Convergent Validity of the Go Time and Go Time Pro Pedometers with the Actigraph Accelerometer

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Summary

Background: Using convergent methods of assessment we evaluated the ability of the Go Time (GT) and Go Time Pro (PRO) pedometers to detect steps and minutes of moderate-to-vigorous physical activity (MVPA) during treadmill walking and free-living.

Methods: Participants (20 female and 9 males, age 23.1 ± 4.7 years) wore GT and PRO pedometers and an Actigraph GT1M accelerometer during a 10 stage treadmill walking protocol and for the following 4-6 days. Prior to the treadmill protocol, stride length was measured then inputted into PRO to assess distance calculations. For the treadmill phase both pedometers used the 110 steps per minute (spm) default setting for MVPA threshold. During treadmill walking we manually counted steps, then recorded steps and MVPA from each of the 3 devices. Before the treadmill test we asked participants to identity which treadmill speed they felt best-represented moderate physical activity, then used the associated stepping rate to set their self-selected MVPA threshold on the PRO pedometer they would wear for free-living. For this phase we used the self-selected MVPA threshold (123 ± 8 spm) for the PRO and the default MVPA threshold (110 spm) for the GT. Accelerometer MVPA was calculated using the Freedson[1] equation for both the laboratory and free-living conditions.

Results: Except at the slowest speeds, GT and PRO steps were similar to actual steps for each treadmill walking stage. Also in the treadmill condition, GT and PRO MVPA were similar to accelerometer MVPA. Free-living steps were similar between all 3 devices and GT MVPA closely matched accelerometer MVPA. When using the self-selected MVPA threshold, significantly fewer MVPA minutes were detected by the PRO. Distance measurement was improved by using measured stride length instead of the default setting.

Conclusion: The GT and PRO pedometers provide good estimates of steps during treadmill walking and free-living. Good MVPA estimates were established when using the 110 spm MVPA threshold. When using the PRO, we recommend inputting the participants' stride length for more accurate distance measurement.

Background

An increased awareness of the health benefits of physical activity has fuelled an interest in physical activity monitoring. Easy to wear, inexpensive and easy to use, pedometers measure the number of steps a person takes. Accumulation of 10,000 steps per day has been proposed as a guideline for a healthy lifestyle. A pedometer is key to keeping track of steps. While 10,000 steps is an excellent goal there is evidence that maximum health benefits are gained if a proportion of that activity is of at least a moderate level. The Canadian Physical Activity Guidelines[2] recommends that adults accumulate at least 150 minutes of moderate-to-vigorous physical activity (MVPA) per week. Traditional pedometers only measure steps but pedometers such as the Go Time (GT) and Go Time Pro (PRO) also estimate the minutes of physical activity that are at MVPA intensity. Pedometers, if valid and reliable, can provide inexpensive objective measures of physical activity.

Accelerometers such as the Actigraph GT1M are research tools that provide detailed information on physical activity, including volume, frequency, steps and estimates of MVPA. Considered the gold-standard in physical activity measurement they are considerably more complicated to use and at over ten times the price of a pedometer are not feasible for the home market or for large-scale population studies. It is the purpose of this report to investigate the convergent validity of the GT and PRO pedometers with the Actigraph GT1M accelerometer during treadmill walking and free-living activities.

Methods

Who were the participants?

See Table 1. Twenty-nine university-aged physical education students (20 females, 9 males; 23.1± 4.7 years) consented to wear a GT, PRO and an accelerometer for a treadmill session and during the following 4-6 days. The study was approved by the Human Research Ethics Board at the University of Victoria. The free-living segment produced 111 person-days of PRO/accelerometer wear and 104 person-days of GT/accelerometer wear for comparison. Most of the participants were within the ideal weight range for their height (76%), having a BMI under 25 kg/m^2. One individual was considered obese and 21% were in the overweight category.

Table 1. Participant Characteristics.

	Mean ± sd
Age (yrs)	23.1 ± 4.7
BMI (kg/m^2)	23.6 ± 2.9
Overweight (BMI ≥ 25.0)	20.7%
Obese (BMI ≥ 30.0)	3.4%
Total days with both accelerometer and GT wear	104
Total days with both accelerometer and PRO wear	111

sd = standard deviation
BMI = Body mass index

What is the difference between an accelerometer and a Go Time pedometer?

The Actigraph accelerometer can be used to measure both steps and MVPA. It is considered by many to be the gold-standard of physical activity measurement. It utilizes a solid state micro-electro-mechanical system accelerometer to sense vertical accelerations. The accelerations are summed for a specified period of time (in our case, one minute) and reported in the form of activity counts. The more intense the activity is the higher the activity counts, thus intensity can be quantified. To determine how much physical activity is at MVPA intensity, formulae are used. The Freedson[1] formula has been used extensively to calculate MVPA with the Actigraph accelerometer.

The GT and PRO use a G-sensor that detects movement and emits an electrical pulse when changes in movement are perceived. Utilizing a tri-axial detection system, these pedometers are reported by their manufacturer to be very accurate no matter what position the device finds itself in. Reportedly, they can be worn on a lanyard or carried in a pocket and still maintain their accuracy. Both the GT and PRO measure steps, MVPA minutes and total activity time. A default setting of 110 spm is used as the MVPA threshold. Any minutes of activity that meet or exceed 110 spm are considered MVPA. As well as these features, the PRO has a 7-day memory, estimates distance travelled, calculates calories burned and has some customizable features. To increase the precision of the distance measure with the PRO, the user can enter their stride length and to improve the caloric expenditure calculation, can enter their body weight. One other modifiable feature of the PRO is the ability to change the MVPA threshold from the default of 110 spm to a different stepping rate.

What did we do?

Treadmill Phase: Each participant took part in a treadmill and free-living phase. At the treadmill session we measured height, weight and stride length, then fitted participants with the 3 devices. Participants walked on a treadmill for 10 1-minute periods, starting at 1.5 mph with speed increasing by 0.3 mph for each stage. Steps were manually counted. Upon completion of each walking stage, steps and PA were recorded from the pedometers. After stage 10, treadmill distance and PRO distance were recorded for later comparison. Steps and counts were extracted from the accelerometers using Kinesoft software. The Freedson[1] equation was used to calculate MVPA. Based on the definition of moderate physical activity provided by the Canadian Physical Activity Guidelines[2] ("… will cause adults to sweat a little and to breathe harder. Activities like brisk walking and bike riding"), we asked participants to identify which treadmill speed they felt best represented moderate physical activity. Following the treadmill test, we set the MVPA threshold on their PRO pedometer based on the actual stepping rate at this self-selected MVPA level.

Free-living Phase: The free-living phase began immediately following the treadmill session. During free-living, individual self-selected MVPA thresholds were used for the PRO (123 ± 8 spm) while the default MVPA threshold (110 spm) was used for the GT. Participants were instructed to wear all 3 devices during waking hours for the following 4-6 days. At the end of each day, participants recorded cumulating steps and MVPA minutes for the GT so we could later calculate daily steps and MVPA. Following the free-living phase, we downloaded daily steps and MVPA from the PRO and accelerometer.

How did we analyze the results?

We used SPSS 22.0 to analyze statistical data. We used repeated measures analysis of variance to examine if there were differences in steps and MVPA between devices. If differences were found, we performed t-tests. To examine the reliability of MVPA and step measures across devices we used intraclass correlations. Finally comparisons were made with other pedometers by comparing their reported step and MVPA values.

Results

How well did the GT and PRO perform during treadmill walking?

Treadmill steps: To determine how well the 3 devices compared to actual steps, we compared absolute percent error scores across the 10 1-minute treadmill stages and compared total treadmill steps for each of the 3 devices to hand-tallied steps. In order to compare step error between devices and manually counted steps at each treadmill stage, we first calculated percent error scores as follows:

(device steps - actual steps)/ actual steps

We then calculated "absolute percent error scores" by converting all percent error scores to positive values before averaging them, so that we didn't under-represent the magnitude of error. For example, if the percent error between actual and GT steps was +5% for one participant and -5% for another and we simply averaged them, it would look like there was no error [(+5 + -5)/2 = 0]. Instead we used their absolute percent error scores [ie. (5+5)/2 = 5] so that the positive and negative values did not cancel each other out. As seen in Figure 1, on the following page, the accelerometer did not count steps accurately for the first 3-4 treadmill speeds but thereafter scored similarly to actual steps. Likewise, the pedometers were less accurate at the slow treadmill speeds and more accurate as speed increased. Keep in mind that these initial walking speeds were very slow. Others [3,4,5] have found that most pedometers and accelerometers do not counts steps as accurately at walking speeds under 2.5 mph and that they tend to underestimate steps. No significant differences were seen between PRO (1090 ± 79), GT (1071 ± 72) and actual steps (1088± 55) during treadmill walking but significantly fewer accelerometer steps (953 ± 95) were recorded during the treadmill protocol. The high accelerometer step count error at the slower speeds, as seen in Figure 1, was responsible for this difference.

For an interesting comparison to our results we present (in Figure 2) the results of McClain and colleagues[3] who compared the absolute percent error of 4 different pedometers (Yamax SW-200, Omron HJ-151, New Lifestyles-1000, Walk4Life W4L Pro) and a GT1M accelerometer using the same treadmill protocol as we did. As seen in Figure 2, all of the pedometers performed relatively poorly at the lower speeds. Some of the pedometers were considerably more accurate than others.

Treadmill MVPA: Overall, across 10 minutes of treadmill walking, the total minutes of MVPA were similar for all 3 devices (GT = 5.5 ± 1.6 min, PRO = 5.5 ± 1.3 min, accelerometer = 6.0 ± 1.4 min: $p > .05$), suggesting that the GT and PRO did a good job of estimating MVPA.

Figure 1. Absolute % error between manually counted and device steps across 10 treadmill walking speeds.

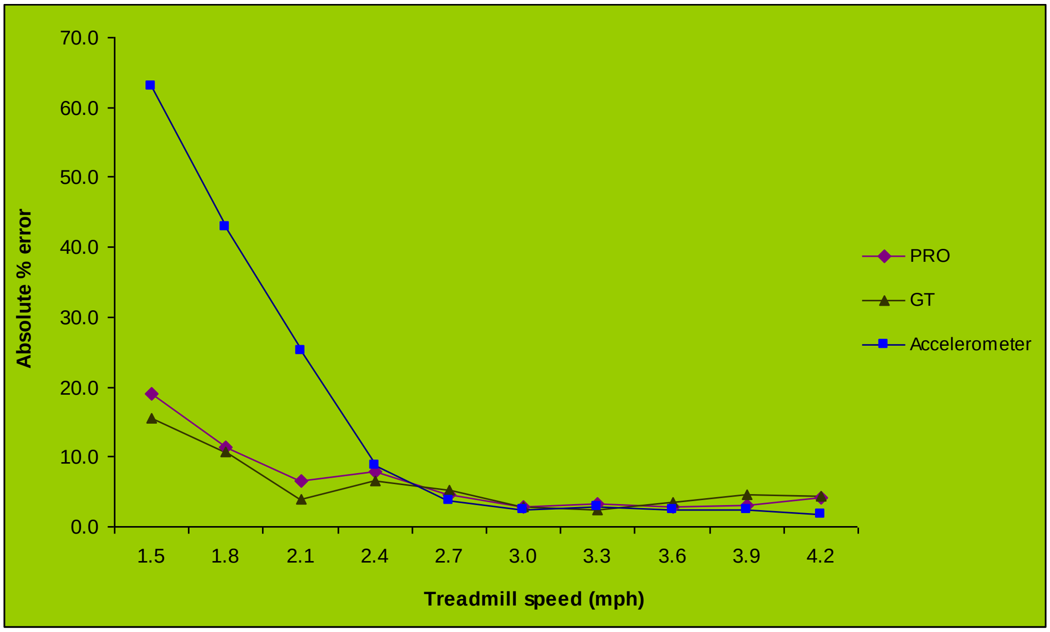
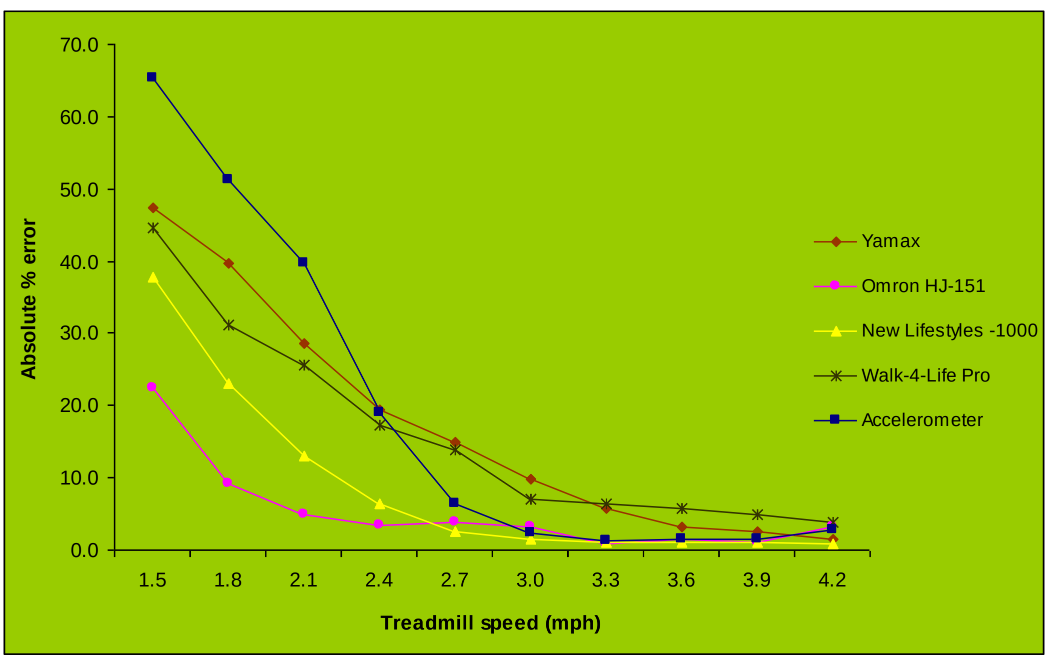


Figure 2. Absolute % error between manually counted and device steps across 10 treadmill walking speeds as reported by McClain et al., 2010[3].



How well did the GT and PRO compare to the accelerometer during free-living?

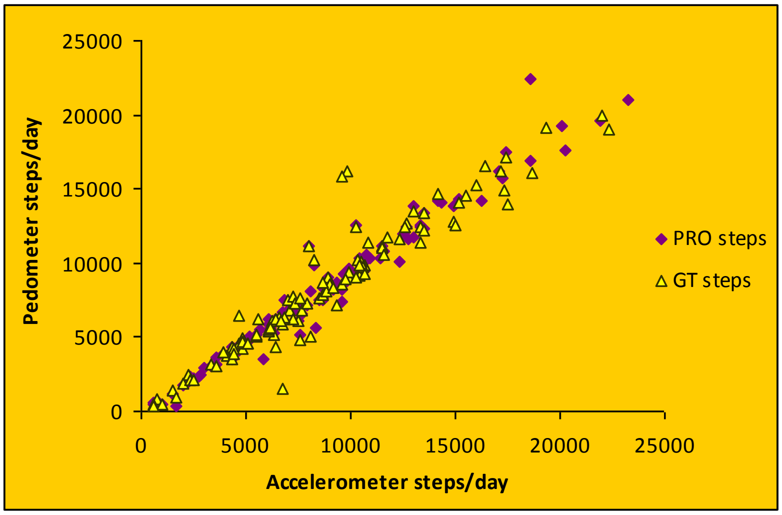
Free-living steps: While it is important that pedometers perform well in the laboratory, it is equally important that they perform well under real-life conditions. During free-living, as seen in Table 2, mean daily pedometer steps were similar to accelerometer steps (within 5%; $p > .05$). As shown in Figure 4, a linear relationship is demonstrated between accelerometer and pedometer step where increases in accelerometer steps are matched by increases in pedometer steps. Furthermore, the intraclass correlations between steps from the accelerometer and pedometers suggest that pedometer steps are strongly correlated with accelerometer steps (accelerometer-GT steps ICC= .95; $p < .001$, PRO-accelerometer steps ICC = .93; $p < .001$).

Table 2. Step comparison for the pedometers and accelerometer during free-living.

Device	Mean Steps/day	% Difference from Accelerometer
Accelerometer	8510 ± 3530 [a]	---
GT pedometer	8365 ± 3487 [a]	-1.7%
PRO pedometer	8085 ± 3454 [a]	-5.0%

[a] Values with matching superscripted letters are not significantly different
[@#] Values with matching superscripted symbols are significantly different (p<.01)

Figure 4. Pedometer versus accelerometer steps during free living.



Free-living MVPA: The intraclass correlation for GT versus accelerometer MVPA suggests strong agreement between the 2 scores (.85; $p < .01$) but the intraclass correlation of .35 between PRO and accelerometer MVPA suggests poor agreement. Further exploration of the free-living results will help explain why the accelerometer-PRO correlation for MVPA is so low. As seen in Table 3 below, average MVPA for the GT and accelerometer are very similar (+ 0.8%; $p > .05$) but average PRO MVPA is very different from the accelerometer (- 51.3%; $p < .01$).

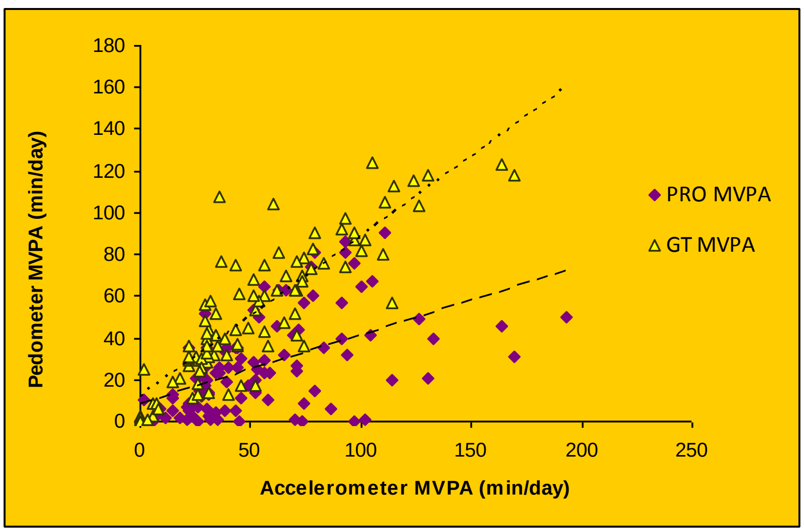
Table 3. Pedometers and accelerometer MVPA during free-living.

Device	Mean MVPA (min/day)	% Difference from Accelerometer	MVPA Range (min/day)
Accelerometer	50.7 ± 28.3 [b @]	---	13.3 - 136.8
GT pedometer	51.1 ± 24.7 [b #]	+0.8%	9.8 - 107.4
PRO pedometer	24.7 ± 16.6 [@ #]	-51.3%	2.0 - 56.0

[a] Values with matching superscripted letters are not significantly different
[@#] Values with matching superscripted symbols are significantly different (p<.01)

Also see that in Figure 5 below, as accelerometer MVPA increased, so did pedometer MVPA but notice that PRO MVPA is consistently lower than GT MVPA for the same accelerometer MVPA. Remember that we customized the PRO MVPA threshold for the free-living segment of the study. Ninety-three percent of the participants overestimated the threshold for moderate physical activity. It is likely that these active young physical education students' idea of moderate activity was inflated compared to a more diverse population. Being able to adjust the PRO MVPA threshold could be useful but as seen here should be used with caution if MVPA is what you really want to measure.

Figure 5. Pedometer versus accelerometer MVPA during free living.



The good news is that PRO steps were similar to GT steps during both laboratory and free-living phases, and that PRO MVPA matched GT MVPA during the treadmill session (when MVPA threshold was set at 110 spm for both devices). It is reasonable to deduce that PRO MVPA was vastly underestimated during free-living because we adjusted the default MVPA threshold upwards. Customizing this setting is not a good idea if your goal is to estimate MVPA (at least in this group of active university students) but could be useful for setting thresholds if, for example, your personal goal was to accrue a set number of minutes per day of vigorous or light activity. If someone found that they weren't able to accumulate enough MVPA at the default setting they might adjust the MVPA threshold downwards in an effort to accumulate 150 minutes/week of this slightly reduced 'MVPA', using this as a step towards the ultimate goal of meeting the Physical Activity Guidelines.

Are there advantages to customizing the PRO?

We customized both the stride length and MVPA threshold functions on the PRO. Using stride length improved distance prediction but using a self-selected MVPA threshold resulted in an under-prediction of MVPA.

Stride length. We compared actual distance travelled during the treadmill protocol to distance calculated using default stride length (70.0 cm) and distance calculated using measured stride length (77.6 ± 5.2 cm). As seen in Table 4 below, using measured stride length resulted in a more accurate measure of distance compared to the default stride length. The default setting for stride length may be appropriate for some people or for specific activities but in these active young adults, walking distance was more accurate using their measured stride length.

Table 4. Actual distance compared to distance calculated with default stride length and measured stride length.

	Actual distance	PRO - default stride length	PRO - measured stride length
Distance (km)	0.759 ± .019	0.659 ± 0.143 [#]	0.729 ± 0.162 [a]
% difference	----	- 13.1%	- 4.0%

[a] - no significant difference from actual distance
[#] - significant difference from actual difference ($p < 0.01$)

MVPA threshold: The treadmill stage where MVPA was first identified by the accelerometer was recognized as the MVPA stage. Actual stepping rate at the MVPA stage (108 ± 11 spm) was similar to what was detected by the accelerometer (105 ± 9 spm), GT (105 ± 15 spm) and PRO (108 ± 7 spm; $p = .31$). However, the self-selected MVPA threshold was significantly faster (123 ± 8 spm; $p < .01$). When our participants chose their own MVPA threshold, they overestimated how much physical effort was required to work at an MVPA intensity, resulting in an underestimation of MVPA. It appears that the default setting of 110 spm for MVPA threshold was appropriate for accurately estimating MVPA.

How well did the GT and PRO compare to other pedometers?

Standards set by Japan's Ministry of Industry and Trading regulations state that Japanese-made pedometers must be accurate within 3% for step counting at 3 mph [6] but other pedometer manufacturing countries have yet to set a similar standard. As a result, some manufacturers are producing sub-standard pedometers. For example, one pedometer available free in a cereal promotion had a 45% absolute percent error for step counting during free-living [7]. Clearly, this is unacceptable. Even though the GT and PRO were manufactured outside of Japan, they met the ± 3% criteria, with absolute percent error scores at 3 mph of 2.8% and 2.9% respectively.

Laboratory studies: A few studies have compared pedometer steps and MVPA to Actigraph accelerometers in adults using similar procedures to ours, enabling us to compare the PRO and GT to other pedometers. The results of these investigations have been compiled and compared to our results in Tables 5 and 6. As seen in Table 5, the GT, PRO, Omron and NL-1000 pedometers met the ± 3% step error standard for 3 mph but the Yamax and Walk-4-Life pedometers failed to do so. Similarly, the pedometers that performed better at 3 mph had lower absolute percent step error over the multi-stage treadmill protocol than the Yamax or Walk-4-Life. Both New Lifestyles and Omron are piezoelectric style pedometers whereas the Yamax and Walk-4-Life rely on a spring-levered mechanism for step-counting. Piezoelectric pedometers have been touted as being more accurate than spring-levered models, particularly at slower walking speeds [8, 9].

Table 5. Pedometer step error during 10 1-minute treadmill stages for various pedometers.

Pedometer	Cost*	Study	Sample	Absolute % step error at 3 mph◊	Absolute % step error (10 treadmill speeds)
Go Time	$20	Current	29 adults	2.8%	6.0%
Go Time Pro	$28	Current	29 adults	2.9%	6.6%
Yamax SW-200	$20	McClain [3]	26 adults	9.8%	17.3%
Walk 4 Life Pro	$27	McClain [3]	26 adults	7.1%	16.1%
Omron HJ-151	$30	McClain [3]	26 adults	3.2%	5.4%
New Lifestyles NL-1000	$55	McClain [3]	26 adults	1.6%	8.9%

* - cost as of December 2013 for a single pedometer (shipping costs are extra and variable)
◊ - pedometer steps were compared to hand-counted

Free-living studies: Under free-living conditions, as shown in Table 6, the GT, PRO, Yamax and Omron pedometers had the lowest percent error for steps, whereas the GT and Kenz Lifecorder had the least error for MVPA. Due to the issue of using self-selected MVPA for the PRO during free-living, free-living PRO MVPA is not included in the table. Also of note is the absence of MVPA data for the Yamax and Walk-4-Life pedometers as they are not capable of detecting MVPA at this time. Costs vary considerably among devices. With reasonable costs and good comparability for MVPA and steps, the GT and PRO pedometers appear to provide good estimates of physical activity at a reasonable price.

Table 6. Pedometer step and MVPA error among various pedomters during free-living conditions.

Pedometer	Cost *	Study	Sample	% difference steps┼	% difference MVPA ♦
Go Time	$20	Current	29 adults	1.7%	0.8%
Go Time Pro	$28	Current	29 adults	5.0%	Not included
Yamax SW-200	$20	McClain [3]	26 adults	-5.3%	NA
Walk 4 Life Pro	$27	McClain [3]	26 adults	-12.0%	NA
Omron HJ-151	$30	McClain [3]	26 adults	-0.8%	-20.7%
New Lifestyles NL-1000	$55	McClain [3]	26 adults	7.2%	-6.9%
Kenz Lifecorder EX	$295	McClain [10]	10 adults	-10.5%	-3.5%

* - cost as of December 2013 for a single pedometer (shipping costs are extra and variable)
┼ - pedometer steps were compared to accelerometer steps
♦ - pedometer MVPA was compared to acceleromtere MVPA
NA - MVPA feature not available

Conclusions

The GT pedometer provides a valid estimate of MVPA and steps during treadmill walking and free-living activities. The PRO pedometer also provides valid estimates of MVPA and steps during treadmill walking and of steps during free-living. Given how well the PRO performed on the treadmill test and that it is constructed using the same G-sensor technology as the GT, had we used the default MVPA threshold for the PRO during free-living, it likely would have performed similarly to the GT. The ability to monitor both steps and intensity of activity (MVPA) with simple, relatively inexpensive devices such as the GT and PRO allows a broad range of people to not only monitor if they are getting enough physical activity but also to evaluate if that activity is intense enough to reap maximum health benefits. The PRO has the option of being able to customize certain measures. The accuracy of the distance function for the PRO was enhanced by customizing it to the individual's stride length. As well, the MVPA threshold for the PRO can be customized. While this can be useful for training and goal-setting, it may decrease the accuracy of MVPA estimates if the user is not a good judge of what constitutes moderate physical activity. The default stepping rate used by the GT (110 spm) for MVPA threshold was appropriate for determining valid MVPA values in this group of healthy, university aged physical education students.

References

1. Freedson PS, Melanson E, Sirard J. Calibration of the Computer Science and Applications, Inc. accelerometer. Med Sci Sports Exerc 1998;30(5):777.

2. Canadian Society for Exercise Physiology. New Canadian Physical Activity Guidelines Available at: http://www.csep.ca/CMFiles/Guidelines/CSEP_PAGuidelines_adults_en.pdf.

3. McClain JJ, Hart TL, Getz RS, Tudor-Locke C. Convergent validity of 3 low cost motion sensors with the ActiGraph accelerometer. J Phys Act Health 2010 Sep;7(5):662-670.

4. Abel MG, Hannon JC, Sell K, Lillie T, Conlin G, Anderson D. Validation of the Kenz Lifecorder EX and ActiGraph GT1M accelerometers for walking and running in adults. Applied Physiology, Nutrition, and Metabolism 2008;33(6):1155-1164.

5. Bassett Jr DR, Ainsworth BE, Leggett SR, Mathien CA, Main JA, Hunter DC, et al. Accuracy of five electronic pedometers for measuring distance walked. Med Sci Sports Exerc 1996;28(8):1071.

6. Hatano, Y. Use of the pedometer for promoting daily walking exercise. International Council for Health, Physical Education, and Recreation 1993;29(4):4-8.

7. Tudor-Locke C, Sisson SB, Lee SM, Craig CL, Plotnikoff RC, Bauman A. Evaluation of quality of commercial pedometers. Canadian journal of public health. Revue canadienne de sante publique 2006;97:S10.

8. Melanson EL, Knoll JR, Bell ML, Donahoo WT, Hill JO, Nysse, LJ, et al. Commercially available pedometers: considerations for accurate step counting. Preventive medicine 2004;39(2):361-368.

9. Crouter SE, Schneider PL, Basset DR. Spring-levered versus piezo-electric pedometer accuracy in overweight and obese adults. Medicine and Science in Sports and Exercise 2005;37(10):1673.

10. McClain JJ, Sisson SB, Washington TL, Craig CL, Tudor-Locke C. Comparison of Lifecorder EX and ActiGraph accelerometers under free-living conditions. Applied Physiology, Nutrition, and Metabolism 2007;32(4):753-761.