However, these comments are one interpretation of the
356 data and should be clarified with further investigation.

357 Importantly, the relevance of physical activity for obesity is corroborated by
358 intervention studies. It has been demonstrated that taking people from an inactive to
359 an active state by means of a regime of supervised daily exercise leads to a
360 significant loss of fat tissue and a gain (or maintenance) of lean mass.[11 13] In
361 contrast when people are shifted from an active to a sedentary state, there is no
362 down-regulation of food intake thereby resulting in a positive energy balance and the
363 potential for weight gain.[38] It is important to recognise that evidence and
364 arguments indicating the importance of low physical activity in adiposity, does not
365 deny the contribution of food intake to obesity. Indeed there is abundant evidence
366 that overconsumption of food is a major cause of a positive energy balance and
367 increased body fatness.[39] Interestingly the dynamic effects of fatness itself
368 exacerbate the energy imbalance; while increasing adiposity serves as a disincentive
369 to perform physical activity, it does not deter food consumption.

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394

395 **CONTRIBUTION**

396 AM, CG, GF and JB designed research; AM conducted research; AM, CG, GF and
397 JB analysed data; AM, CG, GF and JB wrote manuscript. All authors discussed
398 results/interpretation and approved the final manuscript. No authors declare a
399 conflict of interest.

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542 **LEGENDS**

543 Figure 1. The proportion of waking time spent sedentary, in light PA and MVPA. Data
544 presented as percentage of awake time and total minutes.

545 Figure 2. Correlation between proportion of awake time spent sedentary and in
546 MVPA and fat mass.

547 Figure 3. Correlation between fat mass and binge eating.