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Validation of Practical Tools to Identify Walking Cadence to Reach Moderate Intensity

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ABSTRACT

International Journal of Exercise Science 12(4): 1244-1253, 2019. It is recommended that adults get at minimum 150 minutes of moderate-to-vigorous physical activity in bouts of 10 minutes or greater every week. Walking cadence (steps per minute) is one easy way to estimate intensity required, however tools that claim to quantify walking intensity via walking cadence have not been validated in adults. We aimed to validate: 1- the accuracy of walking cadence measurement by the Piezo RxD pedometer, Polar Stride Sensor Bluetooth Smart foot pod, and Garmin Ant+ foot pod at different speeds and slopes and 2- the ability of the Piezo RxD to identify bouts of walking at moderate intensity using walking cadence. Inclusion criteria included being aged 19+ and the ability to reach moderate intensity when walking without incline as determined by a treadmill cardiorespiratory fitness test to determine 40% of VO_2 reserve. Walking cadence measured from the three tools was compared to a manual count of walking cadence during a series of walking stages at several speeds (2.5-5.5 km/h) and inclines (0-15%). The ability of the Piezo RxD to quantify a 10-minute bout was determined by walking for 12 minutes at 40% of VO_2 reserve measured by indirect calorimetry. All correlations between manual walking cadence counts and all devices were significant regardless of speed (r ranging from 0.469 to 0.999; $p \leq 0.05$) and slope (r ranging from 0.887 to 0.996; $p \leq 0.05$). The Piezo RxD was able to correctly measure a 10-minute bout of walking at moderate intensity for 50 of 51 participants. We found that all walking cadence devices provided accurate measurements of walking cadence. The Piezo RxD is an effective tool to quantify bouts of walking done at a minimum of moderate intensity.

KEY WORDS: Steps, pedometer, walking, foot pod

INTRODUCTION

Many agencies recommend that adults perform a minimum of 150 minutes of moderate to vigorous physical activity (MVPA) in bouts of 10 minutes or greater every week (2-3, 15). This amount of physical activity (PA) has been associated with many health benefits such as reduced risk of chronic disease for adults and reduced risk of losing independence for older adults.

Worldwide, walking is the preferred manner of PA for adults (5, 10). Interestingly, the large majority of adults, especially those who are inactive, are able to achieve moderate intensity while walking (12). It was previously believed that taking 10,000 steps per day was sufficient to meet the physical activity guidelines. However, this recommendation neglected intensity and bout length of movements. It has since been demonstrated that taking 10,000 steps per day was not necessarily associated with the expected health outcomes (13).

Walking cadence (steps per minute) is a useful indicator of daily walking because although it still relies on step counts, it also estimates the intensity and duration of bouts. Walking at a faster cadence can be considered to be walking at a greater intensity. Thus, it has been concluded that walking cadence is a potentially useful method of exercise prescription (14). Using one of the various methods of defining exercise intensity, such as $\%HR_{max}$, $\%HR_{reserve}$, $\%VO_2$ max, and $\%VO_2$ reserve, it could be determined at what cadence an individual reaches moderate intensity. Thus, every time an individual walk at or above that walking cadence threshold could be considered moderate intensity.

However, previous work has shown that both active and inactive adults cannot identify if they are working at moderate intensity by estimating if they are walking at the correct cadence (2, 7). This means they require tools to ensure they are actually reaching moderate intensity. Many of the tools currently available have not been validated, thus there is the need to validate affordable, practical tools which can provide live feedback to the exercising individual to help them reach moderate intensity and show when a bout of at least 10 minutes has been completed. A few examples of currently available technology are the Piezo RxD Pedometer, the Polar Bluetooth Smart Stride Sensor foot pod, and the Garmin Ant+ foot pod. The walking cadence threshold for moderate intensity can be set on the Piezo RxD, which, in addition to functioning as a normal pedometer, displays one star for each 10-minute bout of moderate intensity completed by measuring time spent walking at a greater cadence than the threshold for moderate intensity. The Bluetooth Smart Stride Sensor and the Garmin Ant+ foot pod are both able to measure walking cadence and can be paired to a wrist watch which can display live walking cadence measurements to the user.

The first objective of this study was to validate the ability of the Piezo RxD Pedometer, the Polar Bluetooth Smart Stride Sensor foot pod, and the Garmin Ant+ foot pod to measure walking cadence compared with a manual count of steps per minute at different walking speeds and at different slopes. The second objective was to validate the ability of the Piezo RxD to estimate bouts of moderate intensity in adults who could reach moderate intensity by walking.

METHODS

Participants

This validation study occurred over two sessions and included 51 participants aged 19 years old or above. All participants were volunteers recruited from general advertisements and provided informed consent before participating in this research study. All research adhered to the ethical policies set forward by the International Journal of Exercise Science Editorial Board (9).

If potential participants answered 'yes' to one of the questions of the Physical Activity Readiness Questionnaire (PAR-Q+) (4) or had a resting blood pressure greater than 144/94 using standard procedure (4), they were asked to consult a physician before participating in the study.

Protocol

Session One: Participants' characteristics: All anthropometric measures were obtained according to the Canadian Society of Exercise Physiology protocols (4). Height and weight were measured using a Seca GmbH & co. Model 700 beam scale and stadiometer (Hamburg, Germany). Waist circumference was measured with a gulick spring-loaded measuring tape to the nearest 0.5 cm between the iliac crest and the floating rib following a normal expiration. Participants placed their arms across their chest with arms on their shoulders according to protocol. Body composition was estimated using body density with the Bodpod (COSMED, Rome, Italy).

Cardiorespiratory Fitness Test: All participants were required to undergo a treadmill cardiorespiratory fitness test. The protocol for this test was 3.0 km/h with no incline, 4.0 km/h at 5% incline, 5.0 km/h at 10% incline, 6.0 km/h at 10% incline, 7.0 km/h at 10% incline, 7.0 km/h at 15% incline, 8.0 km/h at 15% incline 9.0 km/h at 15% incline, and 10.0 km/h at 15% incline. Each stage lasted two minutes. If the participant registered a respiratory exchange ratio of 0.95 or lower after the first four stages (eight minutes), each proceeding stage lasted one minute to ensure the participant reached maximal exertion in approximately 12 minutes. VO_2 was measured using a Parvo Medics TrueOne 2400 Metabolic Indirect Calorimetry System (Sandy, Utah, USA) with readings every five seconds. The VO_2 max value was calculated using the average VO_2 of the last 30 seconds of the test for an average of seven data points. Participants were then required to wait a minimum of 24 hours before returning for the second session. The range considered to be moderate intensity was between 40% and 60% of VO_2 reserve (1). Participants who achieved a VO_{2max} considered greater than the 75th percentile based on the American College of Sports Medicine sex and age group norms (1) were excluded, the rationale being that these individuals would need to run to reach moderate intensity.

Session 2: Validating tools to record walking cadence: Participants were equipped with the StepCounts Piezo RxD (Ottawa, Canada) to be worn on the right hip. A Garmin Ant+ foot pod (Olathe, USA) was attached to the laces of the left shoe while a Polar Bluetooth Smart Stride Sensor Smart foot pod (Kempele, Finland) was attached to the laces of the right shoe. The foot pods were paired to a Garmin FR60 Olathe, USA) and a Polar M400 (Kempele, Finland) respectively. These watches were able to display walking cadence measured by the foot pods. Participants then completed a series of one-minute walking stages on the treadmill. For each stage, participants began standing still with feet positioned on the side rails. Once the treadmill had been set to the proper speed and incline, the participant was instructed to begin walking. After completing the stage, participants were instructed to return to the start position. During each stage, the examiner recorded step counts using an HLI 8930 Manual Tally Counter and at the end of each stage, average cadence was recorded from the Piezo RxD, Garmin FR60, and Polar M400. After each stage, the participants were given 30 seconds break while the examiner recorded the walking cadence measurements and adjusted the speed or slope for the next stage.

The following one-minute stages were completed: at 2.5 km/h, 3.0 km/h, 4.0 km/h, 4.5 km/h, 5.0 km/h, and 5.5 km/h) with no incline to assess the effects of speed on walking cadence and at 3.0 %, 6.0 %, 9.0 %, 12.0 %, and 15.0 % incline, all with a constant speed 5.0 km/h, to assess the effects of slope on walking cadence.

To validate the ability of the Piezo to record moderate intensity physical activity in bouts of 10 minutes, the researcher set the treadmill at a speed, with no incline, where the participant would reach 40% of VO_2 reserve, as calculated from the cardiorespiratory fitness test. VO_2 was measured via indirect calorimetry (Parvo Medics TrueOne 2400 (Sandy, Utah, USA). Once the individual had reached 40% of VO_2 reserve, five minutes were given to find the correct speed and allow VO_2 measurements to stabilize. Walking cadence was recorded at the end of the five minutes and this value was taken for all participants and averaged to estimate the average walking cadence necessary to reach moderate intensity. This walking cadence was then rounded down to the nearest five and entered into the Piezo as the threshold for moderate intensity. The threshold was rounded down because the threshold for moderate intensity can only be entered in intervals of five on the Piezo. We only rounded down instead of rounding to the nearest five, down or up, to avoid a situation where the participant would reach the cadence necessary to reach moderate intensity but not have this cadence register as moderate intensity in the Piezo due to the Piezo threshold being higher than the actual threshold. Next, the participant was instructed to walk for 12 minutes at the determined cadence with the Piezo worn on the right hip. It was expected that a star representing a 10-minute bout of moderate intensity PA would be displayed on the pedometer screen after the 12 minutes if the participant maintained a walking cadence above the set threshold for moderate intensity. Once the 12 minutes was completed, the presence or absence of a star on the Piezo screen was noted.

Statistical Analysis

All statistics were performed using SPSS 24 (Mission Hills, USA). Pearson coefficients of correlation (r) were performed to determine the strength of the relationship between each of the three step trackers and the manual count of walking cadence for each one-minute walking stage.

To determine if the walking cadence measured by any of the three devices was significantly different compared to the manual count, a Bland-Altman analyses were used. One sample t-tests were used to test for sample bias in the difference between the walking cadence measured by each device and the manual count. Linear regression was used to test the association for walking cadence between each device and the manual count for all speeds, for all slopes, and then for all speeds and slopes together. Bland-Altman plots were created to display the limits of agreement for all speeds and slopes together. Linear regression models were used to determine significant associations between walking cadence needed to reach moderate intensity and characteristics of the sample.

RESULTS

The results should be reported in a logical sequence, giving the main findings first. The use of descriptive text, tables, and figures should be unique and not repeat information. Tables and figures should be restricted to those needed to explain the argument of the paper. Graphs should be used as an alternative to tables with many entries.

Table 1. Descriptive Characteristics of Sample.

Variable	*n* = 51
Sex (% of men)	27 (53)
Age (years)	46.7 (18.6)
Body mass index (kg/m²)	26.0 (4.5)
Waist Circumference (cm)	
Men	97.7 (11.9)
Women	89.5 (10.9)
Body Fat Percentage (%)	
Men	24.2 (8.8)
Women	33.2 (9.4)
Cardiorespiratory Fitness (ml/kg/min)	
Men	34.70 (9.9)
Women	30.8 (8.3)
Walking Cadence at moderate intensity (Steps/minute)	
Polar	123 (12)
Garmin	123 (12)
Stride Length at moderate intensity (cm)	75.62 (10.0)

Data are presented as Mean (SD) or N (%)

For the six one-minute walking stages measuring the effect of speed on walking cadence measurement, statistically significant correlations ($r \geq 0.46$, $p < 0.05$) were observed for walking cadence between all three activity trackers and the manual count at all speeds (Table 2). For the five one-minute walking stages measuring the effect of slope on walking cadence measurement, statistically significant correlations ($r \geq 0.88$, $p < 0.05$) were also observed for walking cadence between all three activity trackers and the manual count at all speeds (Table 2). Table 3 shows the average walking cadence in steps per minute for all three speeds and slopes.

Table 2. Association between walking cadence (steps per minute) for manual count and tested device**s.**

	Garmin	Polar	Piezo RxD
	Different Speed (km/h)		
2.5 km/h	.912*	.961*	.469*
3.0 km/h	.975*	.970*	.753*
4.0 km/h	.976*	.999*	.914*
4.5 km/h	.983*	.985*	.867*
5.0 km/h	.979*	.978*	.937*
5.5 km/h	.967*	.970*	.929*
	Different slope (5.0 km/h)		
3.0 %	.996*	.987*	.900*
6.0 %	.995*	.985*	.951*
9.0 %	.983*	.983*	.887*
12.0 %	.985*	.987*	.910*
15.0 %	.992*	.989*	.955*

Table 3. Average walking cadence (steps per minute) for manual count and tested devices.

	Garmin	Polar	Piezo RxD	Manual
		Different Speed (km/h)		
2.5 km/h	86 ± 8.3	86 ± 7.8	88 ± 21.4	86 ± 7.8
3.0 km/h	93 ± 7.7	93 ± 7.5	95 ± 8.5	94 ± 7.4
4.0 km/h	107 ± 7.5	106 ± 7.6	107 ± 7.8	108 ± 9.2
4.5 km/h	112 ± 6.9	112 ± 6.6	113 ± 8.2	112 ± 7.0
5.0 km/h	116 ± 6.8	116 ± 6.4	117 ± 7.6	117 ± 7.0
5.5 km/h	121 ± 7.4	121 ± 7.0	121 ± 7.7	121 ± 7.2
		Different slope (5.0 km/h)		
3.0 %	116 ± 7.6	116 ± 7.5	116 ± 9.3	116 ± 7.6
6.0 %	116 ± 7.4	116 ± 7.4	116 ± 7.7	116 ± 7.4
9.0 %	116 ± 7.8	116 ± 7.7	116 ± 7.8	116 ± 7.3
12.0 %	116 ± 7.4	116 ± 7.5	116 ± 7.5	116 ± 7.3
15.0 %	117 ± 7.8	117 ± 7.8	117 ± 7.9	117 ± 8.3

When testing the limits of agreement for walking cadence measurements between each device and the manual count, no sample bias was found using one sample t-tests ($p > 0.05$). In testing for agreement between the devices and manual measurement for all speeds and inclines combined, linear regression analysis showed no significant difference in walking cadence measured by the Garmin Ant+ versus walking cadence measured manually ($p = 0.524$), by the Polar Bluetooth Stride Sensor Smart versus walking cadence measured manually ($p = 0.699$), and by the Piezo RxD versus walking cadence measured manually ($p = 0.208$). The limits of agreement for all speeds and slopes combined are represented in the three Bland-Altman plots, where Figure 1A demonstrates the agreement between the Garmin Ant+ and the manual measure, Figure 1B the agreement between the Polar Bluetooth Stride Sensor Smart and the manual measure, and Figure 1C the agreement between the Piezo RxD and the manual measure at all speeds and slopes.

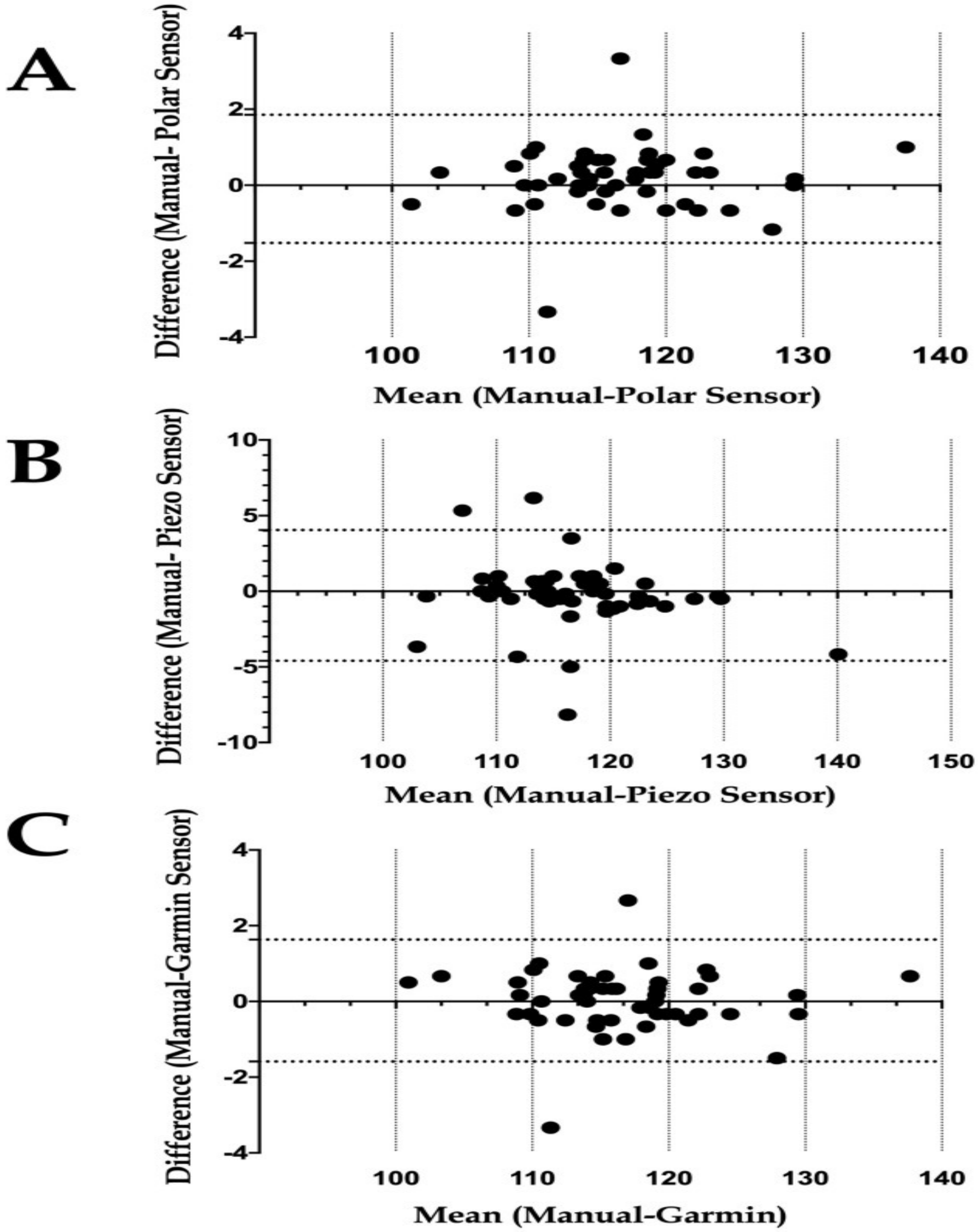

Figure 1. Limits of agreement for walking cadence between all three devices and manual measurements.

When evaluating the ability of the pedometer to record moderate intensity in bouts of 10 minutes or greater, it was determined that the pedometer correctly assigned or correctly did not assign a star for all but one of the participants (50/51, 98%).

DISCUSSION

The first objective of this study was to validate the ability of the Piezo RxD pedometer, Garmin Ant+ foot pod, and Polar Bluetooth Stride Sensor Smart foot pod to quantify walking cadence at several different speeds and slopes. The results showed that all three tools are valid at walking speeds of between 2.5 and 5.5 km/h with no incline and between 0 and 15% of slope at 5.0 km/h when compared with a manual count of cadence. The second objective was to validate the ability of the Piezo RxD to estimate bouts of at moderate intensity in adults who could reach this intensity by walking. We found that the Piezo RxD was able to correctly identify bouts of moderate intensity while walking for all but one participant.

The mean walking cadence required to reach at moderate intensity was 123 steps per minute on flat ground. This is much higher than the 100 steps suggested by Tudor-Locke and Rowe in their 2012 systematic review (13). One possible reason for this is that Tudor-Locke and Rowe defined moderate intensity as 3 METS, while this study used 40% of $VO_{2reserve}$. Another reason is that the Tudor-Locke and Rowe review included many populations who may have had decreased physical functions (13). This observation is important because adults actually need to reach moderate intensity to meet the recommendations. When using METs as the measurement for exercise intensity, it appears that very few adults actually reach that exercise intensity when compared to other means of measuring exercise intensity such as $\%HR_{max}$, $\%HR_{reserve}$, $\%VO_2$ max, and $\%VO_2$ reserve. For example, when using the American College of Sports Medicine recommendation of 46% of VO_2 max as the criteria for at moderate intensity, it was found that the average threshold for at moderate intensity was actually 4.9 METs instead of the generally accepted 3.0 METs (8).

Generally speaking, although we did not test for differences between the correlations, the correlations between walking cadence recorded for the Garmin Ant+ and manual count (R = 0.912-0.996), as well as between the Polar Stride Sensor Bluetooth Smart and manual count (R = 0.961-0.999) appeared to be higher than the correlation between the Piezo RxD and manual count (R = 0.469-0.955). One plausible reason is that the Piezo RxD uses a uniaxial piezoelectric sensor, while the Polar Bluetooth Smart Stride Sensor foot pod and the Garmin Ant+ foot pod each contain a triaxial accelerometer. Previous studies have demonstrated that triaxial devices are typically more accurate in their measurements than uniaxial devices (14). Another possible factor is how the devices were attached to the participant. The foot pods were securely attached to the feet of the participants, but the Piezo RxD was worn on the hip and attached to clothes. Clothing may be loose-fitting and could potentially cause the pedometer to pick up movement beyond that of the wearer. We also observed that the associations between walking cadence measured by the three devices and walking cadence measured manually appeared to be weaker at slower speeds. For example, the correlation between the Piezo RxD and Manual measurement of cadence is 0.469 at 2.5 km/h while the correlations between the foot pods and manual measurement of cadence were both greater than 0.9. This supports previous evidence that step tracking devices are least effective in their measurements of walking cadence at lower speeds (8). Regardless of which device may appear to be better, all three devices appear to be able to accurately measure walking cadence at a variety of different speeds and slopes compared to a manual count.

The Piezo RxD was able to successfully measure 10-minute bouts of moderate intensity during walking, which is recommended by many exercise guidelines in different countries (2-3, 15).

Currently, the Piezo RxD is one of the only devices available that attempts to quantify walking cadence in 10-minute bouts. Since 71.4% of adults choose walking as their exercise option (5), this device could be of immense value to ensure that walking is performed at moderate intensity, thus optimizing benefits for regular walkers of all ages, sexes, body types, and fitness levels.

Given the importance of reaching the physical activity guidelines and the seeming inability of average adult to do so, it is important to have devices capable of aiding adults in reaching the appropriate exercise intensity. This study demonstrated that the Garmin, Polar, and Piezo RxD were all capable of accurately measuring walking cadence at not only different slopes, but also at different speeds. This means that, as long as the user knew at which walking cadence to work at to reach moderate intensity, all three devices could be used to measure walking cadence with confidence at many speeds and slopes. Finally, we were able to show that the Piezo RxD is capable of detecting 10-minute bouts of moderate intensity in the vast majority of the population. Given the popularity of walking, this makes the Piezo RxD Pedometer an excellent tool to help walkers not only reach moderate intensity, but also to help them complete 10-minute bouts as suggested by many PA guidelines.

The main strength of this study was the use of a gold standard measurement of walking cadence (a manual count) to validate the three devices across a wide variety of speeds and slopes and the use of the indirect calorimetry to measure moderate intensity. However, this study was not without limitations. First, every test was performed at 5.0 km/h when testing the influence of slope on walking cadence. Second, the Piezo pedometer required step count thresholds to be rounded to the nearest five steps, which is not ideal.

The Garmin foot pod, Polar foot pod and Piezo RxD are inexpensive, valid tools for the measurement of walking cadence at all speeds and slopes. The Piezo RxD is also effective at recording 10-minute bouts of moderate intensity physical activity. Since walking is such a popular activity, these tools could be a very useful aid for adults and older adults to reach the recommended physical activity guidelines.

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