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

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

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ABSTRACT

Background

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

Methods

Sixty-three female participants aged 37.1 years (SD=13.6) with a body mass index (BMI) of 29.6 kg/m^2 (SD=4.7) had their body composition measured (BodPod, Concord, CA) then were continuously monitored for 5-7 days with the SenseWear Armband (SWA; sleep and activity intensity) and the activPAL (AP; posture). Data from both activity monitors were analysed separately and integrated resulting in a third measure of SB (activity intensity and posture; SED^{INT}). SB outputs were compared according to week or weekend day averages then correlated against body composition parameters after adjusting for moderate-to-vigorous physical activity (MVPA).

Results

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

Conclusions

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

Keywords

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

Key findings:

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

1.1 BACKGROUND

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

The most widely used definition of SB refers to “any waking behaviour characterised by an energy expenditure ≤1.5 METs while in a sitting or reclining posture” [25]. Despite the Sedentary Behaviour Research Network’s attempt to consolidate the two ways in which SB has previously been reported in scientific literature (posture alone [3] and activity intensity alone [26]), there remains no consensus definition of SB [27]. The word ‘sedentary’ originates from the Latin word ‘sedere’, which means to sit, and implies posture is a fundamental facet of SB. However, it is unclear whether the postural element of SB is important from a public health perspective or whether non-sitting behaviours with an activity intensity of <1.5 METs also contribute to health related outcomes such as adiposity. Thus, it is important to evaluate whether posture should be included in the SB definition [27]. Indeed, it has been acknowledged that the specific properties of SB that contribute to diminished health outcomes needs further investigation and the inclusion of different SB definitions in studies to identify differences in health outcomes has been encouraged [27, 28]. Furthermore, if SB is defined by both activity intensity and posture, it is yet to be determined what activities performed in a standing posture with an intensity of <1.5 METs should be categorised as. The newly published SB terminology consensus suggests these activities should be categorised as passive standing, but how such activities relate to health end points is not clear.

The available tools to objectively quantify free-living SB limit researchers' ability to address these questions. It has been noted that there is no single measurement device that provides an accurate measure of both posture and activity intensity simultaneously [14, 27]. To address this measurement limitation a method to integrate data from the SWA mini and AP micro was developed [29]. We demonstrated that it is possible to integrate time-stamped data from the SWA and the AP to measure SB defined by any waking behaviour with an activity intensity of <1.5 METs whilst in a seated or reclining posture. Furthermore, our previous work identified a negative association between SB and adiposity when SB was defined by activity intensity alone, but not when moderate-to-vigorous physical activity (MVPA) was controlled for [15]. This relationship has previously been reported in cross-sectional studies using objective measurement devices to quantify SB based on activity intensity [11, 30, 31], however some studies have reported no association [22-24]. The aim of this study was to explore whether the relationship between SB and adiposity differed depending on the way in which SB was measured and defined. The three measures of SB were defined by i) activity intensity, ii) posture and iii) activity intensity and posture, during waking hours.

1.2 METHODS

1.2.1 Participants

Participants in the current study were initially recruited from a series of three studies conducted at the University of Leeds between December 2014 and June 2016. General recruitment strategies included emails circulated on University mailing lists and poster advertisements. General inclusion criteria were: women, aged between 18 and 70 years, body mass index (BMI) between 18.5 and 45.0 kg/m^2, premenopausal status, reporting good health, no contraindications to exercise and not taking medication known to effect metabolism or appetite. In the present analysis, each study's baseline data was used from participants who had body composition data and ≥5 days (including ≥1 weekend day) of valid SWA and AP data. Written informed consent was obtained before any study procedures were carried out and all studies were approved by either the School of Psychology (University of Leeds) or NHS (NRES Yorkshire and the Humber) Ethics Committees (14-0099, 14-0090 and 09/H1307/7).

1.2.2 Study Design

The three studies included in this cross-sectional analysis followed the same systematic protocol according to laboratory standardised operating procedures. Participants attended the research unit twice over the course of one week. Free-living SB was measured continuously for a minimum of 5 days for >22 hours/day with the SWA and AP simultaneously.

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

1.2.3 Free-living Sedentary Behaviour

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

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

Information on sleep and activity intensity (<1.5 METs) from the SWA and posture (sitting/lying) from the AP were integrated to generate a measure of SB defined by both activity intensity and posture during waking hours. The procedure for integrating data from the SWA and AP has been described in detail previously [29]. This procedure resulted in three SB outputs that were represented by SED^{SWA}, SED^{AP} and SED^{INT}, when referring to data from the SWA, AP and integrated data from both activity monitors, respectively. Table 1 shows the criteria for defining SB based on each of the SB outputs. By subtracting SED^{INT} from SED^{SWA} it was also possible to identify time spent standing at an intensity of <1.5 METs (SED^{STAND}).

Table 1. Classification of sedentary behaviour based on the three sedentary behaviour 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.

1.2.4 Body Composition and Anthropometrics

Body composition was measured using air displacement plethysmography (BodPod, Life Measurement Incorporated, Concord, CA). Waist circumference was measured horizontally in line with the umbilicus. Three measures were taken and averaged. Where possible the same researcher completed all measurements. Height was measured using a stadiometer (Leicester height measure, SECA). Measurements were recorded to the nearest 0.1 cm. Body weight was obtained from the BodPod whilst participants were wearing minimal clothing and BMI was calculated as weight in kg/height in m^2.

1.2.5 Statistical Analysis

Data are reported as mean (SD) throughout. Statistical analysis was performed using IBM SPSS for Windows (Chicago, Illinois, Version 21). Relationships were regarded as statistically significant with a p value < .05. All variables were checked for normality using the Shapiro-Wilk test and indicating that the data was normally distributed [$p > .05$]. Characteristics of the study population were summarised using descriptive statistics. Differences in SED^{SWA}, SED^{AP} and SED^{INT} methods were examined using repeated measures ANOVA with Bonferroni post-hoc tests. To identify differences in SED on weekdays compared with weekend days paired sample t-tests were performed. Pearson correlations were performed to examine the associations between SB (whole week, weekday and weekend day), MVPA and body composition. Partial correlations were performed to control for the potential confounding influence of MVPA in the association between SED^{SWA} / SED^{STAND} and body composition. Independent sample t-tests were conducted to examine differences in time spent in different intensities of PA between those who registered more SED^{SWA} than SED^{AP} (sedentary standers) and those who performed more SED^{AP} than SED^{SWA} (active sitters).

1.3 RESULTS

1.3.1 Participant Characteristics

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

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/m^2)	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.

1.3.2 Differences between the three sedentary behaviour measurement methods

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

1.3.3 Weekday versus weekend day sedentary time

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

1.3.4 Associations between free-living sedentary behaviour and body composition

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

Figure 1 around here

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

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

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

Table 3. Correlation between the different measures of free-living sedentary time and 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
Weekd ay	**SED^{SWA} (min/day)†**	.03	.08	.05	.01	-.01
	SED^{AP} (min/day)†	-.01	-.10	-.05	-.14	.09

	SED^INT (min/day)†	-.07	-.14	-.10	-.15	.04
Weekend day	**SED^SWA (min/day)†**	-.17	-.10	-.17	-.14	-.10
	SED^AP (min/day)†	-.04	-.07	-.07	-.04	.04
	SED^INT (min/day)†	-.10	-.13	-.11	-.07	-.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.

1.4 DISCUSSION

The aim of the current study was to examine whether the way in which SB is operationally defined and objectively measured impacts on the estimation of sedentary time and its association with health related outcomes. More specifically, whether the addition of posture to low intensity behaviour (<1.5 METs) is a stronger predictor of indices of adiposity than measures of low intensity behaviour and posture alone. Furthermore, we tested whether any relationships between the different measures of SB and adiposity were independent of MVPA. Utilising the methodological platform described previously [29] to combine information from two validated activity monitors using a novel integrative procedure, three measures of SB were defined by i) activity intensity (<1.5 METs), ii) posture (sitting/lying) and iii) activity intensity and posture.

This study is the first to report the relationship between SB and adiposity when SB is defined and objectively measured in multiple ways, simultaneously in the same study participant. Our study demonstrates that the method used to measure SB impacts on the observed relationship with adiposity. Furthermore, the relationship between SB (when defined by an EE <1.5 METs) and adiposity is not independent of MVPA. Only when SB was defined by low intensity behaviour (<1.5 METs), and not adjusted for MVPA, was an association with adiposity apparent. Participants who performed more SED^{SWA} had more fat mass, a higher BMI and overall body mass, however the presence or lack of MVPA appears to be a stronger determinant of obesity than SB. These relationships are consistent with our previous work [15]. Previous studies have examined the relationship between objectively measured free-living SB and body fatness and have produced mixed findings [11, 22-24, 30, 31, 37]. The inconsistencies between studies regarding the relationship between SB and adiposity could be explained by the different measurement methods used to quantify SB or whether MVPA is accounted for.

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

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

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

Importantly, the lack of association between posture and adiposity does not rule out the role of sitting in the development of other cardio metabolic health outcomes [40]. Laboratory studies examining the mechanisms underlying negative health outcomes associated with SB indicate that prolonged sitting may trigger a chain of unhealthy molecular responses, including down regulation of lipoprotein lipase activity, which could impact on physiological outcomes such as insulin sensitivity [41], whether engaging in MVPA might ameliorate these relationships is unclear. It also remains unclear whether a change in posture is sufficient to induce improvements in biological markers of metabolic health or whether a change in posture must be accompanied with an increase in energy expenditure before any benefit is accrued. Pulsford et al. [42] recently found that interrupting sitting with repeated short bouts of light intensity walking improved insulin sensitivity, whereas repeated short bouts of standing did not. As with the results of the present study, these findings indicate that the postural element of SB (sitting) is not driving the relationship between SB and negative health outcomes reported in the literature and in fact it is the accumulation of low intensity behaviours (whilst sitting or standing) and/or the absence of MVPA.

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

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

1.4.1 Conclusions

Of the three measures of SB included in this study, only low intensity behaviour (<1.5 METs) was associated with adiposity. This relationship was not apparent after correcting for MVPA. The present research indicates that the relationship between SB and adiposity depends on the measurement device used to measure behaviour and therefore which aspects of SB the device captures, as well as the amount of MVPA that is accumulated. These data suggest that the postural element of SB (sitting) is not sufficient for the accumulation of adiposity. Rather low EE, as a result of high volumes of low intensity behaviour (<1.5 METs) regardless of posture, and a lack of moderate-to-high intensity activity, is associated with higher fat mass.

LIST OF ABBREVIATIONS

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

DECLARATIONS

Ethics approval and consent to participate

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

Consent for publication

Not applicable

Availability of data and material

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

Competing interests

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

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Authors' contributions

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

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