Case Report

Healthc Inform Res. 2015 October;21(4):315-320.
http://dx.doi.org/10.4258/hir.2015.21.4.315
pISSN 2093-3681 • eISSN 2093-369X

HIR
Healthcare Informatics Research

Are Currently Available Wearable Devices for Activity Tracking and Heart Rate Monitoring Accurate, Precise, and Medically Beneficial?

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Objectives: The new wave of wireless technologies, fitness trackers, and body sensor devices can have great impact on healthcare systems and the quality of life. However, there have not been enough studies to prove the accuracy and precision of these trackers. The objective of this study was to evaluate the accuracy, precision, and overall performance of seventeen wearable devices currently available compared with direct observation of step counts and heart rate monitoring. **Methods:** Each participant in this study used three accelerometers at a time, running the three corresponding applications of each tracker on an Android or iOS device simultaneously. Each participant was instructed to walk 200, 500, and 1,000 steps. Each set was repeated 40 times. Data was recorded after each trial, and the mean step count, standard deviation, accuracy, and precision were estimated for each tracker. Heart rate was measured by all trackers (if applicable), which support heart rate monitoring, and compared to a positive control, the Onyx Vantage 9590 professional clinical pulse oximeter. **Results:** The accuracy of the tested products ranged between 79.8% and 99.1%, while the coefficient of variation (precision) ranged between 4% and 17.5%. MisFit Shine showed the highest accuracy and precision (along with Qualcomm Toq), while Samsung Gear 2 showed the lowest accuracy, and Jawbone UP showed the lowest precision. However, Xiaomi Mi band showed the best package compared to its price. **Conclusions:** The accuracy and precision of the selected fitness trackers are reasonable and can indicate the average level of activity and thus average energy expenditure.

Keywords: Fitness Trackers, Accuracy, Precision, Heart Rate, Step Counting

Submitted: September 20, 2015
Revised: October 15, 2015
Accepted: October 20, 2015

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I. Introduction

Addressing the obesity problem worldwide is not only a focus of the pharmaceutical industry, but also the software and hardware technology industry. Nowadays, starting with simple pedometers, highly intelligent technology has been adopted [1]. The fitness-sensing market has been primarily dominated by body-worn sensors, which are often integrated or connected to discrete devices with global positioning system (GPS) receivers [1]. The activity-sensing market is expected to be worth circa $975 million by 2017 [1]. The use of wearable technologies, such as the Fitbit, is becoming increasingly common among the general public [1]. Seventeen million wearable fitness bands are expected to be sold in 2014, rising to 45 million by 2017 and 99 million annually by 2019 [2].

The use of smartphones and wireless smart trackers in healthcare systems depends on recording activity and monitoring vital signs, such as calorie consumption, fitness activity, pulse, weight, heart rate, oxygen level, and sleep pattern [3,4]. New trends of health and fitness trackers have been developed to track calorie intake and activity pattern along with calorie burning rate. Such trackers adopt MotionX technology using 3D accelerometers to identify movement and transform it to calories burnt. They also measure sleep pattern and pulse and translate all of these data into health information [5].

The use and implementation of various sensors, such as 3D accelerometers, pedometers, and heart rate monitors, in mobile and wearable devices has enabled the successful use of such devices in health applications [6]. A three-axis accelerometer measures change in X, Y, and Z coordinates to track activity [7]. An accelerometer also records sleep quality by watching movement during sleep [8].

Devices such as the Apple Watch, Samsung Galaxy Gear 2, and Samsung Galaxy S5 mobile phone include embedded heart rate monitors. They measure the heart rate by using light to track the blood [9]. Such devices illuminate the capillaries with a light-emitting diode (LED), a sensor that measures the frequency at which the blood pumps. Other trackers, such as Garmin Vivofit, are sold with a more accurate heart rate monitor to be used in conjugation with the tracker [10,11]. Another trend is using embedded smartphone cameras to estimate heart beats accurately [12]. Poh et al. [12] developed an algorithm to detect any slight increase in blood volume via light absorption and reflection pattern from the user's face. This idea was commercialized in the Cardiio mobile application. It promises measurement accuracy within 3 beats/min of a clinical pulse oximeter when used at rest in a well-lit environment [12].

The use of smartphones, smart watches, wearable trackers, and new health applications has started a revolution in the healthcare system [13,14]. These devices monitor physical activity and provide a convenient continuous feedback. Despite widespread sales of these devices, there has been little evaluation of their use, accuracy, or precision [15].

The objective of this study was to evaluate the accuracy and precision of currently available wearable devices with respect to their pedometer and heart rate monitor compared with direct observation of step counts and traditional devices for counting the heart rate [16,17].

II. Case Description

1. Materials

The Apple Watch, Samsung Gear Fit, Samsung Gear 1, Samsung Gear 2, Samsung Gear S, iHealth Tracker (AM3), Pebble Steel, Pebble Watch, Qualcomm Toq, Motorola Moto 360, Garmin Vivofit, Mi Band, MisFit Shine, Jawbone Up, Nike+ Fuelband SE, Sony Smartwatch (SWR10), and FitBit Flex were purchased for the assessment of accuracy and precision (Supplementary Figure 1). All of these fitness wearable trackers were selected based on their popularity, availability, consumer surveys, price, and public sales figures during the period from late 2014 until mid-2015 [18]. Table 1 provides a detailed comparison of the various devices included in this study.

2. Methods

This prospective study recruited four healthy adults aged between 22 and 36 years through direct verbal communication. Participants gave verbal informed consent to walk 200, 500, and 1,000 steps. An observer counted steps using a tally counter throughout the period from March 2014 until June 2015. This study was approved by the home institution's ethical committee board.

On the wrist, each participant wore three accelerometers at a time. In one pants pocket, each carried either an Android or iOS device simultaneously running the three corresponding applications of each tracker. Each set was repeated 40 times. Data was recorded after each trial, and the mean step count, standard deviation, accuracy, and precision were estimated for each tracker.

Heart rate was measured by all trackers (if applicable), which support heart rate monitoring, and compared to a positive control, the Onyx Vantage 9590 professional clinical pulse oximeter, which has been well validated for research, measured at the same time on the same hand wearing the tracker. Thirty readings were recorded for each tracker simultaneously.

Finally, the consistency of the synchronization of these trackers with their corresponding mobile application was tested 20 successive times. The number of successful synchronization was counted for each tracker to its corresponding application.

The accuracy and precision were calculated in each study. Accuracy refers to the closeness of measured values to the positive control in each study. The positive controls in case of step counting and heart rate measurements were the observer-counted steps using the tally counter and heart rate measurements obtained using the Onyx Vantage 9590 professional clinical pulse oximeter, respectively. Accuracy

http://dx.doi.org/10.4258/hir.2015.21.4.315

Table 1. Comparison of all fitness devices used in this study

Tracker	Price ($)	Nature	iOS Comp.	Android Comp.	Windows Comp.	Web Interface	Destop Sync	App Quality	Accuracy (%)	CV (%)	Sync Tech.	Battery Life	Screen	Tourch-Screen	Sleep Tracking	Automatic Sleep Monitoring	Custom-ization	Integration with Google Fit	Integration with Apple Health	Ease of Use	Special Charger	Color Options	Heart Rate Monitor	UV Index Monitor	O_2 Monitor	Location	SmartPhone Functions Integration
Apple Watch	349-999+	Smartwatch	Yes	No	No	No	No	Good	99.06	4.48	BL 4.0	~ 1 Day	Yes	Yes	No	No	Yes	No	Yes	NA	Yes	Yes	Yes	No	No	Hands	Yes
Samsung Gear Fit	199		No	Partial (Samsung Only)				Average	85.20	9.67		1-2 Days					No		No	Easy		No					
Samsung Gear 1	299								96.69	7.25		< 1 day										Limited	No				
Samsung Gear 2	299								79.76	10.70												Yes	Yes				
Samsung Gear S	399								82.28	11.39												No		Yes	Yes		
Pebble Watch (MisFit App)	99		Yes	Yes		Depend on App		Good	94.92	10.42		3-6 Days		No				Yes	Yes			Yes	No	No	No		
Pebble Steel (MisFit App)	199								95.91	10.39												No					
Qualcomm Toq	249		No			No			98.02	4.03		3-4 Days		Yes				No	No	Aver-age							
Moto 360	299					Yes			88.96	12.97		< 1 day						Yes					Yes				
Fitbit Flex	99	Fitness Tracker	Yes		Yes	Yes	Yes		80.43	13.70		4-6 Days	No	No	Yes	No	Yes	Yes	Yes	Easy		Yes	No				No
MisFit Shine	99					No	No		99.08	4.04		4-6 Months				Yes					No Charger Needed					Any Where	
iHealth Tracker	69				No			Poor	89.26	12.95		1-2 Days	Yes			No				Hard	No (MicroUSB)	Limited				Hand or Waist	
Jawbone UP	99					Yes		Good	82.51	17.46	Direct Plug-in	5-7 Days	No				No				Yes	Yes				Hands	
Mi Band	14					No		Average	96.56	5.81	BL 4.0	20-30 Days				Yes	Yes			Easy							Yes
Sony SmartBand	76		No					Good	96.05	9.64		2-4 Days				No			No		No (MicroUSB)						
Nike+ FuelBand SE	149		Yes			Yes	Yes		95.64	8.11			Yes				No		Yes		No (Full USB)						No
Garmin VivoFit	99								97.01	4.55		1+ Year				Yes	Yes			Hard	No Charger Needed		With Acces-sory				

percentages were calculated based on the percent by which measurements deviated from the average. The coefficient of variability (CV%), between the repeated measurements for each tracker and user, represents the precision. All data and statistical analysis for each device was estimated using GraphPad Prism version 6.

3. Results

Across all devices, 200, 500, and 1,000 step count observations were recorded for four participants. The participants were all males and had a mean age of 26.5 years (standard deviation [SD] = 12.8 years).

Figure 1 shows the results for the 200, 500, and 1,000 steps trials counted by the tracker devices. Compared with direct observation, the accuracy and precision of the tested wearable devices ranged from 99.1% (MisFit Shine) to 79.8% (Samsung Gear 2) for accuracy and 4% (MisFit Shine and Qualcomm Toq) to 17.5% (Jawbone UP) for precision. Findings were generally consistent between the 200, 500, and 1,000 step trials.

The Apple Watch showed accuracy of 99.1% (SD = 16.6) for 200 step counts, rising to 99.5% (SD = 25.8) for 1,000 step counts. It showed the most precise results for 1,000 steps (CV = 2.6). MisFit Shine showed competitive accuracy of 98.3% (SD = 7.2) for 200 steps, rising to 99.7% (SD = 39.8) for 1,000 steps. However, Samsung Gear 1 showed 97% accuracy (SD = 8.5) for 200 steps, declining to 94% (SD= 103.9) for 1,000 steps. Qualcomm Toq showed about 97% accuracy (SD = 6.9) but it showed the most precise result with CV% of 3.6. Qualcomm Toq maintained very precise results for 500 steps (CV = 5.2) and 1,000 steps (CV = 3.4).

Figure 2 shows the heart rate measurements of the trackers against the Onyx Vantage 9590 professional clinical pulse oximeter as a positive control. Compared to the Onyx Vantage 9590 pulse oximeter, the accuracy and precision of the tested wearable devices ranged from 99.9% (Apple Watch) to 92.8% (Motorola Moto 360) for accuracy and from 5.9% (Apple Watch) to 20.6% (Samsung Gear S) for precision.

The accuracy percentages of heart rate measurements (Figure 2) obtained by the Apple Watch, Motorola Moto 360, Samsung Gear Fit, Samsung Gear 2, Samsung Gear S, Apple iPhone 6 (using Cardiio application), Apple iPhone 5S (us-

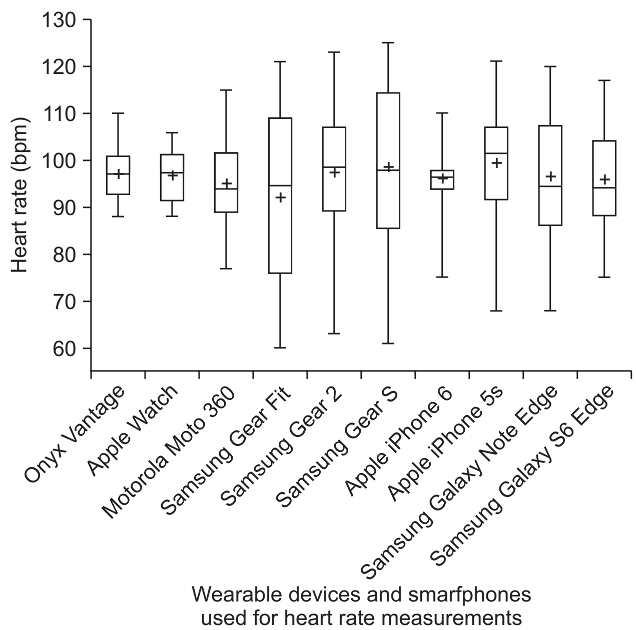

Figure 2. Heart rate measurements (bpm) of various trackers against the Onyx Vantage 9590 as a positive control.

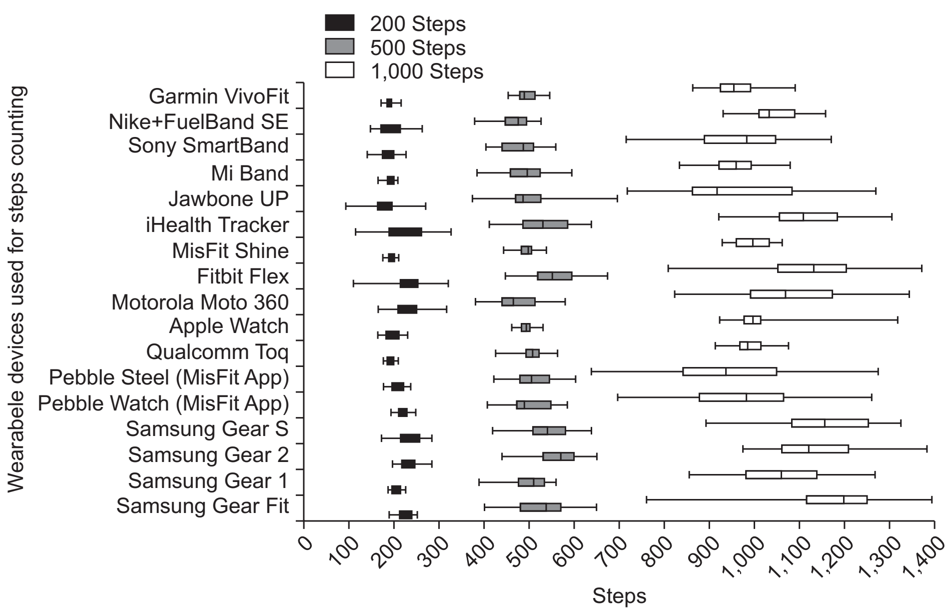

Figure 1. Numbers of steps calculated by the trackers against numbers of steps counted by the observer indicating the accuracy of each tracker. The error bars indicate ±1 standard deviation.

http://dx.doi.org/10.4258/hir.2015.21.4.315

ing Cardiio application), Samsung Galaxy Note Edge, and Samsung Galaxy S6 Edge were 99.9% (SD = 5.7), 92.8% (SD = 14.1), 97.4% (SD = 28.8), 97.7% (SD = 16.5), 95.0% (SD = 20.9), 99.2% (SD = 6.3), 97.6% (SD = 12.4), 99.6% (SD = 14.4), and 98.8% (SD = 11.6), respectively.

Finally, there was no significant difference in the consistency of synchronization with the Apple iOS and Google Android devices. Within Android version 5 (Lollipop) showed the best consistency (Supplementary Figure 2).

III. Discussion

We found that several of the wearable fitness trackers and smart watches were relatively accurate for tracking step counts and heart rate. Generally, the data recorded were slightly different from observed step counts and heart rates, but they could deviate positively or negatively. Some devices reported step counts more than 15% than the observed count, but none exceeded 20% deviation.

Though the accuracy of a tracker is an important characteristic, it is not the only determinant of the quality of a tracker. The associated mobile application, compatibility with a variety of mobile operating systems, customization options, ease of use, efficacy of synchronization with the mobile devices, size, and external appearance affect the final appeal of a tracker to consumers. The mobile application has a major role as it is the interface for interpretation of data collected by a tracker.

In conclusion, consumers use these fitness trackers and smart watches to estimate physical activity, such as distance or calories burned based on step count and sleep monitoring. For such purposes, these trackers were found to be relatively accurate and beneficial. Increased physical activity facilitated by these devices could lead to clinical paybacks with low cost, as in case of the Xiaomi Mi Band priced at $14 [4]. Such devices, along with their tight integration with Apple Health and Google Fit platforms, can significantly help in improving the quality of life of consumers and help in integrating mobile technology into efforts to solve many health problems, such as obesity and heart disease.

Conflict of Interest

No potential conflict of interest relevant to this article was reported.

Acknowledgments

We thank our colleagues from SmartCi center of research excellence (Virginia Tech–Middle East and North Africa [VT-MENA]) who provided insight, support and expertise that greatly assisted this study. We would also like to express our gratitude to Dr. Mustafa Y. ElNainay (Associate Professor of Computer and Systems Engineering, Alexandria University and Adjunct Professor of Electrical and Computer Engineering, Virginia Tech. University, USA) for his valuable comments and suggestions and for supplying us with some of the tested trackers. Finally, we thank Ms. Haidy Haggag, Ms. Nada Ahmed, and Eng. Esraa Mustafa for their comments that greatly improved the manuscript.

Supplementary Materials

Supplementary materials can be found via http://dx.doi.org/10.4258/hir.2015.21.4.315. Figure 1. Trackers tested for accuracy, precision and validity. (A) Apple Watch, (B) Samsung Gear Fit, (C) Samsung Gear 1, (D) Samsung Gear 2, (E) Samsung Gear S, (F) iHealth Tracker (AM3), (G) Pebble Steel, (H) Pebble Watch, (I) Qualcomm Toq, (J) Motorola Moto 360, (K) Garmin Vivofit, (L) Mi Band, (M) MisFit Shine Band, (M) MisFit Shine necklace (O) Jawbone Up, (P) Nike+ Fuelband SE, (Q) Sony Smartband (SWR10), (R) FitBit Flex. Figure 2. Bluetooth synchronization consistency of Xiaomi Mi Band, Nike Fuelband SE, Fitbit Flex, and MisFit Shine across various devices with Google Android and Apple iOS mobile operating systems represented as number of successful synchronization trials per 20 times on each device.

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http://dx.doi.org/10.4258/hir.2015.21.4.315