Published in final edited form as:

Br J Sports Med. 2014 July ; 48(13): 1043–1047. doi:10.1136/bjsports-2014-093520.

Responsiveness of motion sensors to detect change in sedentary and physical activity behaviour

Ann M Swartz^{1,2}, Aubrianne E Rote³, Young Ik Cho^{2,4}, Whitney A Welch¹, and Scott J Strath^{1,2}

¹Department of Kinesiology, University of Wisconsin-Milwaukee, Milwaukee, Wisconsin, USA

²Center on Aging and Translational Research, University of Wisconsin-Milwaukee, Milwaukee, Wisconsin, USA

³Department of Health and Wellness, University of North Carolina-Asheville, Asheville, North Carolina, USA

⁴Zilber School of Public Health, University of Wisconsin-Milwaukee, Milwaukee, Wisconsin, USA

Abstract

Background—The purpose of this study was to determine the responsiveness of two motion sensors to detect change in sedentary behaviour (SB) and physical activity (PA) during an occupational intervention to reduce sitting time.

Methods—SB and PA were assessed using a hip-worn Actigraph GTX3 (AG) and a thigh-worn activPAL (AP) during three consecutive workdays throughout baseline and intervention periods. Mean scores at baseline and intervention were estimated by hierarchical linear models (HLM) with robust SEs, adjusting for random variance of average scores between participants. Change scores (mean baseline minus mean intervention) were calculated for each device. Response to change was assessed for each device using the standardised response mean.

Results—67 adults (45 ± 11 years; 29.3 ± 7.7 kg/m²) wore the acceleration-based motion sensors for 8.3 (SD=1.2) and 8.3 (SD=1.1) h during the baseline and intervention periods, respectively. HLM showed that AP sitting/lying time (−16.5 min, −5%), AP stepping (+7.5 min, 19%), AP steps/day (+838 steps/day, +22%), AP sit-to-stand transitions (+3, +10%), AG SB (−14.6 min, −4%), AG lifestyle moderate-intensity PA (LMPA, +4 min, +15%) and AG MPA (+3 min, 23%) changed significantly between the baseline and the intervention period. Standardised response means for AP sitting/lying time, stepping, steps/day, sit-to-stand transitions and AG SB, LMPA and MPA were above 0.3, indicating a small but similar responsiveness to change.

To request permissions go to: <http://group.bmj.com/group/rights-licensing/permissions>

Correspondence to Professor Ann M Swartz, Department of Kinesiology, University of Wisconsin-Milwaukee, PO Box 413, Milwaukee, WI 53201-0413, USA; aswartz@uwm.edu.

Contributors All authors contributed substantially to the manuscript. AMS, AER and SJS contributed to the conception and design of the study. AMS, AER, YIC, SJS and WAW contributed to the acquisition of data or analysis and interpretation of data. All authors were significantly involved in the writing and/or editing of the manuscript and provided final approval of the version published.

Competing interests None.

Ethics approval University of Wisconsin-Milwaukee IRB.

Provenance and peer review Not commissioned; externally peer reviewed.

Conclusions—Responsiveness to change in SB and PA was similar and comparable for the AP and AG, indicating agreement across both measurement devices.

INTRODUCTION

The positive relationship between physical activity (PA) and health has been well established, and interventions to increase PA are prevalent. Recently, the ill effects of sedentary behaviour (SB) have come to light. Evidence is accumulating on the deleterious effects of sedentary time, showing that high levels of SB, defined as ‘any waking activity characterised by an energy expenditure < 1.5 metabolic equivalents *and* a sitting or reclining posture’,¹ are associated with numerous chronic acquired conditions including obesity,^{2–5} type 2 diabetes,^{6,7} metabolic syndrome,⁸ cardiovascular disease,^{9–11} certain types of cancer¹² and cardiovascular and overall mortality^{7,13–15} in adults and older adults. Since these discoveries, researchers and practitioners have begun to intervene and attempted to break up prolonged sitting bouts and reduce total SB.

There are a number of self-report and objective tools used to assess SB and PA, each using a different approach or technology to measure these behaviours. Two of the most commonly employed objective tools are the activPAL accelerometer/inclinometer (AP; PAL Technologies Ltd, Glasgow, Scotland, UK) and the Actigraph accelerometer-based motion sensor (AG; ActiGraph LLC, Pensacola, Florida, USA). The AP assesses time spent sitting, standing and stepping through accelerometry and measurement of posture with an inclinometer. Time spent sitting or lying is commonly used as a marker of SB. Information on stepping and step rate are used as indicators of PA. The AG assesses times spent being sedentary and in PA of varying intensities by defined cut points.^{16–21} When comparing results across studies using different sedentary and PA measurement tools, it is essential that these tools provide comparable outcomes. Establishing this equivalency allows researchers to draw conclusions surrounding SB, PA and health from a multitude of studies using different assessment tools.

The AP and AG have been evaluated for validity and reliability in assessing sedentary time and PA.^{17,18,22–26} Additionally, the ability of the two devices to assess sedentary time has been compared to each other over a 1-day period in young, active, normal weight individuals,²⁷ and to direct observation over a 6 h period in overweight office workers.¹⁷ Kozey-Keadle *et al*¹⁷ showed that both devices underestimated sitting time assessed by direct observation, but the AP was more precise and more sensitive to reductions in sitting time than the AG. Recently, the convergent validity of the AP and AG showed that the AG recorded over two additional hours of sedentary time over a 15 h period compared with the AP.²⁷ While the validity and reliability of a device are paramount, it is also important that the device is able to detect a change in PA or sedentary time over the course of an intervention. However, no studies have compared the ability of the AP and AG devices to assess change in sedentary time and PA in adults over multiple days. Therefore, the purpose of this study was to determine congruency in the responsiveness of two accelerometer-based motion sensors (AP and AG) to detect change in free-living, occupational sedentary time and PA during an intervention to disrupt sitting time.

METHODS

Participants

Participants were recruited from a large Midwestern university via flyers posted on university bulletin boards and emailed to university employees. Included in this study were individuals over 20 years of age whose occupation was sedentary, such as working at a desk or on a computer, and self-reported sitting for at least 60% of their workday. This quantification of sedentary occupation was based on previous research showing that office workers sat an average of 66% of their workday.²⁸ Self-reported workday sitting time of at least 60% was confirmed during the baseline monitoring period using the AP. Individuals were excluded from participation if they walked with a limp, had a lower extremity fracture within the past 3 months, had any amputations of the lower limbs other than toes or used an assistive device to aid in ambulation.

Protocol

Throughout the 2-week study period, participants met with the research team three times. The first visit took place in the laboratory. Participants read and signed an informed consent that had been approved by the University Institutional Review Board. A health history questionnaire was completed and height and weight were measured following standardised procedures.²⁹ Height was measured using a stadiometer (Detecto 3PHTROD-WM, Webb City, Missouri, USA) and weight was measured using a balance beam scale (Detecto 339, Webb City, Missouri, USA). Finally, participants were given instructions on how to wear the AP and AG activity monitors.

There were two data collection periods, a baseline period and an intervention monitoring period. For each collection period, researchers met with participants at their workstation to issue the monitors. The intervention prompts (a wrist-worn device and a desktop computer application) were provided after completion of the baseline period and before the intervention period. These prompts were programmed to disrupt sedentary time every 60 min.³⁰ The baseline and intervention monitoring periods assessed SB and PA during all working hours on the same three consecutive weekdays, over 2 weeks. At the end of each monitoring period, monitors were collected by the research team.

Measures

The variables of interest for the current study included average time spent in sitting/lying, standing, stepping; steps/day; number of sit-to-stand transitions from the AP monitoring device and time spent in SB, light-intensity PA (LPA), lifestyle moderate-intensity PA (LMPA), MPA and vigorous-intensity PA (VPA) from the AG.

AP accelerometer-based motion sensor—The AP is a small ($35 \times 53 \times 7$ mm), lightweight (20 g), piezoresistive uniaxial accelerometer, with a dynamic range >2 g. The AP was worn on the midline of the right thigh and was attached using the manufacturer provided PALstickies hydrogel adhesive pads between the device and leg and athletic tape over the top of the device. Data from the AP were recorded in 15 s epochs at a sampling rate of 10 Hz. In addition to the accelerometer, the AP contains an inclinometer that provides

information based on the posture of an individual. Using manufacturer-determined angle and acceleration thresholds, the inclinometer can detect sit-to-stand (angle greater than 32° and a 0.53 g acceleration for a minimum of 10 s) and stand-to-sit transitions (angle less than 22° and a 0.38 g acceleration for a minimum of 10 s). The AP has previously been shown to be valid and reliable in detecting body positioning and activity in different populations.²²²³

Actigraph GT3X—The AG GT3X (Pensacola, FL; 3.8 × 3.7 × 1.8 cm; 27 g) is a triaxial accelerometer-based PA monitor with a dynamic range of 2 g. Participants wore the AG accelerometers on the right hip. Data were collected in 15 s epochs at 30 Hz. The AG signals are passed through a bandpass filter (0.25–2.5 Hz) that excludes signals outside the range of human movement. In addition, this monitor offers a low-frequency extension option in order to increase sensitivity to low-intensity activities. For the current study, this low-frequency extension was not employed since it has not been shown to improve detection of steps accumulated through slow walking and light-intensity activity.³¹ The AG accelerometer has been shown to be a valid and reliable activity monitor across many different populations.^{171824–26}

Data processing

Data for the AP and AG were downloaded onto a laboratory computer and processed using manufacturer provided software. All additional data processing was performed in Excel. Data were averaged over the 3-day baseline period (T1) and the intervention period (T2).

The AP software (activPAL V.6.4.1) classified individuals as sitting, standing or walking. Steps/day, number of sit-to-stand transitions are also recorded by the device.

The AG data were analysed using ActiLife 6 software. Only accelerations in the vertical plane were analysed. A combination of Freedson *et al*¹⁸ and Matthews and coworkers¹⁶²⁶ cut points were used to determine time spent sedentary and in PA. Sedentary was defined as <100 cpm,¹⁶ LPA was defined as 100–759 cpm, LMPA was defined as 760–1951 cpm, MPA was defined as 1952–5724 cpm and VPA was defined as ≥ 5725 cpm from the AG.¹⁶¹⁸²⁶ In conjunction with log data, each participant's data were individually evaluated to precisely determine monitor on/off time, and to ensure that data from the two monitors were time synced for comparability.

Statistical analysis

Descriptive statistics were run for demographic, PA and sedentary variables. Response to change was assessed for each device using the standardised response mean (SRM) and effect size. SRM (also known as the mean standardised response) was calculated as the absolute value of the mean change score divided by the SD of the individual's change score. Effect size was calculated as the absolute value of the mean change score divided by the SD of the individual's baseline score. SRM and effect size can be interpreted as follows: <0.20 trivial, 0.20 to <0.50 small, 0.50 to <0.80 moderate and ≥ 0.80 large.^{32–34}

Change scores were calculated for each device based on mean values during baseline monitoring minus mean values during intervention monitoring. Owing to the fact that the scores, repeatedly measured at baseline and intervention, were nested within each

participant, mean scores at baseline and intervention were estimated by hierarchical linear models (HLMs) with robust SEs, adjusting for random variance of average scores between participants. Also, the changes between the two time points (ie, slope for time) were treated as randomly varied between individuals. This estimation model also controls for participant characteristics including age, gender, race, education and body mass index (BMI). All these variables were mean-centred. A generic two-level model was specified as:

$$\text{Level-1 model: } \text{outcome}_{ti} = \pi_{0i} + \pi_{1i}(\text{time} - 2_{ti}) + e_{ti} \quad (1)$$

$$\text{Level-2 model: } \pi_{0i} = \beta_{00} + \beta_{01}(\text{age}_i) + \beta_{02}(\text{gender}_i) + \beta_{03}(\text{white}_i) + \beta_{04}(\text{EDU}_i) + \beta_{05}(\text{BMI}_i) + r_{0i} \quad (2)$$

$$\pi_{1i} = \beta_{10} + r_{1i} \quad (3)$$

π_{0i} is a score of the participant i at baseline. π_{1i} is the coefficient for time 2 (intervention), which is the measure of change between the two time points. The individual score (π_{0i}) is then predicted by the background variables in the level-2 model, equation (2) with a random error (r_{0i}). The coefficient for time, π_{1i} , is also specified to vary between individuals (r_{1i}) in the equation (3). All statistical analyses were conducted using HLM 7³⁵ and SPSS V.21.0 for Windows (SPSS Inc, Chicago, Illinois, USA). Significance was set at an α level of $p < 0.05$.

RESULTS

Ninety individuals were enrolled and screened for participation in this study. Twelve did not qualify because they were too active as determined by AP assessed sitting time during the baseline period; 11 were excluded because they did not meet the wear time criteria or had equipment malfunction. Sixty-seven individuals successfully completed the study. Participants were predominantly white (87%) and female (72%), with an average age of 45 years. Eight per cent of the participants completed high school, 50% completed college and 42% completed graduate school. Participants, in general, were 'overweight' based on their average BMI score (mean=29.3 kg/m², SD=7.7 kg/m²; table 1). On average, participants wore the acceleration-based motion sensors for 8.3 (SD=1.2) h during the baseline period and 8.3 (SD=1.1) h during the intervention period. Because wear time was not significantly different between baseline and intervention days ($p < 0.05$), and results of analyses using outcome measures as absolute values and relative to wear time were similar, all SB and PA data are reported in absolute values.

The HLM showed that SB and PA measured by the AG and AP were, in general, changed significantly between the baseline and the intervention period with the exception of standing time, LTPA and VPA (see tables 2 and 3 for time 2 coefficients, π_1). Models also showed that the baseline averages of those measures were significantly varied between individual participants (r_0). The changes of activity between the two time points, however, did not vary between participants (r_1). Individual demographic variables did not influence SB and PA (β_{01} – β_{04}). BMI was negatively associated with sitting and lying time with $p < 0.05$ ($b = -16.68$; $SE = 1.72$).

Estimated means (adjusted for age, gender, race, education and BMI) of outcome variables at times 1 (at baseline) and 2 (during intervention), and the changes between these two time points for AP-measured and AG-measured SB and PA are presented in table 4. Both devices were able to determine changes in SB and aspects of PA from the baseline to the intervention period. According to the AP output, average sitting/lying time decreased significantly by approximately 5% from baseline, while stepping time, steps/day and sit-to-stand transitions increased by 19%, 22% and 10%, respectively. As also shown in table 2, standing time did not change from baseline to intervention for the group. AG data detected a significant decrease in SB (4%), while LMPA and MPA increased by 15% and 23%, respectively.

SRM and effect size values for the AP and AG are shown in table 4. SRM values for the AP sitting/lying time, stepping, steps/day and sit-to-stand transitions were above 0.3, indicating a small responsiveness to change. SRM values for the AG SB, LMPA and MPA were also above 0.3, indicating a small responsiveness to change. SRM values for the AP and AG across all measures of SB and PA were therefore comparable.

DISCUSSION

When comparing results across studies using different SB and PA measurement tools, it is essential that these tools are congruent. Establishing this consistency allows researchers to draw conclusions regarding SB, PA and health from a multitude of studies using different assessment tools. Although accelerometer-based motion sensors have become a widely used tool to assess these SB and PA, and research has published studies on the validity and reliability of these devices, little research has focused on comparing the ability of these devices to detect change in these behaviours. This study fills an important gap in the literature, demonstrating that the AP and AG were similarly responsive to change in SB and PA during a free-living intervention that aimed to disrupt sedentary time, while controlling for factors that may impact the outcome such as age, gender, education and BMI. AP SRMs were highest when assessing change in sitting/lying time, stepping time, steps/day and sit-to-stand transitions. AG SRMs were highest when detecting change in SB, LMPA and MPA.

The SRM values for the AP and AG are considered small.³²³³ Despite various statistical methodologies, populations and intervention designs, the SRMs are comparable to other studies that evaluated objective sedentary and PA monitoring devices.¹⁷³⁶³⁷ The AP has previously been shown to be sensitive to changes in SB in overweight inactive office workers over a 6 h period; however, during 6-month intervention to reduce dietary intake, reduce SB and increase PA in breast cancer survivors, the reported responsiveness index³⁸ (RI) was lower than in the current study (RI=0.13).¹⁷³⁷ The AG was able to detect change in SB (SB<100 cpm) in older adults between two 6-day monitoring periods (responsiveness statistic=0.39)³⁶³⁹ but was not sensitive to change in SB (SB<50, 100, 150, 200, 250 cpm; low-frequency filter applied) in overweight inactive office workers between two 6 h periods.¹⁷

The AP and AG SRM values to detect change in SB were similar (AP: 0.300; AG: 0.327), indicating that both devices were able to detect a similar magnitude of change in SB.

Interestingly, when examining the mean SB values during the baseline and intervention periods, the AP recorded 30.8 and 32.7 fewer minutes in sedentary time compared with the AG, but change scores were similar (AP: -16.5, AG: -14.6 min), demonstrating their congruency to detect change in SB. The difference in recorded SB between the devices could be due to the body position of the participants during sitting activities, or the AG SB cut point applied. At times, the research staff observed participants sitting at their desks with their legs extended in front of their bodies. Since the AP is worn on the thigh (and AG on the hip), this could cause a misclassification of the body position by the AP due to the separate stand and sit thresholds. For the AP to capture a movement from the sitting to the upright posture, the acceleration must exceed the threshold of 0.53 g (approximately 32°), and maintain that posture for a minimum of 10 s. If individuals extend their legs out in front of them while sitting, this threshold could be exceeded and therefore improper classification could occur. The difference in recorded SB between the devices could also be due to the AG SB cut point applied (SB<100 cpm). There are multiple cut point values available to determine time spent in SB (<50, <100, <150 cpm), and the application of cut point values has been shown to alter time spent in SB.²⁶⁴⁰ The higher SB values by the AG compared with the AP in the current study are in contrast to the results of Kozey-Keadle *et al*¹⁷ whose results showed the AG (SB<100 cpm) recording of approximately 9 fewer minutes of sedentary time than the AP, over a 6 h period in a small sample of overweight or obese adults. However, the purpose of this study was to determine congruency in responsiveness of the AP and AG to detect change in sedentary time and PA, which is independent of any cut point applied.

Despite differing technologies, assessment methodologies and outputs of PA, SRMs for assessing PA by the AP (stepping= 0.376, steps/day=0.436) and AG (LPA=0.245, LMPA=0.350, MPA=0.371, VPA=0.220) were comparable, demonstrating a small but similar responsiveness to measures of PA. Because these devices do not measure the same aspects of PA, studies on PA including both monitors are scarce; however, research has demonstrated that the responsiveness of numerous PA questionnaires is similar to the responsiveness of the AP and AG for PA seen in this study. Responsiveness values assessed by Tuley *et al*'s formula³⁸ for the Community Health Activities Model Program for Senior (CHAMPS) Questionnaire, Active Australia Questionnaire (AAQ) and the US National Health Interview Survey (USNHIS) ranged from 0.45 (USNHIS) to 0.43 (AAQ) for walking frequency and from 0.27 (USNHIS) to 0.24 for walking duration; the AAQ showed a responsiveness level of 0.43 for moderate-to-vigorous intensity 0.43 (AAQ), and the CHAMPS showed a responsiveness level of 0.32 for moderate-to-vigorous duration.⁴¹ Therefore, although responsiveness of the AP and AG for changes in PA has not been explored previously, the rates are similar to widely used subjective methods for assessing PA.

The use of SRM is a strength of this study. It is a fairly simple calculation with easy to understand output. Further, SRM allows the responsiveness to changes to be evaluated across a spectrum (small vs moderate vs large). The limitations of this study warrant consideration when evaluating the results. This study does not include a criterion measure of SB such as direct observation, and therefore the accuracy of the responsiveness was not

determined. Second, this study included a short duration baseline and intervention monitoring periods. Future studies should evaluate the responsiveness of these devices over a longer period of time. Finally, the population in this study included office workers with sedentary occupations, and therefore generalisability is limited.

CONCLUSION

The results of this study demonstrate the agreement in responsiveness of two accelerometer-based motion sensors (AP and AG) to detect change in free-living, occupational sedentary time and PA during an intervention to disrupt sitting time. This important new information is vital when assessing change in these behaviours as the result of an intervention, and enabling synthesis of the literature in this area to draw conclusions pertinent to efficacy and health outcomes.

Acknowledgements

The authors would like to acknowledge the Clinical and Translational Science Institute of Southeastern Wisconsin (1-UL1-RR031973) for support of this project. They also thank Nick Thielke for assistance with data collection. Finally, they thank the participants for their contributions to this study.

Funding This work was supported by funding source 1-UL1-RR031973.

REFERENCES

1. Sedentary Behaviour Research Network. Standardized use of the terms 'sedentary' and 'sedentary behaviours'. *Appl Physiol Nutr Metab*. 2012; 37:540–542. [PubMed: 22540258]
2. Hu FB. Sedentary lifestyle and risk of obesity and type 2 diabetes. *Lipids*. 2003; 38:103–108. [PubMed: 12733740]
3. McDowell MA, Hughes JP, Borrud LG. Health characteristics of U.S. adults by body mass index category: results from NHANES 1999–2002. *Public Health Rep*. 2006; 121:67–73. [PubMed: 16416700]
4. Tucker LA, Friedman GM. Television viewing and obesity in adult males. *Am J Public Health*. 1989; 79:516–518. [PubMed: 2929820]
5. Tucker LA, Bagwell M. Television viewing and obesity in adult females. *Am J Public Health*. 1991; 81:908–911. [PubMed: 2053671]
6. Healy GN, Wijndaele K, Dunstan DW, et al. Objectively measured sedentary time, physical activity, and metabolic risk: the Australian Diabetes, Obesity and Lifestyle Study (AusDiab). *Diabetes Care*. 2008; 31:369–371. [PubMed: 18000181]
7. Proper KI, Singh AS, van Mechelen W, et al. Sedentary behaviors and health outcomes among adults: a systematic review of prospective studies. *Am J Prev Med*. 2011; 40:174–182. [PubMed: 21238866]
8. Dunstan DW, Salmon J, Owen N, et al. Associations of TV viewing and physical activity with the metabolic syndrome in Australian adults. *Diabetologia*. 2005; 48:2254–2261. [PubMed: 16211373]
9. Wijndaele K, Healy GN, Dunstan DW, et al. Increased cardiometabolic risk is associated with increased TV viewing time. *Med Sci Sports Exerc*. 2010; 42:1511–1518. [PubMed: 20139784]
10. Stamatakis E, Davis M, Stathi A, et al. Associations between multiple indicators of objectively-measured and self-reported sedentary behaviour and cardiometabolic risk in older adults. *Prev Med*. 2012; 54:82–87. [PubMed: 22057055]
11. Stamatakis E, Hamer M, Dunstan DW. Screen-based entertainment time, all-cause mortality, and cardiovascular events: population-based study with ongoing mortality and hospital events follow-up. *J Am Coll Cardiol*. 2011; 57:292–299. [PubMed: 21232666]

12. Lynch BM, Friedenreich CM, Winkler EA, et al. Associations of objectively assessed physical activity and sedentary time with biomarkers of breast cancer risk in postmenopausal women: findings from NHANES (2003–2006). *Breast Cancer Res Treat.* 2011; 130:183–194. [PubMed: 21553294]
13. Lee IM, Shiroma EJ, Lobelo F, et al. Effect of physical inactivity on major non-communicable diseases worldwide: an analysis of burden of disease and life expectancy. *Lancet.* 2012; 380:219–229. [PubMed: 22818936]
14. Katzmarzyk PT, Church TS, Craig CL, et al. Sitting time and mortality from all causes, cardiovascular disease, and cancer. *Med Sci Sports Exerc.* 2009; 41:998–1005. [PubMed: 19346988]
15. Warren TY, Barry V, Hooker SP, et al. Sedentary behaviors increase risk of cardiovascular disease mortality in men. *Med Sci Sports Exerc.* 2010; 42:879–885. [PubMed: 19996993]
16. Matthews CE, Chen KY, Freedson PS, et al. Amount of time spent in sedentary behaviors in the United States, 2003–2004. *Am J Epidemiol.* 2008; 167:875–881. [PubMed: 18303006]
17. Kozey-Keadle S, Libertine A, Lyden K, et al. Validation of wearable monitors for assessing sedentary behavior. *Med Sci Sports Exerc.* 2011; 43:1561–1567. [PubMed: 21233777]
18. Freedson PS, Melanson E, Sirard J. Calibration of the Computer Science and Applications, Inc. accelerometer. *Med Sci Sports Exerc.* 1998; 30:777–781. [PubMed: 9588623]
19. Matthews CE. Physical activity in the United States measured by accelerometer: comment. *Med Sci Sports Exerc.* 2008; 40:1188. author reply 9. [PubMed: 18496095]
20. Troiano RP, Berrigan D, Dodd KW, et al. Physical activity in the United States measured by accelerometer. *Med Sci Sports Exerc.* 2008; 40:181–188. [PubMed: 18091006]
21. Matthews CE, Ainsworth BE, Hanby C, et al. Development and testing of a short physical activity recall questionnaire. *Med Sci Sports Exerc.* 2005; 37:986–994. [PubMed: 15947724]
22. Grant PM, Ryan CG, Tigbe WW, et al. The validation of a novel activity monitor in the measurement of posture and motion during everyday activities. *Br J Sports Med.* 2006; 40:992–997. [PubMed: 16980531]
23. Ryan CG, Grant PM, Tigbe WW, et al. The validity and reliability of a novel activity monitor as a measure of walking. *Br J Sports Med.* 2006; 40:779–784. [PubMed: 16825270]
24. Staudenmayer J, Pober D, Crouter S, et al. An artificial neural network to estimate physical activity energy expenditure and identify physical activity type from an accelerometer. *J Appl Physiol.* 2009; 107:1300–1307. [PubMed: 19644028]
25. Freedson PS, Lyden K, Kozey-Keadle S, et al. Evaluation of artificial neural network algorithms for predicting METs and activity type from accelerometer data: validation on an independent sample. *J Appl Physiol.* 2011; 111:1804–1812. [PubMed: 21885802]
26. Matthews CE. Calibration of accelerometer output for adults. *Med Sci Sports Exerc.* 2005; 37:S512–S522. [PubMed: 16294114]
27. Hart TL, Ainsworth BE, Tudor-Locke C. Objective and subjective measures of sedentary behavior and physical activity. *Med Sci Sports Exerc.* 2011; 43:449–456. [PubMed: 20631642]
28. Ryan CG, Grant PM, Dall PM, et al. Sitting patterns at work: objective measurement of adherence to current recommendations. *Ergonomics.* 2011; 54:531–538.
29. Heyward, VH.; Wagner, DR., editors. *Applied body composition assessment.* 2nd edn.. Champaign, IL: Human Kinetics; 2004.
30. Owen N, Bauman A, Brown W. Too much sitting: a novel and important predictor of chronic disease risk? *Br J Sports Med.* 2009; 43:81–83. [PubMed: 19050003]
31. Feito Y, Bassett DR, Thompson DL. Evaluation of activity monitors in controlled and free-living environments. *Med Sci Sports Exerc.* 2012; 44:733–741. [PubMed: 21904249]
32. Husted JA, Cook RJ, Farewell VT, et al. Methods for assessing responsiveness: a critical review and recommendations. *J Clin Epidemiol.* 2000; 53:459–468. [PubMed: 10812317]
33. Stratford PW, Riddle DL. Assessing sensitivity to change: choosing the appropriate change coefficient. *Health Qual Life Outcomes.* 2005; 3:23. [PubMed: 15811176]
34. Cohen, J. *Statistical power analysis for the behavioral sciences.* New York: Academic Press; 1977.

35. Raudenbush, SW.; Bryk, AS.; Cheong, YF., et al. HLM 7: hierarchical linear and nonlinear modeling. Chicago, IL: Scientific Software International; 2011.
36. Gardiner PA, Clark BK, Healy GN, et al. Measuring older adults' sedentary time: reliability, validity, and responsiveness. *Med Sci Sports Exerc.* 2011; 43:2127–2133. [PubMed: 21448077]
37. Clark BK, Winkler E, Healy GN, et al. Adults' past-day recall of sedentary time: reliability, validity, and responsiveness. *Med Sci Sports Exerc.* 2013; 45:1198–1207. [PubMed: 23274615]
38. Tuley MR, Mulrow CD, McMahan CA. Estimating and testing an index of responsiveness and the relationship of the index to power. *J Clin Epidemiol.* 1991; 44:417–421. [PubMed: 2010785]
39. Guyatt G, Walter S, Norman G. Measuring change over time: assessing the usefulness of evaluative instruments. *J Chronic Dis.* 1987; 40:171–178. [PubMed: 3818871]
40. Atkin AJ, Gorely T, Clemes SA, et al. Methods of measurement in epidemiology: sedentary behaviour. *Int J Epidemiol.* 2012; 41:1460–1471. [PubMed: 23045206]
41. Reeves MM, Marshall AL, Owen N, et al. Measuring physical activity change in broad-reach intervention trials. *J Phys Act Health.* 2010; 7:194–202. [PubMed: 20484758]

What are the new findings?

- ▶ The activPAL and Actigraph GTX3 acceleration-based motion sensors were able to determine change in sedentary behaviour (SB) and aspects of physical activity (PA) from the baseline to the intervention period.
- ▶ The responsiveness of both devices was comparable with the most standardised response mean values for activPAL and Actigraph GTX3 variables above 0.3, indicating a small responsiveness to change.
- ▶ ActivPAL standardised response means were highest when assessing change in sitting/lying time, stepping time, steps/day and sit-to-stand transitions.
- ▶ Actigraph standardised response means were highest when detecting change in SB, lifestyle moderate-intensity PA and moderate-intensity PA.

How might it impact on clinical practice in the near future?

- ▶ The activPAL or the Actigraph GTX3 are viable options to detect change in daily SB over the course of an intervention.
- ▶ The activPAL or the Actigraph GTX3 are viable options to detect change in daily PA behaviour over the course of an intervention.
- ▶ Standardised response means for activPAL and Actigraph in this study were similar to previously published standardised response means for questionnaires.

Table 1

Descriptive characteristics of participants at baseline

Background characteristics	Mean or per cent	SD	Minimum	Maximum
Male (%)	28.4		0	1
Age (years; mean)	45	11	21	67
White (%)	86.6		0	1
Education (mean)	3.28	0.67	2	4
BMI (kg/m ² ; mean)	29.3	7.7	18.5	51.1
Monitor wear time (min; mean)	499	74	357	780

Education: 1, completed elementary education; 2, completed high school education; 3, completed college education; 4, completed graduate school education.

BMI, body mass index.

Table 2
Hierarchical linear models for activPAL measured sedentary and physical activity behaviours

Fixed effect	Sitting/lying (min/day)		Standing (min/day)		Stepping (min/day)		Steps/day		Sit-to-stand transitions	
	b	(SE)	b	(SE)	b	(SE)	b	(SE)	b	(SE)
Intercept, β_{00}	353.79	(9.69)***	97.19	(8.77)***	41.86	(3.45)***	3762.62	(284.17)***	28.66	(1.29)***
Age, β_{01}	-0.34	(0.70)	1.11	(0.77)	0.30	(0.26)	28.36	(23.84)	0.16	(0.11)
Male, β_{02}	44.34	(22.32)	-17.22	(19.33)	7.65	(8.89)	414.06	(745.38)	-0.37	(2.74)
White, β_{03}	16.63	(34.15)	-40.33	(37.13)	-17.17	(17.27)	-1533.30	(1417.49)	1.34	(3.00)
Education, β_{04}	24.25	(15.66)	-16.67	(18.14)	-4.00	(4.34)	-323.43	(375.03)	-2.42	(1.82)
BMI, β_{05}	-3.68	(1.72)*	2.57	(1.70)	0.19	(0.36)	12.43	(32.57)	-0.09	(0.18)
Time 2, π_1	-16.48	(6.71)*	7.76	(5.97)	7.86	(2.55)**	838.09	(235.06)***	3.06	(0.94)***
Random effect	Variance		Variance		Variance		Variance		Variance	
	[χ^2]		[χ^2]		[χ^2]		[χ^2]		[χ^2]	
Between-subject, τ_0	74.16	[315.37]***	67.61	[328.29]***	25.91	[278.70]***	4 246 860.05	[221.11]***	94.96	[283.56]***
(time 2-time1), τ_1	19.62	[75.51]	17.87	[76.03]	7.64	[76.05]	479 478.57	[75.64]	7.64	[75.53]
Within-subject, e	36.57		32.42		13.86		1 639 445.63		26.48	

* $p < 0.05$;

** $p < 0.01$;

*** $p < 0.001$.

BMI, body mass index; b, unstandardised beta.

Table 3
Hierarchical linear models for Actigraph measured sedentary and physical activity behaviours

Fixed effect	Sedentary behaviour (min/day)			LPA (min/day)			LMPA (min/day)			MPA (min/day)			VPA (min/day)		
	b	(SE)		b	(SE)		b	(SE)		b	(SE)		b	(SE)	
Intercept, β_{00}	384.62	(7.70)***		69.33	(4.04)***		25.93	(2.58)***		13.03	(1.28)***		0.18	(0.08)*	
Age, β_{01}	0.34	(0.60)		0.42	(0.41)		0.25	(0.17)		0.11	(0.15)		0.00	(0.01)	
Male, β_{02}	26.89	(17.95)		-8.22	(10.77)		6.25	(5.43)		4.19	(3.02)		0.50	(0.26)	
White, β_{03}	-9.64	(20.57)		-21.38	(19.89)		-5.52	(10.71)		3.14	(2.17)		0.00	(0.16)	
Education, β_{04}	3.68	(10.72)		-2.51	(5.95)		-1.27	(2.63)		1.05	(1.78)		0.07	(0.09)	
BMI, β_{05}	-1.46	(0.98)		0.63	(0.51)		0.35	(0.22)		-0.23	(0.18)		-0.01	(0.01)	
Time 2, π_1	-14.59	(5.45)*		5.87	(2.92)		4.11	(1.43)**		3.12	(1.03)**		0.29	(0.16)	
Random effect	Variance	[χ^2]		Variance	[χ^2]		Variance	[χ^2]		Variance	[χ^2]		Variance	[χ^2]	
Between-subject, τ_0	3418.24	[303.85]***		938.64	[288.98]***		423.76	[574.06]***		90.93	[249.07]***		0.09	[75.24]	
(time 2-time1), τ_1	268.38	[76.13]		73.24	[75.51]		35.20	[88.16]*		12.95	[80.44]		0.99	[145.26]***	
Within-subject, e	875.13			254.00			52.25			29.59			0.41		

Sedentary behaviour: <100 cpm; LPA: 100–759 cpm; LMPA: 760–1951 cpm; MPA: 1952–5724 cpm; VPA: 5725 cpm.

* $p < 0.05$;

** $p < 0.01$;

*** $p < 0.001$.

BMI, body mass index; LMPA, lifestyle moderate-intensity physical activity; LPA, light-intensity physical activity; MPA, moderate-intensity physical activity; VPA, vigorous-intensity physical activity.
b, unstandardised beta.

Table 4

SRMs of activPAL and Actigraph for sedentary and physical activity behaviours

	Baseline		Intervention		(Intervention –baseline)		SRM	Effect size
	Mean	(SE)	Mean	(SE)	Mean	(SE)		
activPAL								
Sitting/lying (min/day)	353.8	(9.7)	337.3	(9.5)	–16.5	(6.7)*	0.300	0.208
Standing (min/day)	97.2	(8.8)	104.9	(9.2)	7.8	(6.0)	0.159	0.108
Stepping (min/day)	41.9	(3.5)	49.7	(3.2)	7.9	(2.6)**	0.376	0.278
Steps/day	3763	(284)	4601	(299)	838	(235)***	0.436	0.360
Sit-to-stand transitions	28.7	(1.3)	31.73	(1.3)	3.1	(0.9)**	0.397	0.289
Actigraph								
Sedentary behaviour (min/day)	384.6	(7.7)	370.0	(7.2)	–14.6	(5.5)**	0.327	0.232
LPA (min/day)	69.3	(4.0)	75.2	(4.1)	5.9	(2.9)*	0.245	0.177
LMPA (min/day)	25.9	(2.6)	30.0	(2.0)	4.1	(1.4)**	0.350	0.194
MPA (min/day)	13.0	(1.3)	16.2	(1.5)	3.1	(1.0)**	0.371	0.298
VPA (min/day)	0.2	(0.1)	0.5	(0.2)	0.3	(0.2)	0.220	0.432

* p<0.05;

** p<0.01;

*** p<0.001 for non-directional t test. Sedentary behaviour: <100 cpm; LPA: 100–759 cpm; LMPA: 760–1951 cpm; MPA: 1952–5724 cpm; VPA: 5725 cpm.

LMPA, lifestyle moderate-intensity physical activity; LPA, light-intensity physical activity; MPA, moderate-intensity physical activity; SRM, standardised response mean; VPA, vigorous-intensity physical activity.