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Validation of consumer wearable activity tracker as step measurement in free-living conditions

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Abstract

Different generations of consumer wearable activity trackers are prevalent with the increasing demands in health and physical activity monitor. This pilot study aims to validate one of the consumer wearable activity trackers, the Mi band 2 as a step measurement in free-living conditions.

Thirty-one healthy volunteers, aged 23 to 45 with 16 female (52%), wore both Mi band 2 and ActiGraph GT9X Link on their dominant hand's wrist for seven consecutive days. The validity of the electronic activity devices was assessed objectively by average steps/day using i) Paired sample t-tests; ii) Pearson correlation. In addition, Bland-Altman plots was constructed to visually inspect the data and to assess agreement with the ActiGraph accelerometer.

There was a high correlation in steps/day between the reference device, Actigraph accelerometer and Mi Band 2 ($r = 0.97$, $p < 0.001$). No significant mean different in steps/ day and no apparent systematic biases in the Bland-Altman plots between step count measurements obtained using the Mi Band 2. Xiaomi Mi Band 2 provided valid step count measurement in the free-living conditions.

Keywords: e-health, step count, accelerometer

Introduction

Healthy practices could be facilitated by different technological means [1-2]. In the recent years, the increasing popularity of consumer wearable activity tracker brings researchers' interests in using it as one of the tools in physical activity [3-4] and walking [5] interventions. As consumer wearable devices provide feedback and offer interactive behavior change tools via a mobile device, or computer for long-term tracking and data storage, there are concerns in the validation of these devices [6].

Steps is intuitive, objective and easy to measure as a metric for assessing physical activity and the number of steps per day is usually used for quantifying ambulatory physical activity [7]. The validity for steps measurement of consumer wearable activity trackers are usually performed by comparing its counted steps against different criterion measures, such as manual step counting, either in-person [8] or with video recordings [9], or steps recorded by pedometer [10] or accelerometer [11]. Different brands and models of wrist-worn consumer wearable devices were examined for its accuracy in step measurement in laboratory setting, e.g. treadmill walking [12], level walking [13] and stair walking [10]. Most of these consumer wearable devices showed high in correlations in step measurement with the reference criteria in the systematic review [14]. However, mixed results of different brands and models were found in evaluating its step accuracy in free-living conditions [15]. For example, Garmin Vivofit showed higher validity than Polar Loop in measuring daily step counts in free-living conditions [16] while Fitbit One and Fitbit Flex showed no difference in step measurement with the criterion measures in free-living conditions [17].

To our knowledge, the validation of popular new device, Mi Band 2 (Xiaomi Corp. China) has not yet been covered in free-living conditions. Therefore, the purpose of this pilot study is to assess the validity of the step count of this popular model of electronic activity monitor device in a population of healthy adults during free-living environment.

Methods

Study population

A convenience sample of 40 healthy volunteers was recruited. This is comparable to the sample size used in previous electronic activity devices validation studies of step measurement in free-living conditions [11,18]. It was suggested that step count of consumer-level activity monitors in free-living conditions correlated with reference devices above r =.80 [3]. To detect weather a correlation of 0.80 differs from zero, with α =.05 and β =0.20, a sample size of 9 participants would be needed [19]. Participants were eligible for inclusion if they were aged 18 years or above, willing to monitor their activity for a seven day period, worked or studied in the University and could walking freely without restrictions and aids. Participants were excluded if they were in injured or being affected by illness for mobility. In this study, 40 volunteers with the ability to walk without aid were recruited from the university community. Participants' step count, measured by the accelerometer, ActiGraph GT9X Link, was taken as the criterion measure for steps.

Research ethics

The study was approved by the Senate Committee on the Use of Human and Animal Subjects in Teaching and Research, of the University. The participants were asked to consent to the research and were informed about the use of the data.

Procedure

The Informed consent was obtained from the volunteers after the explanation of possible risks and benefits associated with the experimental procedure. Participants' demographic data (age, height, mass, gender, and dominant hand) were measured and collected at the beginning of the test. Height, mass and gender data were entered into the Mi Band 2 account and setting in accelerometer for each participant prior to the 7-day walking test. The devices were set up with unique user accounts.

Instruments

The Mi Band 2 devices were bought from a retailer directly while the manufactures of the Mi Band 2 device has no role in the funding, design or conduct of the study, or analysis of the results. Mi Band 2 has a military-grade accelerometer that converts acceleration to step counts using proprietary algorithms. Both designs of Mi Band 2 and ActiGraph GT9X Link are fit for wearing as wristband.

All individuals were invited to wear a Mi Band 2 (Xiaomi Corp., China) with and ActiGraph GT9X Link accelerometer (Actigraph Inc., USA) at their wrists of dominant hands. Participants were asked to wear both devices during the waking hours, except swimming and bathing. They were also suggested to remove the devices during sleeping. Participants completed an online daily diary to record number of steps.

After seven days, participants were invited to return the devices and provide their written feedback on Mi Band 2, using a utility questionnaire adapted from previous research of Tully [20] in order to further investigate participants' acceptability to use Mi Band 2 as step measurement in the future.

Data treatment

Daily steps were recorded for each participant. An average steps/day was calculated for each participant. This was calculated by summing the total number of steps taken between testing and dividing by the number of valid whole days (i.e. 5 days). Data was cleaned by removing non-wear time for the Actigraph accelerometer. Non-wear time was analysed as a run of zero counts lasting more than 150 minutes. To be included in the analysis, subjects had to provide at least five valid days of the Actigraph data. A valid day was defined as a 24 hour period in which at least 10 hours of data wear time was recorded in an electronic spreadsheet. Data from Mi Band 2, i.e. steps per day was recorded from the apps. The researcher conducted the data at the end of the 7-day wear period and average steps/day was calculated. At the end of the study, the Actigraph data was analysed using Actilife version 6.13.3 (Actigraph Inc., USA) to calculate steps per day in these seven days.

Data analysis

Statistical analysis was performed using Statistical Package for the Social Science (SPSS) (Version 23). Descriptive statistics were calculated for each variable. Normality was assessed (Shapiro-Wilk test of normality) on the step count data to determine the use of nonparametric or parametric techniques.

The validity of Mi Band 2 as step measurement of free-living physical activity was assessed by comparing its output (steps/day) with that of the Actigraph accelerometer (steps/day). The testing protocol is based on the recommendations from Welk's study [21] and previous activity monitor validation study [20]. To test the validity of electronic wearable activity tracker, Welk and his research team suggested that three aspects are needed to demonstrate the following agreement. First, the two measures being compared must yield equivalent group estimates (evidenced by mean difference). Besides, the measures must be associated with each other (evidenced by correlation coefficients). In addition, the measures must be free from bias (evidenced by Bland-Altman plots).

As normality shown on data, it was analysed into three aspects:1) Paired sample t-tests were used to evaluate mean difference in step counts between the Mi Band 2 and the ActiGraph accelerometer. 2) Pearson's correlation coefficients and the p-values were calculated to provide an indication of the relationship between the recorded step counts from the Mi Band 2 and ActiGraph accelerometer. In order to assess the agreement between measurement of these two devices, Bland-Altman plot was used as the standard method [22], both visually and statistically interpretation. The difference in the step count measured by the two devices, is plotted against the averages.

Results

There were 40 volunteers for the study at the beginning of study. Three individuals failed to participate in the test while six individuals' records were less than four valid days. At the end of the one week recording period, valid data was available for 78% (n=31/40) of those who participated. There were 31 participants, mean (SD) age 32.5 (7.15) years, participated and 53% of (n=16) of the cohort were female. The mean and interquartile range of cohort's characteristics are provided in Table 1.

There are no statistically significant difference observed in steps between the Mi Band 2 and Actigraph accelerometer. Comparing the Mi Band 2 with the reference device demonstrated high correlation with steps/day measured (r = 0.97). Table 2 shows the figures of the pair sample t-test of Mi Band 2 and Actigraph accelerometer.

Table 1. Descriptive Characteristics of the Cohort (n=31, Male=15, Female =16).

Measure	Mean (IQR)
Age	32.5 (10)
BMI	22.3(4.5)
Mi Band 2 measured steps per day	10951 (2630)
Actigraph measured steps per day	11098 (2726)

*IQR = Interquartile range

Table 2. Pair Sample t-test on step measurements of Mi Band 2 and the Actigraph (n=31).

	Mean bias	t	Sig.(2 tailed)
Mi Band 2 vs Actigraph (steps/day)	146	1.67	.105

Table 3. Comparison of the Mi Band 2 with the Actigraph Accelerometer (n=31).

	Pearson correlation	ICC(95% Confidence Intervals)
Mi Band 2 vs Actigraph (steps/day)	0.97**	0.98(0.97-0.99)

**indicates significance at p < 0.001.

The Pearson's correlation coefficients of Actigraph and Mi Band 2 were 0.97 (p <0.001) (Table 3). According to the rule of thumb for interpreting the size of correlation coefficient [23], it was the very high correlation. The limits of agreement (± 1.96SD) reflect where 95% of all differences between measurements are expected to lie. There was a significant (p < 0.001) and very strong correlation between step count measured by the Mi Band 2 and corresponding step count measurement using the Actigraph accelerometer.

For visually and statistically interpretation, Bland-Altman plot was used to illustrate the differences between step count measurement by Actigraph accelerometer and Mi Band 2. It revealed no systematic differences between the Mi Band 2 and Actigraph measured steps/day (Figure 1).

Overall speaking, there was a high acceptability of the Mi Band 2 among the respondents. All of the participants commented that it was easy to use the Mi Band 2 in measuring step every day. The majority of respondents rated the Mi Band 2 as acceptable to use and easy to integrate into their daily routine. All of the participants commented that it was not annoying to use the Mi Band 2 (Table 4).

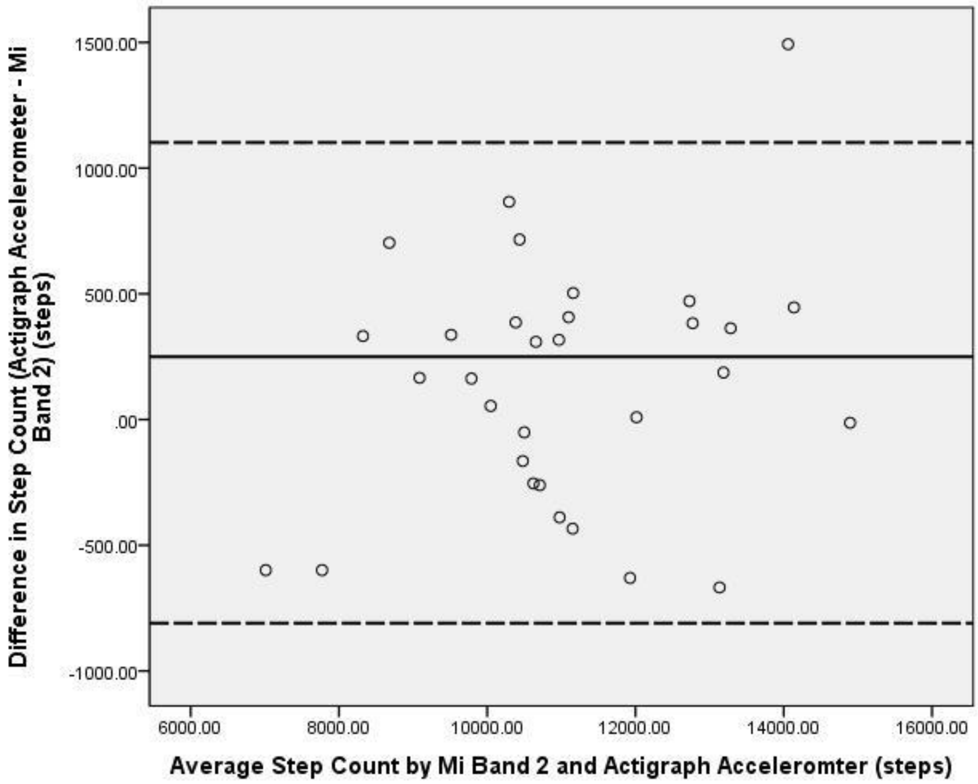

Figure 1. Bland and Altman representing comparison between the criterion measure (Actigraph Accelerometer) and the Mi Band 2 step count output. Solid line indicates the mean difference between Actigraph Accelerometer and Mi Band 2, and the dashed lines indicate the limits of agreements (1.96 ± SD). SD, standard deviation.

Table 4. Participants' responses towards utility of the Mi Band 2 physical activity monitor.

Question	Response
Was using the Mi Band 2 every day for 7 days an acceptable method to measure your daily step?	Not acceptable (n=0) Neither 32% (n=10) Very acceptable 68% (n=21)
Was there any problem to use the Mi Band 2 every day?	Difficult to remember (n=0) Neither 32% (n=10) No problem 68% (n=21)
Did using the Mi Band 2 interfere with your daily routine?	Interfered greatly 6% (n=2) Neither 35% (n=11) Did not interfere at all 58% (n=18)
Was the Mi Band 2 annoying to use?	Extremely annoying (n=0) Neither 42% (n=12) Not annoying 58% (n=18)

Discussion

The use of consumer wearable activity tracker is associated with modest changes in steps, blood pressure and HDL cholesterol in previous study [4]. As the number of steps per day is usually used for quantifying ambulatory physical activity [7], it is crucial to have accurate step measurement of these trackers for health benefits. In this pilot study, Mi Band 2 is a valid device for monitoring step counts in free-living conditions. It is proven by the following evidences. First, there is no significant difference between Mi Band 2 measured steps/day with that of the criterion measure, Actigraph accelerometer. Besides, the high level of Pearson's correlation coefficients (0.97, p<0.001) of Mi Band 2 and the accelerometer reflected that their number of measured steps are highly associated. In this experiment, most data collected by Mi Band 2 fell within the 95% limits of agreement with that of the accelerometer. Furthermore, from the Bland-Altman plot, we found that there is no apparent systematic bias. Therefore, the use of Mi Band 2 as a measure of step in free-living environment is recommended. This is echoed with author's research that Mi Band 2 is a reliable and valid device for step counts in the laboratory setting [24]. The result is also consistent with the systematic review that consumer wearable activity trackers are high in validity in step measurement in different circumstances [3].

Besides, as consumer wearable activity devices have become more and more popular, it is important that these devices are user-friendly for health status monitoring, recording and exercise promotion. User perceptions and experiences in using these devices are therefore crucial. In the cross-sectional study of users' experiences of wearable activity tracker [25], it is clearly stated that users find activity trackers appealing and useful tools for increasing perceived physical activity levels over a sustained period. The survey from this pilot study supported that most of the participants favourably rated the utility of the Mi Band 2 and it is not difficult to use it every day for step recording. Consumer wearable devices are one of the useful intervention tools for increasing physical activity among different populations [26-28]. This implied that Mi Band 2 could be further used as one of the interventional tools in promoting daily step and physical activity level.

There were limitations of this pilot study. First, the convenience sampling may limit the generalizability of the study. The participants of this pilot study were university students or employees. Further investigation may necessary for validation in other population, e.g. different age groups. However, the included participants undertook a wide range of physical activity levels (ranged from 6712 to 14901 steps/day), suggesting they are representative of the population. Besides, validation of other new models and brands could also be included in the further study in order to have a comprehensive comparison among these consumer wearable activity trackers in measuring steps in free-living conditions.

In conclusion, Xiaomi Mi Band 2 provided valid step count measurement in the free-living conditions. Furthermore , the relatively low cost of Mi Band 2 (USD $30) may attract more and more people willing to take the lead to use electronic activity devices to facilitate their health status monitoring, recording and physical activity participation.

Conflict of interest statement

There is no commercial association with Xiaomi Corp. that might create conflicts of interest relevant to this study. Ka Man Tam is the Lecturer of Hong Kong Institute of Vocational Education. No competing financial interests exist.

References

[1] Chaudhry B, Wang J, Maglione M, Mojica W, Roth E. Systematic review: impact of health information technology on quality efficiency and costs of medical care. Ann Intern Med. 2006 May 16;144(10):742-52. https://doi.org/10.7326/0003-4819-144-10-200605160-00125

[2] Starfield B. Patient Lists and Patient-Focused Care Overtime. New York: Oxford University Press; 1998.

[3] Wang JB, Cadmus-Bertram LA, Natarajan L, White MM, Madanat H, Nichols JF, Pierce JP. Wearable sensor/device (Fitbit One) and SMS text-messaging prompts to increase physical activity in overweight and obese adults: a randomized controlled trial. Telemed J E Health. 2015 Oct;21(10):782-92. https://doi.org/10.1089/tmj.2014.0176

[4] Thorndike AN, Mills S, Sonnenberg L, Palakshappa D, Gao T, Pau CT, Regan S. Activity monitor intervention to promote physical activity of physicians-in-training: Randomized controlled trial. PLoS One. 2014 Jun 20;9(6):e100251. https://doi.org/10.1371/journal.pone.0100251

[5] Cadmus-Bertram LA, Marcus BH, Patterson RE, Parker BA, Morey BL. Randomized Trial of a Fitbit-Based Physical Activity Intervention for Women. Am J Prev Med. 2015 Sep;49(3):414-8. https://doi.org/10.1016/j.amepre.2015.01.020

[6] Fokkema, T, Kooiman TJM, Krijnen WP, Van Der Schans CP, De Groot M. Reliability and validity of ten consumer activity trackers depend on walking speed. Med Sci Sports Exerc. 2017 Apr;49(4):793-800. https://doi.org/10.1249/MSS.0000000000001146

[7] Bassett DR, Toth LP, LaMunion SR, Crouter SE. Step Counting: A review of measurement considerations and health-related applications. Sports Med. 2017 Jul;47(7):1303-1315. https://doi.org/10.1007/s40279-016-0663-1

[8] Case MA, Burwick HA, Volpp KG, Patel MS. Accuracy of smartphone applications and wearable devices for tracking physical activity data. JAMA. 2015 Feb 10;313(6):625-6. https://doi.org/10.1001/jama.2014.17841

[9] Diaz KM, Krupka DJ, Chang MJ, Peacock J, Ma Y, Goldsmith J, Davidson KW. Fitbit®: An accurate and reliable device for wireless physical activity tracking. Int J Cardiol. 2015 Apr 15;185:138-40. https://doi.org/10.1016/j.ijcard.2015.03.038

[10] Huang Y, Xu J, Yu B, Shull PB. Validity of FitBit, Jawbone UP, Nike+ and other wearable devices for level and stair walking. Gait Posture. 2016 Jul;48:36-41. https://doi.org/10.1016/j.gaitpost.2016.04.025

[11] Noah JA, Spierer DK, Gu J, Bronner S. Comparison of steps and energy expenditure assessment in adults of Fitbit Tracker and Ultra to the Actical and indirect calorimetry. J Med Eng Technol. 2013 Oct;37(7):456-62. https://doi.org/10.3109/03091902.2013.831135

[12] Sears T, Avalos E, Lawson S. Wrist-worn physical activity trackers tend to underestimate steps during walking. Int J Exerc Sci 2017;10(5):764-773.

[13] Takacs J, Pollock CL, Guenther JR, Bahar M, Napier C, Hunt MA. Validation of the Fitbit One activity monitor device during treadmill walking. J Sci Med Sport. 2014 Sep;17(5):496-500. https://doi.org/10.1016/j.jsams.2013.10.241

[14] Evenson KR, Goto MM, Furberg RD. Systematic review of the validity and reliability of consumer-wearable activity trackers. Int J Behav Nutr Phys Act. 2015 Dec 18;12:159. https://doi.org/10.1186/s12966-015-0314-1

[15] Ferguson T, Rowlands AV, Olds T, Maher C. The validity of consumer-level, activity monitors in healthy adults worn in free-living conditions: A cross-sectional study. Int J Behav Nutr Phys Act. 2015 Mar 27;12:42. https://doi.org/10.1186/s12966-015-0201-9

[16] Simunek, A, Dygryn J, Gaba A, Jakubec L, Stelzer J, Chmelik F. Validity of Garmin Vivofit and Polar Loop for measuring daily step counts in free-living conditions in adults. Acta Gymnica. 2016;46(3):129–135. https://doi.org/10.5507/ag.2016.014

[17] Reid RER, Insogna JA, Carver TE, Comptour AM, Bewski NA, Sciortino C, Andersen RE. Validity and reliability of Fitbit activity monitors compared to ActiGraph GT3X+ with female adults in a free-living environment. J Sci Med Sport. 2017 Jun;20(6):578-582. https://doi.org/10.1016/j.jsams.2016.10.015

[18] Farina N, Lowry RG. The validity of consumer-level activity monitors in healthy older adults in free-living conditions. J Aging Phys Act. 2018 Jan 1;26(1):128-135. https://doi.org/10.1123/japa.2016-0344

[19] Hulley SB. Designing clinical research (3rd ed.). Philadelphia, USA: Lippincott Williams & Wilkins; 2007.

[20] Tully MA, McBride C, Heron L, Hunter RF. The validation of Fitbit Zip™ physical activity monitor as a measure of free-living physical activity. BMC Res Notes. 2014 Dec 23;7:952. https://doi.org/10.1186/1756-0500-7-952

[21] Welk GJ, McClain J, Ainsworth BE. Protocols for Evaluating Equivalency of Accelerometry-Based Activity Monitors. Med Sci Sports Exerc. 2012 Jan;44(1 Suppl 1):S39-49. https://doi.org/10.1249/MSS.0b013e3182399d8f

[22] Bland JM, Altman DG. Statistical Methods for Assessing Agreement between Two Methods of Clinical Measurement. Lancet. 1986 Feb 8;1(8476):307-10. https://doi.org/10.1016/S0140-6736(86)90837-8

[23] Hinkle DE, Jurs SG, Wiersma W. Applied statistics for the behavioral sciences. Brantford, Ont.: W. Ross MacDonald School Resource Services Library; 2011

[24] Tam KM, Cheung SY. Validation of Electronic Activity Monitor Devices During Treadmill Walking. Telemed J E Health. 2018 Oct;24(10):782-789. https://doi.org/10.1089/tmj.2017.0263

[25] Henriksen A, Mikalsen MH, Woldaregay AZ, Muzny M, Hartvigsen G, Hopstock LA, Grimsgaard S. Using fitness trackers and smartwatches to measure physical activity in research: Analysis of consumer wrist-worn wearables. J Med Internet Res. 2018 Mar 22;20(3):e110. https://doi.org/10.2196/jmir.9157

[26] Cadmus-Bertram LA, Marcus BH, Patterson RE, Parker BA, Morey BL. Randomized Trial of a Fitbit-Based Physical Activity Intervention for Women. Am J Prev Med. 2015 Sep;49(3):414-8. https://doi.org/10.1016/j.amepre.2015.01.020

[27] Wang JB, Cadmus-Bertram LA, Natarajan L, White MM, Madanat H, Nichols JF, Ayala GX, Pierce JP. Wearable Sensor/Device (Fitbit One) and SMS Text-Messaging Prompts to Increase Physical Activity in Overweight and Obese Adults: A Randomized Controlled Trial. Telemed J E Health. 2015 Oct;21(10):782-92. https://doi.org/10.1089/tmj.2014.0176

[28] Rote AE. Physical activity intervention using Fitbits in an introductory college health course. Health Educ J 2017;76(3):337–348. https://doi.org/10.1177/0017896916674505