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The bit doesn't fit: Evaluation of a commercial activity-tracker at slower walking speeds

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A B S T R A C T

Accelerometer-based commercial activity trackers are a low-cost and convenient method for monitoring and assessing health measures such as gait. However, the accuracy of these activity trackers in slow walking conditions on a minute-by-minute basis is largely unknown. In this study, the accuracy of a hip-worn commercial activity tracker (FitBit Ultra) was examined through step counts. Accuracy was evaluated through four minute trials of treadmill walking at speeds representative of older adults (0.9, 1.1, and 1.3 m/s). Minute-by-minute step count was extracted through the FitBit API and compared it to observer counted steps through video recordings. Results highlighted a significant over-reporting of steps at the highest speed, and a significant under-reporting of steps at the slowest speed, with the FitBit Ultra failing to count steps for one or more minutes at the slowest speed for 11 participants. This study highlights problems with using the FitBit Ultra by slow-walking populations, and recommends that researchers and clinicians should carefully consider the trade-off between accuracy and convenience when using commercial activity trackers with slow-walking populations.

1. Introduction

Activity trackers can assist in the monitoring and assessment of health indicators, such as walking [10], and have been shown to incentivize physical activity [1–3]. However, *step-count accuracy* has been a major factor in motivating long-term usage of activity trackers and inaccuracy has been a contributing factor in low adoption rates [4–6]. This is particularly so for slower walking populations such as older adults [7–9] where walking is a key component for much of the physical activity undertaken [11]. For instance, while older adults are accepting and willing to use activity trackers, step-count inaccuracy was a primary reason why many abandoned the technology in as few as two weeks [9]. And accurate measurements of physical activity are crucial in understanding health outcomes for this population [12].

Commercial activity trackers offer a low-cost and convenient method of assessing walking behavior, being widely available to the average consumer and providing feedback to users. Previous research has used commercial devices such as pedometers for step count monitoring with older adults [11,13], with limited success. Many commercially available activity trackers (such as the FitBit line) now utilize tri-axial accelerometers to record changes in movement in the X, Y, and Z planes. This movement is interpreted through algorithms to produce metrics such as step counts or stride length [14,15]. Encouragingly, various Fitbit models (e.g., the Fitbit Tracker, Ultra, and One) have been shown to have high step detection sensitivity, low noise-capture, reliability, and validity for typical adult walking speeds and high intensity activity [9,12,22,23]. In addition, the FitBit Ultra has been shown to have high inter-device reliability [24] and validity [25] with a range of speeds and environments [26,28]. For instance, a recent investigation of the FitBit One showed high step count accuracy in treadmill walking at speeds representative of older adults [3]. However, some accelerometers have been shown to underestimate step counts at slower speeds [16–18,26]. This underestimation may occur due to the algorithms used, [19,20] hardware sensitivity, [21] or sensor position on the body [12,15] and this underestimation can lead to significant errors over long periods of time [27].

One concern with these prior studies have determined the accuracy (or inaccuracy) of an accelerometer based on an aggregated step count from minutes to days and have foregone a minute-by-minute assessment of device accuracy. This may be because the commercially available Fitbit application only provides total steps in five to fifteen minute intervals. In order to extract minute-by-minute step count data, researchers must code a script utilizing the Fitbit API. In addition, the inexact nature of identifying the start and stop time precludes achieving high precision in calculating the number of steps participants take for a single minute of a trial. Therefore, we followed methods in which we can reliably examine exact step counts gathered within a specific time period [25,29].

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By using activity tracker study design best practices to extract and assess the minute-by-minute step-counts for a comparison of slow and average walking speeds (0.9, 1.1, and 1.3 m/s), [CW1] we aimed to better identify occurrences of underreporting in Fitbit devices. Our findings have revealed the problems the Fitbit Ultra encountered in step detection on a minute-by-minute basis as speed decreased. We discuss how these findings narrow the applicability of using commercial fitness trackers with a wider population.

2. Methods

2.1. FitBit Ultra

The FitBit Ultra (San Francisco, CA) is a commercial activity tracker that is clipped to the waist. It has been shown to be a reliable and valid device for step counts and physical activity [25,29]. The FitBit Ultra can be synchronized to a computer to provide a step count estimate. We chose the FitBit Ultra as it was one of the most popular waist-mounted activity trackers on the market at the time of this study.

2.2. Study design

A 2 (Step Count) x 3 (Speed) within-subjects experimental study was conducted to examine the accuracy of the FitBit Ultra at a range of walking speeds. Each participant wore a sensor belt to which a Fitbit Ultra was attached at the right hip. The participants first spent time acclimating to both the sensor belt and the treadmill. [RK2] [CW3] Each participant walked on a treadmill at three different speeds (0.9, 1.1, and 1.3 m/s) for a period of four minutes at each speed[CW4] . The order of speeds was randomized to minimize the likelihood of order effects.

Participants had 5 min to rest or acclimate to the next speed and could also request breaks. There was no reporting of fatigue. Our randomized order of speeds walked ensured that any effect of fatigue would not severely impact our findings.

2.2.1. Participant selection

Twenty-five participants (12 female, 13 male) were recruited. Ages ranged from 19 to 53, (mean age: 26, median age: 28, SD: 7.86); participants had no reported disabilities or affected gait (see Table 1 for demographics). Human subjects approval was obtained from the UMBC Institutional Review Board.

We selected from a healthy population for participant safety and control of gait variability. It would not have been safe for slower-walking populations to walk on a treadmill for four minutes without a harness system – such systems are necessary when evaluating certain patient populations walking on a treadmill [8,28]. In addition, if the Fitbit Ultra did not detect steps within a healthy population with no/limited gait variability, then it would not work for a slower-walking older or gait impaired population.

Informed consent was obtained before participation, and participant demographics and details of gait were collected with a questionnaire at the beginning of the experiment.

2.2.2. Speed selection

The walking speeds selected for treadmill walking were based on our target populations. Older adults (60 +) on average walk at 1.22 m/s +- 0.2 m/s and have an average step count of around 113 steps per minute [28,30,31]. Studies undertaken with this population have shown a range of speeds from slow to average (0.9, 1.1, 1.3 m/s) [3,7,32,33,35] – therefore, these three speeds were selected for use in our study. While these walking speeds may be on the higher end of what might be considered slow speeds, they provide an indication of how well the Fitbit performs in average versus slower walking conditions.

2.2.3. Walking condition

Two walking conditions have been used for validation of step counts on flat ground: hallways and treadmills [20,31]. Both have been used to test slower-walking populations, but treadmills were selected for this study for consistency and time. With hallway walking, it is difficult for a participant to consistently walk at a specific speed for several minutes; failure to do so may lead to inaccuracies and noise within the data. In addition, one of the speeds chosen for the study was meant to encompass the average walking speed of older adults, which would be hard to replicate without a controlled setting, which would result in difficulties in measurement.

Several studies have used treadmills as a method for collecting consistent walking data to examine gait factors such as average step count [20,23,28,29]. Prior validation studies of the Fitbit have also shown that the treadmill is preferred due to the ability to collect uninterrupted data over a longer period of time [8,20,23,30]. In addition, the treadmill restricts variability that may occur with participants walking below their preferred walking speeds [35]. Most of these studies collected data over a 4–5 min period, which informed our period of data collection.

2.2.4. Sensor position

While treadmill walking will produce different gait patterns than those which are seen during normal walking, previous research has shown that this does not affect step count accuracy unless the sensors are incorrectly positioned on the body [12,27,35,38,40]. Positioning an activity tracker at different locations on a user's body can lead to differing levels of accuracy, with specific positions yielding significant error at certain speeds [12]. In the context of walking, our tri-axial accelerometer was positioned at the right hip. This is not only recommended by Fitbit [34]; doing so has been shown to lead to greater accuracy in activity detection [3,36]. Other parts of the body (namely the wrist or arm) were not as accurate with slower-walking populations in determining basic measurements, such as step count, as walking aids often interfere with activity trackers when they are worn on the wrist [36]

2.3. Data collection and analysis

A video camera was positioned approximately 5 feet away to capture the participant's footsteps. The participants were then videotaped while walking on the treadmill. Start and stop times were determined on the video recordings by having the participant jump on to and off of

Table 1
Demographic information for participants with zero, non-zero step count minutes, and all participants.

	Participants with a Zero Step Count (n = 11)		Participants with a Non-Zero Step Count (n = 14)		All Participants (n = 25)	
	Mean ± SD	Range	Mean ± SD	Range	Mean ± SD	Range
Age (yr)	25.00 ± 6.70	19–40	26.57 ± 8.95	18–53	25.96 ± 7.86	18–53
Height (cm)	175.49 ± 10.80	160.02–190.50	170.18 ± 55.80	149.86–185.42	172.92 ± 11.31	149.86 ± 190.50
Weight (kg)	83.08 ± 18.01	59.02–115.77	73.99 ± 21.96	54.54–130.90	78.00 ± 20.29	54.43 ± 130.63
BMI (kg m^{-2})	26.88 ± 5.22	21.00–37.80	25.58 ± 4.58	20.20–30.00	25.81 ± 4.85	20.18–37.76