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Accuracy of inclinometer functions of the activPAL and ActiGraph GT3X+: A focus on physical activity

Hyun-Sung An, MA[a], Youngwon Kim, PhD[b], Jung-Min Lee, PhD[a,*]

[a] School of Health, Physical Education, and Recreation, University of Nebraska at Omaha, 6001 Dodge Street, Omaha, NE, 68182, USA
[b] MRC Epidemiology Unit, University of Cambridge School of Clinical Medicine, Box 285 Institute of Metabolic Science, Cambridge Biomedical Campus, Cambridge, CB2 0QQ, United Kingdom

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ABSTRACT

Purpose: The purpose of the study was to examine the accuracy of inclinometer functions of the ActiGraph GT3X+ (AG) (worn on the waist and wrist) and the activPAL (AP) in assessing time spent sitting, standing, and stepping.
Methods: A total of 62 adults (age: 18–40 yrs; male:37; female:25) wore three activity monitors (AG waist, and AG wrist, and AP) while completing 15 different types of activities. The 15 activities were classified into 3 different postures (sitting, standing, and stepping) based on the directly observed behaviors. Minutes estimated from the inclinometers of the three monitors were directly compared to those from direct observation (criterion method) using mean absolute percent error (MAPE) values, effect sizes (Cohen's D), and equivalence testing.
Results: The AP was more accurate than the both waist- and wrist-worn AG in both sitting and standing activities, but the AG was more accurate than the AP in stepping activity when the stepping activity was determined with 0.7 step/s threshold. Equivalence testing indicated that the time measured by the waist-, wrist-worn AG, and AP showed significant equivalence to the time in the equivalence zone (90% confidence interval: 2.7 to 3.3 min) for 6, 5, and 7 activities, respectively.
Conclusions: The AP was reasonably accurate for detecting sitting, standing, and stepping, and the AG was very accurate for classifying stepping when the stepping activity was determined by the formula created by 0.7 step/s threshold. It is expected that the result of the study would contribute to performing movement pattern analyses and health promotion research for classifying activities.

1. Introduction

Contemporary adults spend about 55 to 70% of their waking hours being sedentary [1]. Epidemiological studies have demonstrated that un-interrupted sedentary behaviors have detrimental effects on various health outcomes, including obesity [2,3], metabolic syndrome [4,5], type 2 diabetes [2,3,6], cardiovascular disease [7], and cancer [8]. Prolonged sitting, as a predominant form of sedentary behavior, has been highly associated with the risk of metabolic syndrome [9] and biomarkers of chronic diseases such as Body Mass Index (BMI), waist circumference, fasting insulin, and C-reactive protein have been linked with sedentary time [10]. Given that sitting is the most prevalent form of sedentary behavior [11] and specified in the definition of sedentary behavior (SB) [12], it is important to test methods to correctly classify sitting from other postures.

Physical activity (PA) monitors have been usually used for estimating PA energy expenditure and classifying different intensities of PA [13]. However, as sedentary behavior has emerged recently as a modifiable risk factor [14], considerable efforts have been placed into utilizing typical accelerometer-based activity monitors as a means of differentiating different body postures including sitting, standing, and stepping. Several innovative analytical techniques (e.g. machine learning and artificial neural network) have been proposed to classify different types and/or postures of activities. However, these techniques are in an early phase of development and more importantly, require considerable analytical expertise, which may then limit its widespread use in research. An inclinometer function is a lot easier to use, user-friendly, and already incorporated as a generic analytical option in typical activity monitors. Therefore, it is important to test and

* Corresponding author.
E-mail addresses: han@unomaha.edu (H.-S. An), Youngwon.Kim@mrc-epid.cam.ac.uk (Y. Kim), jungminlee@unomaha.edu (J.-M. Lee).

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compare the accuracy of inclinometer functions of commonly used accelerometers.

The ActiGraph GT3X+ (AG) and activPAL (AP), as two widely used accelerometry-based monitors, have incorporated generic inclinometer functions in their respective software programs. This advantage enables researchers without advanced analytical skills to easily use the inclinometer functions to distinguish different body postures (i.e. SB and PA) for various research applications. A few previous studies have investigated the accuracy and utility of inclinometer functions of the AG and AP [15,16]. However, little is known about the relative accuracy of the inclinometer functions of these monitors compared to a strong reference method. Moreover, no research has investigated the accuracy of inclinometer functions of the AG placed on the waist versus wrist. Therefore, the purpose of this present study was to examine the validity of the built-in inclinometer functions of the two activity monitors (AG and AP) in relation to directly observed data. There are two hypotheses on this study: 1. The inclinometer of the two activity monitors classify sitting, standing, and stepping posture. 2. Standing can be differentiated from stepping activity in the AG.

2. Method

2.1. Participants

Data for the present study were obtained from a larger study focused on evaluating energy expenditure estimates from different activity monitors [17,18]. A total of sixty-two (males:37; females:25) participants between the ages of 18 and 40 volunteered to participate in the study. The inclusion criteria were healthy adults who can perform given activities while wearing the activity monitors. Study protocols and design were approved by the Iowa State University Institutional Review Board and the informed consent was obtained from each participant before participation in the study.

2.2. Instrument

Participants were asked to wear two different types of activity monitors (i.e. AP and AG while performing a given set of activities (for approximately 90 min). Each participant wore two AGs (one on the wrist and one on the waist) and one AP on the right thigh. ActiLife (version 6.5.3) and activPAL Research Edition (version 6.4.1) were used to initialize AG and AP, respectively, according to the manufacturers' instructions. The AGs were set at a sampling rate of 80 Hz and data were obtained at 1-s epoch.

2.2.1. The ActiGraph GT3X+ (ActiGraph Corp, Pensacola, FL, USA) (AG)

The AG is the most widely used in research and clinical settings [13]. The AG is a small (4.6 cm × 3.3 cm × 1.5 cm and 19 g), tri-axial, and solid-state accelerometer. The accelerometer of the AG produces an inclinometer information, based on the data collected from the accelerometer, which is capable of classifying an individual's posture such as sitting, standing, and lying and 'off' (non-wear) [19,20]. Data from inclinometer display both percentage for overall statistics and time unit for each activity. Hourly inclinometer graphs are also provided, showing each activity time measured over 24 h. The placement of the AG includes both waist and wrist on the body. If the AG is worn on the wrist, the option for wrist placement should be activated on the software (i.e. ActiLife) when initializing.

2.2.2. The activPAL (PAL Technologies Ltd, Glasgow, UK) (AP)

The AP is a small (5.3 cm × 3.5 cm × 0.7 cm and 15 g) and capacitance-based accelerometer. The monitor is equipped with a memory of 16MB and a battery lasting about 10 days. The AP is designed to be worn on the thigh. The AP has the inclinometer function to detect limb positions and activity. Specifically, it has the ability to distinguish three different activities; sitting/lying, standing, and stepping [21]. The data from the inclinometer function are extracted, and displayed on the result sheet with a time (second) unit. The number of second is displayed for each 15 epoch, and summarized over 24 h at 10 Hz sampling frequency.

2.3. Study protocol

Participants' height and weight were measured at the beginning of the data collection and Participants' BMI was calculated as weight (kg)/height squared (m^2). After initialization, the AGs were placed on the participants' wrist and waist, and APs were attached to their right thigh with the PAL stickie. The participants were asked to complete an activity protocol designed to simulate true free-living activities. The testing protocol included 15 activities, and the 15 activities were classified to 3 activity categorizes: 1) Sitting: supine resting, sitting reading a book, sitting typing at a computer, sitting fidgeting, and stationary biking, 2) Standing: standing reading a book, standing typing at a computer, standing fidgeting, and throwing/catching a ball, 3) Stepping: climbing stairs, walking at 2.0 mph, walking at 3.0 mph, walking at 3.0 mph typing at TrekDesk, running at 4.5 mph, and running at 5.5 mph. Each activity lasted 5 min and participants had 1-min resting periods between them. This directly observed data served as a criterion measure and was temporarily aligned with the monitor data.

The AP's inclinometer function is capable of quantifying sitting, standing, and stepping time. However, the inclinometer function of the AG can distinguish lying, sitting, and standing time. Since the inclinometer of the AG does not measure any stepping activity, in order to make a direct comparison between the AP and AG for estimating 'stepping' time, a new 'stepping' variable for both waist- and wrist-worn AG was generated as follows: if a step count from the AG over a 1 min period/[standing time (s) + sitting time (s) + lying time (s) over the same 1 min period] is greater than 1, the activity was classified as 'stepping'. If a step count collected over a 1 min period/[standing time (s) + sitting time (s) + lying time (s)] is less than 1, the activity was categorized as a non-stepping activity. Activities that were originally classified as standing or sitting, but that had a value (from the above calculation) greater than 1, were reclassified as 'stepping'. This formula was developed based on assuming the participant walk when he or she made more than 1 step per second (step/s). The stepping time determined by the formula was compared to the direct observation data to examine the accuracy of the calculation for the inclinometer function of AG. In addition to 1 step/s, 0.5 and 0.7 step/s were examined to compare the overall accuracy of stepping activity for the AG.

2.4. Data analysis

Minute by minute inclinometer data from all the three monitors were directly compared to the direct observation (criterion method) using equivalence testing, which is a novel statistical approach to test for equivalence (rather than zero differences) between different measures [22]. All 1-min transitioning intervals between different activities as well as the first and the last minute of each 5-min activity trial were excluded to remove data noise. So, only the three middle minutes of each activity were used for data analyses. Mean absolute percent error (MAPE) was calculated by averaging the absolute difference between each monitor and the direct observation value divided by the direct observation value, then multiplying by 100. Cohen's D was calculated, and used as an index to examine the effect sizes of differences. In this study, smaller effect sizes represented smaller differences between