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Original article

Wearable monitors criterion validity for energy expenditure in sedentary and light activities

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Abstract

Background: Wearable monitors (WMs) are used to estimate the time spent in sedentary behaviors (SBs) and light-intensity physical activities (LPAs) and their associated energy cost; however, the accuracy of WMs in measuring behaviors on the lower end of the intensity spectrum is unclear. The aim of this study was to assess the validity of 3 WMs (ActiGraph GT3X+; *activ*PAL, and SenseWear 2) in estimating the intensity of SB and LPA in adults as compared with the criterion measure of oxygen uptake (VO_2) measured by indirect calorimetry.
Methods: Sixteen participants (age: 25.38 ± 8.58 years) wore the ActiGraph GT3X+, *activ*PAL, and SenseWear 2 devices during 7 sedentary-to-light activities. VO_2 (mL/kg/min) was estimated by means of a portable gas analyzer, Oxycon Mobile (Carefusion, Yorba Linda, CA, USA). All data were transformed into metabolic equivalents and analyzed using mean percentage error, equivalence plots, Bland-Altman plots, kappa statistics, and sensitivity/specificity.
Results: Mean percentage error was lowest for the *activ*PAL for SB (14.9%) and LPA (9.3%) compared with other WMs, which were >21.2%. None of the WMs fell within the equivalency range of ±10% of the criterion mean value. Bland-Altman plots revealed narrower levels of agreement with all WMs for SB than for LPA. Kappa statistics were low for all WMs, and sensitivity and specificity varied by WM type.
Conclusion: None of the WMs tested in this study were equivalent with the criterion measure (VO_2) in estimating sedentary-to-light activities; however, the *activ*PAL had greater overall accuracy in measuring SB and LPA than did the ActiGraph and SenseWear 2 monitors.

Keywords: Accelerometers; Accuracy; Low intensity; Metabolic estimations; Objective measurement; Sedentary behaviors

1. Introduction

Sedentary behavior (SB) is an important determinant of health.[1] Accurate assessment of this behavior is useful for epidemiologic research and to evaluate changes for interventions and programs.[2] Self-report has been the most common method of quantifying SB; however, its validity is still under assessment.[3,4] Therefore, objective measurement with sophisticated wearable monitors (WMs) has emerged to overcome self-reporting biases, yet many challenges accompany their use.[5–9] To date, the treatment and understanding of the data obtained from WMs is still very limited.[5,10] Furthermore, most of the available WMs have been extensively evaluated for accuracy in estimating moderate-to-vigorous physical activity (MVPA) and not SB or light-intensity physical activity (LPA).

Because many of the adults from developed and developing countries spend most of their time in SB and LPA,[11] it is critical to assess the validity of WMs in measuring SB and LPA. Early work in understanding energy expenditure (EE) has described the lack of ability of WMs to measure EE in the sedentary-to-light intensity spectrum.[12] More recently, Calabró et al.[13] assessed the validity of a variety of WMs in estimating EE during light-to-moderate intensity activities, finding a percentage error ranging from 9.5 to 30.5. Even though their work provides important information for considering whether to use a WM when there is interest in tracking low-intensity activities, several questions remain regarding which are the most valid and reliable objective wearable measures of SB and LPA.

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Currently, there are many types of WM brands available (e.g., ActiGraph (ActiGraph, Pensacola, FL, USA); *activ*PAL (PAL Technologies Ltd., Glasgow, UK); and SenseWear 2 (Body Media, Pittsburgh, PA, USA)) to measure PA and SB that have been extensively evaluated for accuracy in estimating MVPA. However, their ability to estimate EE on the lower end of the intensity spectrum, such as for SB and LPA, is less well known. For example, the ActiGraph, a triaxial accelerometer, measures acceleration in 3 individual axes (vertical, anteroposterior, and mediolateral) and provides activity counts for separate and composite vector magnitude of these 3 axes; however, the primary determination of SB by the ActiGraph is often based on only 1 axis, using an intensity threshold of <100 counts per minute (cpm). There has been some concern about the accuracy of this threshold because it has underestimated sitting time by 5%. Although 150 cpm seems to be a more accurate cutoff point for the ActiGraph WM,[14] there are several proposed cpm thresholds that classify SB in different studies: 50 cpm,[15] 100 cpm,[16] 150 cpm,[14] and 500 cpm.[17] Another monitor is the *activ*PAL PA logger, a uniaxial accelerometer and inclinometer that identifies walking, sitting, standing, steps, and instantaneous cadence.[18] The *activ*PAL has shown accuracy in distinguishing sitting or lying down from standing postures and in classifying time stepping;[14,19] however, the estimated metabolic equivalent (MET) values from the *activ*PAL at various speeds (2–4 mph) are significantly different ($p < 0.0001$) from the criterion of oxygen uptake (VO_2).[20] A third example of a monitor to measure SB and LPA is the SenseWear 2, which integrates information from a biaxial accelerometer and other physiological sensors (heat flux, temperature, and galvanic skin response) to provide estimates of EE using a proprietary algorithm.[21] This WM overestimates EE at various walking and running speeds ranging from 2 to 8 mph ($p < 0.0001$) as compared with the criterion of oxygen uptake (VO_2).[22]

The accuracy (validity) for each of these WMs in estimating EE during sedentary-to-light activities is unclear. One way to assess validity of the WM is to compare its outputs against a criterion measure (criterion validity). The criterion validity describes the relationship between WM outputs and physiological measures that reflect more directly the energy cost of the activity. Thus, the goal of this study was to examine the validity of 3 WMs (ActiGraph GT3X+, *activ*PAL, and SenseWear 2) in estimating intensity for sedentary-to-light activities in adults as compared with VO_2 measured in mL/kg/min. We hypothesized that the validity of EE estimates made by the tested WM (ActiGraph, *activ*PAL, and SenseWear 2) would be low because most of the WMs are validated for measuring MVPA but not SB or LPA.

2. Materials and methods

2.1. Participant information

A convenience sample of 16 participants ($n = 8$ men, $n = 8$ women) with an age range of 19–47 years (25.38 ± 8.58 years), body mass index range of 18.8–35.0 kg/m^2 (24.6 ± 4.6 kg/m^2), no contraindications for exercise (assessed with the PA readiness questionnaire (PAR-Q)),[23] and ability to walk unassisted on a motorized treadmill at 2.0 mph participated in the study. Prior to participation, all participants read and signed an informed consent document approved by the Arizona State University Institutional Review Board.

2.2. Procedures

Participants were instructed to avoid vigorous exercise the day before the testing and to eat their usual diet. Each participant performed 7 sedentary-to-light activities in a randomly assigned order. Activities close to the LPA threshold of 1.5 METs were selected based on values listed in the 2011 Compendium of Physical Activities.[24] Every activity was performed for 7 min, with 4 min of rest between activities. Participants were instructed to be silent during the monitoring periods. The activities were performed twice, with at least 24 h between trials. Participants were instructed to perform the activities as follows:

1. Treadmill walking at 1.0 mph (0.45 m/s), 1.5 mph (0.67 m/s), and 2.0 mph (0.90 m/s)—walk using their normal gate at each speed and not using the handrails for support.
2. Cleaning a kitchen (cleaning)—simulate cleaning a kitchen and dishes using a dry rag. Tasks included clearing dishes off a counter, simulating washing and drying dishes, placing dishes in a cupboard, and wiping the counter.
3. Standing while reading (reading)—stand in place and read a book silently.
4. Sitting while typing (typing)—sit at a computer to type a given paragraph. Participants were instructed to sit up straight and maintain that posture while typing.
5. Sitting while gaming (gaming)—be seated and quietly play a board game, which required the participant to put 5 objects in a defined order. Participants also rolled a die and moved their game piece a certain number of spaces based on their score from ordering the objects. Participants competed against the researcher to more accurately simulate playing a board game.

2.3. WMs

Each participant wore the 3 WMs under assessment and the criterion monitor simultaneously during the 7 selected activities. The criterion measure, VO_2 in mL/kg/min, was determined with the Oxycon Mobile portable metabolic unit (Carefusion, Yorba Linda, CA, USA);[25] the unit was calibrated before each test according to the manufacturer's specifications.

The ActiGraph was worn on an elastic belt on the right hip. The ActiGraph was initialized to collect data at 30 Hz. The *activ*PAL was worn on the anterior and medial portion of the right thigh attached to the skin by hypoallergenic medical tape. The SenseWear 2 was worn on the left upper arm of the individual using the factory-provided elastic strap.

2.4. Data management and processing

Researchers kept a written record of the time when each activity was performed; for example, walking 1 mph was performed from 1:00 p.m. to 1:07 p.m. When data collection was complete, data were downloaded from each of the WMs to a