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Sensitivity to Change of Objectively-Derived Measures of Sedentary Behavior

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The aim of this study was to examine the sensitivity to change of measures of sedentary behavior derived from body worn sensors in different intervention designs. Results from two intervention studies: Stand up for Your Health (pre-post home-based study with older adults not in paid employment) and Stand Up Comcare (non-randomized controlled trial in the workplace) were analyzed to quantify sensitivity to change of measures of total and accumulation of sedentary time obtained from hip-worn Actigraph and thigh-worn activPAL monitors. Sensitivity to change varied with intervention design and population considered. The activPAL was generally more sensitive but not consistently for all measures and designs. Measures of sedentary time accumulation, in particular half-life bout duration ($W_{50\%}$), were consistently more sensitive than total sedentary time. Measurement devices used in intervention studies need to be appropriately selected to be sensitive to changes in the behavioral target. For sedentary behavior interventions, measures of accumulation should be considered as outcomes.

Keywords: accelerometry, behavior change, responsiveness, sitting

Cross-sectional and prospective studies have consistently demonstrated that sedentary time is deleteriously associated with health outcomes in adults, after controlling for the influence of moderate- to vigorous-intensity physical activity (Owen, Healy, Matthews, & Dunstan, 2010; Thorp, Owen, Neuhaus, & Dunstan, 2011; Wilmot et al., 2012). Some evidence suggests that the pattern of accumulation of sedentary time is also important, as deleterious effects may be compounded when sedentary time is aggregated in prolonged continuous bouts (Dunstan et al., 2012; Healy et al., 2008). Accordingly, public health recommendations concerning sedentary behavior reduction have started to appear. This includes the incorporation of sedentary time reduction recommendations as part of physical activity guidelines, such as by the World Health Organization, Canada, Australia, the United Kingdom, Ireland, Finland, New Zealand, France, and the United States (Department of Health, 2011; The Australian Government, 2014). As precise dose–response
relationships between sedentary time and health are not known, these recommendations are currently broad—with the key elements being limiting sedentary time, particularly extended, unbroken bouts of sedentary time. Further research is required to build the evidence around duration of sedentary time and frequency of interruptions to sedentary time in order to refine these guidelines. In particular, the next phase of the sedentary behavior research agenda will require intervention trials examining the feasibility of changing sedentary behavior (amount and pattern) and evaluating the effectiveness of different behavior change strategies at an individual, group and population level, as well as assessing any consequent impacts on health and well-being outcomes (Owen et al., 2011). The ability to detect and quantify change in the targeted behavior(s) is critical for the success of this phase of research. Identification of measures that are capable of detecting sedentary behavior changes is critical for both population level research and interventions at the individual level.

Objective measures using body-worn sensors are advocated to assess time spent in sedentary behaviors as they can provide measures of sedentary time free of recall error and are accurate and reliable (albeit, to varying degrees) (Chastin & Granat, 2010; Healy et al., 2011). A variety of devices have been validated (Kozey-Keadle, Libertine, Lyden, Staudenmayer, & Freedson, 2011; Ryan, Grant, Tigbe, & Granat, 2006) and to some extent are capable of assessing both total sedentary time and the duration and number of bouts of sedentary time. This is important because understanding the relationships between bout frequency, bout duration, and total volume of sedentary time can facilitate better evaluation of sedentary behavior changes in interventions and longitudinal studies (Stephens et al., 2014; Tieges et al., 2015). This information can be used to construct measures that characterize the pattern of accumulation of sedentary time. The accuracy of posture-based devices, such as the activPAL, is excellent for both assessing amount and accumulation of sedentary time (Grant, Ryan, Tigbe, & Granat, 2006; Kozey-Keadle et al., 2011; Lyden, Kozey-Keadle, Staudenmayer, & Freedson, 2012). The accuracy of non-postural accelerometers, such as the ActiGraph, is adequate for amount of sedentary time but is notably less accurate than posture-based devices for measures of sedentary time accumulation (Lyden et al., 2012). Another important measurement characteristic is the capacity of the measure to detect changes, whether in an intervention or for population surveillance (Husted, Cook, Farewell, & Gladman, 2000; Stratford, Binkley, & Riddle, 1996). By comparison with numerous cross-sectional validation studies, the extent to which the measures from these devices are sensitive to detecting changes in sedentary time has received limited attention.

There is no uniformly agreed terminology to describe this measurement attribute. It has been interchangeably termed “sensitivity to change” or “responsiveness.” Here, the authors use the term “sensitivity” as referring to the ability of a measure to detect a true change in an individual or group outcome above the natural variability of the outcome in the individual or group. This is different from the term “sensitivity” as used to describe the discriminant or diagnostic clinical metrics of an outcome measure. Notably, sensitivity to change is not a static attribute of a measure. Rather, it depends highly on the circumstances of measurement, including the measurement tool, the summary scores derived, and the study design (Beaton, 2001).

Sensitivity to change depends on several factors of intervention design, as highlighted in the taxonomy of responsiveness (Beaton, 2001). Subsequently, there are numerous statistical indices to assess the sensitivity of a measure to change, with two independent reviews (De Yébenes Prous, Rodríguez Salvanés, & Carmona Orteils, 2008; Husted et al., 2000) documenting 31 different measures. Different indices are required depending on the following.

- **Who the results are presented for**: individual-level or group-level assessment of change (typically individual behavioral interventions versus interventions manipulating factors affecting whole populations/groups).
- **Which scores are being contrasted**: contrast between-subjects (typically trials involving a control group) or within-subject change (typically quasi-experimental trials or longitudinal studies).
- **What type of change is quantified**: change in measured scores over a specific time frame (internal sensitivity) or the related change in clinical or health status associated with the change in score (external sensitivity).

Previous studies (Lyden et al., 2012; Swartz, Rote, Cho, Welch, & Strath, 2014) examining responsiveness to change measures derived from body worn sensors have only considered a single design (within subject) and mainly reported sensitivity to change in total sedentary time. The aim of this article is to give a more complete assessment of the sensitivity to change of objective measures of sedentary time for different study designs, time frames, and populations. To achieve this, a range of sensitivity to change statistics, based on the taxonomy of responsiveness (Beaton, 2001), were tested for a variety of different measures of sedentary time and sedentary accumulation, using data from two of the first published intervention studies aimed primarily at changing sedentary behavior (Gardiner, Eakin, Healy, & Owen, 2011; Healy et al., 2013).

**METHODS**

**Interventions, Participants, and Sedentary Behavior Assessment**

*Home-based intervention trial.* The *Stand up for Your Health* study evaluated intervention feasibility with
60 older adults not in paid employment, aged ≥ 60 years, and used a pre-test, post-test single group design (Gardiner et al., 2011). It involved a 6-day baseline assessment period at the end of which participants received a face-to-face intervention session designed to help them reduce their time spent sedentary, especially the time accrued in prolonged sedentary bouts (longer than 30 minutes), followed immediately by another 6-day post-intervention assessment phase. The two intervention messages were to (a) reduce periods of prolonged sitting, and (b) to stand up at least every 30 minutes. Detailed information about the intervention protocol and study participants can be found in the primary outcomes article (Gardiner et al., 2011). During the baseline and post-intervention periods, participants wore (hip; waking hours only) an ActiGraph accelerometer (model GT1M), with acceleration counts recorded in 1-minute epochs. Of the study participants, 53 (88%) provided sufficient data for the present analyses (≥ 10 hours wear for at ≥ 3 days pre-intervention and another ≥ 3 days post-intervention).

**Worksight intervention trial.** The Stand Up Comcare study outcomes (Healy et al., 2013) and the intervention design (Neuhaus et al., 2014) have previously been described in detail. It was a two-arm, non-randomized controlled intervention trial conducted in a single workplace. The authors used a multicomponent approach comprised of organizational, environmental (Ergotron sit–stand workstations), and individual elements with a key intervention message of “Stand Up, Sit Less, Move More.” The specific messages covered the entire day but emphasized time at the workplace. Messages encouraged reducing both the number and length of sitting bouts (with a particular focus on reducing prolonged, unbroken sitting bouts of 30 minutes or more) via increases in both standing and stepping time, with the workstation element primarily facilitating increases in standing. Sedentary time was assessed at baseline and at the end of the 4-week intervention via concurrently worn thigh-mounted activPAL3 activity monitors (worn continuously 24 hours/day) and hip-mounted Actigraph GT3X+ accelerometers (worn during waking hours) for 7 days. Of the 22 intervention and 22 control participants, 36 (21 intervention) provided sufficient data for the present analyses: ≥ 10 hours of waking wear time for ≥ 3 days pre- and ≥3 days post-intervention for both monitors.

**Sedentary Behavior Outcome Measures**

Intervention outcomes typically summarize changes in sedentary behavior in terms of changes in daily total sedentary time, which is made up of the sum total of many bouts (continuous, uninterrupted periods) of sedentary time occurring throughout the day, of durations as short as a few seconds or longer than an hour, such as when watching a film. The pattern of sedentary time accumulation may be important in its own right as well as providing a general means of assessing changes in sedentary behavior. Tremblay et al. (Tremblay, Colley, Saunders, Healy, & Owen, 2010) advocated a system analogous to the Frequency, Intensity, Time, Type (FITT) principle used for physical activity, quantifying bout frequency (number of bouts), and their durations. Accordingly, the authors evaluated sensitivity of measure of total sedentary time but also of measures quantifying the pattern of accumulation including: bout frequency, bout duration, and combinations of these (in “hybrid” measures; see supplemental material).

**Total sedentary time.** Total daily sedentary time was calculated as the duration of all sedentary bouts each day. It is reported as a percentage of total device-worn waking wear time to take into account variations in wear time during waking hours.

**Frequency.** Two measures of how frequently participants engaged in sedentary behavior were assessed: (1) total number of sedentary bouts per day and (2) the average time between bouts of sedentary behavior (termed, “period”), which is the time between the end of a sedentary bout and the start of the following one. Number of sedentary bouts is equivalent to the number of “breaks” in sedentary time (Healy et al., 2008). As the length of periods between sedentary behavior bouts is log-normally distributed, the mean period is calculated by maximum likelihood estimates for mean and standard deviation (details in supplemental material).

**Duration.** Estimating robust and meaningful summary statistics for bout duration is difficult as sedentary bout length is power-law distributed (Chastin & Granat, 2010). In practical terms, this means that the vast majority of bouts are very short, so the mean is not a valid statistic and the median is always close to the minimum duration recorded by the device. The bout duration above and below which half of all sedentary time is accrued offers a better alternative, and can be described validly via a statistic termed W50% (Chastin & Granat, 2010), which can be derived for an individual or used to describe a group. One can think of this statistic as a weighted median bout duration, a sedentary bout “half-life,” or as the “usual” bout duration. Of the various ways the W50% can be calculated, the authors used a method suited to automated processing. Specifically, a non-linear regression technique was used (Levenberg-Marquart) to fit the sigmoid function of the form \( f(t) = \frac{a}{(t^n + W_{50\%}^n)} \) where \( t \) is the bout duration and \( n \) a free parameter to the accumulation curve (this is described in detail in the supplementary material).

**Hybrid outcomes.** The authors assessed sensitivity for two hybrid measures, termed “hybrid” because they measure more than one dimension of the accumulation of sedentary time. \( \alpha \) was assessed, described by Chastin and Granat
(2010), which is the slope of the frequency distribution of bout duration. This measure quantifies the relationship between the duration and the frequency of sedentary bouts, where larger values indicate a tendency to accrue sedentary time in shorter bouts (Chastin & Granat, 2010). The fragmentation index, $F$, which was calculated as the total number of sedentary bouts divided by total sedentary time (Chastin, Ferriolli, Stephens, Fearon, & Greig, 2012), was also examined, being a commonly reported measure of sedentary patterns (Lyden et al., 2012). While this statistic is non-specific regarding the extent to which any changes were due to frequency and/or amount of sedentary time, an increase in fragmentation reflects a positive behavior change as it can occur only if the number of breaks increases relative to the change in total sedentary time.

Data Processing

Data were processed using the same methods as the original intervention studies (Gardiner et al., 2011; Healy et al., 2013) with the additional extraction of the summary measures described above for each individual, for each day. All outcomes were computed on a daily basis and averaged over the pre- and post-monitoring period using at least 3 valid days in each period. Data from the workplace trial were processed both overall and specifically during work hours, in light of the primary (but not exclusive) emphasis the workplace trial on time spent at the workplace. Briefly, the activPAL activity monitor collects information on thigh angle and acceleration and via proprietary software, accurately records precisely the start and duration of each sitting/lying (sedentary) bout (Chastin & Granat, 2010; Kozey-Keadle et al., 2011) and, therefore, provides direct information on sedentary bout number and duration. The hip-worn ActiGraph monitors used in these interventions record acceleration (as raw signals collected with very high frequency in the case of the GT3X+ model) that were summed over longer periods of time, epochs ($\tau$). Epochs of 1 minute were selected, and were then classified as each intensity (such as “sedentary,” “light,” etc.) using methods consistent with the original interventions. Specifically, all 1-minute epochs with $< 100$ counts/minute of vertical acceleration were classified as sedentary time (Freedson, Melanson, & Sirard, 1998). Data processing and derivation of sedentary outcome measures is illustrated schematically in Figure 1.

Sensitivity to change, responsiveness. Based on Beaton’s taxonomy of responsiveness (Beaton, 2001), the authors applied the appropriate sensitivity indices for the two intervention designs (Table 1). These included minimal detectable change (MDC), standardized effect size (SES), and Guyatt’s responsiveness index (GRI). In the absence of clearly defined-dose response relationships for these various measures with health outcomes, the authors concentrated on internal sensitivity and considered only change in measured scores of sedentary behavior.

The MDC (Haley & Fragala-Pinkham, 2006) reflects the minimal change in outcome score that corresponds to a real change in sedentary behavior for an individual, with the most sensitive measures having the lowest MDC. An indicator of individual sensitivity, MDC was computed as

$$MDC = z \times \sigma^2 \times \sqrt{2(1 - ICC)},$$

where $z$ is the $z$-score for level of confidence (here set at 95% with $z = 1.96$), $\sigma^2$ is the average standard deviation of the score for individuals (computed from the intra-participant variability at baseline), and the two-way random model intraclass correlation reliability coefficient (ICC) computed from daily average scores at baseline (at least 3 valid days at baseline are required). If an individual’s behavior is very variable at baseline, only a large change in behavior can be detected (high MDC).

The SES (Beaton, 2001), also known as Cohen-$d$, assesses whether the observed change is larger than natural variability at baseline. The lower the baseline

![FIGURE 1](image) Schematic representation of a pattern of activity and of sedentary time accumulation outcomes.
variability between participants, the more sensitive the measure will be. This was calculated according to Equation (2), where \( \Delta X_i \) is the mean change in score amongst the study participants and \( SD(X_i) \) the standard deviation of the scores among the study participants at baseline:

\[
SES = \frac{\Delta X_i}{SD(X_i)}. \tag{2}
\]

GRI (Guyatt, Walter, & Norman, 1987) compares the mean change in the treatment group \( \Delta X_{Tx} \) against the mean change in the control group \( \Delta X_{Control} \):

\[
GRI = \frac{\Delta X_{Tx}}{\Delta X_{Control}}. \tag{3}
\]

A measure that is stable in the control group, but changes with intervention, will have a large GRI.

### RESULTS

Characteristics of the participants included in the present study are described in Table 2.

#### Mean Changes in the Interventions

Both studies reported statistically significant reductions in terms of total sedentary time, sedentary bout duration, and frequency, which are detailed in the respective outcomes articles (Gardiner et al., 2011; Healy et al., 2013; Stephens et al., 2014). For context, the size of the mean changes for each of the sedentary behavior measures is described in Table 3. In both interventions, across the whole day, the changes were modest reductions in sedentary time and sedentary bout duration, fewer bouts or breaks of sedentary time (but more per minute of sedentary time), and longer periods between sedentary bouts. The same changes but slightly larger were seen during work hours in the workplace intervention.

Assessment of Individual Change

The results for MDC obtained in workers in the workplace intervention showed that a change in total sedentary time corresponds to a real change in behavior if it exceeds 7.00% (ActiGraph) or 7.76% (activPAL) of recorded waking hours or 6.57% (ActiGraph) or 6.73% (activPAL) of recorded time at work (Table 3). These approximately equate to just over an hour per day across a 16-hour waking day or half an hour per 8-hour workday. For older adults, the MDC was lower at 2.70% of recorded waking hours (approximately half an hour per 16-hour day).

The MDCs observed for the various sedentary pattern outcomes appeared to vary depending on the interventions/intervention populations, the monitor used, and the period examined. When examining the workplace intervention, the MDCs were similar for both monitors for most of the measures.
A negative change between pre- and post-intervention indicates a positive behavior change toward reduction in sedentary behavior. A positive change between pre- and post-intervention indicates a positive behavior change toward reduction in sedentary behavior.

(e.g., 8.0–8.7 for number of bouts). However, whenever large differences were apparent, the changes detectable by activPAL were smaller than those from Actigraph. For example, the change detectable in usual bout duration ($W_{50\%}$) was 6.44 and 7.03 minutes with the activPAL device during waking and working hours, respectively, while with the ActiGraph device it was 12.43 minutes (waking hours) and 22.11 minutes (working hours). Nevertheless, the results are intervention/population specific to a degree as the MDC for usual bout duration was only 6.23 minutes for ActiGraph in the older adults’ intervention.

**Within-Subject Differences**

SES, being unitless unlike the MDC, showed differences in sensitivity between the various sedentary behavior outcome measures as well as differences between the interventions, time period, and monitor. In both interventions, greater sensitivity (highest value of SES) was observed for most of the sedentary accumulation measures than for total daily sedentary time (Table 3). This occurred as the intra-subject variability in total sedentary time (as a percentage of wear time) was higher than for some of the sedentary pattern outcome variables. The differences were least pronounced in the home-based intervention with older adults.

$W_{50\%}$ was the most sensitive bout duration measure in all cases except when using the activPAL to assess change during work hours. Neither frequency measure was consistently more sensitive than the other. Similarly, neither hybrid measure was observed to be more sensitive than the other in all cases. When considering only the most sensitive measure, $W_{50\%}$ was most sensitive for changes during the overall waking day using ActiGraph and the period was the most sensitive for changes during work hours using activPAL. Comparing the monitors separately for each sedentary measure showed the ActiGraph was consistently the most sensitive for duration (for both $W_{50\%}$ and median bout duration); and, ActivPAL was consistently most sensitive for the hybrid measures ($\alpha$ and $F$). No monitor was consistently most sensitive for total sedentary time.

**Between-Subject Differences**

The monitor with the greatest observed sensitivity for detecting differences between groups in changes in total sedentary time was Actigraph for overall waking hours and activPAL for work hours. For the sedentary accumulation measures, the sensitivity observed when using the activPAL measures consistently was higher than the sensitivity observed for the same measure obtained using ActiGraph data. Bout frequency had the best sensitivity when measured by activPAL both for period, the more sensitive frequency measure, and for number of bouts or breaks. Bout duration had the higher observed sensitivity for comparing changes between groups when assessed by activPAL rather than ActiGraph, both for the more sensitive duration measure, median bout duration, and for $W_{50\%}$. Both $\alpha$ and $F$ were more sensitive measured by activPAL than ActiGraph, with $\alpha$ typically being more sensitive than $F$, except when assessing changes during work hours using ActiGraph data.

**Table 3**

<table>
<thead>
<tr>
<th>TABLE 3</th>
<th>Sensitivity and Mean Changes in Sedentary Behavior Outcomes in Two Interventions Assessed Using Hip-Worn Actigraph and Thigh-Worn ActivPAL Monitors</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><strong>Home-based intervention</strong></td>
</tr>
<tr>
<td></td>
<td><strong>Workplace Intervention</strong></td>
</tr>
<tr>
<td></td>
<td><strong>Waking Hours</strong></td>
</tr>
<tr>
<td></td>
<td><strong>Waking Hours</strong></td>
</tr>
<tr>
<td></td>
<td><strong>Work Hours</strong></td>
</tr>
<tr>
<td></td>
<td><strong>AG</strong></td>
</tr>
<tr>
<td>Mean change</td>
<td>Sedentary time (% of wear)</td>
</tr>
<tr>
<td></td>
<td>−2.35</td>
</tr>
<tr>
<td>Bouts or breaks (n)</td>
<td>−2.94</td>
</tr>
<tr>
<td>Period (min)</td>
<td>0.6</td>
</tr>
<tr>
<td>$W_{50%}$ (min)</td>
<td>−2.18</td>
</tr>
<tr>
<td>Median bout (min)</td>
<td>−0.32</td>
</tr>
<tr>
<td>$a$</td>
<td>0.03</td>
</tr>
<tr>
<td>$F$ (bouts/hour)</td>
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</tr>
<tr>
<td>Minimal detectable change</td>
<td>Sedentary time (% of wear)</td>
</tr>
<tr>
<td></td>
<td>2.70</td>
</tr>
<tr>
<td>Bouts or breaks (n)</td>
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</tr>
<tr>
<td>Period (min)</td>
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</tr>
<tr>
<td>$W_{50%}$ (min)</td>
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</tr>
<tr>
<td>Median bout (min)</td>
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<tr>
<td>$a$</td>
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<tr>
<td>$F$ (bouts/hour)</td>
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<tr>
<td>Standardized effect size</td>
<td>(unitless)</td>
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<tr>
<td>Sedentary time</td>
<td>0.24</td>
</tr>
<tr>
<td>Bouts or breaks</td>
<td>0.22</td>
</tr>
<tr>
<td>Period</td>
<td>0.23</td>
</tr>
<tr>
<td>$W_{50%}$</td>
<td>0.31</td>
</tr>
<tr>
<td>Median bout</td>
<td>0.24</td>
</tr>
<tr>
<td>$a$</td>
<td>0.22</td>
</tr>
<tr>
<td>$F$</td>
<td>0.27</td>
</tr>
</tbody>
</table>

Guyatt’s Responsiveness Index (unitless)

| Sedentary time | −28.75 | 8.50  | 15.31 | 26.13 |
| Bouts or breaks | −1.74  | 1.90  | 5.63  | 12.64 |
| Period | −3.40  | 249.05 | 6.72  | 70.4  |
| $W_{50\%}$ | −0.39 | 1.86  | 0.54  | 1.70  |
| Median bout | −0.49  | 4.78  | 2.54  | 9.03  |
| $a$ | −0.88  | 7.82  | 0.72  | 4.79  |
| $F$ | −0.31  | 3.73  | 3.83  | 4.20  |

Note: Hip-worn Actigraph (AG) and thigh-worn activPAL (AP).

A negative change between pre- and post-intervention indicates a positive behavior change toward reduction in sedentary behavior. A positive change between pre- and post-intervention indicates a positive behavior change toward reduction in sedentary behavior.
DISCUSSION

This is the first study that comprehensively quantifies sensitivity for detecting changes for individuals, within-subjects, and between-subjects across a variety of objective measures of sedentary time and sedentary accumulation patterns.

Instrument Choice—Sensitivity and Other Concerns

The most sensitive measure (using a particular instrument) varied depending on whether the purpose was to assess changes within individuals or to compare changes between individuals. In the current study, the measures obtained using the ActiGraph sometimes showed better sensitivity, and sometimes poorer sensitivity, for assessing within-subject change than the corresponding measures from activPAL. The findings did not conflict with a prior validity study that saw better sensitivity to change within a single-group design (assessed by lower p-values for change) in what they termed break-rate (i.e., fragmentation index, with time in hours) when using activPAL monitors (Lyden et al., 2012). In that study, changes were assessed by comparing one baseline day with 1 day of an intervention condition that involved reducing and breaking up sedentary time. Similarly, in a single-group design with a brief intervention that involved computer and device-based prompts to interrupt sedentary time, Swartz et al. (2014) observed similar sensitivity, assessed as standardized response mean, for activPAL (0.30), and ActiGraph (0.32) monitors in total sedentary time. Sit–stand transitions as measured by the activPAL was the only sedentary accumulation measure for which sensitivity was reported; its standardized response mean (0.40) was similar or slightly higher than was observed for total sedentary time.

To the best of the author’s knowledge, none of the previous studies evaluated sensitivity for detecting differences between groups in changes in objectively measured sedentary behavior in the context of a two-arm intervention trial. For comparing changes between individuals, such as in a controlled trial, in terms of sedentary accumulation measures, activPAL showed better sensitivity. Both activPAL and ActiGraph were sensitive for total sedentary time—effectively, the amount of change greatly exceeded background variation more than eight-fold—with the more sensitive monitor depending whether overall waking hours or work hours were assessed.

Instruments are often selected based on their availability to the researcher or clinician rather than their clinimetric properties. An implication for trial design of the sensitivity findings are that larger sample sizes are likely needed when using the less sensitive instrument over a more sensitive instrument (particularly when there is a desire to measure any of the specific sedentary behavior outcomes for which low sensitivity was observed). Further, other clinimetric properties, such as validity, need to be considered in addition to sensitivity. The most sensitive measure is not necessarily the most valid. While validity has not been assessed for all of the sedentary accumulation measures whose sensitivity we evaluated, existing evidence favors the activPAL over the ActiGraph on validity grounds (Kozey-Keadle et al., 2011; Lyden et al., 2012). The activPAL records the beginning and ending of each period of sitting/lying, standing, and stepping (recorded to at least the nearest .1 second) as determined directly from thigh angle (posture) as well as acceleration, and classifies these activities relative to direct observation with almost perfect agreement for each individual bout classification (Lyden et al., 2012). By contrast, using 1-minute epoch data from hip-worn accelerometers involves assigning a single classification to the activity level of each epoch (e.g., sedentary/not), thus affecting the accuracy with which it is possible to measure number of bouts or bout durations (e.g., no bout can be <1 minute duration). Using shorter epochs is likely to improve accuracy of detecting the start and end of sedentary bouts, thus improving accuracy of measure of duration and frequency. However, using shorter epochs will not necessarily ensure that the detected start and end actually correspond to real bouts of sitting as this can only be robustly measured via inclinometry of the thigh.

Other intervention studies should be encouraged to similarly report these clinimetrics across a variety of sedentary behavior measures to provide evidence informed by a wider array of interventions and intervention populations. In the interim, these findings can be used to inform instrument selection (out of two commonly used monitors, activPAL, and ActiGraph), and selection of sedentary behavior measures capable of detecting changes. The degree of sensitivity observed was monitor-specific; extrapolation to sensitivity of other instruments is not possible.

Choices Between Measures of Sedentary Behavior

The authors examined an array of measures that reflect distinct dimensions of sedentary behavior, such as total volume of time spent sedentary, how frequently sedentary time occurs or is interrupted, and for how long at a time sedentary behavior continues uninterrupted. The low validity of breaks and fragmentation index derived from ActiGraph data (Lyden et al., 2012) casts doubt that these and other sedentary accumulation measures obtained via such ActiGraph data accurately capture the specific dimensions of sedentary behavior in question (e.g., frequency, duration). Despite these validity concerns, the good sensitivity of some of the sedentary accumulation measures suggests that for an intervention aiming for improvements across all of these dimensions, these measures may be useful as indicators of overall improvements in sedentary behavior, even if their capacity to finely distinguish various dimensions of sedentary accumulation patterns is limited.
One of the key findings was that the most sensitive of the measures examined was seldom total sedentary time, and was never provided by the simplest approaches to assessing sedentary accumulation, such as counting the number of sedentary bouts or breaks. Thus, there may be merit to using highly sensitive pattern statistics as general indicators of behavior change in sedentary behavior interventions for individuals and groups. Usual bout duration \( W_{50\%} \) was usually the most responsive of the measures for within-subject changes and the time between bouts (period) was the most responsive of all the measures for between-subject comparisons. With total wear time kept constant, sedentary time can only be reduced if there are fewer and/or shorter sedentary bouts. In interventions, such as the workplace intervention, that have an emphasis on reducing prolonged periods of continuous sitting, the replacement of one very long bout of sitting (e.g., 1 hour) with another activity (e.g., standing) can reduce total sedentary time by this amount, and would reduce \( W_{50\%} \) (which is heavily affected by long bouts), but would only reduce the number of bouts or breaks by one. Similarly, while the authors examined primarily a measure of frequency of interrupting sedentary time, longer periods between sedentary bouts is also related to sedentary bout duration and overall sedentary time. For example, if total wear time is fixed and the number of sedentary bouts does not change markedly, longer periods between bouts inevitably means also shorter sedentary bout durations and less sedentary time.

Implications of Study Results for Clinical Decision Making and Feedback to Individuals

To assess individuals, in clinical settings or for personalized intervention and feedback, using an instrument that measures sedentary behavior directly via posture recognition means more accurate assessment of sedentary behavior (and behavior change). Regardless of the instrument used (which likely also depends on availability and participant willingness), considering changes relative to the MDC for each individual should help improve decision making clinically and give more appropriate feedback to the patient or client. Ideally, multiple days of baseline monitoring should be used to estimate background variation: Optimally an entire week is preferable in view of systematic variations between weekdays, Saturdays and Sundays (Matthews, Hagströmer, Pober, & Bowles, 2012). This would provide the best indication as to whether any subsequent measures have improved beyond natural variations for a particular individual. The MDC results reported in this study are also useful in these regards.

Caution about Interpreting the Results

This study deals solely with sensitivity to change of metrics describing both the total amount of time spent sedentary and the pattern of accumulation of sedentary time, it makes no claims about whether these metrics represent a positive or negative change in behavior. Notably, caution should be expressed about using any metrics for characterizing either the frequency (such as the number of breaks or bouts) and bout duration. Therefore, the authors are wary of inferring whether these measures reflect an overall change in sedentary behavior. The goal was to ascertain their sensitivity to detect a change in this specific dimension (frequency or time). Considering one of these two dimensions in isolation is not enough to identify whether or not a positive behavior change occurred. These two dimensions have to be considered in tandem (see supplementary material). This is also why hybrid measures that contain information about both frequency and duration dimensions have been developed. While these metrics can give a direct interpretation about the direction of behavior change and information about how this occurred in both the frequency and the duration dimensions, they appear to be less sensitive to change.

Limitations and Strengths

Chief among this study’s limitations is that the sensitivity assessment was conducted using data from only two trials, each with a homogenous sample. It is likely sensitivity will differ for other distinct age groups and populations and in diverse general population samples. Their likely greater variability in many of these sedentary behavior measures than these workers and older adults is likely to mean less sensitivity than was observed in these two interventions and intervention populations. Regarding conclusions as to which of the two monitors provides the most sensitivity, the authors cannot evaluate the extent to which this is likely to be intervention and/or population specific, as only one of the current interventions used both tools. The workplace intervention contained a strong sit-stand workstation component and resulted in large decreases in sedentary time achieved mostly through increased standing (Stephens et al., 2014). It may be infeasible to suggest that trials routinely use more than one monitor to establish this more definitively. However, it is reasonable to recommend that trials report sensitivity for whichever tool or tools they used across a varied range of sedentary behavior measures, so that future sedentary behavior interventions can be designed more efficiently in light of this information. Finally, it is worth reiterating that sensitivity to change is a less well understood and characterized clinicalmetric compared with validity for example. However, there is a growing interest to develop more accurate and meaningful indices. With objective sensors becoming routinely used in intervention trials that seek to modify human activity, similar investigations should be conducted to ascertain the sensitivity to change in physical activity as well as sedentary behavior.
CONCLUSION

The ability to detect true meaningful change in sedentary behavior following intervention varied depending on the instrument, the sedentary behavior outcome measure, and the intervention and/or intervention population. These considerations should be taken into account during the design of intervention studies and while making clinical decisions or giving feedback to individuals. While reducing total sedentary time is most likely to be the primary target of interventions, assessing total sedentary time might not be the most sensitive measure of behavior change. Inference should be conducted with, or at least checked against, change in parameters describing patterns of sedentary behavior. Parameters that are robust to differences in measurement protocol (e.g., recording time) tended to display the most sensitivity, such as the usual sedentary bout duration or half-life and the time between sedentary bouts (period). The authors observed better sensitivity to change with posture-based measures derived from activPAL data for the between-subject design than with non-postural 1-minute hip-worn ActiGraph data. For the within-subject design, the difference was less marked. Instrument choice should also take into consideration accuracy and validity characteristics.

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SUPPLEMENTARY MATERIAL

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REFERENCES


