Validation of Accelerometer Thresholds and Inclinometry for Measurement of Sedentary Behavior in Young Adult University Students

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Abstract: Sedentary behavior (SB) is a major contributor to obesity and significant morbidity and mortality in adolescence and adulthood, yet measurement of SB is still evolving. The purpose of this study was to assess the degree of construct validity of the inclinometer function and single-axis and vector magnitude accelerometry metrics of the ActiGraph GT3X+ in objectively measuring SB and physical activity in 28 young adult university students who performed nine semi-structured activities, each for five minutes: lying, sitting, reading, seated video gaming, video watching, seated conversation, standing, stationary biking, and treadmill walking. Inclinometry and four output metrics from the ActiGraph were analyzed in comparison to direct observation by a researcher recorded each minute. For overall accuracy in measuring both SB and physical activity, all four accelerometer metrics (94.7–97.8%) outperformed the inclinometer function (70.9%). Vector magnitude accelerometry with a threshold of 150 counts per minute as the cut point for sedentary behavior was superior to other methods. While accelerometry was more accurate overall at detecting the behaviors tested, inclinometry had some advantages over accelerometry methods at detecting walking, biking, and standing. The findings support use of accelerometry as a valid objective measure of body movement, while use of inclinometry as a sole measure is not recommended. Additional research would be beneficial to improve the calibration of the inclinometer and explore ways of combining this with accelerometer data for objectively measuring SB and physical activity. © 2015 Wiley Periodicals, Inc.

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Sedentary behavior (SB) is a major contributor to obesity and significant morbidity and mortality in adolescence and adulthood, yet measurement of SB is still evolving. The purpose of this study was to assess the degree of construct validity of the inclinometer function and single-axis and vector magnitude accelerometry metrics of the ActiGraph GT3X+ in objectively measuring SB and physical activity in 28 young adult university students who performed nine semi-structured activities, each for five minutes: lying, sitting, reading, seated video gaming, video watching, seated conversation, standing, stationary biking, and treadmill walking. Inclinometry and four output metrics from the ActiGraph were analyzed in comparison to direct observation by a researcher recorded each minute. For overall accuracy in measuring both SB and physical activity, all four accelerometer metrics (94.7–97.8%) outperformed the inclinometer function (70.9%). Vector magnitude accelerometry with a threshold of 150 counts per minute as the cut point for sedentary behavior was superior to other methods. While accelerometry was more accurate overall at detecting the behaviors tested, inclinometry had some advantages over accelerometry methods at detecting walking, biking, and standing. The findings support use of accelerometry as a valid objective measure of body movement, while use of inclinometry as a sole measure is not recommended. Additional research would be beneficial to improve the calibration of the inclinometer and explore ways of combining this with accelerometer data for objectively measuring SB and physical activity.

SB is associated with obesity, acute and chronic disease development, and early mortality (Daniels et al., 2005; Fontaine, Redden, Wang, Westfall, & Allison, 2003; Freedman, Khan, Dietz, Srinivasan, & Berenson, 2001; Ogden, Carroll, Kit, & Flegal, 2012). SB plays a unique role in health regardless of other factors, including engagement in exercise. For example, the impact of SB on cardiovascular health is significant, independent of physical activity.

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(Healy et al., 2008). Furthermore, independent of other variables, SB is linked with metabolic syndrome, hypertension, and colorectal cancer in adulthood (Healy et al., 2008; Marchand, Wilkens, Kolonel, Hankin, & Lyu, 1997).

Because of its independent importance, defining and measuring SB is critical to accurately determine its effect on the health of individuals. Quantifying SB is challenging because of difficulty measuring such low activity levels with existing self-reports or instrumentation. Valid measurements of SB are needed to better estimate its outcomes, explore appropriate levels of SB, and evaluate the effects of interventions designed to reduce SB (Bennett, Winters-Stone, Nail, & Scherer, 2006; Freedson, Pober, & Janz, 2005; Pate, O’Neill, & Lobelo, 2008; Sasaki, John, & Freedson, 2011).

Currently, accelerometry is the standard for objectively measuring SB. Accelerometers use counts per minute (cpm) of whole-body movement, similar to steps per minute for pedometers. A count is the amount of movement and speed in a particular direction (acceleration). Older accelerometers measure movement on a single axis, in the vertical plane (Y-axis). In the young adult population SB has been defined as less than 100 cpm using Y-axis-only accelerometers, and these cut points have been used in NHANES (Troiano et al., 2008).

Some newer accelerometer models can measure movement on X-, Y-, and Z-axes. Measurement of movement in three dimensions can be used to calculate a single vector, termed vector magnitude. Little is known about the appropriate threshold between sedentary and non-sedentary behavior using vector magnitude. Although the typical accelerometer cut point for SB is <100 cpm (Treuth et al., 2004; Troiano et al., 2008), there is evidence that a higher threshold is more accurate (Romanzini, Petroski, Ohara, Dourado, & Reichert, 2012) such as <150 cpm (Kozey-Keadle, Libertine, Lyden, Staudenmayer, & Freedson, 2011). A higher threshold may be called for when using vector magnitude because it reflects movement on three axes, rather than a single axis.

A novel method of investigating SB is by measuring body position using a device called an inclinometer. The inclinometer is new technology with some initial validation (Carr & Mahar, 2012). Because lying and sitting positions have been previously described as sedentary (Pate et al., 2008), detecting these positions through body position may prove useful beyond measuring total body movement as done by accelerometry. An inclinometer would not only discriminate between sedentary and active behaviors but would also report type of behavior (lying, sitting, or standing), which an accelerometer cannot. An inclinometer, however, does not identify physical activity intensity, as the accelerometer does.

One device, the ActiGraph GT3X+ (ActiGraph, LLC, Pensacola, FL), houses both an inclinometer and accelerometer within the same unit and can gather both data simultaneously. The accelerometry feature of the GT3X+ is highly precise when measuring SBs in both laboratory (Carr & Mahar, 2012; Sasaki et al., 2011) and in free-living conditions (Kaminsky & Ozemek, 2012; Santos-Lozano et al., 2012) according to accepted standards (Landis & Koch, 1977). Criterion validity in comparison to the older accelerometer model has been supported (de Vries, Bakker, Hopman-Rock, Hirasing, & van Mechelen, 2006; Kaminsky & Ozemek, 2012; Sasaki et al., 2011). The GT3X+ accelerometer’s reliability and construct validity is high in children and young adults, typically ranging $r = 0.39–0.90$ (de Vries et al., 2006). For SB specifically, reliability was between 80–98% in agreement with direct observation (Carr & Mahar, 2012; Hänggi, Phillips, & Rowlands, 2013).

While impressive, past researchers assessed validity using only single-axis movement and did not take advantage of the ability of the GT3X+ to obtain the vector magnitude. The construct validity of the GT3X+ inclinometer has been investigated in only one sample, which included young adults, with a result of 63–67% agreement with direct observation (Carr & Mahar, 2012).

When accurate and precise measurements of SB have been established in controlled settings, researchers can then use these techniques to measure these behaviors in natural environments involving free-living conditions. The purposes of this descriptive, cross-sectional study were to 1) explore the degree of construct validity of the inclinometer function within the ActiGraph GT3X+ device, and 2) assess ability to distinguish sedentary from non-sedentary behaviors using accelerometer thresholds of 100 cpm and 150 cpm using both single-axis and vector magnitude methods.

**Methods**

**Sample**

The target population included young adult university students of varying socio-demographic backgrounds and body sizes. Study participants included a convenience sample of 18- to 20-year-old undergraduate students enrolled at a large public university in the Mid-Atlantic region. Sample size was based on studies with similar methods and outcomes (Carr & Mahar, 2012; Kozey-Keadle et al., 2011).

Recruitment inclusion criteria included young adult males and females aged 18- to 20-years-old who were able and agreed to wear the ActiGraph GT3X+ device and perform the following nine activities: lie down, sit, read a book while seated, play a seated video game, watch a video, engage in seated conversation/talk on the phone, stand, pedal on a stationary bike, and walk unassisted. Additional criteria included understanding written and spoken English, and no lower body injury or condition such that performing the activities was difficult, worsened the condition, or significantly altered the participant’s ability to perform the behaviors. Participants were compensated with...
a $10 gift card for completing the study. Once institutional review board approval was granted for the study, participants were recruited through flyers, word-of-mouth, and electronic university announcement emails sent by various departments to the appropriate age group of students.

The 28 participants who elected to participate in the study (12 male, 16 female) were evenly distributed across the ages of 18 (29%), 19 (32%), and 20 (32%), and 25% were non-white or mixed ethnicity. The mean BMI was 22.8 kg/m² (SD = 3.1). The mean waist circumference was 86.6 cm (SD = 9.1) for males and 84.2 cm (SD = 7.7) for females. Seven (25%) participants were overweight based on BMI (≥25 kg/m²) or waist circumference (≥102 cm for males, ≥88 cm for females). A summary of the sample demographics appears in Table 1.

Instrument

The ActiGraph GT3X+ was used to gather both inclinometry and accelerometry data simultaneously. The GT3X+ is a small, unobtrusive, and essentially tamper-resistant device weighing only 19 grams that is well-tolerated by young adults and does not hinder activity (ActiGraph, 2013; de Vries et al., 2006). Utilizing the low-frequency extension option for the accelerometer improved detection of low-frequency movement; SB fits into the low-frequency category.

Participants were fitted with this device at the level of the waist, secured with an elastic band and buckle, and placed over the right hip. Direct observation of all behaviors by the researcher provided a criterion measure of both SB and body position, which was recorded each minute.

The inclinometer data were categorical and were coded as lying, sitting, standing, or off. Sedentary was defined as lying or sitting positions for the inclinometer method (standing was accepted as the appropriate code for the standing activity).

Accelerometry was captured in 3 axes and expressed in terms of cpm. The ActiGraph GT3X+ collected data at 30 Hz and then aggregated the data during the post-collection processing stage into 10-second epochs. Accelerometry data aggregation included two methods. First, the standard single-axis-only method was applied, using cut points of both 100 cpm (Axis100) and 150 cpm (Axis150) to determine sedentary versus active behavior, because cut points of both <100 cpm and <150 cpm for SB have been supported (Kozey-Keadle et al., 2011). Then, a vector magnitude calculation was done using all three axes, also using both the 100 cpm (VM100) and 150 cpm (VM150) cut points to define SB.

The following is a simplified recap of the data collected using the GT3X+:

(a) Inclinometer—inclinometer measurement only, with SB defined as lying and sitting positions.
(b) Axis100—single-axis measure only, with a definition of SB as <100 cpm.
(c) Axis150—single axis measure only with a definition of SB as <150 cpm.
(d) VM100—vector magnitude with a definition of SB as <100 cpm.
(e) VM150—vector magnitude with a definition of SB as <150 cpm.

Procedures

Anthropometrics. After obtaining informed written consent, participants were weighed twice to the nearest 0.1 pound using a digital scale (Seca Scale Robusta 813, Birmingham, UK), and an average of the two measures was used. Similarly, participants’ heights were measured twice using a stadiometer (Shorr Height Measuring Board, Olney, MD) to the nearest 0.1 cm, and an average of the two measures was used. Waist circumference was

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Males</th>
<th>%</th>
<th>Females</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>18</td>
<td>2</td>
<td>(16.7)</td>
<td>6</td>
<td>(37.5)</td>
</tr>
<tr>
<td>19</td>
<td>4</td>
<td>(33.3)</td>
<td>7</td>
<td>(43.8)</td>
</tr>
<tr>
<td>20</td>
<td>6</td>
<td>(50.0)</td>
<td>3</td>
<td>(18.8)</td>
</tr>
<tr>
<td>Race</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>White</td>
<td>9</td>
<td>(75.0)</td>
<td>12</td>
<td>(75.0)</td>
</tr>
<tr>
<td>Other/mixed</td>
<td>3</td>
<td>(25.0)</td>
<td>4</td>
<td>(25.0)</td>
</tr>
<tr>
<td>Body mass index (kg/m²)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Overweight (≥25.0)</td>
<td>2</td>
<td>(16.7)</td>
<td>3</td>
<td>(18.8)</td>
</tr>
<tr>
<td>Not overweight (&lt;25.0)</td>
<td>10</td>
<td>(83.3)</td>
<td>13</td>
<td>(81.2)</td>
</tr>
<tr>
<td>Waist circumference (cm)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Above normal (male ≥102, female ≥88)</td>
<td>1</td>
<td>(8.3)</td>
<td>5</td>
<td>(31.2)</td>
</tr>
<tr>
<td>Normal range (male &lt;102, female &lt;88)</td>
<td>11</td>
<td>(91.7)</td>
<td>11</td>
<td>(68.8)</td>
</tr>
</tbody>
</table>
averaged using two measures with a Lifetime Tape Measure (Pymr-Dritz Corp., Spartanburg, SC) taken at the level of the iliac crest, just below the umbilicus to the nearest 0.5 cm. Participants completed a simple form gathering demographic information on gender, age, semesters completed at school, and race/ethnicity.

**Activity measurement setting and sequence.** The study location was in a private space within an exercise physiology laboratory in a research center focused on healthy youth development. There were nine stations, one for each of the tested behaviors. Participants moved from station to station in a predetermined order that was rotated between participants in an effort to reduce bias associated with completing the behaviors in any particular arrangement. The first six behaviors received a designation of typical, everyday SB, and the order was balanced to prevent any order effects. The last three behaviors (standing, stationary biking, walking) were also performed in a balanced order.

Of the nine behaviors measured in the study, two were explicitly active by design: riding a stationary bike and walking on a treadmill. Riding the stationary bike had particular interest for this study, because pedaling at a moderate intensity is active yet performed in a seated position. Therefore, this activity determined whether inclinometry and/or accelerometry could accurately detect this form of seated exercise. Walking on a level treadmill at 3.0 miles per hour served as a standard for active behavior. All participants completed the study in its entirety with no device failures.

**Sedentary behaviors.** The investigator reviewed the protocol instructions for each behavior with participants before beginning and reminded participants to perform the behaviors as they would at home or school. Participants performed each behavior for five minutes, with a one- to two-minute break between activities. The following section describes the participant’s positioning for each behavior.

**Lying down.** Participants were in the supine position on a padded laboratory exam table with pillow support for the head and were to lie quietly with eyes open so as to not fall asleep.

**Sitting.** Participants sat in a comfortable, padded, non-mobile upright chair for the sitting behavior. Participants were able to move and shift positions as long as they remained seated.

**Reading.** The reading behavior was done in the same fashion as the sitting behavior, with participants sitting at a table and having the option of reading *Harry Potter* or one of their own books.

**Gaming.** Participants played a free, popular online game—requiring minimal instruction and needing only the mouse to operate—using a desktop computer. Seating was similar to the sitting behavior criteria.

**Watching video.** Participants viewed a five-minute digitally animated film on a laptop computer. Participants sat in the same manner as above.

**Talking.** While seated, participants had the option of talking on their personal cell phones or having a casual conversation with the researcher.

**Standing.** Participants were required to stand for the duration of the testing period without moving, although they could shift positions as needed.

**Physical activities.** Each of these also was performed for five minutes.

**Biking.** Participants used a Monark 868 stationary bike (Monark Exercise, Sweden) at moderate intensity, equivalent to speeds between 50 and 60 revolutions per minute, while maintaining a workload of approximately 100 watts. Seat and handlebar height were adjusted to a comfortable position for each participant. Participants stayed within the moderate intensity limits and remained seated for the duration of the testing.

**Walking.** A Quinton Q65 treadmill (Quinton Instrument Co., Seattle, WA) was set to a speed of 3.0 miles per hour, with no incline. Participants were instructed not to hold the side or front handlebars and to maintain a natural walking gait.

### Statistical Analyses

Statistical analyses were performed using SPSS 22.0 (IBM Corp., Chicago, IL). The five data categories (inclinometer, Axis100, Axis150, VM100, VM150) were compared against the criterion of direct observation of body position measured each minute by the researcher. Validity was calculated as the percent agreement with the criterion measure of direct observation of inclinometer data on time spent lying and sitting, and of accelerometer data on time spent performing SB. All of the device data were available in 10-second epochs. Because each activity was performed for five minutes, there were 30 device data points per activity. Percent agreement of time was calculated as mean percentage of those 30 data points that matched the direct observation. The 95% confidence interval for the mean was also calculated for each method.

### Results

In considering the mean percentage of time that was coded correctly, the accelerometer data outperformed the inclinometry data in every category except for walking (for which all methods were 100% valid), and for using the stationary bike using single-axis measurement methods (Axis100 and Axis150). The inclinometer validity varied in correctly distinguishing sedentary from active behaviors, from a low of 44.9% during seated video gaming to a high of 100% for walking. The validity of the Axis100 and Axis150 accelerometer methods in measuring these behaviors ranged from 98.8% to 100%, with the exception of the stationary bike activity, which was correct 54.8% and 48.8% of the time, respectively. Both vector magnitude methods perfectly distinguished active behaviors, and validity for measuring SB
defined as measuring sedentary and active behaviors, with the caveat validating the ActiGraph GT3X ensuring SB. In general, accelerometry using any of the four single-axis measures only (Y-axis) with sedentary defined as <100 counts/minute; VM100 = vector magnitude combining X-Y-Z axes with sedentary defined as <100 counts/minute; VM150 = vector magnitude combining Y-Z axes with sedentary defined as <150 counts/minute.

Table 2. Mean Percent Agreement With Direct Observation for Five Measurement Methods of the ActiGraph GT3X+ for Sedentary Behaviors, Active Behaviors, and Across all Behaviors

<table>
<thead>
<tr>
<th>Method</th>
<th>Sedentary Behaviors</th>
<th>Active Behaviors</th>
<th>Overall</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean % 95% CI</td>
<td>Mean % 95% CI</td>
<td>Mean % 95% CI</td>
</tr>
<tr>
<td>Inclinometer</td>
<td>66.5 59.1–73.9</td>
<td>86.5 80.0–92.9</td>
<td>70.9 65.0–76.9</td>
</tr>
<tr>
<td>Axis100</td>
<td>99.7 99.0–100.4</td>
<td>77.4 67.9–86.9</td>
<td>94.7 92.4–97.0</td>
</tr>
<tr>
<td>Axis150</td>
<td>100.0 100.0–100.0</td>
<td>74.4 65.0–83.8</td>
<td>94.3 92.2–96.4</td>
</tr>
<tr>
<td>VM100</td>
<td>94.4 91.0–97.8</td>
<td>100.0 100.0–100.0</td>
<td>95.6 93.0–98.3</td>
</tr>
<tr>
<td>VM150</td>
<td>97.1 95.0–99.3</td>
<td>100.0 100.0–100.0</td>
<td>97.8 96.1–99.4</td>
</tr>
</tbody>
</table>

Note. CI, confidence interval. Sedentary behaviors = lying down, sitting, reading, video gaming, watching a video, seated conversation, standing. Active behaviors = walking, stationary biking. Inclinometer = inclinometer only, with a definition of lying and sitting positions as sedentary; Axis100 = single-axis measure only (Y-axis) with sedentary defined as <100 counts/minute; Axis150 = single-axis measure only (Y-axis) with sedentary defined as <150 counts/minute; VM100 = vector magnitude combining X-Y-Z axes, with sedentary defined as <100 counts/minute; VM150 = vector magnitude combining X-Y-Z axes with sedentary defined as <150 counts/minute.

The results support the GT3X+ as a valid device for measuring SB. In general, accelerometry using any of the four methods outperformed inclinometry for measuring SB and for overall validity. Results were congruent with the literature validating the ActiGraph GT3X+ accelerometer in measuring sedentary and active behaviors, with the caveat that the standard of <100 cpm as the definition of sedentary should be raised to <150 cpm when using vector magnitude.

The stationary bike activity played a major factor in determining the validity of each method, particularly with the single-axis accelerometer (Axis100, Axis 150) methods. Both vector magnitude accelerometer methods detected biking as an active behavior 100% of the time, while the single-axis methods were only 54.8% (Axis100) and 48.8% (Axis150) accurate. The discrepancy between the two methods probably is due to the fact that minimal up-and-down (Y-axis) movement occurs, while side-to-side (Z-axis) or forward-and-back (X-axis) movement may be used to maintain speed and momentum of pedaling. Any activity done while sitting would face similar measurement challenges, because the very nature of sitting would take away or limit the factor of the vertical axis in contributing to the overall activity detected by the device.

The results of this study suggest that vector magnitude accelerometer data might be better than single-axis measurements in two specific ways. First, vector magnitude was an excellent method for measuring seated but active behaviors such as biking. Both vector magnitude methods surpassed single-axis methods at both the 100 cpm and 150 cpm cut points for the biking activity. Whether single-axis versus vector magnitude is the best method for measuring sedentary and activity level is still under discussion (Freedson et al., 2005; Howe, Staedemayer, & Freedson, 2009). While overall accuracy in measuring all nine behaviors favors use of vector magnitude over a single axis, use of vector magnitude for detecting SB and physical activity is still relatively new, particularly in the younger age groups, and has had mixed results.

Further examination of single-axis versus vector magnitude accelerometer would enhance research in the area of SB and physical activity (Freedson et al., 2005; Howe et al., 2009). Additional research is needed to help define appropriate sedentary, light, moderate, and vigorous...
activity in terms of three-dimensional movement (Sasaki et al., 2011). Furthermore, the thresholds for SB and the various levels of physical activity differ depending on the population of interest (Freedson et al., 2005; Kozey-Keadle et al., 2011; Mattocks et al., 2007; Troiano et al., 2008; Trost, Loprinzi, Moore, & Pfeiffer, 2011). As vector magnitude is a relatively new way of analyzing accelerometer data, investigators should be clear when describing data processing methods on whether single-axis or vector magnitude was used. This information ultimately will influence the choice of activity cut points, such as the 100 versus 150 cpm threshold for SB.

The inclinometer feature of the ActiGraph GT3X+ was approximately 70% accurate in determining sedentary versus non-sedentary behavior overall, which is congruent with another study using the ActiGraph inclinometer function (Carr & Mahar, 2012). Although it had high (86.5%) accuracy for detecting active versus sedentary behaviors, it was unable to discriminate light, moderate, or vigorous activity, because all of these would be coded as “standing.” Thus, the best use of the inclinometer is to detect body position or use in conjunction with accelerometer data when assessing both sedentary and physical activity levels. While the inclinometer function within the ActiGraph device

### Figure 1.

Percent agreement with direct observation of five measurement methods for detection of sedentary behavior across nine behaviors. Inclinometer = inclinometer only, with a definition of lying and sitting positions as sedentary; Axis100 = single-axis measure only (Y-axis) with sedentary defined as <100 counts/minute; Axis150 = single-axis measure only (Y-axis) with sedentary defined as <150 counts/minute; VM100 = vector magnitude combining X-Y-Z axes, with sedentary defined as <100 counts/minute; VM150 = vector magnitude combining X-Y-Z axes with sedentary defined as <150 counts/minute.
has the potential to help define behaviors in terms of body position, its use as the sole measure of SB is not supported by the results of this study.

In particular, the inclinometer was only 27.0% accurate for detecting a sitting position on the stationary bike. Per the manufacturer’s design, when the GT3X+- device reaches a movement threshold of 6 counts per second, the inclinometer output will automatically code position as standing (Hawk, 2012). This feature explains why the inclinometer’s walk accuracy (100%) is better than the stand accuracy (93.7%). If detecting body position were the ultimate goal, this feature would prevent an accurate measurement. On the other hand, if the intent of the research is to distinguish between sedentary versus active behaviors, this design element is beneficial, as it will default to the standing output regardless of the actual body incline. Accuracy jumped to 73.0% when the reading of a standing position during biking was redefined as “active.” This redefinition has drawbacks, because using “standing” as a default code for “active” would categorize standing in place as active, when in reality it expends little energy. However, standing perfectly still may not be common, and standing has been considered by some as non-sedentary, as it may contribute to improved insulin and lipid management over lying or sitting sedentary positions (Duvivier et al., 2013). Considering these two dilemmas, the inclinometer may play a useful role when analyzing inclinometer and accelerometer data together, because integrating the two would enable researchers to more accurately identify “sitting but active” and “standing but sedentary.”

Rigorous scientific research could further improve the inclinometer by validating categorization of the angles of lying, sitting, and standing. An option to adjust these angle definitions through ActiGraph’s software may allow for correcting incline data, though accurately determining activities such as bicycling could continue to be problematic. Body position has been implicated as a strong factor in determining what is defined as sedentary (Pate et al., 2008). Therefore, the inclinometer has potential for future use in measuring SB, although future research must explore how and when such use is valid. Because it does not rely on constant body movement to gather data, like the accelerometer, the inclinometer could become a good way to detect low-threshold behaviors, which SB dominates.

While other inclinometer devices exist, the advantage of developing the inclinometer function for the ActiGraph would be that both metrics (inclinometer and accelerometer) would be available from a single unit and would reduce participant burden. Both the accelerometer and the inclinometer add a unique perspective to measuring sedentary and active behaviors. Together, they measure both intensity and type of behavior. While the accelerometer differentiates the spectrum of total body movement, the inclinometer offers the ability to categorize how the body is engaged, be it lying, sitting, or standing. Future research to investigate combining inclinometer data with that of the accelerometer may give additional insight into what constitutes SB and physical activity.

**Limitations**

Limitations of this study include a small, mostly Caucasian sample. Results are not generalizable beyond the age ranges examined in this study. In addition, we examined more SBs than active behaviors, by design, and the study was limited to discriminating typical lying and sitting behaviors against walking and biking. The behaviors studied did not enable full discrimination between SB and light physical activity, given that the aim was to discriminate SB from routine physical activities predominant in the young adult university student population. Body positioning during the behaviors may not have always been the natural position because participants were not in their free-living condition. Increasing testing time might give a more accurate perspective on SB as participants settle into the environment and the behavior being tested. Also, the behaviors tested may not be typical of SB in every population.

**Summary**

Because of its important health consequences, there is a need to establish objective measurement standards for SB before the variable is accepted for use in research. In this study we expanded the knowledge of objective measurement of SB by contributing evidence about the validity of the ActiGraph GT3X+ and various methods of using its data in quantifying sedentary and active behaviors.

The technology of inclinometry has demonstrated potential in contributing to the measurement of SB using body position as a criterion. The inclinometer is moderately accurate overall, and would be improved with additional testing and calibration. Accelerometry remains a good standard by which to measure SB; however, as vector magnitude data becomes the standard, refinement of appropriate thresholds for SB and for light, moderate, and vigorous physical activity are needed across all age groups.

As technology constantly advances, continuous assessment of the validity and reliability of methods for determining SB and physical activity is needed to guide researchers in proper measurement. Collaborative efforts that include nursing, medicine, exercise physiology, public health, and others are needed to interpret SB measurement and to explore the implications of SB on healthy lifestyles.

**References**


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