JOURNAL OF BEHAVIORAL HEALTH, 2017
VOL 6, NO. 4 PAGE 189–192
10.5455/jbh.20170813081246

eJM eJManager

SHORT COMMUNICATION

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Accuracy of the ActiGraph GT9X Inclinometer to assess human body postures

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ABSTRACT

Objective: Accelerometer-determined physical activity, sedentary behavior, and energy expenditure estimation may be influenced by the accuracy of accelerometer-assessed inclinometer. The purpose of this study is to examine the accuracy of the ActiGraph GT9X (most recent ActiGraph model) inclinometer across participant body habitus, and in particular, differences in central adiposity.

Methods: Eighteen participants (M_{age} = 21.5 years) completed a series of 11 consecutive activities that varied in both movement (i.e., no movement, walking, and pedaling) and anatomic position (i.e., lying, sitting, and standing). During the trials, the participants wore an ActiGraph GT9X accelerometer and direct observation is used to compare body position determination derived from the ActiGraph GT9X inclinometer.

Results: The ActiGraph GT9X inclinometer demonstrated moderate accuracy (>68%) in body position determination for sedentary behaviors, high accuracy (>95%) in body position determination for ambulatory-based activities (e.g., walking and jogging), and had varied accuracy (100% *vs.* 32.1%) in identifying non-wear.

Conclusion: The exclusive use of inclinometry for sedentary behavior and non-wear determination is not recommended.

ARTICLE HISTORY

Received January 07, 2017
Accepted July 07, 2017
Published September 01, 2017

KEYWORDS

Accelerometry; body posture; energy expenditure

Introduction

Independent of physical activity participation, emerging research demonstrates that prolonged sedentary behavior is positively associated with various cardiometabolic parameters [1]. There also appears to be a gradient in energy expenditure among non-exercise activities. For example, compared with metabolic rate while in a supine position, energy expenditure may increase by approximately 4% when sitting motionless; and by 13%, when standing motionless [2]. As such, in addition to the importance of measuring sedentary behavior, research should also focus on the posture (e.g., time spent lying down, sitting, and standing) of sedentary behaviors [3].

Accelerometry is becoming the method of choice for measuring sedentary behavior, with the ActiGraph accelerometer being one of the most widely used monitors in physical activity and sedentary behavior research [4]. Newer ActiGraph models (GT3X and GT9X) include an inclinometer that attempts to measure body position. Based on the angle of the inclinometer, the inclinometer algorithms predict whether the individual is lying down, sitting, standing, or if the monitor is not being worn (off the participant). Few studies have examined the validity of the ActiGraph inclinometer. Among 36 young adults (23.0 years), Carr and Mahar [5] reported that the ActiGraph GT3X monitor correctly identified four sedentary activities 60.6% and 66.7% of the time, with 71.8% of light-intensity walking correctly identified as standing. Hanggi et al. [6] examined the validity of the ActiGraph GT3X inclinometer among 49 children aged 10–15 years and reported that the inclinometer correctly classified standing 20%, lying 15%, sitting 94%, and the off position 45% of the time. An et al. [7] recently demonstrated that the ActiGraph GT3X

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inclinometer has very good accuracy in stepping activities at select intensities.

Given these somewhat discrepant findings coupled with few studies on this topic, the purpose of the present brief study was to examine the accuracy of the ActiGraph GT9X (most recent ActiGraph model) inclinometer among young adults. Unlike the previous studies, particular attention is focused on the potential influence of central adiposity on inclinometer accuracy as greater central adiposity may induce a greater tilt angle on the waist-worn monitor, possibly influencing the accuracy of the inclinometer.

Methods

This study was approved by the authors' institutional review board and participants provided written informed consent prior to participation. A total of 18 participants were recruited, comprising of individuals with varying degrees of central adiposity. Ultimately, participants were stratified as above and below the sample median (33 mm) for abdominal skinfold.

Participants completed a series of 11 consecutive activities that varied in both movement (i.e., no movement, walking, and pedaling) and anatomic position (i.e., lying, sitting, and standing). The ActiGraph GT9X monitor was placed on the right hip (mid-axillary line) at the level of the iliac crest.

Activities were identified as either sedentary, light, or moderate or higher intensity based on the physical activity compendium [8]. The 11 trials included:

- Lying still with legs straight and flat on back in a horizontal position
- Lying still with legs straight and flat on stomach in a horizontal position
- Sitting relaxed but upright in a chair while using a computer with feet on the floor
- Sitting relaxed but slouched forward in a chair while using a computer with feet on the floor
- Standing upright while completely still
- Walking slowly on a treadmill at 2 mph
- Walking slowly on a treadmill at 3.5 mph
- Cycling slowly on a cycle ergometer at 50 rpm while sitting upright (0 kg resistance)
- Jogging on a treadmill at 5.5 mph
- The monitor removed from the participant and placed on a table, with the monitor facing up
- The monitor removed from the participant and placed on a table, with the monitor on its side.

Each activity lasted 5 minutes, with a 2-minute break between activities. All activities were observed by a researcher as the criterion measure in which the inclinometer output was compared. The first and last minutes were removed from analyses, resulting in 3 minutes (minutes 2, 3, and 4) for comparison of each activity. The ActiGraph GT9X was initialized to collect all data in 1-second epoch lengths.

Validity of the ActiGraph GT9X inclinometer function was examined by comparing the monitor recorded time (total percentage of time out of 3 minutes) codes as lying down, sitting, standing and/or non-wear with the criterion of direct observation.

Results

Table 1 displays the demographic characteristics of the analyzed sample. Participants, on an average, were 21.5 years, had a mean BMI of 25.4 kg/m^2, and had a mean abdominal skinfold of 30.3 mm.

Table 2 displays the classification accuracy of the ActiGraph GT9X inclinometer across the 11 activity trials. As shown in this table, the accuracy of the ActiGraph GT9X inclinometer did not appear to appreciably differ among those above and below the median skinfold. Thus, these narrative results will report the findings for the entire sample.

For the lying down trials (trials 1 and 2), the inclinometer correctly classified the individual as lying between 68.8% and 83.5% of the time. For the sitting trials (trials 3 and 4), the inclinometer correctly classified the individual as sitting between 69.5% and 74.1% of the time. For the standing without ambulation trial (trial 5), the inclinometer correctly classified the individual as standing between 86.8% of the time. For the slow walking trials (trials 6 and 7), the inclinometer correctly classified the individual as standing between 96% and 100% of the time. For the cycling trial (trial 8), the inclinometer correctly classified the individual as sitting 87.4% of the time. For the jogging trial (trial 9), the

Table 1. Demographic characteristics of the analyzed sample.

Variable	Point estimate	95% CI
Age, mean years	21.5	19.4–23.5
Gender, % female	72.2	
Race-ethnicity, %		
White	88.9	
Black	5.6	
Other	5.5	
Body mass index, mean kg/m^2	25.4	23.8–27.0
Abdominal skinfold, mm	30.3	26.1–34.5

CI = confidence interval.

Table 2. Classification accuracy of the ActiGraph GT9X inclinometer across various activity trials.

			Inclinometer classification			
Trial #	**Description**	**Sample**	**% Lying**	**% Standing**	**% Sitting**	**% Off**
1	Lying still supine with legs straight	Entire	68.8	2.3	0	28.9
		AMCF	67.6	4.9	0	27.5
		BMCF	69.8	0	0	30.2
2	Lying still prone with legs straight	Entire	83.5	0	0	16.5
		AMCF	82.8	0	0	17.2
		BMCF	84.2	0	0	15.8
3	Sitting relaxed but upright in a chair while using a computer with feet on floor	Entire	0	11	69.5	19.5
		AMCF	0	22	58.9	19.1
		BMCF	0	0	80	20
4	Sitting relaxed but slouched back in a chair while using a computer with feet on the floor	Entire	0	0	74.1	25.9
		AMCF	0	0	73.2	26.7
		BMCF	0	0	75	25
5	Standing upright while completely still	Entire	0	86.8	7.9	5.3
		AMCF	0	88.6	7.9	3.5
		BMCF	0	85	7.9	7.1
6	Walking slowly on a treadmill at 2 mph	Entire	0	96	4	0
		AMCF	0	100	0	0
		BMCF	0	92	8	0
7	Walking slowly on a treadmill at 3.5 mph	Entire	0	100	0	0
		AMCF	0	100	0	0
		BMCF	0	100	0	0
8	Cycling slowly on a cycle ergometer at 50 rpm while sitting upright	Entire	0	87.4	12.6	0
		AMCF	0	87.4	12.6	0
		BMCF	0	87.5	12.5	0
9	Jogging on treadmill at 5.5 mph	Entire	0	95.9	4.1	0
		AMCF	0	91.9	8.1	0
		BMCF	0	100	0	0
10	Placed on a table with monitor facing up	Entire	0	0	0	100
		AMCF	0	0	0	100
		BMCF	0	0	0	100
11	Placed on a table with monitor on its side	Entire	67.9	0	0	32.1

AMCF = above median (≥33 mm abdominal skinfold) central fat; BMCF = below median (<33 mm abdominal skinfold) central fat.

inclinometer correctly classified the individual as standing 95.9% of the time. The results for the last two trials (trials 10 and 11) were substantively different. When the monitor was placed on the table with the monitor facing up (trial 10), the inclinometer correctly classified it as "off the participant" 100% of the time. However, when the monitor was placed on the table with the monitor on its side (trial 11), the inclinometer correctly classified it as "off the participant" only 32.1% of the time.

Discussion

Research demonstrates that physical activity and sedentary behavior are independently associated with various health outcomes [3,9–13]. Thus, it is critical that we employ objective methodology that accurately measures both physical activity and sedentary behavior. The purpose of this brief report was to evaluate the accuracy of the ActiGraph GT9X inclinometer. The main findings of this study were that the ActiGraph GT9X inclinometer 1) accurately classified standing posture during ambulatory-based trials (i.e., walking and jogging), and 2) for the majority of the time (i.e., >68%), correctly classified lying and sitting postures. Non-wear (or "off the participant") was only correctly classified (100% *vs.* 32.1%) when the monitor was placed facing up (versus on its side).

Placed within the context of other studies on this topic that evaluated the classification accuracy of earlier ActiGraph models (GT3X), our findings are, generally, in agreement with theirs [5,6]. Carr and Mahar [5] reported that the ActiGraph GT3X monitor correctly identified four sedentary activities 60.6% and 66.7% of the time. Our findings demonstrated that the ActiGraph GT9X accelerometer correctly classified sedentary behaviors 68.8% (trial 1), 83.5% (trial 2), 69.5% (trial 3), and 74.1% (trial 4) of the time, with the average of these four trials

being 74%. This average (74%) is similar (70.9%) to a recent study evaluating the accuracy of the ActiGraph GT3X inclinometer across a variety of sedentary behaviors among young adults [14]. Carr and Mahar [5] also reported that 71.8% of light-intensity walking was correctly identified as standing, with our estimates averaging 98% (96% for trial 6, 100% for trial 7). We also note the high classification as standing during treadmill jogging (95.9%, trial 9).

Conclusion

In conclusion, the findings of this brief report demonstrates that the ActiGraph GT9X inclinometer has moderate accuracy (>68%) in body position determination for sedentary behaviors, has high accuracy (>95%) in body position determination for ambulatory-based activities (e.g., walking and jogging), and has varied accuracy (100% *vs.* 32.1%) in identifying non-wear. Central adiposity does not appear moderate with ActiGraph GT9X inclinometer accuracy. The exclusive use of inclinometry for sedentary behavior and non-wear determination is not recommended.

Conflict of Interest

We declare no conflicts of interest.

Funding

No funding was used to prepare this manuscript.

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