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Authors: Robyn M. Lamont, Hannah L. Daniel, Caitlyn L. Payne, Sandra G. Brauer

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Accuracy of wearable physical activity trackers in people with Parkinson's disease.

Authors:
Robyn M Lamont[a] Hannah L Daniel[a], Caitlyn L Payne[a], & Sandra G Brauer[a]

Affiliations:

[a] Division of Physiotherapy, School of Health and Rehabilitation Sciences, University of Queensland, Australia

Running title: Accuracy of activity trackers in people with Parkinson's disease

Corresponding Author

Robyn Lamont [a]

School of Health and Rehabilitation Sciences, The University of Queensland, St Lucia, Qld,

Australia, 4072

Ph: +61 3365 3299

Fax: +61 7 3365 1662

Email: r.lamont@uq.edu.au

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Highlights

- Wrist-worn wearable activity monitors are accurate in people with PD
- Accuracy is high at self-selected speed but poor at low walking cadences
- Intensity of walking activity increases with increasing walking cadence
- Cadence measured on the wrist-worn monitors was only weakly related to intensity

ABSTRACT

Introduction: The purpose of this study was to determine the accuracy of the Fitbit Charge HR™ and Garmin vívosmart® HR in measuring steps and reflecting intensity of activity in people with Parkinson's disease (PD).

Methods: Thirty-three people with mild-moderate PD performed six, two-minute indoor walks at their self-selected walking pace, and at target cadences of 60, 80, 100, 120 and 140 beats/minute. A 500m outdoor walk with terrain challenges was also performed. Step count was recorded by the two wrist-worn activity trackers (Fitbit Charge HR™ and Garmin vívosmart® HR) and compared to an accelerometer (ActivPAL^{3}™). Intensity was recorded by a portable breath-by-breath gas analyser (VO_2), heart rate and Borg scale.

Results: Both commercial activity trackers had low error (<3%) and moderate to high consistency at self-selected pace both indoors and outdoors (ICC 0.88-0.97; $p<0.05$) compared to the ActivPAL^{3}™. The Garmin recorded low error (<5%) and high agreement (ICCs >0.68; $p<0.001$) for all target cadences ≥80steps/minute. The Fitbit had higher error was less consistent for all target cadences ≥80steps/minute. Cadence measured by the Fitbit and Garmin weakly reflected increases in heart rate (ICCs 0.27-0.28; $p<0.05$), and did not reflect VO_2 or Borg (ICCs 0.08-0.15, $p>0.05$).

Conclusion: The Garmin device was more accurate at reflecting step count across a broader range of walking cadences than the Fitbit, but neither strongly reflected intensity of activity. While not intended to replace research grade devices, these wrist-worn devices may be a clinically useful adjunct to exercise therapy to increase physical activity in people with PD.

Keywords:

Parkinson's disease; body fixed sensor; physical activity; wearable devices; gait

Introduction

Physical activity is known to improve physical function and capacity and cognitive functions in people with PD[1]. Physical activity may also play a neuroprotective role, slowing the progression of PD and delaying the onset of secondary problems[1]. Despite these known benefits, people with PD are substantially less physically active than healthy age-matched controls[2]. Furthermore, increasing physical activity behaviours in sedentary people with PD has proven difficult even with extensive coaching, goal setting and feedback[3].

Recent trials in people with PD have demonstrated that exercise interventions can result in positive improvements in physical and cognitive function in the short to medium term[4,5]. Promoting longer term physical activity behaviour change has however proven more challenging[3]. Motivation and exercise self-efficacy are two identified barriers to exercise participation in people with PD[6,7]. Consumer activity monitors provide visual feedback on the volume of physical activity performed and may therefore promote motivation and self-efficacy for exercise and physical activity.

Wearable activity monitors include a number of behaviour change techniques often used to increase physical activity such as self-monitoring and feedback on goal attainment[8]. Most

people, including older adults are accepting of the technology and able to quickly learn to use activity trackers[9]. Furthermore, wearable activity monitors have been shown to be an effective adjunct to supporting behaviour change in adults over the age of 50[10]. These devices may prove useful in improving physical activity in people with PD, however their accuracy in this population is yet to be tested.

Accuracy of wearable activity monitors can be influenced by pattern and speed of gait, and anatomical placement of the device [11]. Waist-worn activity monitors have been shown to be more accurate than wrist-worn devices at counting steps at gait speeds ranging from slow to fast [11]. The accuracy of wrist-worn devices may be further reduced in people with PD due to reduced arm swing often experienced during gait in this population. Indeed, in people with stroke and acquired brain injury, a wrist-worn activity monitor had an error rate of over 30%[12]. Despite the impact on accuracy, in older adults' wrist-worn devices were often preferred possibly due the immediate feedback provided by and easily read on the digital screen[9]. As such, the accuracy of wrist-worn activity tracking devices in people with PD should be investigated.

Physical activity guidelines recommend that all adults, including those with gait impairments, should participate in at least 150 minutes of moderate, or 75 minutes of vigorous intensity physical activity per week[13]. Monitoring performance relative to these guidelines requires a method of estimating activity intensity. Measuring cadence during ambulant activities is an easy way to understand and monitor intensity of activity and has been used to categorise physical activity as low, moderate or high intensity in healthy adults[14], people with stroke[15] and people with PD[16]. In people with PD, reduced gait speed and step length is often associated with increased cadence[17]. These gait impairments may increase the energy expenditure of

walking in people with PD compared to those without[18] Estimates of cadence-based descriptors of activity intensity should therefore be verified in this population.

The aim of this study was to determine the accuracy of commercially available wrist-worn activity tracking devices, the Fitbit Charge HR™ and Garmin vívosmart® HR, to measure step count and reflect intensity of activity in people with PD across a variety of walking speeds and conditions.

Methods

Participants

Thirty-three community dwelling people with idiopathic PD were recruited through movement disorder specialists, a database of volunteers and PD support organisations. To be included in the study, participants had to have a diagnosis of idiopathic PD confirmed by a neurologist; the ability to walk for at least 2 minutes without stopping; and be willing and able to provide informed consent. People with conditions other than PD that affected their walking, and those with unstable medical conditions, were excluded. All participants provided written informed consent. The study was approved by the institutional ethical review board.

Procedure

Participants attended one assessment session at a university gait laboratory when their usual anti-parkinsonian medications were reported to be maximally effective. They were asked to abstain from vigorous exercise or consuming caffeine and tobacco products for 3 hours prior to the assessment. Characteristics including age, gender, disease duration, falls history and dopamine dosage was collected by interview. Disease severity was measured using the motor

subscale of the Unified Parkinson's Disease Rating Scale (UPDRS-III)[19] and stage of disease rated using Hoehn and Yahr scale (HY)[20]. Severity of gait freezing was measured using the Freezing of Gait Questionnaire (FOG-Q)[21]. To characterise gait capacity, comfortable and fast gait speed were measured while participants walked 10m over a 7m instrumented GAITrite mat (CIR Systems Inc, NJ, USA) positioned in the middle of the path. Current levels of physical activity were captured using the National Aeronautics and Space Administration/Johnson Space Centre physical activity status scale (NASA)[22]. Participants wore a Fitbit and Garmin device on each wrist, and an ActivPAL^{3}™ on the right anterior mid-thigh.

Participants completed six two-minute walks on an indoor, uncluttered 44m circuit. The first walk was performed at their self-selected walking pace. For the following five walks, participants were asked to walk in time with a metronome set at 60, 80, 100, 120 and 140 steps per minute. These cadences were selected as they are currently used in definitions of walking intensity to measure free-living ambulatory activity in healthy adults[14], people with PD[16] and after stroke[15]. The order of walks was randomised, and each participant was given a 30 second familiarisation period. After each walk participants rested in sitting for at least 2 minutes or until their heart rate returned to its resting level. Participants then completed a 500m outdoor walking circuit. The route incorporated both terrain challenges (slopes, grass and stairs) and crowds to reflect challenges commonly identified by people with PD when walking in the community[23].

Instruments and measures

The Fitbit Charge HR™ (Fitbit Inc, San Francisco, California, USA) and Garmin vívosmart® HR (Garmin International, Olathe, USA) are small, wearable activity trackers that are worn like a watch. Each participant wore four devices: one of each type on each wrist, with the one

placed most distally randomised between individuals. Step count was recorded from both devices at the beginning and end of each walking trial and the difference was calculated to determine the number of steps taken. An ActivPAL^{3}™ (PAL Technologies Ltd., Glasgow, UK) was affixed to the anterior middle right thigh with hypoallergenic tape. It is a 15g triaxial accelerometer which records at a frequency of 20Hz and provides measures at 15 second epochs. It has established accuracy for measuring step count in older adults with and without impaired motor function[24], and has been used widely in people with PD[2,16]. Step count and cadence (steps/minute) were calculated for each trial.

Intensity of activity was measured via three methods. Oxygen consumption (VO_2) during each walking test was measured using a portable breath-by-breath gas analyser, the Metamax (CORTEX, Leipzig, Germany). Heart rate was measured via a calibrated chest worn heart rate monitor affixed (Polar Ltd., Australia). Perceived exertion was rated out of 20 by participants at the beginning and end of each circuit using the Borg Scale[25].

Data analysis

Data were screened for normality via Shapiro-Wilk and extreme outliers removed. Descriptive statistics were used to summarise participant characteristics. Activity tracker data was separated into most or least affected side, as determined by the individual's combined score on the rigidity and bradykinesia items from the motor subsection of the UPDRS. To compare the accuracy of the devices with the ActivPAL^{3}™, the mean difference, absolute percentage error (APE) and limits of agreement (LOA) were calculated (see formula below) and paired t-tests performed. Bland –Altman LOA plots were created[26].

$$APE = \frac{|\textit{mean difference (device- ActivPAL}^{3}\text{™)}|}{} \quad X\ 100$$

$$\frac{}{|mean\ (device,\ ActivPAL^{3}\text{™})|}$$

$$LOA = \quad mean\ difference \pm (1.96\ X\ standard\ deviation\ of\ the\ mean\ difference)$$

The strength of association between the outputs from each of the devices was compared to the ActivPAL^{3}™ using Intra-class Correlation Coefficients ($ICC_{3,1}$). Repeated-measures ANOVA were used to determine differences between devices and to determine differences in measures of activity intensity (oxygen consumption, perceived exertion and heart rate) across the different speeds and conditions (60, 80, 100, 120, 140 steps per minute). ICCs were performed to determine the strength of the relationship between measures of activity intensity (oxygen consumption, perceived exertion and heart rate) and cadence. Data was analysed using SPSS 22.0 (IBM. Chicago, Illinois, USA) and significance level was $P<0.05$.

Results

A total of 33 people (64% male) with mild to moderate PD (94% HY stage 1 or 2), a mean(SD) age of 69(8) years, and disease duration of 6(6) years participated (Table 1). There was no significant difference between the number of steps counted on the most and least affected sides ($p > 0.078$) therefore, only data from the devices worn on the most affected side were included in the analysis.

When walking at a self-selected pace indoors or out, both wrist-worn devices recorded with low error (APE <3.0%) and high consistency (ICC ≥ 0.88) compared to the ActivPAL^{3TM} (Table 2). Both devices recorded with greater consistency during the outdoor walk (ICC = 0.94 - 0.97) compared to the indoor walk (ICC = 0.88 – 0.93). Compared to the ActivPAL^{3TM}, both wrist-worn devices showed high error levels (APE 37-60%) and poor consistency (ICC = 0.36)

at the lowest cadence (60 steps/min), tending to underestimate step counts. For cadences of 80 and above, the Garmin device demonstrated low error (APEs < 5.0%). At these cadences, the step count recorded by the Garmin device, was also strongly associated with the ActivPAL^{3TM} (ICC: 0.68 – 0.89, $p < 0.05$). The Fitbit device counted steps with greater error (APE 3.5 - 17.6%) and poorer consistency (ICCs: 0.17 – 0.42; $p > 0.065$) for each of the cadences between 80 and 140 steps/minute.

There was a main effect of cadence for oxygen consumption ($p < 0.001$), heart rate ($p < 0.001$) and perceived exertion ($p < 0.037$) (Table 3). There was a significant increase in oxygen consumption, heart rate and perceived exertion for each increase in cadence from 60 to 140 steps/minute, suggesting that altering cadence was an appropriate means to change intensity of activity. Fitbit Charge HR^{TM} and Garmin vivofit® HR step counts were weakly associated with increases in heart rate across cadences of 60-140 steps/min (ICCs 0.27-0.28; $p<0.05$), and did not reflect changes in oxygen consumption or perceived exertion (ICCs 0.08-0.15, $p>0.05$) (Table 4).

Discussion

This study aimed to determine whether two wrist-worn activity trackers, the Garmin vívosmart® HR and Fitbit Charge HR^{TM} could accurately determine step count and reflect activity intensity in people with PD while walking at difference cadences, indoors and out. Contrary to our hypothesis, we found that both devices provided valid measures of step count during indoor and outdoor walking at a self-selected pace, however, both activity trackers were less accurate at low cadence. Step count recorded by the Garmin vívosmart® HR was highly consistent with the ActivPAL^{3TM} across cadences of 80-140 step/min but the Fitbit Charge HR^{TM} was less accurate at these walking paces. Overall, the Garmin vívosmart® HR may offer

a more valid measure of steps in people with Parkinson's disease. Step count measures from both devices were not reflective intensity of activity.

To be useful to monitor free-living activity, devices need to accurately record activity with a variety of environmental challenges. In the current study, both devices demonstrated low error when walking at a self-selected speed whether indoors or out. Greater accuracy was found in the outdoor walking condition, where terrain and environmental challenges were encountered. These findings suggest that either monitor may be beneficial for recording continuous outdoor walking activity. Further research is however required to confirm the accuracy of wrist-worn devices in "free-living" conditions where there are likely to be periods of slower walking, shorter and longer walking distances and periods of upper limb use that may influence device accuracy[27].

The reduced accuracy of the devices at the lowest cadence supports previous research of wrist and waist-worn devices that show greater error at slower speeds[11]. Inaccuracy may be related to changes in gait pattern and strategies used to maintain pace and balance when walking at a slower or faster pace than usual. Arm swing is often reduced in people with PD, and this is likely to be further reduced at slow gait speeds, potentially contributing to the underestimation of steps at a lower cadence in people with PD. Whether this degree of reduced arm movement often observed in people living with stroke or more advanced PD adversely affects accuracy the accuracy of wrist-worn activity monitors remains to be investigated.

Basic activity trackers such as pedometers have been shown to aid in increasing physical activity in various populations and may be used to promote behaviour change strategies such as goal setting[28]. With advances in technology, wearable armbands have become relatively

affordable and most incorporate a variety of behaviour change techniques designed to promote increased physical activity[8]. The largest study to improve physical activity in PD concluded that an intervention using a physical activity monitor for feedback and personalized motivational coaching alone was no more effective at increasing self-reported physical activity in sedentary people with PD than advice promoting safe movement[3]. Post hoc analysis of this data however revealed that participants with greater levels of physical fitness and better walking ability demonstrated greater increases in physical activity than the control group[29]. These results suggest real-time feedback using activity monitoring may be an effective adjunct to interventions aiming to increase physical activity in people with PD.

Results of previous studies suggest that wrist-worn activity monitors are less accurate than hip, waist and leg-worn devices in healthy populations and people with gait changes related to neurological conditions[11,12]. Only wrist-worn commercially available devices were investigated in this study as they offer the ability to monitor activity in real time, using the easy to read digital screen and may therefore be more suited to monitor and increase physical activity. It is not suggested that wrist-worn commercial devices should be considered a substitute for research grade activity monitoring devices that are typically hip, waist or leg mounted for greater step count accuracy.

Neither of the wrist-worn activity trackers reflected the intensity of activity in people with PD. A weak association was found between step count and heart rate, and there were no associations with VO_2 or perceived exertion. This differs from a recent study in young adults in which step-count recorded by the Garmin Vivofit correlated with criterion measures of energy expenditure. This was measured across a much broader range of gait speeds (0.7m/s to 3.33m/s) that included running. In the current study, the perceived exertion of walking ranged from ‘very

light' to 'somewhat hard'. A broader range of exertion, particularly including higher intensity activity may reveal a relationship between energy expenditure and step-count in this population. The results of the current study suggest that in order to achieve adequate intensity of physical activity, people with PD may benefit from a period of supervised exercise practice, using reliable methods to establish exercise intensity.

A strength of this study is that we investigated readily-available wrist-worn consumer devices and used a protocol incorporating a range of cadences and indoor and outdoor walking with challenges in people with PD. Our participant sample had low baseline activity levels, thus reflects the population in most need of increased physical activity. We did not include those with advanced PD. Our protocol could have been improved by completing a longer indoor circuit with fewer turns (>44m/lap), as this creates the potential for inconsistency in stepping which may have influenced accuracy in the indoor conditions. Participants were assessed when their anti-Parkinsonian medication was reported to be maximally effective. Our findings may not accurately represent people with PD during periods of sub-optimal medication who may experience different gait deficits such as freezing. Finally, the scope of this study was to explore the accuracy of commercially available wrist-worn activity monitoring devices. These devices were selected due in part to their growing popularity in the population in addition to the behavior change techniques that they include. No comparison to the accuracy of hip, waist or leg-worn devices was conducted. It is not suggested that commercially available wrist-worn devices should be considered a replacement for more rigorous research grade activity monitors.

Conclusion

Commercially available wrist-worn activity monitors are a feasible and effective solution for monitoring step count in people with mild-moderate PD walking at their usual pace. The

Garmin vívosmart® HR was more accurate at reflecting step count across a broader range of walking cadences than the Fitbit Charge HR™, but neither were able to strongly reflect intensity of activity. While not intended to replace research grade trunk or leg-worn devices, the Garmin vívosmart® HR and Fitbit Charge HR™ may be useful to monitor step count for clinical applications in people with PD. The Garmin vívosmart® HR did however outperform the Fitbit Charge HR™ at lower cadences. In addition to the use of activity monitoring, people aiming to achieve the physical activity guidelines would likely benefit from a period of exercise familiarisation using more accurate methods to ensure they are exercising at a sufficiently high intensity.

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Conflicts of interest

The authors have no conflict of interest to report. No funding was received for this study.

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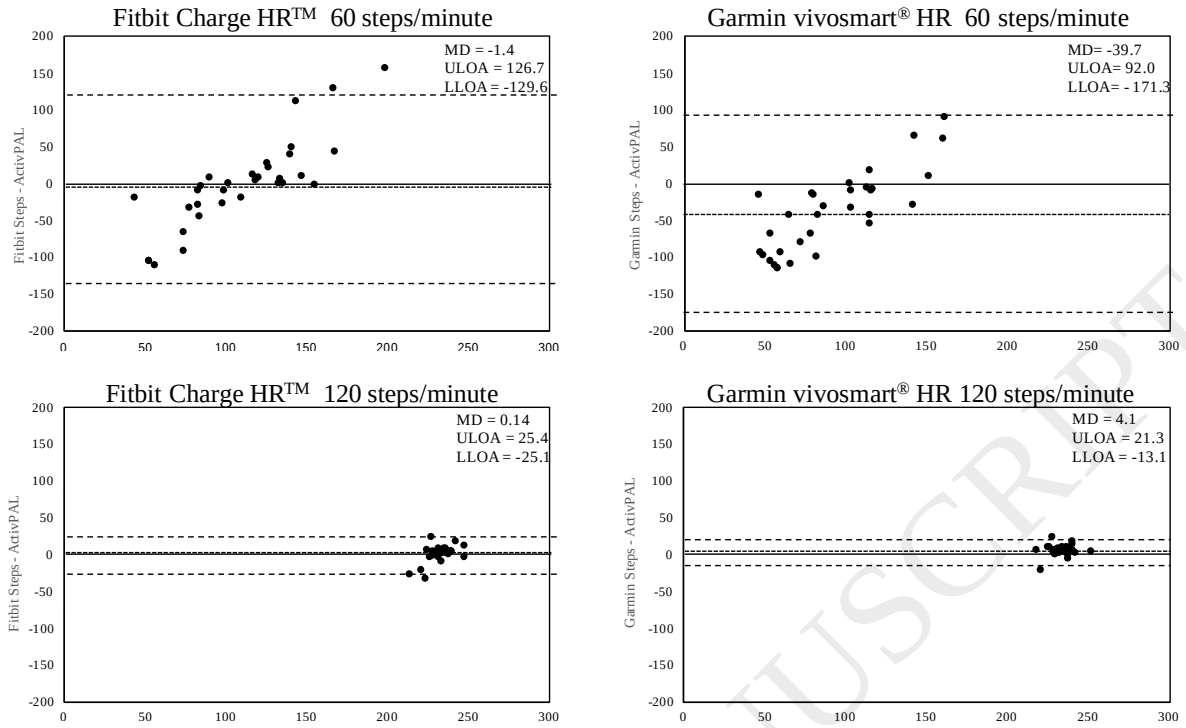
Figure 1.



Bland-Altman plots of the differences between Fitbit/Garmin devices and the ActivPAL^3™ (y-axis) and the mean of the two measurements (x-axis) measured as the participant walked for two minutes attempting to walk at 60 and 120 steps/minute. Limits of agreement and mean differences are demonstrated by the dotted lines. MD= Mean difference; LLOA= Lower limit of agreement; ULOA= Upper limit of agreement.

Figure 1. Bland-Altman limits of agreement plots comparing steps measured by the ActivPAL^3™ to the Fitbit and Garmin devices worn on the most affected side.

Table 1. Demographic and clinical characteristics (n = 33)

Characteristic	Mean (SD)
Age (years)	68.8 (8)
Disease duration (years)	7.3 (6.1)
Males, n (%)	9 (36%)
Dopamine dosage (mg)	446 (110)
Fallers, n (%)	12 (48%)
Comfortable gait speed (m/s)	1.2 (0.2)
Fast gait speed (m/s)	1.7 (0.3)
Average self-selected cadence (steps/minute)	109.2 (6.6)
UPDRS Motor subsection score	32.2 (12.9)
Hoehn and Yahr scale score, n (%)	
Stage I	11 (44%)
Stage II	12 (48%)
Stage III	2 (8%)
Freezing of gait questionnaire (score/24)	3.3 (2.6)
NASA physical activity (score/10)	4.7 (2.5)

Data presented as mean (SD) or n (%). Fallers = participants who reported falling in the last 12 months

Table 2. Step count measured by the Fitbit and Garmin devices compared to the ActivPAL^{3}™ for self-selected (indoors and outdoors) and set cadences

Cadence	Mean ActivPAL (SD)	Mean Device (SD)	Mean difference (SD)	APE (%)	LLOA	ULOA	ICC	95% CI
Fitbit								
Self-selected, in	218.2 (13.5)	219.0 (20.3)	0.4 (11.2)	2.8	-24.0	24.8	0.88*	0..76 to 0.94
Self-selected, out	685.8 (82.5)	677.9 (66.7)	-6.6 (25.6)	1.5	-64.5	51.4	0.94*	0.86 to 0.97
60	109.4 (22.4)	109.8 (65.6)	-1.4 (61.0)	37.2	-129.6	126.7	0.36	-0.29 to 0.69
80	164.6 (12.2)	188.6 (43.9)	24.1 (43.3)	17.6	-82.3	130.5	0.18	-0.67 to 0.59
100	199.6 (6.2)	213.4 (23.0)	12.6 (22.7)	6.9	-44.1	69.3	0.17	-0.72 to 0.60
120	232.2 (7.1)	233.1 (12.1)	0.14 (12.1)	3.5	-25.1	25.4	0.37	-0.39 to 0.71
140	257.0 (16.2)	255.6 (38.2)	-1.9 (35.5)	8.8	-77.7	73.9	0.42	-0.18 to 0.72
Garmin								
Self-selected, in	218.2 (13.5)	223.0 (14.6)	5.2 (7.3)	2.7	-13.9	24.3	0.93*	0.85 to 0.97
Self-selected, out	687.9 (89.0)	686.1 (82.1)	0.3 (25.2)	1.9	-54.8	55.3	0.97*	0.93 to 0.99
60	111.3 (20.0)	71.6 (59.4)	-39.7 (54.9)	60.0	-171.3	92.0	0.36	-0.30 to 0.68
80	164.5 (12.2)	162.8 (14.8)	-1.6 (8.6)	3.6	-19.9	16.8	0.89	0.76 to 0.95
100	200.7 (8.8)	204.4 (6.9)	5.4 (5.8)	3.1	-10.2	20.9	0.71*	0.40 to 0.86
120	232.2 (7.1)	236.3 (7.9)	4.1 (7.2)	2.5	-13.1	21.3	0.68*	0.39 to 0.85
140	257.0 (16.2)	254.3 (22.6)	-2.7 (18.9)	4.8	-43.3	38.0	0.70*	0.40 to 0.85

*APE= Absolute percentage error; LLOA= Lower limit of agreement; ULOA= Upper limit of agreement; ICC = Intraclass Correlation Coefficient; 95% CI = 95% Confidence interval. * $p < 0.05$.*

Table 3. Mean (SD) of intensity measures across cadences of 60-140 steps/min

Intensity Measure	60	80	100	120	140	p-value
VO_2 (ml.kg/min)	7.1 (1.7)	7.9 (1.6)	9.0 (2)	10.8 (2.3)	12.0 (3)	<0.001
Perceived exertion (Borg score/20)	8.8 (2.3)	9.5 (1.8)	10.1 (2.1)	10.8 (2.4)	12.2 (2)	<0.037
Heart rate (beats/min) *	82.8 (11.1)	84.8 (11.1)	87.5 (11.8)	92.8 (13.2)	96.7 (15)	<0.001

*Heart rate based on n = 31 due to two missing values.

Table 4. Association between cadence (60-140 steps/min) when measured by each device and measures of intensity of physical activity

	ICC (95% CI)		
Intensity Measure	ActivPAL	Fitbit	Garmin
VO_2 (ml/kg/min)	0.23 (-.05 to .44)*	0.12 (-0.19 to 0.35)	0.15 (-0.16 to 0.37)
Perceived exertion (Borg score/20)	0.16 (-.15 to .38)	0.08 (-0.25 to 0.32)	0.1 (-0.23 to 0.34)
Heart rate (beats/min)	0.47 (.27 to .61)*	0.27 (-0.002 to 0.46)*	0.28 (0.01 to 0.47)*

* $p < 0.05$