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Accuracy of Xiaomi Mi Band 2.0, 3.0 and 4.0 to measure step count and distance for physical activity and healthcare in adults over 65 years

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ABSTRACT

Background: The measurement of step count and distance covered are of interest in healthcare and rehabilitation medicine, so fitness trackers and smartwatches have incorporated these metrics. In 2014, the introduction of new brands of these devices peaked, although the highest number of new devices was introduced in 2015. Even though *Mi Band Xiaomi* was among the top 5 regarding sales, it is not at the top of the fitness bands considered in research articles.
Research question: this study aimed to assess the validity of *Xiaomi Mi Band 2.0, 3.0* and *4.0* for recording steps and distance covered.
Method: The data were recorded from 26 elderly adults (71.2 ± 3.2 years old; 169.3 ± 5.8 height; 72.1 ± 9.2 weight), who covered the maximum distance possible at walking speed in a delimited outdoor space following different trajectories to compare data with the criterion measure, using three wristband devices (*Xiaomi Mi Band* versions *2.0*, *3.0.* and *4.0.*).
Results: In step count, the average bias was small (<2.6 steps) and no statistical differences were found between instruments ($p > 0.76$; t=0.30). However, *Xiaomi Mi Band 4.0* obtained questionable validity (ICC = 0.76) for distance estimation.
Significance: The accuracy of Mi Band Xiaomi 2.0., 3.0. and 4.0. may be considered as good to count the number of steps for physical activity monitoring, whereas distance estimation is considered questionable.

1. Introduction

Since it has been highlighted that physical activity (e.g. walking patterns) of patients can affect the treatment of different pathologies such as diabetes, cerebral palsy, cerebrovascular accidents and neuromuscular dystrophies [1], step counts and distance covered are the most commonly used measurements in healthcare and rehabilitation medicine [2–5]. Thus, the development of technology is presented in light of showing the importance of such devices in activity monitoring, and how both the medical profession and private consumers can benefit from them [6,7]. To date, Electronic Performance and Tracking Systems [8] are a suitable method for physical activity monitoring. However, the advances in Microelectromechanical Systems (MEMS) has made it feasible to manufacture Inertial Measurement Units (IMU) with sensors (i.e. accelerometer, gyroscope, barometer) that are low cost, low on power consumption and also lightweight [9,10].

An IMU is a set of sensors that can potentially track changes in gait over time, by extracting spatiotemporal gait parameters from acceleration and angular velocity data [9]. Among others, IMUs can be incorporated into a Wireless Body Sensor Network (WBSN), or smartwatches and fitness bands. The former one is a group of wearable sensor nodes with computational, storage, and wireless transmission capabilities, that are allocated on different body segments to monitor body motion, skin temperature, heart rate, and more [11]. However, the later represent a simpler approach based on a single node, and their computation follows the pedometer concept [10]. Since WBSN seems more accurate in assessing overall health conditions [11], manufacturers of smartwatches and fitness bands have tried to develop their algorithms to improve precision.

Concurrent validity, the agreement between the observed value and

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the true or criterion value of a measure, is one of the most important aspects of measurement error [12]. Thus, a model with a high degree of veracity is of great importance to report a precise estimation of user's movement patterns, specifically, when it is used to plan, prescribe, and monitor patient activity [13]. The precision and validity of automated algorithms have been assessed to partition IMU waveforms into step intervals and estimate parameters such as mean step duration, walking speed, and symmetry [14,15]. The popularity of smartwatches and fitness bands for physical activity has increased exponentially since 2014 [5], where their accuracy became fundamental for them to be commercially competitive for healthcare and medical treatment uses. Since *Mi band Xiaomi* has become one of the top five devices in sold units [5], it is one of the most popular smart wristbands devices for activity monitoring and healthcare. However, until 2018 a systematic review [5] reported that only 1 study had assessed the validity of Xiaomi devices [16], and to our knowledge, although more studies have considered these brand devices since 2018, all of them validated the *Mi Band Xiaomi 2.0* model and the validation of the new Xiaomi models is lacking in the literature. Therefore, this study aimed to assess the validity of *Xiaomi Mi band versions 2.0*, *3.0* and *4.0* for step counting; and *Xiaomi Mi Band* version *4.0* for distance covered.

2. Methods

2.1. Participants

26 elderly adults (13 male and 13 female) were enrolled in the present study (71.2 ± 3.2 years old; 169.3 ± 5.8 height; 72.1 ± 9.2 weight). The participants were included based on two inclusion/exclusion criteria: (1) more than 65 years old; and, (2) not lower limb pathology or other medical conditions (e.g., neuromuscular or cardiopulmonary impairments) affecting walking ability. The University of Murcia approved the study (Reg. code: 2061/2018). Informed consent was obtained from all participants before they participated in the study.

2.2. Design

A cross-sectional design was followed to evaluate the concurrent validity of different wristband and inertial devices for step counting and distance measurement. For this purpose, each participant wore three wristband devices (*Xiaomi Mi Band* versions *2.0.*, *3.0.* and *4.0.*) and a WIMU PRO^{TM} inertial device at the scapular level (considered as a gold standard).

Participants covered the maximum distance possible at walking speed and choosing their own route in an outdoor space following different trajectories to compare data between the criterion measure and assessed devices for step count and distance measurement.

2.3. Instruments

2.3.1. WIMU PRO ^{TM}

This device is composed of different tracking (indoor, ultrawide band, UWB, 18 Hz; outdoor, global navigation satellite systems, GNSS, 10 Hz) and microelectromechanical sensors (MEMS) such as four 3-D accelerometers (output range: ±16, ±16, ±32 and ±400 g), three 3-D gyroscopes (output range: ±2000, ±2000, ±4000 grades/second), a magnetometer and a barometer, among others. MEMS recorded at a 100 Hz sampling frequency in the present study. These sensors were used for step count, with the validity and reliability of WIMU PRO^{TM} at the scapular level having been reported previously [17]. Similarly, the UWB technology in this device has shown satisfactory results for distance measurement [18]. As the criterion measure, a WIMU PRO^{TM} was placed at the scapular level for recording steps through microelectromechanical sensors and distance through UWB.

2.3.2. Xiaomi Mi Band 2.0

Xiaomi Mi Band 2.0: is a wristband that detects steps and heart rate for daily activity. The device measures 40.3 × 15.7 × 10.5 mm and weighs 7 g. It integrates an efficient 3-D accelerometer to detect steps and a photoelectric sensor to detect heart rate.

2.3.3. Xiaomi Mi band 3.0

Xiaomi Mi band 3.0: is a wristband that detects steps and heart rate for daily activity. The device measures 46.9 × 17.9 × 12 mm and weighs 20 g. It integrates an efficient 3-D accelerometer to detect steps and a photoelectric sensor to detect heart rate.

2.3.4. Xiaomi Mi Smart band 4.0

Xiaomi Mi Smart band 4.0: is a wristband that detects steps and heart rate for daily activity. The device measures 47 × 21.6 × 10.8 mm and weighs 22.1 g. It integrates a 3-D accelerometer and a 3-D gyroscope to detect steps and estimated distance covered, and a photoelectric sensor to detect heart rate.

All Xiaomi Mi Smart band versions (2.0, 3.0 and 4.0) allow the configuration of sex, date of birth, height, weight and activity target. All parameters were configured previously to recording from the data obtained using a rod stadiometer (SECA, Hamburg, Germany) and an 8-electrode segmental body composition monitor (TANITA model BC418-MA, Tokyo, Japan).

2.4. Procedures

Participants were cited 30-minutes previously to the trials to place the wristbands and the inertial devices. The inertial devices were placed on the scapulae in a special neoprene vest. The wristbands were placed on the wrist with the specific watchband. The elderly adults walked continuously for five sets of four minutes on an outdoor futsal court with a concrete surface. They walked at a comfortable pace (speed avg: 2.76 ± 0.21 km/h) and in the preferred direction. During trials, participants could talk to each other with the aim of simulating a walking routine.

For the UWB system, the study methodology proposed by Rico-González, Los Arcos, et al., [19] to warrant the strict protocol has been followed. Positional data were gathered by a time-motion tracking system using a commercial Local Positioning System (LPS) (IMU; WIMU PRO^{TM}, RealTrack Systems, Almeria, Spain) based on ultrawide band (UWB) technology. The UWB technology operates on much wider frequency band than other traditional radio communication technologies (at least, 0.5 GHz), and a previous study did not report any problems in UWB-based tracking system accuracy in multipath condition (i.e. 28 devices turned on) [18]. In addition, satisfactory results were found in accuracy of distance with respect to the real measurement (Mean of differences: 0.03 m; magnitude differences = 0.21 %; CV < 1%) [20] and step counting with respect to video-analysis (mean of differences = 0.03 steps; ICC = 0.99; CV = 0.02 %) [17].

The data were recorded in a training space further to metallic materials. The UWB system is composed of a reference system and devices tracked carried by the players. The first one is composed of antennae that are transmitters and receivers of the radio-frequency signals. The antennae (mainly the master antenna) computerize the position of the devices that are into the area, while the device receives that calculation using Time Difference of Arrival (TDOA). The eight antennae were set up around the field forming an octagon to better signal emission and reception at a height of 3 m and held by a tripod [21]. Once installed, they were switched on one-by-one, with the master antenna turned on last. From that moment, it was necessary to respect a 5-minute protocol to avoid a technology lock. To allow data time synchronization, the master antenna incorporates a clock which allows data recording from all devices at the same time.

2.5. Statistical analysis

Walking steps and distance were measured with the WIMU PRO^{TM} inertial device and *Xiaomi Mi Band* versions *2.0.*, *3.0.* and *4.0.* (wristband devices) for concurrent validity. The WIMU PRO^{TM}at the scapular level with accelerometers and UWB tracking technology was considered as the criterion measure for step count and distance measurement following previous research [17,22]. Data obtained through the inertial and wristband devices are reported as mean ± standard deviation. The average results from 5 × 4-min walking trials of each participant were used for analysis. To assess the concurrent validity and to identify potential systematic bias for measuring steps, Bland-Altman plots are reported to show the bias and 95 % limits of agreement with intraclass correlation coefficient (ICC) analysis with 95 % interval confidence was performed. ICC was calculated from the formula provided by Shrout & Fleiss for one-way classification [23]:

$$\rho = \frac{\sigma_s^2}{\sigma_s^2 + \sigma_e^2}$$

This last statistical method (ICC) was interpreted following Vincent & Weir [24]: questionable (ICC < 0.80), moderate (0.80 > ICC > 0.90), and high (ICC > 0.90). Analyses and figures were completed and designed using IBM SPSS Statistics (release 24.0; SPSS Inc., Armonk NY, USA) and GraphPad Prism (release 7; GraphPad Software, La Jolla CA, USA).

3. Results

Table 1 and Fig. 1 shown the accuracy results of wristband devices and WIMU PRO^{TM} inertial devices for step count. Xiaomi devices obtained nearly perfect validity with respect to the criterion (ICC > 0.99). Although these devices obtained higher values than the criterion, the average bias was small (<2.6 steps) and no statistical differences were found ($p > 0.76$; t=0.30).

In addition, Table 1 and Fig. 2 show the accuracy results of the wristband device *Xiaomi 4.0.* for distance measurement with respect to the criterion (WIMU PRO^{TM} UWB). *Xiaomi 4.0.* obtained questionable validity (ICC = 0.76; 95 % CI = 0.53 to 0.69). In the Bland-Altman analysis, the differences with respect to the criterion were -0.009 ± 0.016 (95 % LOA= -0.040 to 0.022). In addition, *Xiaomi 4.0.* obtained higher values than the criterion at lower distances, and lower values than the criterion at higher distances.

Table 1
Descriptive analysis and concurrent validity for steps counting and distance covered.

Comparison	Device (M ± SD)	Criterion (WIMU^{TM} UWB) (M ± SD)	Bias ± SD	95%LOA (L to U)	ICC	95% CI (L to U)
	Steps (count)					
Xiaomi Mi Band 2.0.	244.2 ± 20.4	241.8 ± 20.9	2.3 ± 2.0	−1.5 to 6.1	0.99	0.99 – 1.00
Xiaomi Mi Band 3.0.	243.6 ± 20.5	241.8 ± 20.9	1.8 ± 2.3	−2.6 to 6.2	0.99	0.98 – 1.00
Xiaomi Mi Band 4.0.	244.0 ± 20.3	241.8 ± 20.9	2.1 ± 2.1	−1.9 to 6.2	0.99	0.99 – 1.00
	Distance covered (km)					
Xiaomi Mi Band 4.0	0.169 ± 0.02	0.178 ± 0.03	−0.009 ± 0.016	−0.040 to 0.022	0.76	0.53 – 0.69

Note. SD: Standard deviation; Bias: Mean difference between units' measurement; LOA: Limits of the agreement; ICC: Intraclass correlation coefficient; L: Lower; U: Upper.

4. Discussion

The purpose of this study was (1) to assess the validity of *Xiaomi Mi band versions 2.0*, *3.0* and *4.0* for step counting, and (2) *Xiaomi Mi Band* version *4.0* for distance covered, comparing these wearables against the officially certified WIMU^{TM} (IMU; WIMU PRO^{TM}, RealTrack Systems, Almeria, Spain). The main findings revealed that the average bias was small (<2.6 steps) and no statistical differences were found between instruments ($p > 0.76$; t=0.30) for step count. However, the results showed that *Xiaomi Mi Band 4.0* obtained questionable validity (ICC = 0.76) for distance estimation.

In 2014, the introduction of new brands of fitness trackers and smartwatches peaked, although the highest number of new devices was introduced in 2015 [5]. From then on, sensor support has increased every year, and in addition to the accelerometer, a photoplethysmograph for estimating heart rate has joined them as the most common sensor [5]. In 2018, 423 unique devices from 132 different brands were identified (i.e., 47 % of brands released only one device), and out of the brands available, the top 5 in 2015 and 2016 in sold units were Fitbit, Xiaomi, Apple, Garmin, and Samsung. However, the five most often used in research projects are Fitbit, Garmin, Misfit, Apple, and Polar, and Xiaomi has been assessed only once [16]. Therefore, there is a lack of research on the *Mi Band Xiaomi* models.

Since 2018, different studies have considered *Mi band Xiaomi* for accuracy assessment in physical activity and healthcare, however, to our knowledge, all of them considered version *2.0.* [13,25,26], and none compared it with UWB technology, which has been considered as the most accurate system in most research [8,22,27,28]. In this respect, Stamm and Hartanto [13] developed a study of walking on a treadmill at different intensities, finding that *Mi Band 2.0.* from Xiaomi had the strongest agreement with the IMU in comparison with FitBit, Samsung, and Vidonn wearables. Moreover, Tam and Cheung [25] found a very strong correlation between step count and distance measured by the observer and the corresponding step count using the Mi Band 2.0. So, as in the present study, *Mi Band 2.0.* seems accurate for walking step count. However, there is a lack research on the validity of Mi Band Xiaomi 3.0. and 4.0.

In the present study, in addition to the corroboration of the validity and suitability of Mi band 2.0. against an officially certified WIMU^{TM} system with well-above (Q1 minus 1.5*IQR to 25th percentile) and above (25th percentile to median) accuracy results in speed and position [29] and near perfect validity in distance (Mean of differences: 0.03 m; magnitude differences = 0.21 %; CV < 1%) [20] and step counting (mean of differences = 0.03 steps; ICC = 0.99; CV = 0.02 %) [17], the agreement was assessed between different models from the same company (*Xiaomi Mi Band 3.0.* and *4.0.*). The results found nearly perfect validity with respect to the criterion (WIMU^{TM}*scapulae*) (ICC > 0.99) in step count. Besides, although these devices obtained higher values than the criterion, the average bias was small (<2.6 steps) and no statistical differences were found ($p > 0.76$; t=0.30).

However, due to the development in models, *Xiaomi Mi Band 4.0* integrates a 3-D accelerometer and a 3-D gyroscope to detect steps and estimate distance covered. While the step count obtained high accuracy, the results showed that *Xiaomi Mi Band 4.0* obtained questionable validity (ICC = 0.76) for distance estimation. Fig. 2 shows a systematic bias in outcomes with a saw tooth relationship suggesting that the way of determining the distance is directly related to cadence of stepping and this algorithm leads to differences in agreement [30]. In this respect, the bias is increased in adults who walk slower obtaining a poorer detection of distance. These results could be explained as the Xiaomi Mi Band versions do not allow the configuration of stride length and estimate this parameter from the height of the athlete. A previous research identified that the configuration of one parameter only seems to be insufficient due to leg lengths is not directly associated with athletes' heights, as well as with stride frequency [30,31]. Therefore, to improve accuracy on distance covered it seems necessary to incorporate this parameter (other

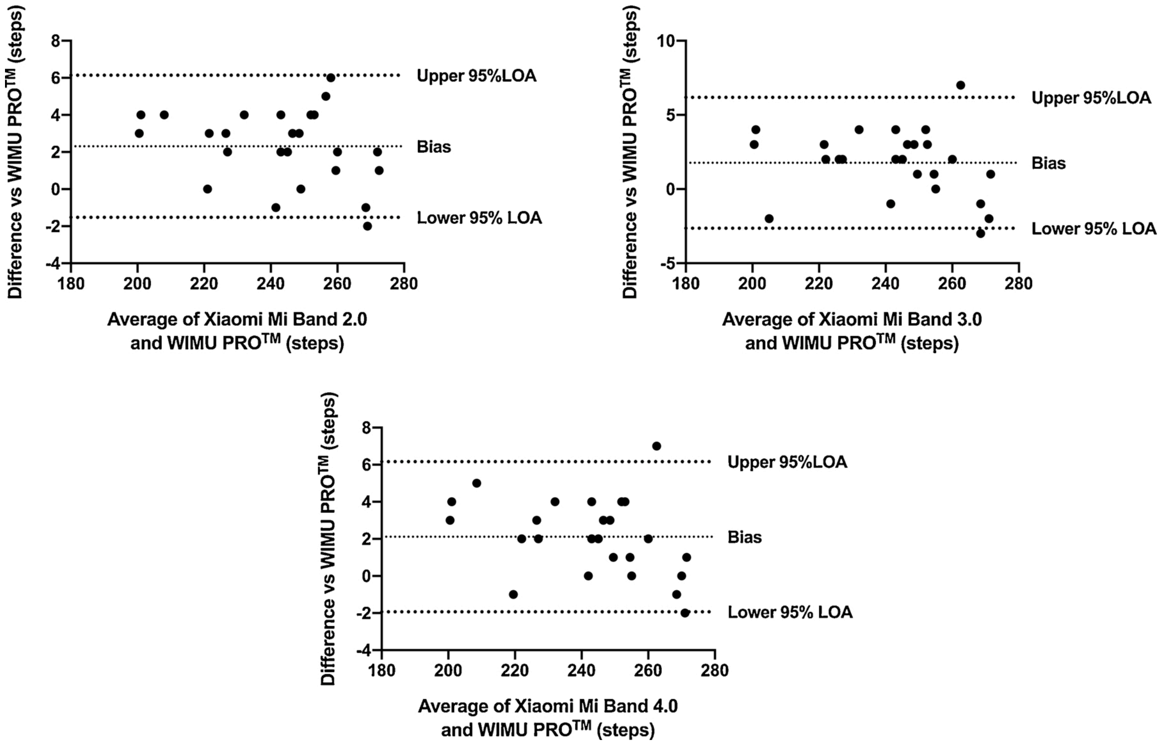

Fig. 1. Bland-Altman plots with bias and 95 % LOA to analyze concurrent validity between criterion (WIMU PRO^{TM}) and Xiaomi Mi Band versions (2.0, 3.0 and 4.0) for step counting.

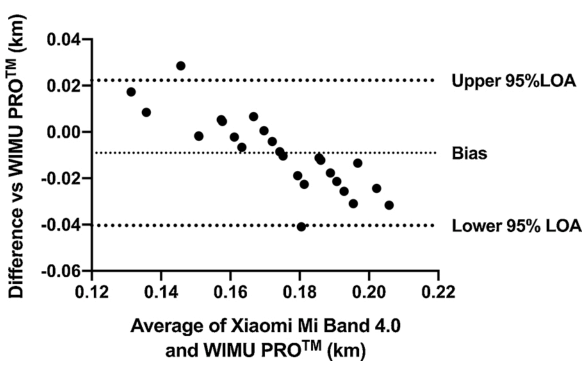

Fig. 2. Bland-Altman plots with bias and 95 % LOA to analyze concurrent validity between criterion (WIMU PRO^{TM}) and Xiaomi Mi Band version 4.0 for distance covered.

companies incorporate this parameter in their configuration, hardware or/and software) and modify the algorithm based on stepping cadence.

5. Limitations

Despite the fact that the considered *gold standard* is not a manual count or a treadmill (considered as a *gold standard* in step count and distance measures), the results were compared against a validated device, which has been awarded FIFA's *quality certificate* [29].

6. Conclusions

The accuracy of *Mi Band Xiaomi 2.0., 3.0.,* and *4.0.* may be considered as good as the accuracy of the WIMU PRO^{TM} and therefore they could be interchangeable in terms of counting the number of steps for physical activity monitoring for healthcare, medical prescription, and rehabilitation. However, due to the shown questionable distance measures by *Mi Band Xiaomi 4.0* in comparison with the WIMU PRO^{TM} with UWB tracking technology, alternative methods should be used to analyze distance covered.

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Author contributions

Conceptualization: M. R.-G. Data curation: J. P.-O. Formal analysis: J. P.-O., and C. G. C. Funding acquisition: C. G. C. Investigation: J. P.-O., C. G. C., and M. R.-G. Methodology: J. P.-O., C. G. C., and M. R.-G. Project administration: J- P.-O. Software: J. P.-O. Supervision: J. P.-O., C. G. C., and M. R.-G. Validation: J. P.-O., C. G. C., and M. R.-G. Visualization: J. P.-O., C. G. C., and M. R.-G. Roles/Writing - original draft: M. R.-G. Writing - review & editing: J. P.-O., C. G. C., and M. R.-G.

Authorship conformation form

All authors have participated in (a) conception and design, or analysis and interpretation of the data; (b) drafting the article or revising it critically for important intellectual content; and (c) approval of the final version.

Declaration of Competing Interest

The authors declare that they have no competing financial interests.

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