A Validation Study of Two Wrist Worn Wearable Devices for Remote Assessment of Exercise Capacity

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Abstract

We determined wearable device errors in assessing a 6-Minute Walk Test (6MWT). 16 healthy adults (male 7(44%), mean age±SD 27±4 years) performed a standard (6MWT-S) and modified, 'free range', (6MWT-FR) protocols with a Garmin and Fitbit smartwatch to measure three parameters: distance, step count and heart rate (HR). Distance during the 6MWT-FR was measured with smaller errors during 6MWT-S for both Garmin (Mean Absolute Percentage Error, MAPE=9.8% [4.6%,12.6%] vs 18.5%[13.0%,27.4%], p<0.001) and Fitbit (MAPE=9.4%[4.5%,13.3%] vs 22.7%[18.3%,29.3%], p<0.001). Steps were measured with smaller errors with Garmin (MAPE=2.3%[1.1%,2.9%]; r=0.96) than Fitbit (Fitbit: MAPE=8.1%[5.0%,12.9%]; r=0.24). Heart rate at rest, peak exercise and recovery was measured with median MAPE ranging between 1.2% and 2.9%, with no evidence of difference between the two devices. Wearable measurements of the 6MWT provide insights about exercise capacity which could be monitored and evaluated remotely.

1. Introduction

Exercise capacity, defined as the maximal or sub-maximal amount of physical exertion that an individual can sustain during a designated exercise test, is a strong independent predictor of cardiovascular and all-cause mortality and is a useful diagnostic and prognostic health indicator for patients in clinical and research settings alike.[1]

Well-established tests to assess exercise capacity are usually conducted in a clinical setting, which limits the frequency at which they can be performed and their use in very large epidemiological studies. The 6-minute walk test (6MWT) is a useful, simple and easy to administer sub-maximal test of exercise capacity that correlates with VO2max. [2] The test involves a self-paced 6-minute walk in which the participant is asked to cover as much distance as possible, without running on a level surface of at least 30 meters in length.[2] Its use in the community would be beneficial, however, a modified protocol allowing individuals to walk freely instead of along 30m straight paths is required.

Novel wrist-worn wearable technologies, in the context of healthcare, have been described as technology that 'enables the continuous monitoring of human physical activities and behaviours, as well as physiological and biochemical parameters during daily life'[3]. This provides an opportunity to monitor metrics such as heart rate and step count, in addition to recording exercise and physical capacity assessments outside of the clinical environment, at more frequent or regular intervals, at scale. This would enable the identification of trends over time, with positive implications in terms of staff burden, frequency of clinic visits and associated costs. [4-6]

Yet, there are very few studies validating the use of such technology to perform standardised tests of exercise or functional capacity in the community setting. Schubert and colleagues observed a moderate correlation (p<0.001, r=0.69) between time spent in moderate activity (passive recording) and 6MWT distance (n=107 datasets). [7] Rens and colleagues also assessed distance covered in the context of the 6MWT performed in clinic and at home as a predictor of frailty (<300m distance). Their work used the Apple watch and iPhone and found in clinic agreement of walked distance and agreement in the community to be good (better correlation seen with steps rather than GPS distance).[8]

A formal assessment of agreement between a wearable-based assessment of submaximal exercise capacity and a clinic-based assessment (that considers heart rate in addition to distance covered/step count) would be a useful addition to both the literature and the development of a framework for remote, unsupervised, 6MWT. The aim of this study was to determine wearable device accuracy in assessing exercise capacity to develop a framework for a remote, unsupervised, 6MWT.

2. Methods

2.1. Study Population

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Participants were recruited from staff and students at University College London (UCL) and were considered eligible for enrolment into the study if they fulfilled the inclusion criteria and none of the exclusion criteria as defined below:

Inclusion criteria: Ability to provide written informed consent. Exclusion criteria: < 18 years old; considered a vulnerable adult; participant unwilling to consent; terminal illness or severe comorbidities affecting attendance or study investigations; pregnancy; inability or presence of a contra-indication for exercise testing [9]

All participants were asked to provide written informed consent to participate and for their data to be stored in accordance with the General Data Protection Regulation and Data Protection Act 2018. Investigations were conducted at the UCL Bloomsbury Centre for Clinical Phenotyping and Tavistock Square Gardens, London.

2.2. 6-Minute Walk Tests

16 healthy adults (male 7(44%), age 27[26-29] years) were enrolled to perform 6MWTs using two protocols: 1) standard - straight 30m laps (6MWT-S) and 2) Free range – circular 240m laps (6MWT-FR).

Each participant was fitted with a Garmin vivoactive4 and Fitbit Sense wrist-worn wearable to measure the following parameters: distance, step counts and heart rate (HR) response. Wrist positioning was randomised and reference measures were obtained through a meter-wheel, hand tally counter (rounded to closest 10 steps) and ECG (Faros 180, Bittium) respectively. All tests were supervised and performed across two visits.

An appropriate activity recording was started on the wearable devices followed by a 1-minute standing resting phase. Study participants were directed to walk up and down a 30-meter flat stretch marked by cones for the 6MWT-S protocol. For the 6MWT-FR protocol, study participants were directed to walk freely around a park (240-meter laps). Participants were asked to walk at a pace as fast as could be maintained without running.

Both protocols were followed by a 3-minute standing recovery and activity recordings were stopped after completion of the recovery phase.

The total distance covered (number of 30m lengths or 240m laps and the distance covered from the start to the stop position) was measured using a meter wheel. The number of steps taken were measured by hand tally counter. Heart rate was measured by ECG (Faros 180, Bittium) using bespoke software [10]. Mean HR was measured during three intervals: 1) at rest (30 seconds prior to the onset of exercise); 2) at peak exercise (from the 5th to 6th minute of exercise) and 3) during recovery (from the 1st to the 2nd minute post exercise).

2.3. Statistical Analysis

Statistical analyses were performed using MATLAB and STATA 17. Sample characteristics are described using median [interquartile range, IQR] for continuous variables. Categorical variables are summarised as frequency (percentage). Agreement is assessed using Bland-Altman plots and presented as mean differences [limits of agreement (LOA), i.e. ± 1.96 x standard deviation of differences]. Correlations are assessed using the Spearman’s correlation coefficient (ρ) and mean absolute percentage error (MAPE), reported as median [IQR]. Differences between matched and unmatched samples were assessed using the signrank Wilcoxon and ranksum Wilcoxon tests, respectively.

3. Results

3.1. Study Characteristics

The characteristics of the 16 study participants are summarised in Table 1.

Table 1. Study participant characteristics. Data expressed as median [interquartile range, IQR] or frequency (%). BMI, Body Mass Index.

Median [IQR] or frequency(%)	n=16
Sex (male)	7(44%)
Age (years)	27[26,29]
Height (cm)	170.5[161.1,174.8]
Weight (kg)	67.3[63.4,77.0]
BMI (kg/m^2)	23.9[22.4,25.7]

3.2. Distance

Distance covered during the 6MWT-FR (677m[648m,746m]) was measured with smaller errors than during 6MWT-S (646m[618m,693m]) for both Fitbit (6MWT-S: MAPE=22.7%[18.3%,29.3%]; r=0.54; 6MWT-FR: MAPE=9.4%[4.5%,13.3%]; r=0.86) and Garmin (6MWT-S: MAPE=18.5%[13.0%,27.4%]; r=0.18; 6MWT-FR: MAPE=9.8%[4.6%,12.6%]; r=0.71), indicating that the 6MWT-FR protocol is more suitable for remote monitoring (Figure 1). MAPE for distance was not significantly different between Garmin and Fitbit in either 6MWT-S or 6MWT-FR protocol, p=0.27 and p=0.91 respectively.

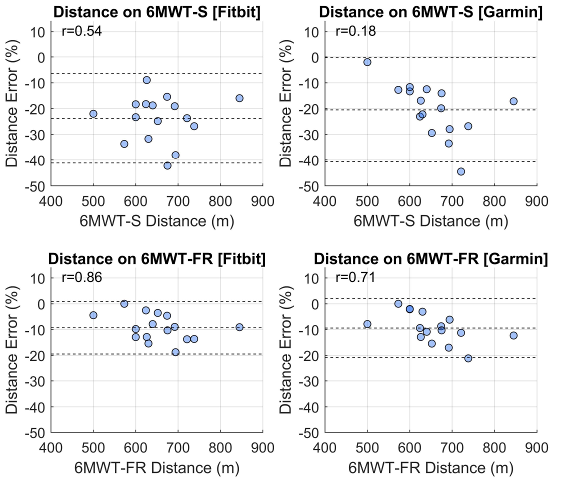


Figure 1. Bland-Altman plots demonstrating levels of agreement between wearable devices (GPS) and distance (meter wheel) during 6MWT-S and 6MWT-FR.

3.3. Step Count

The Garmin device showed smaller errors with reference to step count for both 6MWT-S (Fitbit:MAPE=8.1%[5.0%,12.9%]; vs Garmin:MAPE=2.3%[1.1%,2.9%], p<0.001;) and 6MWT-FR (Fitbit:MAPE=9.6%[3.9%,18.0%]vs Garmin:MAPE=1.5%[0.6%,2.1%] p<0.001) (Figure 2).

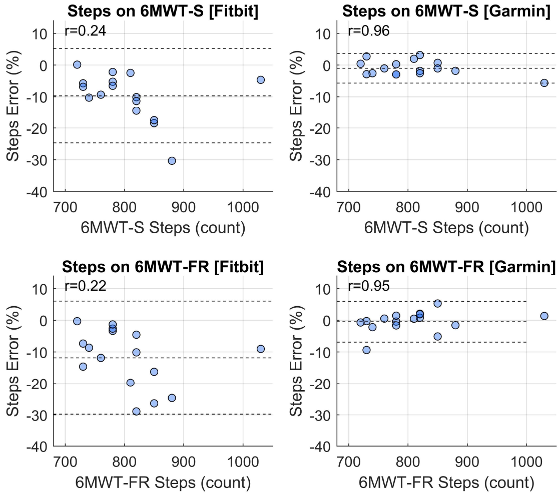
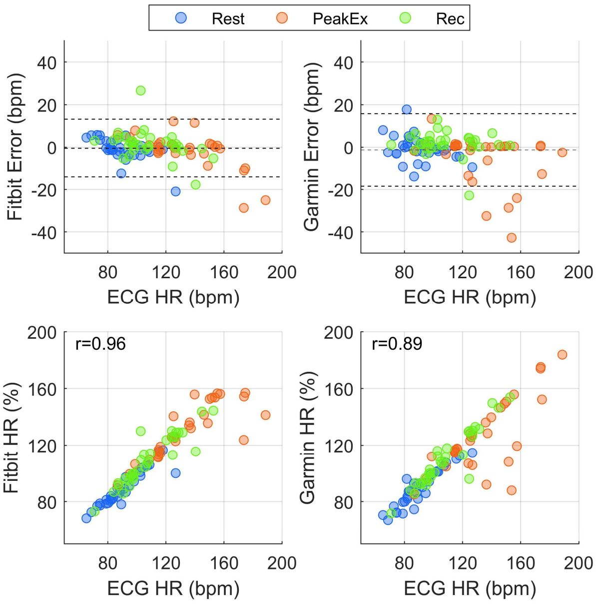


Figure 2. Bland-Altman plots demonstrating levels of agreement between wearable devices (step count) and reference measure of step count (hand tally counter) during 6MWT-S and 6MWT-FR.

3.4. Heart Rate

Heart rate results and Figure 3 present a pooled analysis for both 6MWT protocols. Both devices showed small errors in measuring heart rate at rest (Fitbit:MAPE=2.4%[1.4%,4.3%];Garmin:MAPE=2.9%[1.5%,6.4%]) and recovery (Fitbit: MAPE=2.9%[1.1%, 5.1%]; Garmin: MAPE=2.9%[1.0%-5.1%]).
Error during peak exercise for Fitbit was MAPE=2.0%[1.0%,6.9%] and for Garmin: MAPE=1.2%[0.4%-9.6%]).

Figure 3. Bland-Altman and correlation plots demonstrating levels of agreement between wearable devices (heart rate) and ECG HR in a pooled analysis of both 6MWT-S and 6MWT-FR.



4. Discussion

We sought to establish the accuracy of two wrist-worn wearable devices for distance, step count and heart rate during 6MWT performed in the traditional standardised manner and to compare this to ‘free range’ walking. One of the main findings was that both devices had smaller errors of distance for the 6MWT-FR protocol (median MAPE <10%) compared to the 6MWT-S protocol. Both devices measure distance through the activation of GPS and the greater errors seen in the 6MWT-S is likely due mainly to the protocol which consists of a short 30m stretch which requires time spent turning and a frequent number of turns per test. All tests were performed in an inner city which in turn may contribute errors in GPS measured distance, however, this reflects realistic scenarios of remote monitoring.

Step count is measured by both devices using a composite of stride length (estimated by pre-programmed height) and tri-axial accelerometry data. In agreement with Rens and colleagues’ findings, we observed better accuracy in step count compared to distance. [8] The Garmin device performed better than the Fitbit with a median MAPE of <2.5% compared with ~10% for Fitbit. This finding likely also relates to the turning requirement in 6MWT-S and the small pivot steps required to do so which may be underestimated by the devices.

In addition to the primary metric of the 6MWT, distance/steps covered, wearables offer the opportunity to have continuous HR data throughout the test, (at rest, during peak exercise and in recovery). Resting HR, heart rate at peak exercise and heart rate recovery (HRR) post exercise are independently associated with mortality [11,12]. Both devices demonstrated good HR accuracy at rest and recovery. During peak exercise, measured during the final minute of exercise, errors slightly increased in both devices, although median MAPE for HR was found to be < 5%.

Limitations relating to wearable devices tend to be twofold and include technological factors such as motion artefact and signal cross-talk, in addition to biological factors such as adiposity, wrist dominance, wrist circumference and skin tone. [13,14] Investigation into the potential sources of inaccuracies is part of ongoing work. Other limitations of this study include its small sample size, and the age and healthy condition of participants. Nevertheless our results suggest wearable technology provides an exciting opportunity to be able to monitor exercise capacity frequently and its trajectory at scale.

5. Conclusion

Wearable measurements of the 6MWT provide insights about exercise capacity which could be monitored and evaluated remotely using modified protocols to suit community testing.

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