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Validity of GT3X and Actiheart to estimate sedentary time and breaks using ActivPAL as the reference in free-living conditions

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ABSTRACT

Sedentary time, specifically sitting/reclining, is a risk factor for many non-communicable diseases and premature mortality. Inclinometers have been used as a valid measurement of sedentary time and its patterns; however, there is a lack of information regarding the validity of alternative accelerometry and heart rate methods. The validity of GT3X and Actiheart in estimating changes in daily sedentary time and breaks, during free-living settings, using ActivPAL as the reference was examined. A crossover randomized control trial of an intervention that aimed to reduce ~3 h/day of sitting time included 10 overweight/obese adults (37–65 years). Participants had a total of 74 valid days for the three devices (29 controls; 45 interventions). For ActivPAL, sedentary time was measured directly based upon posture (sitting/reclining); Actiheart, the presumed MET cutpoint for sedentary time (<1.5 METs) based on accelerometry + heart rate; GT3X, the traditional <100 counts min^{-1}. A break in sedentary time was defined as when the participants were above the aforementioned cutoffs. GT3X overestimated and Actiheart underestimated sedentary time (bias = 135 min; bias = −156 min, respectively) and both methods overestimated breaks in sedentary time (bias = 78; bias = 235 breaks, respectively). The GT3X method was in better agreement with the ActivPAL sedentary time (r^2 = 0.70; concordance correlation coefficient (CCC) = 0.56) than the Actiheart (r^2 = 0.24; CCC = 0.31). The present results highlight the magnitude of potential errors in estimating sedentary time and breaks from common alternative methods other than ActivPAL. Because misclassification errors from the commonly used surrogates are potentially large, this raises concern that alternative methods used in many epidemiological observations may have underestimated the true effects caused by too much sitting (ClinicalTrials.gov ID:NCT02007681).

1. Introduction

Physical activity (PA) and sedentary behaviors are distinct entities and the lack of moderate-to-vigorous PA (MVPA) does not directly imply higher sedentary time. A paradigm shift first proposed in 2004 by Hamilton et al. [1] and updated since [2] states that behaviors and physiology of sitting inactive (inactivity physiology) is qualitatively different from what has been the traditional focus of much less frequent, more brief, and generally more vigorous physical activities associated with exercise. This has raised the need for being able to quantify behaviors like sitting and light activity that historically have not been measured objectively. One of the most heavily studied aspects comes from the possibility that many common diseases are caused by large amounts of sitting behaviors, which are potentially preventable by replacing them with non-fatiguing low intensity PA, separate from traditional exercise recommendations [1–3]. Recently, there has been an emergence in an appreciation for studies that focus on sitting time. However, devices used to quantify sitting time and breaks have relied less often on methods actually designed to directly measure postural allocation (such as ActivPAL) than the more indirect surrogate measures. Thus, with some exceptions [4–7], there is still much to learn regarding how well existing commercial technologies commonly used in the epidemiological studies estimate sedentary time and breaks in the free-living condition.

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Accelerometers have been the preferred method to study patterns of PA. The ActiGraph GT3X and earlier versions of similar devices have been utilized and, in general, have been quite useful for estimating MVPA [8]. However, when considering sedentary time, ActivPAL (an inclinometer-based device that detects postures) has been presented as the best alternative due to its high precision and accuracy compared to gold standard methods such as direct observation [5]. ActivPAL also allows for longer data collection periods [9–11]. Accelerometers (count-based data) have been presented as less accurate for detecting low intensity behaviors [5,12] because they do not discern sitting from non-sitting time. Rather, accelerometers estimate sedentary time based on a lack of movement (<100 counts min^{-1}), which may often erroneously incorporate light PA behaviors (standing) as sedentary time. One study found GT3X to accurately detect changes in sedentary time and PA comparable with ActivPAL [13]. Conversely, evidence suggests that the GT3X may not be able to identify breaks in sedentary time given its biased and imprecise estimates of total sedentary time [5].

To overcome some of the accelerometers' limitations, a combined heart rate (HR) with accelerometer device (Actiheart) [14,15] has been used to estimate energy expenditure (EE) [16]. Actiheart utilizes both accelerometer and HR, and calculates activity EE (AEE) by differently weighting the data from the two components depending on the dominance of activity or HR using a validated branched model calculation. Essentially, when both accelerometer and HR are low, the accelerometer AEE estimates have more weight, whereas when accelerometer and HR values are high, the HR AEE estimates are the predominant contributor to AEE. To minimize the influence of HR increase not related to PA, the normal HR data weighting is reduced where HR increases in the absence of sufficient counts [15].

Actiheart has been shown to accurately estimate AEE compared to the gold standard doubly labeled water technique [16]. By combining accelerometer and HR data, Actiheart may prevent accelerometer only misclassification when low body movement (but high HR) exists. Regardless, the advantages that Actiheart presents for MVPA estimation are still to be investigated when examining sedentary time patterns, with no data for the accuracy of Actiheart in sedentary time estimations. Therefore, the aim of this study was to examine the agreement between GT3X and Actiheart with ActivPAL for capturing sedentary time and breaks in overweight/obese adults engaged in a free-living intervention to reduce sedentary time.

2. Materials and methods

The study was approved by the Ethics Council from Faculdade de Motricidade Humana, Universidade de Lisboa, (approval number: 14/2013) and conducted in accordance with the Ethical Standards in Sport and Exercise Science [17]. Written informed consent was obtained from each participant. Inclusion criteria consisted of: currently employed in a full time academic or administrative role that involves >7 h day^{-1} of computer based work; aged 18–65 years old; body mass index (BMI) >25.0 kg m^{-2}; not taking medication or dietary supplements; physically inactive (not meeting the MVPA recommendations and not exceeding 5000 steps·day^{-1}); and free from any major disease.

This was a crossover randomized clinical trial (ClinicalTrials.gov ID: NCT02007681). Participants were randomly assigned for two treatment arms (intervention/control) by an automated computer generated randomization scheme (a detailed description available as supporting information; CONSORT flow diagram and checklist). Data were collected between September and December 2013 and analyzed in 2014.

To ensure that participants were physically inactive (<30 min day^{-1} of MVPA and $\sim$5000 steps·day^{-1}) and to assess habitual steps·day^{-1}, PA, and sedentary time, participants were fitted with a pedometer (Omron Hj-113 Pocket Pedometer, Walking Style-II) and an accelerometer ActiGraph GT3X+ (ActiGraph, Pensacola, FL) prior to intervention. The trial consisted of two 1-week conditions performed in a random order, both under free-living conditions: intervention (3 h reductions in sitting time) and control (habitual sitting time). Participants were instructed to maintain the same eating patterns during the trial.

The intervention included a software program (Workrave, GitHub) that gave hourly alerts to participants to break up their sitting time for 7 min. During transportation/home/domestic leisure time contexts, individual goals for number of steps·day^{-1} were set, based on an expected step cadence for ambulatory activities ($\sim$90–120 min·day^{-1}) and by adding 6000 steps to their initial habitual daily amount.

Anthropometric variables were measured according to the standardized procedures described elsewhere [18]. BMI was calculated as body mass (kg)·$height^{-2}$ (m).

The ActivPAL Professional (Pal Technologies Ltd., Glasgow, UK) was worn on the middle anterior line of the right thigh and provided objectively processed variables, including total time spent sitting/lying. From the ActivPAL raw data, it was possible to extract the periods of time spent in sedentary behavior. The device was sealed with a non-allergenic adhesive tape attached to the skin and used continuously for 24 h for 14 days, except for water-based activities such as showering and swimming. Data was recorded in 15 s epochs. Participants were asked to record waking/sleeping hours and ActivPAL wear time in a logbook. A valid day was defined as having 600 or more min ($\geq$10 h) of monitor wear during waking hours. They were also asked to record timing and reasons for every occasion the ActivPAL was removed.

Participants wore an accelerometer ActiGraph GT3X+ (ActiGraph, Pensacola, FL) on the right hip, near the iliac crest programmed to collect data from the vertical axis in 15 s epochs and initialized using the normal filter (AG-Norm). Accelerometers were worn for 14 days during all waking hours and removed for sleeping and during water-based activities [19]. The delivery and fitting of the accelerometers was conducted face to face [20]. The device activation/download/processing were performed using the Actilife software (v.6.9.1). A valid day was defined as having 600 or more min ($\geq$10 h) of monitor wear [20]. The cutoff value used to define sedentary time was <100 counts min^{-1} [21]. Participants were asked to record waking/sleeping hours and accelerometer' wear time in a logbook. They were also asked to record timing and reasons for every occasion the accelerometer was removed.

The Actiheart (Actiheart, CamNtech Limited, UK) is a lightweight (10 g) combined HR and movement (uniaxial accelerometer oriented to measure acceleration along the body's longitudinal axis) sensor that utilizes both piezoelectric accelerometer and HR data synchronously. This sensor is capable of storing time-sequenced data for several days and was worn on an adapted polar band placed on the chest. The Actiheart software allows two types of calibration; an individual calibration using a standardized step test that consists of step up and down a 15 cm high step, progressively increasing step frequency from 15 to 32.5 body lifts per minute (rate of change: 2.5 body lifts per min^2) and a group calibration inbuilt function. Given that some of the participants were not able to finish the step test, we performed a group calibration that is available in the software (version 4.0.99). The Actiheart was started at the long term mode to record HR and acceleration with 15 s epochs. Participants wore the Actiheart 24 h day^{-1} for 14 days and a valid day was defined as having 600 or more min ($\geq$10 h) of monitor wear during waking hours. Data from the Actiheart were downloaded into the commercial software. The camNtech software algorithm allowed data cleaning, recovering, and interpolation of missing and noisy HR. Using the raw data from

the branched combined model that uses activity (acceleration) and HR, it was possible to extract and quantify the daily sedentary time (<1.5METs). Participants were also instructed to register the periods in which they removed the device for water activities.

Sedentary time from the three devices was accounted for by the total time spent in sedentary behavior while considering the same awake hours in the three devices. For ActivPAL, sedentary time was created based on posture (sitting/reclining). For GT3X, the traditional <100 counts min^{-1} intensity cut off was used to estimate sedentary time. Finally, for Actiheart, the presumed MET cut point for sedentary time (<1.5METs) based on accelerometry + HR was used. A break in sedentary time was considered whenever participants were above the aforementioned cut offs.

For the comparisons between devices, the 15 s epochs' data from GT3X, Actiheart, and ActivPAL were reintegrated in 1 min epochs for data analyses. GT3X was only worn during waking hours and removed for sleeping. Therefore, to be able to distinguish sleeping hours (recorded in Actiheart and ActivPAL as sedentary time) from actual sedentary time spent during waking hours, only the hours from the three devices corresponding to the waking period were matched and synchronized in each participant. Thus, the variable sedentary time (min/day) is the sum of the time spent in sedentary time in all the valid hours during the waking period for each participant. The days that were simultaneously valid in all three monitors were considered.

To ensure that no sleeping hours were considered in the analysis, we crossed the data from the three devices with the information reported in the logbooks.

Statistical analysis was performed using SPSS Statistics for Windows version 22.0, 2012 (SPSS Inc., an IBM Company, Chicago IL, USA). Descriptive analysis included means ± SD. To assess differences between devices' estimations, we used paired samples *t*-test. The participants' random effects for the differences between methods were tested using the univariate analysis of variance model. The coefficient of determination (r^2) and standard error of estimate (SEE) were used to assess validity, respectively, to assess the predictive power and the association between methods. To examine the amount of agreement for GT3X and Actiheart sedentary time estimates using ActivPAL as a reference, we calculated the concordance correlation coefficient (CCC) using the Lin approach [22] with MedCalc vs. 11.1.1.0 (2009) software. The CCC (ρc) contains a measurement of precision ρ and accuracy ($\rho c = \rho$ Cb), where ρ is the Pearson correlation coefficient and Cb is a bias correction factor. As CCC is defined without ANOVA assumptions, we also calculated the intraclass correlation coefficient (ICC) which has been traditionally used for assessing reliability between multiple methods. Definitions of different versions of ICCs depend on the assumptions of specific ANOVA models. Therefore, we calculated type A ICC using an absolute agreement definition for the two-way mixed models available on SPSS.

Agreement between methods was assessed using the Bland–Altman method [23]. ρ was also used to test if the differences between methods were related with the mean of the methods. Statistical significance was set at $p < 0.05$.

3. Results

There was approximately 13% lost data for the GT3X (insufficient daily wear time), and approximately 35% of lost days for the Actiheart (no HR data). All 10 participants completed both trial conditions but due to lost data, we finished with a total of seven participants and 74 valid days (29 control; 45 intervention). For both total sedentary time and breaks in sedentary time, the unit of analysis was the participant/day. One participant was overweight and six were obese, and the sample was not equally distributed according to gender (five women; two men). Mean age was 49.7 ± 12.6 (range = 37–65) years; mean BMI was 34.7 ± 5.07 (range = 29–41).

The difference in sedentary time between control and intervention valid days was not significant (−18.5 ± 38.5 min) (Table 1). Participants significantly increased MVPA (control: 22.1 ± 10.7 vs. intervention: 47.4 ± 21.6, $p < 0.001$) and daily steps (control: 5618 ± 2193 vs. intervention: 11,355 ± 2196, $p < 0.001$).

Table 1 presents the means and the differences between methods for the daily sedentary time and breaks in sedentary time estimations obtained by GT3X and Actiheart methods using ActivPAL as the reference.

As shown in Table 1, GT3X significantly overestimated while Actiheart underestimated ActivPAL's sedentary time. Both alternative methods overestimated breaks in sedentary time compared with ActivPAL.

No significant interaction for the condition with the differences between both alternative and reference methods was observed ($p \geq 0.05$). Significant random effects for the participants' factor with the differences between both methods and the reference were observed ($p < 0.001$) for both sedentary time and breaks in sedentary time.

The results from the regression analyses are presented in Table 2.

As presented in Table 2, significant associations were observed for the GT3X and Actiheart estimations with ActivPAL sedentary time and breaks in sedentary time. However, while GT3X and Actiheart explained 70% and 24% of ActivPAL's sedentary time, the two devices only explained 8% (GT3X) to 5% (Actiheart) of ActivPAL's breaks in sedentary time estimation. Additionally, for both GT3X and Actiheart, the estimation obtained by each method and the reference method differed from the line of identity. Indeed, considering ICC and CCC values (Table 2), GT3X presented the best agreement with ActivPAL's sedentary time estimation with a precision of 0.84 and an accuracy of 0.66, whereas Actiheart had a precision and accuracy of 0.46 and 0.66, respectively. For the breaks in sedentary time, both devices presented lower ICCs and CCCs. A precision of 0.28 and accuracy of 0.17 were observed for GT3X, whereas a precision of 0.22 and an accuracy of 0.03 were observed using Actiheart.

The agreement for GT3X and Actiheart's sedentary time estimations with ActivPAL as the reference is shown in panel A on Fig. 1. A significant trend was found between the differences and the mean of the alternative, and the reference method for GT3X ($p < 0.001$) but not for Actiheart ($p = 0.337$). Wide limits of agreement were observed for both methods to predict ActivPAL's sedentary time (panel A on Fig. 1).

For the breaks in sedentary time estimations, agreement for GT3X and Actiheart with ActivPAL as the reference is shown in panel B on Fig. 1. A significant trend was found between the differences and the mean of both alternative and reference methods for both GT3X and Actiheart ($p < 0.001$). Wide limits of agreement were observed for both methods to predict ActivPAL's breaks in sedentary time (panel B on Fig. 1).

Table 1
Means and differences for sedentary time and breaks in sedentary time estimations for GT3X and Actiheart using ActivPAL as the reference, by condition.

	Intervention		Control	
	Estimation (Mean ± SD)	Alternative-reference (Mean ± SD; *p*)	Estimation (Mean ± SD)	Alternative-reference (Mean ± SD; *p*)
Sedentary time (min·day^{-1})				
	ActivPAL (496 ± 172)		ActivPAL (515 ± 142)	
GT3X	636 ± 138	140 ± 83.0; <0.001	642 ± 94.4	127 ± 96.9; <0.001
Actiheart	342 ± 158	−154 ± 144; <0.001	356 ± 126	−159 ± 174; <0.001
Breaks in sedentary time (number·day^{-1})				
	ActivPAL (53.7 ± 15.2)		ActivPAL (46.6 ± 16.7)	
GT3X	136 ± 34.5	82.3 ± 30.4; <0.001	128 ± 43.6	81.4 ± 46.5; <0.001
Actiheart	305 ± 79.2	251 ± 77.3; <0.001	258 ± 79.8	211 ± 79.4; <0.001

The total number of valid-days for the three methods comparison was 74 days; 29 days of control and 45 days of intervention.
ActivPAL was used as the reference for the comparisons with GT3X and Actiheart.
Abbreviations: Actiheart a combined heart rate and motion sensor; ActivPAL inclinometer; GT3X accelerometer; SD standard deviation.

Table 2
Regression for GT3X and Actiheart using ActivPAL as the reference for the daily sedentary time and breaks in sedentary time estimations.

	r	r^2	Slope	Intercept	SEE	95% CI	Trend	CCC	ICC[§]
	Sedentary time (min·day^{-1})								
GT3X	0.84[*]	0.70	1.10	−199	88.1	0.93–1.27	**0.45**[#]	0.56	0.72
Actiheart	0.48[*]	0.24	0.54	317	141	0.31–0.76	0.11	0.31	0.48
	Breaks in sedentary time (number·day^{-1})								
GT3X	0.28[*]	0.08	0.13	37.7	16.8	0.03–0.23	**0.68**[#]	0.05	0.09
Actiheart	0.23[*]	0.05	0.32	414	15.8	0.00–0.09	**0.93**[#]	0.01	0.02

The total number of valid days for the three methods comparison was 74 days; 29 days of control and 45 days of intervention.
ActivPAL was used as the reference for the comparisons with GT3X and Actiheart.
Abbreviations: Actiheart, a combined heart rate and motion sensor; ActivPAL, inclinometer; *r*, coefficient of correlation; r^2, coefficient of determination; CI, confidence intervals; CCC, concordance correlation coefficient; ICC, intraclass correlation coefficient; GT3X, accelerometer; SEE, standard error of estimation.
[*] Significant correlation for the alternative method with the reference method.
[#] Significant trend for the differences and the means for the alternative method with the reference method.
[§] Intraclass correlation coefficient using an absolute agreement definition for two-way mixed effects model.

4. Discussion

The present study examined the validity of GT3X and Actiheart to estimate daily sedentary time and breaks in sedentary time using ActivPAL as the reference method, in physically inactive overweight/obese working adults engaged in a multi component intervention to reduce sedentary time. An empirical evaluation and comparison of these tools will further inform research aiming to measure and interpret sedentary time and its associated health outcomes. This is of particular importance given that ActiGraph was the tool used in many studies providing evidence that breaks from sedentary time might be favorably related to health [24,25].

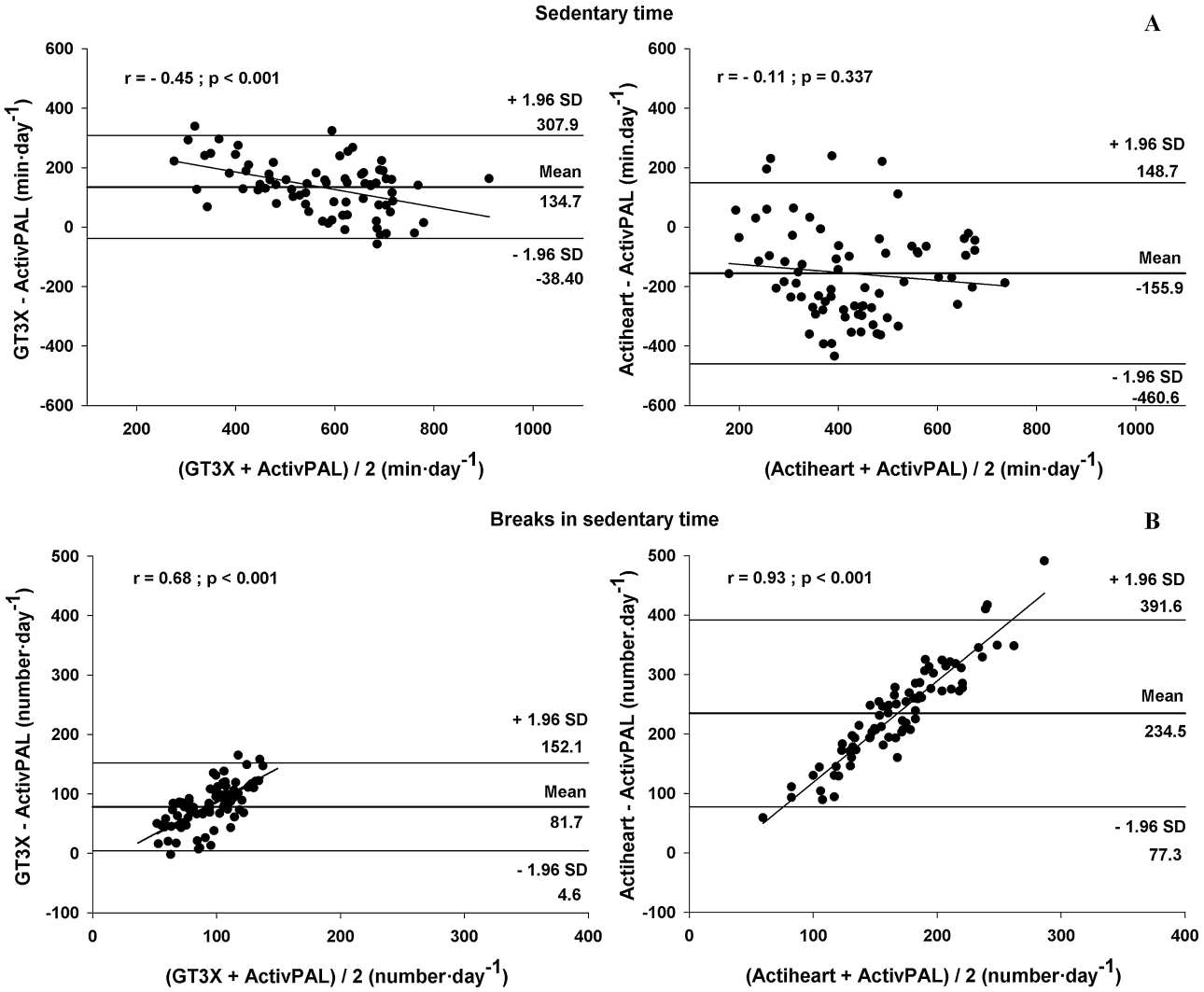

Fig. 1. A Bland–Altman analysis of between-methods agreement in estimate daily sedentary time and breaks in sedentary time.
The middle solid line represents the mean differences between both methods. The upper and lower lines represent ±2SD from the mean, that is, 95% limits-of-agreement (±1.96 SD). Trend line represents the association between the differences of the methods and the mean of both methods.

Some studies have assessed the validity of GT3X in estimating sedentary time, with ActivPAL as the reference [5,11] without as much prior understanding regarding comparisons with Actiheart outcomes (accelerometry + HR). The comparison of three distinct methods to estimate sedentary time and breaks in sedentary time in free-living conditions provides new insights to this recent scientific area of study. The inclusion of a device that combines HR and accelerometry information (a method without background in the evaluation of sedentary time) makes this comparison especially meaningful. Our comparison is of particular interest since observational findings regarding the independent associations of sedentary time with disease outcomes have been obtained by using distinct analytical approaches to measure sedentary time and generally not used ActivPAL or other validated devices to measure postural allocation.

The results showed Actiheart to significantly underestimate sedentary time compared to ActivPAL (~155 min). In addition, the ICC and CCC between Actiheart and the reference method were low with Actiheart, explaining only 24% of ActivPAL's sedentary time total variability. Despite the low association between equipment and the significant bias, Actiheart underestimated ActivPAL's sedentary time independently on the magnitude of sedentary time values (panel-A on Fig. 1). This means that Actiheart underestimated sedentary time in a constant manner, with no influence of sedentary time levels in the error between methods.

Actiheart combines the information from accelerometry and HR monitor and uses one of four branched equations. Normally in the branched model, the contribution to EE from accelerometry and HR is weighted epoch by epoch according to certain activity and HR thresholds. At running speeds, HR is a very reliable measure of EE. On the other hand, for sedentary and low intensity activities, HR is a poor measure of intensity; movement registration is more reliable. Thus, HR is weighted 10% on the HR-EE relationship. Therefore, with 90% of sedentary time estimation being dependent on accelerometry data only, it was expected that Actiheart would overestimate sedentary time similarly to what occurs in GT3X. However, the 10% inclusion of HR in the branched equations associated with a different wearing position (chest) may explain why Actiheart underestimated sedentary time compared to ActivPAL. Participants were obese and physically inactive with generally poor fitness. Therefore, even when sitting they were more susceptible to external stimulus and may have presented an elevated HR which would be classified as non-sedentary time ($\geq$1.5METs) by the Actiheart.

The large limits of agreement and the lack of precision presented in panel A on Fig. 1 indicate that Actiheart is not a good method for estimating sedentary time, both at group or individual level. Actiheart can be suitable to estimate sedentary time if accounting for the constant bias, once no trend along the magnitude of sedentary time levels was found.

Positive but weak association was found for the breaks in sedentary time estimated by Actiheart compared to ActivPAL. However, Actiheart significantly overestimated (235 breaks·day^{-1}) the number of daily breaks in sedentary time. The Bland–Altman plots showed a trend between the difference and the mean of both methods (panel B on Fig. 1) with large limits of agreement and lack of precision. Therefore, Actiheart is not valid both at individual and group levels for the breaks in sedentary time. Actiheart combines information from accelerometry and HR, and the vulnerability of this former parameter to external stimulus may explain the higher number of transitions from sedentary time to light PA that could be independent of postural changes (sit to stand) and, therefore, justify the discrepancies with ActivPAL's breaks estimation.

Data comparing and validating accelerometer estimates of sedentary time against ActivPAL are accumulating [6,26]. However, the findings are equivocal, with studies finding good agreement between these two methods [27–29] and others showing weak concordance, specifically because GT3X output of count thresholds is less sensitive to detect sitting/standing transitions compared to ActivPAL [6,30]. These controversial results can be partially explained by the variability in studies' conditions (laboratory or free-living), and the fact that previous studies have used different cutoffs to define sedentary time when using accelerometry. In addition, there is a basic difference inherent to what these two types of devices evaluate. While GT3X evaluates intensity of movement, the ActivPAL assesses postures.

For the comparison of GT3X with ActivPAL, our results are in accordance with former studies that found accelerometry to overestimate sedentary time compared to ActivPAL. A significant trend was revealed (panel B on Fig. 1), with a higher overestimation of sedentary time for the lower sedentary levels and a better agreement between methods for the higher sedentary levels. Therefore, in opposition to what occurred with Actiheart, the error between GT3X and ActivPAL was not constant along sedentary time levels. This is of great importance, since the reliability of GT3X to measure sedentary time seems to vary with sedentary levels. Therefore, interventions that aim to examine sedentary time changes over time may be weakened or enhanced by this inconsistent error. The ICC between GT3X and ActivPAL methods was 0.72, indicating that despite the mean bias of GT3X overestimating ActivPAL, there is a moderate to high agreement between the two methods. Furthermore, GT3X explained 70% of ActivPAL's sedentary time total variability, providing a much higher power to explain ActivPAL's variability compared to Actiheart.

The discrepancies between GT3X and ActivPAL estimations of sedentary time may be explained by an important limitation of using accelerometry counts alone to define sedentary time. Much of the standing time demanding muscular activity without high amounts of hip acceleration may be inadequately included by the hip mounted accelerometer as sedentary time, resulting in a sedentary time overestimation. For example, the GT3X monitor output for standing activities such as cooking or washing dishes can be below 100 counts min^{-1}, and these activities are not sedentary.

In general, the ability of GT3X to distinguish between sedentary time and light intensity physical activity time is not known. Moreover, although GT3X is a triaxial accelerometer, only the information from the vertical axis was considered, because there are still no cutoffs for sedentary time using the triaxial information. While for some activities in the sitting position, the antero-posterior and mediolateral axes are able to record accelerations, the vertical axis indicates acceleration equal to zero. Therefore, we can only assume that the poor agreement observed for GT3X with ActivPAL was specific to its uniaxial measure, since only information on the vertical axis was considered. A positive but weak association was found for the breaks in sedentary time estimated by GT3X compared to ActivPAL, with GT3X overestimating (81.5 breaks·day^{-1}) daily breaks in sedentary time.

A trend between the difference and the mean of both methods (panel B on Fig. 1) with large limits of agreement and lack of precision was found. Therefore, GT3X showed poor agreement with ActivPAL both at individual and at a group level for the breaks in sedentary time. These results are in accordance with previous findings that found GT3X to significantly overestimate breaks in sedentary time compared to direct observation with good accuracy for the ActivPAL method [6].

This study has some limitations that should be noted. Our results showed significant random effects for the participant factor with the differences between both GT3X and Actiheart with ActivPAL estimations for both sedentary time and breaks in sedentary time. This was in addition to the fact that the sample was

restricted to overweight/obese participants, and that limits the generalizability of these results to a broader population. As mentioned before, another limitation was that the low agreement observed for GT3X with ActivPAL is specific to its uniaxial measure, since no information from the other two axes was considered. Using GT3X's triaxial information could improve the accuracy of this method to estimate sedentary time and breaks, but this still needs to be investigated in future studies (when thresholds for the triaxial information of the GT3X are developed).

Finally, although ActivPAL has been validated in the laboratory compared with a criterion measure (direct observation) and found to be 100% accurate for measuring sitting, standing, and walking, it cannot be considered a criterion measure for sedentary time assessment. Therefore, introducing a reference method like direct observation would enrich this study.

There are important strengths to this study. We were able to collect more than 750 free-living hours of valid data in all three devices. As an additional strength, we assessed each monitor's accuracy to detect change in behavior by examining breaks from sedentary time in all three devices. To our knowledge, no other study has examined the ability of a combined motion sensor and HR device to estimate sedentary time or breaks in sedentary time, which represents a novel finding in this field.

5. Conclusion

The present results suggest a relatively low agreement for GT3X and Actiheart with ActivPAL as the reference for sedentary time and breaks in sedentary time estimations. However, at the group level, the GT3X provided acceptable validity in estimating sedentary time. When comparing the efficacy of free-living interventions to reduce sedentary time, especially if assessing sedentary time patterns, one must be careful when interpreting findings or making conclusions about sedentary behavior when using these alternative methods.

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Conflict of interest

The authors declare that there are no conflicts of interest.

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