©Journal of Sports Science and Medicine (2023) **22**, 196-211
http://www.jssm.org DOI: https://doi.org/10.52082/jssm.2023.196

Research article

Validity of the Xiaomi Mi Band 2, 3, 4 and 5 Wristbands for Assessing Physical Activity in 12-to-18-Year-Old Adolescents under Unstructured Free-Living Conditions. Fit-Person Study

Carolina Casado-Robles [1], Daniel Mayorga-Vega [2], Santiago Guijarro-Romero [3]✉ and Jesús Viciana [1]
[1] Department of Physical Education and Sport, University of Granada, Granada, Spain; [2] Departamento de Didáctica de las Lenguas, las Artes y el Deporte, Facultad de Ciencias de la Educación, Universidad de Málaga, Málaga, España; [3] Department of Didactic of Musical, Plastic and Corporal Expression, University of Valladolid, Valladolid, Spain

Abstract

The purpose was to assess the validity of four generations of Xiaomi Mi Band wristbands for the assessment of step count and physical activity (PA) levels among adolescents aged 12- 18 years under free-living conditions. One hundred adolescents were invited to participate in the present study. The final sample consisted of 62 high-school students (34 females), aged 12 - 18 years old (M_{age} = 14.1 ± 1.6 years), who wore an ActiGraph accelerometer on their hip (PA and step count reference measures) and four activity wristbands (Xiaomi Mi Band 2, 3, 4, and 5) on their non-dominant wrist during the waking time of one day. Results showed that the agreement between daily PA levels (i.e., slow, brisk, and slow-brisk pace walking, total PA and moderate-to-vigorous PA) measured by Xiaomi Mi Band wristbands and the accelerometer were poor (ICC, 95% CI = 0.06 - 0.78, 0.00 - 0.92; MAPE = 50.1 - 150.6%). However, agreement between daily step count measured by the accelerometer and the Xiaomi Mi Band wristbands were between acceptable (MAPE = 12.2 - 13.6%) to excellent (ICC, 95% CI = 0.94 - 0.95, 0.90 - 0.97). Furthermore, the Xiaomi Mi Band wristbands have a good to excellent validity for correctly classifying adolescents as meeting or not meeting the recommended 10,000 steps per day (P = 0.89 - 0.95, k = 0.71 - 0.87) and the recommended 60 minutes of moderate-to-vigorous PA per day (P = 0.89 - 0.94, k = 0.69 - 0.83). Furthermore, comparability between the four Xiaomi Mi Band generations were poor to excellent (ICC, 95% CI = 0.22 - 0.99, 0.00 - 1.00) for the daily PA levels outputs, although it was excellent (ICC, 95% CI = 0.99 - 1.00, 0.96 - 1.00; MAPE = 0.0 - 0.1%) for daily step count. Different models of Xiaomi Mi Band wristbands were comparable and presented good validity for measuring adolescents' step count, and they accurately classified adolescents as meeting or not meeting the PA recommendations under free-living conditions.

Key words: Consumer-wearable activity tracker, wearables, fitness tracker, accelerometer, accuracy, youth.

Introduction

The regular practice of moderate-to-vigorous physical activity (MVPA) is a protective behavior that provides numerous health benefits for adolescents, such as cardiometabolic health, cognitive outcomes or healthy weight (World Health Organization, WHO, 2020). Furthermore, daily total physical activity (PA) levels (i.e., sum of minutes at all intensities or step count per day) is also associated with relevant health indicators and quality of life in adolescents (Poitras et al., 2016). For these reasons, the WHO (2020) recommends for adolescents to achieve, on average, at least 60 minutes daily of MVPA throughout the week. Furthermore, Parra Saldías et al. (2018) and Mayorga-Vega et al. (2021) translated these PA guidelines to a simple and easier-to-understand recommendation for adolescents of 10,000 steps per day. However, four out of five adolescents aged 11 to 17 do not meet these PA recommendations (Guthold et al., 2020). This is worrying due to physical inactivity being considered a global pandemic, and a leading risk factor for global mortality (WHO, 2020). Therefore, the promotion of adequate PA levels has been considered a scientific research priority, and a global action plan on PA has been developed to reverse these current trends (WHO, 2018).

However, in order to check the effectiveness of these global policies and monitor their progress, it is necessary to objectively measure adolescents' PA levels across time (Brooke et al., 2014; Metcalf et al., 2012). Among the large number of methods for the assessment of adolescents' PA levels, research-grade accelerometers (e.g., ActiGraph accelerometers) have been highlighted as the most common and valid method for objectively assessing adolescents' PA levels during free-living conditions (Romanzini et al., 2014; Van Hecke et al., 2016). These research-grade accelerometers provide information about the intensity, frequency, and volume of PA (Dhurandhar et al., 2015). Nevertheless, these research-grade accelerometers are usually very expensive instruments, in addition, they are unattractive and not interactive with the users (only the new models present a limited programmable display showing step count and kcals), which make them not very useful to promote adolescents' PA practice (ActiGraph Corporation, 2021; Šimůnek et al., 2019). On the contrary, the new consumer-wearable activity trackers share elements of research-based devices and they are generally cheaper, more interactive, more user-friendly, and are increasingly being used in research not only for measuring but also for promoting PA levels (Gorzelitz et al., 2020; Henriksen et al., 2018).

These consumer-wearable activity trackers are electronic devices worn on the body as an accessory to monitoring and recording daily PA and fitness-related metrics, and providing users real-time behavioral feedback (Ruiz and Goransson, 2015; Strath and Rowley, 2018). They usually integrate an accelerometer to automatically track physical movements and their outputs are generally based on

Received: 25 October 2022 / Accepted: 27 March 2023 / Published (online): 01 April 2023

step counts, the amount and intensity of PA, energy expenditure, periods of inactivity, sleep time, or heart rate (Franssen et al., 2020). These devices can be synchronized with their specific smartphone applications, personal computers, or websites to obtain more detailed feedback over days and weeks (Alley et al., 2016). Moreover, these devices often include other features using real-time feedback that also may be facilitators of users' positive behavior changes such as personalized goal-setting (i.e., a goal based on daily step count or minutes of PA), self-efficacy, peer comparison, or social support (Brickwood et al, 2019; Rich and Miah, 2016). Therefore, these devices can be an ideal and cost-effective option both to objectively-measure adolescents' PA levels, as well as a motivational instrument to promote their PA practice through a self-monitoring behavior technique (Casado-Robles et al., 2022; Michie et al., 2013; Strath and Rowley, 2018).

Furthermore, the widespread sales of the consumer-wearable activity trackers in recent years reflect the increasing popularity of these devices among the general public (International Data Corporation, 2020). However, there are different kinds of wearables (e.g., wristbands, smartwatches, or pedometers), as well as a large number of ever-growing brands and models available on the market, which can vary considerably in terms of the features they include, their accuracy, or their cost (Henriksen et al., 2018). Specifically, wristband devices are preferred by the general population, especially by younger users, due to their low weight, size, price, easy use or smart design (Alley et al., 2016; Stamm and Hartanto, 2018). Regarding the wide range of brands and models, the Xiaomi Mi Band (MB) is one of the top-3 most worldwide used wristbands, reflected in the millions of units shipped internationally year-after-year, also they have a lower price (Henriksen et al., 2018; International Data Corporation, 2020). Furthermore, the Xiaomi MB wristbands presented the highest rating for users' willingness to buy and wear this device in comparison to other recognized brands such as Apple, Samsung, Huawei, or Fitbit (Jia et al., 2018). This makes the Xiaomi MB an excellent cost-effective option to measure and promote adolescents' PA levels.

Nevertheless, although the use of wristbands to monitor PA levels is increasingly widespread, its validity has not been sufficiently studied, especially among children and adolescents (Fuller et al., 2020; Gorzelitz et al., 2020; Johnston et al., 2021). Furthermore, previous studies specifically assessing the validity of the Xiaomi MB to measure PA are still very scarce. Specifically, the systematic reviews by Fuller et al. (2020) and Henriksen et al. (2018) highlighted that the validity of Xiaomi MB are the least studied wristbands, including only two and one studies respectively, compared to more than 40 studies conducted with the most studied brand (i.e., Fitbit). In addition, none of them were carried out among adolescents, and they only considered the oldest generations (i.e., MB and MB 2), while other systematic reviews about this topic did not include any study with the Xiaomi brand (e.g., Evenson et al., 2015; Gorzelitz et al., 2020). Besides that, more recent studies have assessed the validity of Xiaomi MB wristbands (i.e., MB 2, 3, and 4) but most of them were carried out in the adult population and/or under laboratory settings (e.g., de la Casa Pérez et al., 2022; DeGroote et al., 2020; Hartung et al., 2020; Pino-Ortega et al., 2021; Stamm and Hartanto, 2018; Tam and Cheung, 2018; Topalidis et al., 2021). To our knowledge, only the studies by Hao et al. (2021), Campos-Meirinhos et al. (2019), and Yang et al. (2019) assessed the validity of the Xiaomi MB 2 wristbands to measure total PA among adolescents under free-living conditions. Therefore, assessing the validity of the newest generations of the Xiaomi MB wristbands for assessing PA among adolescents under free-living conditions is still scarce and interesting due to the fact that they are supposed to incorporate better technologies and algorithms. As a consequence, it is necessary to check whether this actually translates into an improvement of their validity, and therefore, the main purpose of the present study was to assess the validity of four generations of Xiaomi MB wristbands (i.e., MB 2, 3, 4, and 5) for the assessment of step count and PA levels among adolescents aged 12-18 years under free-living conditions. The secondary aim of this study was to assess the comparability of the four generations of the Xiaomi MB wristbands for estimating daily PA.

Methods

Participants

The present study is reported according to the GRRAS guidelines (Kottner et al., 2011). The protocol of the present study conforms to the Declaration of Helsinki statements (64th WMA, Brazil, October 2013) and it was approved by the Ethical Committee for Human Studies at the University of Granada. The present study followed a cross-sectional design.

A priori sample size calculation was estimated with the Arifin's web-based sample size calculator (Arifin, 2018). Based on step count values, parameters were set as follows: ICC, $\rho_0 = 0.70$ (Nunnally, 1978); $\rho_1 = 0.85$ (Campos-Meirinhos et al., 2019), $\alpha = 0.05$, $1 - \beta = 0.80$, $k = 2$, dropout = 23% (Howie and Straker, 2016). Kappa, $k_0 = 0.40$ (Cicchetti, 2001); $k_1 = 0.80$ (Mayorga-Vega et al., 2021), $p = 0.25$ (Guthold et al., 2020), $\alpha = 0.05$, $1 - \beta = 0.80$, $k = 2$, dropout = 23% (Howie and Straker, 2016). A final sample size of at least 53 adolescents (minimum initial sample size equal to 69) was estimated. In addition to exceed the minimum required sample size, the aim was also to obtain a sample balanced by grade and gender.

A public high school located in the city of Motril (Granada, Spain) was chosen by convenience. A total of 100 adolescents from 12 to 17 years old (i.e., from 7th to 11th grade, inviting 10 males and 10 females per grade; mean age = 14.1 ± 1.6 years) enrolled in the selected school were invited to participate in the present study. Anthropometric data of the included participants are listed in Table 1. The inclusion criteria were: (a) being enrolled in the selected high school (i.e., in the 7th to 11th grade); (b) being free of any health disorder that would make them unable to engage in PA normally; (c) presenting the corresponding signed written informed assents of the adolescents, and (d) presenting the corresponding signed written informed consents of their legal guardians. The exclusion criterion was not having complete and valid data from the four wristbands and the accelerometer.

Table 1. **General characteristics of the analyzed participants**

	Sample (n = 62)
Age (years)	14.1 (1.6)
Grade (1st/2nd/3rd/4th/5th)	22.6/17.7/19.4/21.0/19.4
Gender (males/females)	45.2/54.8
Body mass (kg)	58.5 (12.7)
Body height (cm)	161.5 (8.3)
Body mass index (kg/m^2)	22.4 (4.5)
Overweight/obesity (no/yes)	66.1/33.9
Non-dominant hand (left/right)	88.7/11.3
Self-reported habitual PA (days/week)	2.2 (1.5)

Data are reported as mean (standard deviation) or percentage.

Figure 1 shows the flow diagram of the participants throughout the study. An initial sample of 70 adolescents agreed to participate in the study and met the inclusion criteria. Since some adolescents met the exclusion criterion, the final sample consisted of 62 participants (i.e., non-compliance rate of 11.4%). Table 1 shows the general characteristics of the included participants.

Measures

Demographic characteristics

Adolescents' age (in years), grade (7th to 11th grade), gender (males/females), and non-dominant hand (left/right) information was self-reported.

Anthropometric measures

Adolescents' anthropometric measurements were measured following the International Standards for Anthropometric Assessment (Stewart et al., 2011). Firstly, body mass (Seca, Ltd., Hamburg, Germany; accuracy = 0.1 kg) and height (Holtain Ltd., Pembs, United Kingdom; accuracy = 0.1 cm) were measured. Then, the body mass index was calculated as body mass divided by body height squared (kg/m^2). Finally, adolescents' body weight status was categorized by gender- and age-adjusted body mass index thresholds as overweight/obesity or non-overweight/obesity (Cole et al., 2000). Body mass index and body weight status scores have shown high evidence supporting validity among adolescents (Cole et al., 2000).

Daily physical activity

Adolescents' daily PA (days/week) was estimated by the adapted and validated Spanish version of the Physician-based Assessment and Counseling for Exercise questionnaire (PACE) for adolescents (Martínez-Gómez et al., 2009). It consists of two questions that assess how many days in the last week (i.e., "In the last 7 days, how many days did you do PA for 60 minutes or more?") and in a normal week (i.e., "In a normal week, how many days do you do PA for 60 minutes or more?") at least 60 minutes of PA are performed. The items were preceded by a brief explanation about what PA is and some examples, indicating that the time spent in school physical education should not be included. A scale ranging from 0 to 7 days was used. Then, the mean of two items was calculated. The Spanish version of the PACE questionnaire has shown adequate convergent validity with respect to accelerometry for assessing PA among adolescents (r = 0.43; Martínez-Gómez et al., 2009).

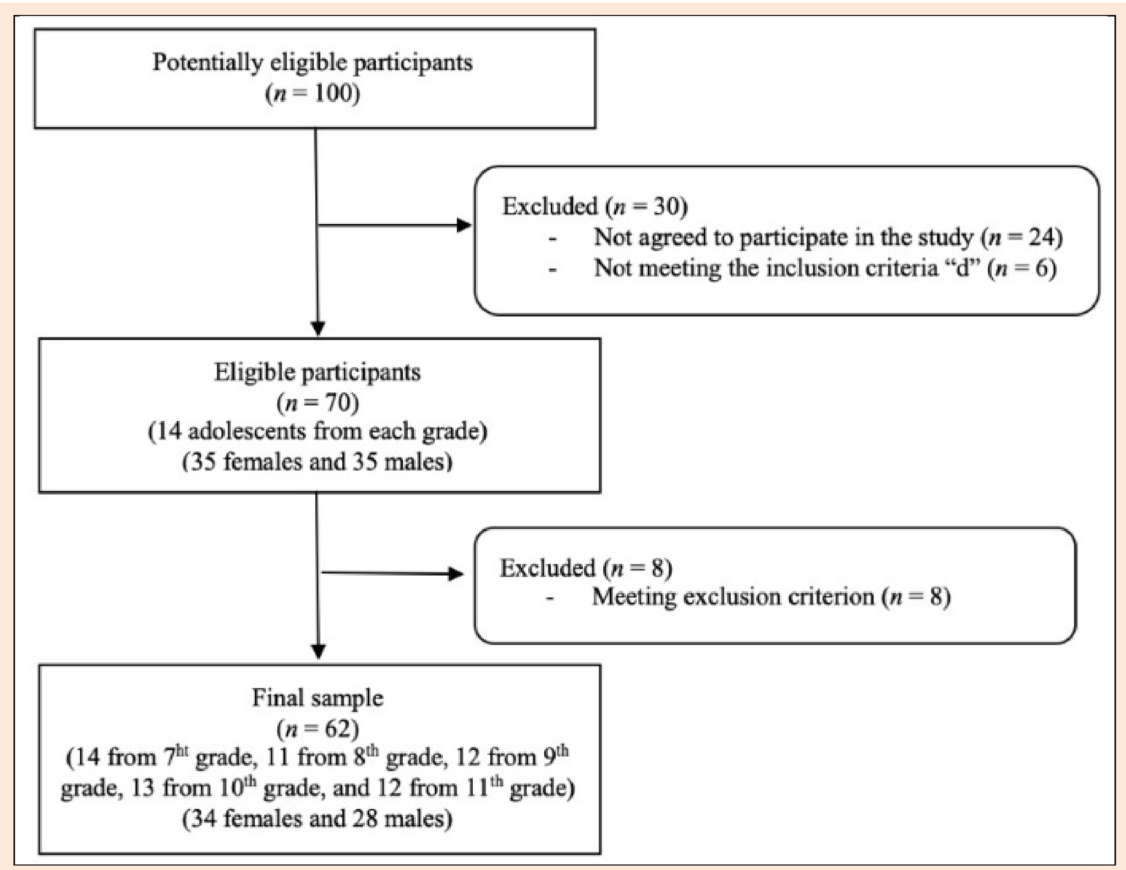


Figure 1. Flow diagram of the participants through the studies.

Mi Band wristbands

Adolescents' PA levels were estimated by the Xiaomi MB 2, 3, 4, and 5 wristbands (Xiaomi, Pekin, China). According to the user manual, the wristbands were fit snugly on the top of adolescents' non-dominant wrist, close to and above the wrist bone. Moreover, the four devices' displays were blinded as to not show adolescents' PA feedback, avoiding potential biases due to adolescents' reactivity. These wristbands are characterized as small, light-weight, and rather inexpensive considering their launch price in Spain (MB 2: 4.30 x 1.57 x 1.05 cm, 7.0 g, and 25€; MB 3: 4.69 x 1.79 x 1.20 cm, 20.0 g, and 30€; MB 4: 4.70 x 1.81 x 1.08 cm, 22.1 g, and 35€; MB 5: 4.69 x 1.81 x 1.24 cm, 11.9 g, and 35€). The models MB 2, 3, 4 and 5 are based on tri-axial built-in accelerometers and models 4 and 5 have a tri-axial gyroscope as well. Furthermore, these wristbands have their own algorithmic equation to estimate the daily step count and the minutes engaged in each specific intensity-related PA. Wristbands data were synchronized via Bluetooth to its specific application to download and store data (i.e., Mi Fit version 5.3.2 for Android), and the features of interest were calculated from the data shown in this application at the end of the data collection.

Regarding the data scoring, the number of steps were registered as directly reported in the Mi Fit application. However, specific information regarding PA algorithms used to calculate the time (minutes) engaged in each specific intensity-related PA is not made publicly available by Xiaomi. Therefore, intensity-related PA scores (minutes) were calculated as follows: (a) "slow walking" was calculated by adding up the total time spent on all the bouts of "slow walking" [according to the Youth Compendium of PA (Butte et al., 2018), this measured variable corresponded to light PA as measured by the ActiGraph]; (b) "brisk walking" was calculated by adding up the total time spent on all the bouts of "fast walking" [according to the Youth Compendium of PA (Butte et al., 2018), this measured variable corresponded to moderate-to-vigorous PA as measured by the ActiGraph]; (c) "MVPA" was calculated by adding up the total time spent on all the bouts of "moderate activity" and "vigorous activity"; (d) "slow-brisk walking" was also calculated by adding up the total time spent on all the bouts of "slow walking" and "fast walking" [according to the Youth Compendium of PA (Butte et al., 2018), this measured variable corresponded to total PA as measured by the ActiGraph]; and (e) "total PA" was registered as directly reported in the Mi Fit application as "active minutes", assuming that the measured variable corresponded to total PA as measured by the ActiGraph.

ActiGraph wGT3X-BT

Adolescents' reference standards of step count and PA were determined by wGT3X-BT accelerometers (ActiGraph, LLC, Pensacola, FL, USA), adjusted on the adolescents' right hip. This model is a small (1.5 x 3.03 x 4.06 cm) and light-weight (19 g) triaxial accelerometer. Accelerometer data were initialized, downloaded, and processed using the ActiLife Lifestyle Monitoring System Software version 6.13.3 (ActiGraph, LLC, Pensacola, FL, USA). Accelerometers were initialized with a sample ration of 30 Hz (Migueles et al., 2017). A 15-second epoch was used when downloading the data (Evenson et al., 2008; Migueles et al., 2017). Valid wear time was set as equal to or higher than 10 hours per day (Migueles et al., 2017), with non-wear periods set as 60 minutes or more of consecutive zero-count *epochs* with up to a two minute spike tolerance (Oliver et al., 2011).

Regarding the data scoring, step count was assessed by the default settings of ActiLife for step count. Furthermore, the Evenson's cut-points were applied to categorize the time (minutes) engaged in each specific intensity-related PA (i.e., light PA = 101 - 2295 *counts*/min; MVPA $\geq$ 2,296 *counts*/min; and total PA $\geq$ 101 *counts*/min; Evenson et al., 2008). According to the cross-validation study performed by Trost et al. (2011), these cut-off points have demonstrated the best evidence supporting score validity for assessing intensity-related PA among adolescents. Finally, adolescents' step count and MVPA were dichotomized as achieving or not achieving the daily recommendation of at least 10,000 steps and 60 minutes of MVPA, respectively (Mayorga-Vega et al., 2021; WHO, 2020). ActiGraph accelerometer scores have shown high evidence supporting validity for assessing step count and intensity-related PA among adolescents (Romanzini et al., 2014; Trost et al., 2011).

Procedure

Firstly, the principal and the physical education teachers of the high school were contacted. They were informed about the project, and permission to conduct the study was requested. After the approval of the school was obtained, all the students and their legal guardians were fully informed about the features of the project. Afterward, adolescents' demographic characteristics, anthropometric measurements, and self-reported habitual PA levels were recorded. Then, wristbands and accelerometers were adjusted on adolescents from Monday to Thursday, while Fridays were used to collect the activity trackers, download data, and charge batteries. Due to the limitations of material resources, waves of seven adolescents per day were carried out.

For each wave, adolescents were met from 8:00 to 8:30 a.m. in the school gym. According to the user manual, the four wristbands were simultaneously adjusted on the adolescents' wrists of the non-dominant hand (Hartung et al., 2020), while the accelerometer was adjusted on the adolescents' right hip using an elastic waistband. In order to avoid that the relative position of the four wristbands on the wrist influenced the results, they were adjusted in random order varying across adolescents (Hartung et al., 2020). Moreover, adolescents were instructed to wear the activity trackers for one whole day until bedtime, and to only take them off when they took a bath/shower. In order to not influence participants' PA patterns, they were instructed to maintain their habitual PA levels. Lastly, adolescents were also instructed to remove the wristbands and the accelerometer when they go to the bed, leaving them in a plastic box inside their schoolbags. In the morning of the following day, the activity trackers were collected and adjusted to the next seven participants following the same protocol.

Statistical analysis

Descriptive statistics for all the variables of the included participants were calculated. Firstly, all the statistical tests assumptions were checked and met (e.g., histograms and Q - Q plots for normality). Furthermore, univariate (i.e., $z \pm 3.0$) and multivariate outliers (i.e., Mahalanobis distance) were removed. Afterward, the agreement between the PA scores (i.e., continuous variables) measured by the wristbands and the accelerometers were calculated as follows: a) Equivalence test with the Confident Interval method (90% CI) (Dixon et al., 2018); b) Limits of Agreement (LOA) with its confident intervals (95% CI) (Bland and Altman, 1986); c) Mean Absolute Error (MAE) (Willmott and Matsuura, 2005); d) Mean Absolute Percentage Error (MAPE) (Johnston et al., 2021); and e) Intraclass Correlation Coefficient (ICC), and its 95% CI, by a two-way random effects model with absolute agreement and single measurement [also known as ICC(2,1)] (Koo and Li, 2016). Additionally, LOA plots, which are the individual participant differences between the two scores plotted against the respective individual means, were performed (Bland and Altman, 1986). Heteroscedasticity was also examined objectively by calculating the Pearson's correlation coefficient (r) between the absolute differences and the individual means (Atkinson and Nevill, 1998). Based on Cohen's (1992) benchmarks, a correlation coefficient > 0.50 was considered as indicative of heteroscedasticity. Finally, the agreement between the PA scores dichotomized as achieving or not achieving the daily recommendations of 10,000 steps (Mayorga-Vega et al., 2021) and 60 min of MVPA (i.e., categorical variables) (WHO, 2020) measured by the wristbands and the accelerometers were calculated as the proportion of agreement [P = number of agreements/ (number of agreements + disagreements)] and kappa coefficient (k) (Hernaez, 2015). Agreement values were interpreted as follows: Equivalence test, the mean reference standard being within ± 15% of the mean wristbands is considered acceptable (Dixon et al., 2018); MAPE, > 15.0% poor, 10.1-15.0% acceptable, 5.1 - 10.0% good, and 0.0 - 5.0% excellent (Johnston et al., 2021); ICC, 0.00 - 0.69 poor, 0.70-0.79 acceptable, 0.80 - 0.89 good, and 0.90 - 1.00 excellent (Nunnally, 1978); k, 0.00 - 0.39 poor, 0.40-0.59 acceptable, 0.60 - 0.74 good, and 0.75 - 1.00 excellent (Cicchetti, 2001). Based on statistical inference, each ICC value was interpreted according to its 95% CI, that means, there was 95% chance that the true ICC value landed on any point between the 95% CI range (Koo and Li, 2016). All statistical analyses were performed using the SPSS version 25.0 for Windows (IBM® SPSS® Statistics), except for the equivalence testing where the Jamovi version 2.3 (The Jamovi project, https://www.jamovi.org) was used. The statistical significance level was set at $p < 0.05$.

Results

Validity of the Xiaomi Mi Band wristbands for estimating daily physical activity

Table 2 shows the validity of the Xiaomi MB wristbands for estimating daily PA. According to the validity results of the step number based on the values of 90% CI of the equivalence test, the 90% CI of the all the generations of the Xiaomi MB wristbands scores were inside the equivalence region of reference standard. Similarly, based on the values of the 95% CI of the ICC, the validity results of the step count assessed by all the studied generations of the Xiaomi MB were excellent. Furthermore, based on the MAPE values, all studied generations of the Xiaomi MB showed an acceptable validity. However, the validity results of all the studied generations of the Xiaomi MB for assessing slow, brisk, and slow-brisk pace walking, total PA and MVPA was poor. Figure 2, Figure 3, Figure 4, Figure 5, Figure 6, and Figure 7 show the LOA plots. Pearson's correlation coefficients did not show heteroscedasticity with any wearable band on step count and brisk walking scores. However, heteroscedasticity was found for slow and slow-brisk pace walking, MVPA and total PA by all the generations of Xiaomi MB wristbands (except for the Xiaomi MB 4 and 5 with MVPA; Table 3).

Table 4 shows the validity of the Xiaomi MB wristbands for estimating the daily PA recommendations. A total of 24.2% and 29.0% of adolescents met the accelerometer-measured step- and MVPA-based recommendations, respectively. The validity results of the daily step-based recommendations assessed by the Xiaomi MB wristbands ranged from good to excellent. Moreover, based on the brisk pace walking score of the Xiaomi MB wristbands, the validity results of the daily MVPA-based recommendations also ranged from good to excellent. However, based on the MVPA score of the Xiaomi MB wristbands, the validity results of the daily MVPA-based recommendations were poor.

Comparability of the four generations of Xiaomi Mi Band wristbands for estimating daily physical activity

Table 5 shows the comparability of the Xiaomi MB wristbands for estimating daily PA. According to the comparability results of the step count, brisk pace walking, slow-brisk pace walking and total PA based on the values of 90% CI of the equivalence test, the 90% CI between all the studied generations of the Xiaomi MB wristbands scores were inside the equivalence region of reference standard. Similarly, based on both the values of the MAPE and the 95% CI of the ICC, the comparability results of those variables between all the generations of the Xiaomi MB wristbands were between good and excellent. On the other hand, regarding the slow pace walking, although the equivalence test and MAPE showed an adequate comparability, based on the values of the 95% CI of the ICC, the comparability results between all the studied generations of the Xiaomi MB wristbands were between questionable and acceptable. Finally, as regards the MVPA score, the comparability results between all the studied generations of the Xiaomi MB showed that the scores were outside the equivalence region of the reference standard, as well as that the ICC values were poor; however, based on the MAPE values, all studied generations of the Xiaomi MB showed an acceptable comparability. Pearson's correlation coefficients did not show heteroscedasticity between any wristband scores (except for between the Xiaomi MB 2-3 and 3-4 with MVPA) (Table 6).

Table 2. Validity of the Xiaomi Mi Band wristbands for estimating daily physical activity (*n* = 62).

Instrument	Mean (SD)	Equivalence test (90% CI)	LOA (95% CI)	MAE	MAPE	ICC (95% CI)
Steps (n)						
ActiGraph wGT3X-BT	7,066.8 (3622.3)	-1,060.0, 1060.0	-	-	-	-
Xiaomi Mi Band 2	7,287.0 (4017.2)	-462.8, 22.3	-220.2 (-2461.5, 2021.1)	791.8	12.3	0.95 (0.93, 0.97)
Xiaomi Mi Band 3	7,193.9 (4041.0)	-392.1, 137.7	-127.2 (-2574.8, 2320.4)	890.6	13.6	0.95 (0.91, 0.97)
Xiaomi Mi Band 4	7,544.0 (4124.2)	-742.4, -212.1	-477.2 (-2927.2, 1972.8)	916.9	13.2	0.94 (0.90, 0.97)
Xiaomi Mi Band 5	7,441.9 (4068.2)	-619.6, -130.6	-375.1 (-2634.2, 1884.0)	824.5	12.2	0.95 (0.92, 0.97)
Slow pace walking (min)[a]						
ActiGraph wGT3X-BT	169.1 (59.5)	-25.4, 25.4	-	-	-	-
Xiaomi Mi Band 2	40.1 (30.3)	119.1, 139.0	129.1 (37.2, 221.0)	129.1	77.7	0.11 (0.00, 0.36)
Xiaomi Mi Band 3	40.6 (31.5)	118.4, 138.7	128.6 (35.1, 222.1)	128.6	77.0	0.11 (0.00, 0.36)
Xiaomi Mi Band 4	45.1 (30.6)	113.7, 134.4	124.0 (28.4, 219.6)	124.0	74.4	0.11 (0.00, 0.35)
Xiaomi Mi Band 5	43.1 (30.1)	116.4, 135.7	126.0 (36.4, 215.6)	126.0	75.7	0.12 (0.00, 0.38)
Brisk pace walking (min)[b]						
ActiGraph wGT3X-BT	45.1 (28.4)	-6.8, 6.8	-	-	-	-
Xiaomi Mi Band 2	57.5 (34.7)	12.1, 18.3	15.2 (-13.2, 43.6)	17.6	50.1	0.78 (0.18, 0.92)
Xiaomi Mi Band 3	71.1 (47.6)	14.1, 20.7	17.4 (-12.8, 47.6)	19.9	54.9	0.74 (0.08, 0.90)
Xiaomi Mi Band 4	45.8 (29.0)	11.7, 18.1	14.9 (-14.9, 44.7)	17.7	50.1	0.78 (0.22, 0.91)
Xiaomi Mi Band 5	76.7 (34.9)	10.5, 17.1	13.8 (-16.6, 44.2)	17.5	51.6	0.78 (0.31, 0.91)
Slow-brisk pace walking (min)[c]						
ActiGraph wGT3X-BT	214.2 (71.1)	-32.1, 32.1	-	-	-	-
Xiaomi Mi Band 2	70.0 (46.1)	134.2, 154.3	144.2 (51.1, 237.3)	144.2	69.6	0.18 (0.00, 0.50)
Xiaomi Mi Band 3	68.3 (44.7)	135.4, 156.5	145.9 (48.5, 243.3)	145.9	69.8	0.16 (0.00, 0.48)
Xiaomi Mi Band 4	75.3 (47.2)	128.4, 149.5	138.9 (41.3, 236.5)	138.9	66.7	0.18 (0.00, 0.51)
Xiaomi Mi Band 5	74.4 (47.4)	129.6, 150.1	139.8 (45.1, 234.5)	139.8	67.2	0.19 (0.00, 0.52)
Moderate-to-vigorous physical activity (min)						
ActiGraph GT3X+	45.1 (28.4)	-6.8, 6.8	-	-	-	-
Xiaomi Mi Band 2	29.9 (30.4)	-21.2, -3.7	-12.4 (-93.2, 68.4)	35.3	110.8	0.15 (0.00, 0.37)
Xiaomi Mi Band 3	27.7 (31.3)	-37.3, -14.7	-26.0 (-130.5, 78.5)	43.5	137.5	0.06 (0.00, 0.27)
Xiaomi Mi Band 4	30.1 (31.3)	-8.6, 7.0	-0.8 (-72.9, 71.3)	29.6	89.2	0.18 (0.00, 0.41)
Xiaomi Mi Band 5	31.3 (30.4)	-40.8, -22.5	-31.6 (-116.1, 52.9)	42.4	150.6	0.06 (0.00, 0.24)
Total physical activity (min)						
ActiGraph wGT3X-BT	214.2 (71.1)	-32.1, 32.1	-	-	-	-
Xiaomi Mi Band 2	86.9 (40.9)	117.1, 137.5	127.3 (32.6, 222.0)	127.3	60.1	0.19 (0.00, 0.52)
Xiaomi Mi Band 3	86.1 (41.6)	117.6, 138.6	128.1 (31.1, 225.1)	128.1	60.4	0.19 (0.00, 0.51)
Xiaomi Mi Band 4	89.8 (42.2)	114.3, 134.6	124.4 (30.5, 218.3)	124.4	58.7	0.20 (0.00, 0.54)
Xiaomi Mi Band 5	88.0 (41.3)	115.8, 136.7	126.2 (29.8, 222.6)	126.2	59.5	0.19 (0.00, 0.52)

SD = Standard deviation; LOA = Limits of agreement; 90%/95% CI = 90%/95% confident interval; MAE = Mean absolute error; MAPE = Mean absolute percentage error; ICC = Intraclass correlation coefficient; [a] Compared with the accelerometer-measured light physical activity (min); [b] Compared with the accelerometer-measured moderate-to-vigorous physical activity (min); [c] Compared with the accelerometer-measured total physical activity (min).

Table 3. Pearson's correlation coefficient (*r*) between the absolute differences and the individual means (*n* = 62).

Variable	Xiaomi Mi Band 2	Xiaomi Mi Band 3	Xiaomi Mi Band 4	Xiaomi Mi Band 5
Steps (n)	0.38‡	0.40‡	0.50†	0.45†
Slow pace walking (min)[a]	0.68†	0.65†	0.66†	0.70†
Brisk pace walking (min)[b]	0.07	0.16	0.09	0.00
Slow-brisk pace walking (min)[c]	0.56†	0.57†	0.52†	0.53†
MVPA (min)	0.51†	0.64†	0.37‡	0.37‡
Total physical activity (min)	0.66†	0.64†	0.64†	0.65†

MVPA = Moderate-to-vigorous physical activity; [a] Calculated with the accelerometer-measured light physical activity (min); [b] Calculated with the accelerometer-measured moderate-to-vigorous physical activity (min); [c] Calculated with the accelerometer-measured total physical activity (min). * $p < 0.05$, ‡ $p < 0.01$, and † $p < 0.001$

Table 4. Validity of the Xiaomi Mi Band wristbands for estimating the daily physical activity recommendations (*n* = 62).

						ActiGraph wGT3X-BT						
			10,000 steps				60 min of MVPA				60 min of MVPA	
Instrument		%TP	*P*	*k*		%TP	*P*	*k*		%TP	*P*	*k*
Xiaomi Mi Band 2	10,000 steps	25.8	0.92	0.79†	60 min of brisk pace walking	22.6	0.94	0.83†	60 min of MVPA	38.7	0.58	0.07
Xiaomi Mi Band 3		25.8	0.95	0.87†		17.7	0.89	0.69†		53.2	0.56	0.15
Xiaomi Mi Band 4		29.0	0.89	0.71†		21.0	0.92	0.79†		37.1	0.53	-0.05
Xiaomi Mi Band 5		27.4	0.94	0.83†		21.0	0.92	0.79†		64.5	0.48	0.08

MVPA = Moderate-to-vigorous physical activity; %TP= Wearable-based percentage of total positive cases according to the recommendation; *P* = Proportion of agreement; *k* = Kappa coefficient. † $p < 0.001$

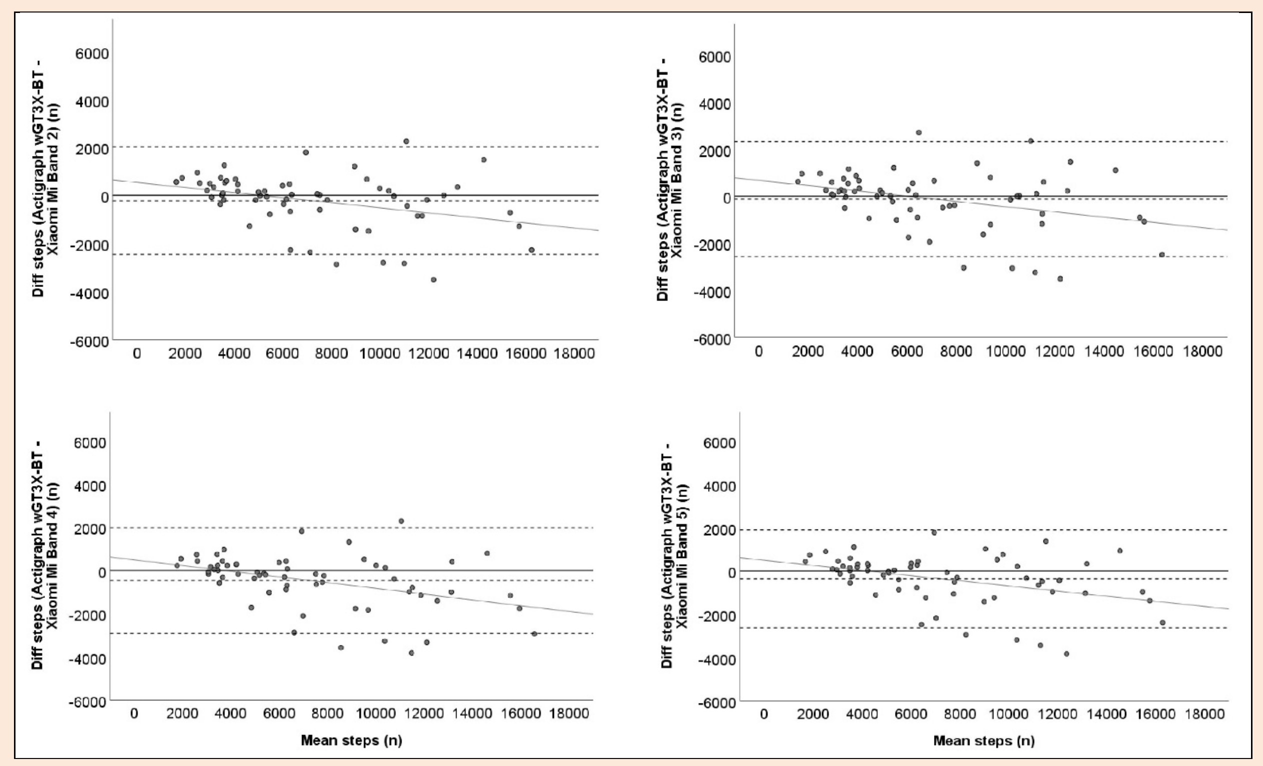


Figure 2. Bland-Altman plots of the four devices for measuring step count under free-living conditions. The middle line shows the mean difference between the measurements of step count of the four Xiaomi Mi Band trackers and the ActiGraph, and the dashed lines indicate the limits of agreement.

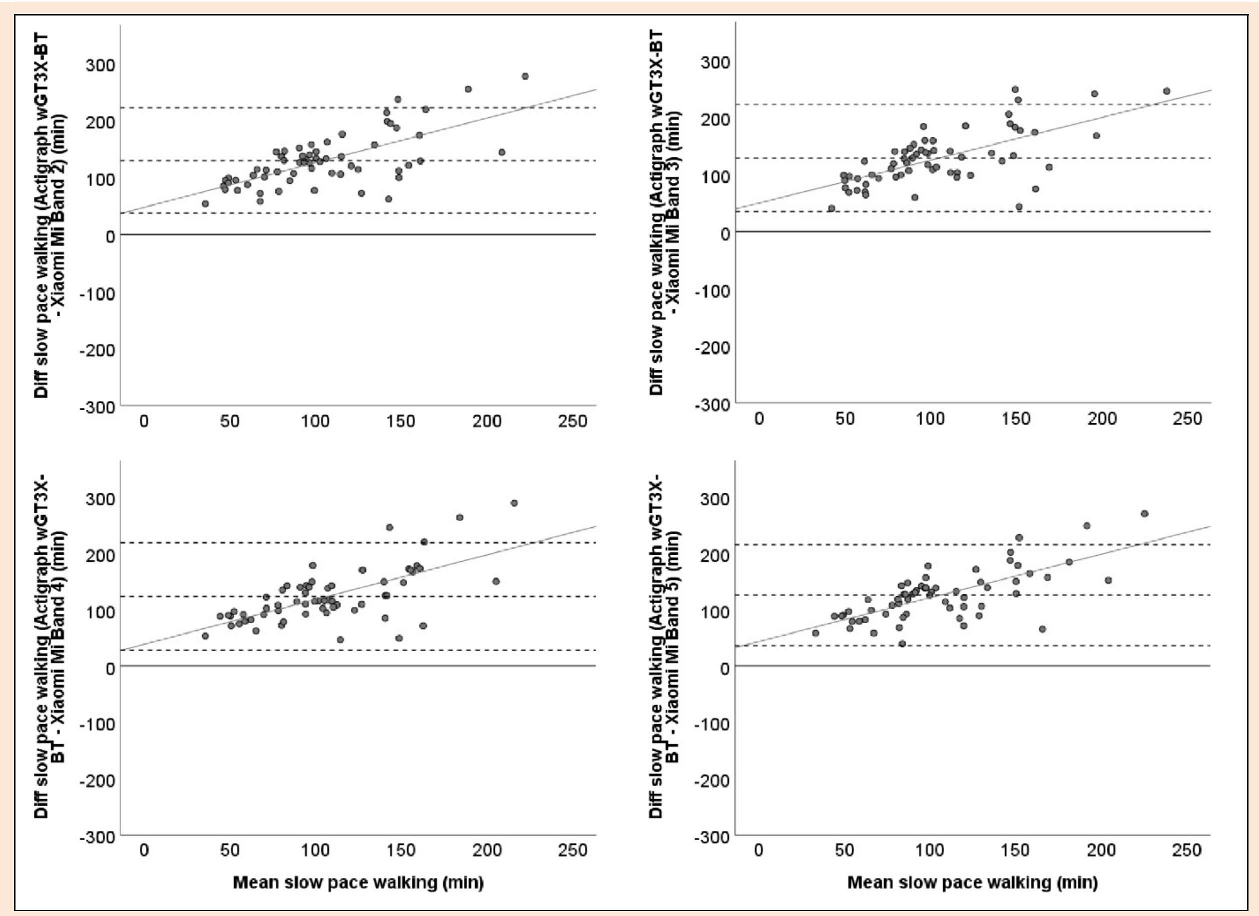


Figure 3. Bland-Altman plots of the four devices for measuring slow walking (i.e., light physical activity) under free-living conditions. The middle line shows the mean difference between the measurements of slow walking (i.e., light physical activity) of the four Xiaomi Mi Band trackers and the ActiGraph, and the dashed lines indicate the limits of agreement.

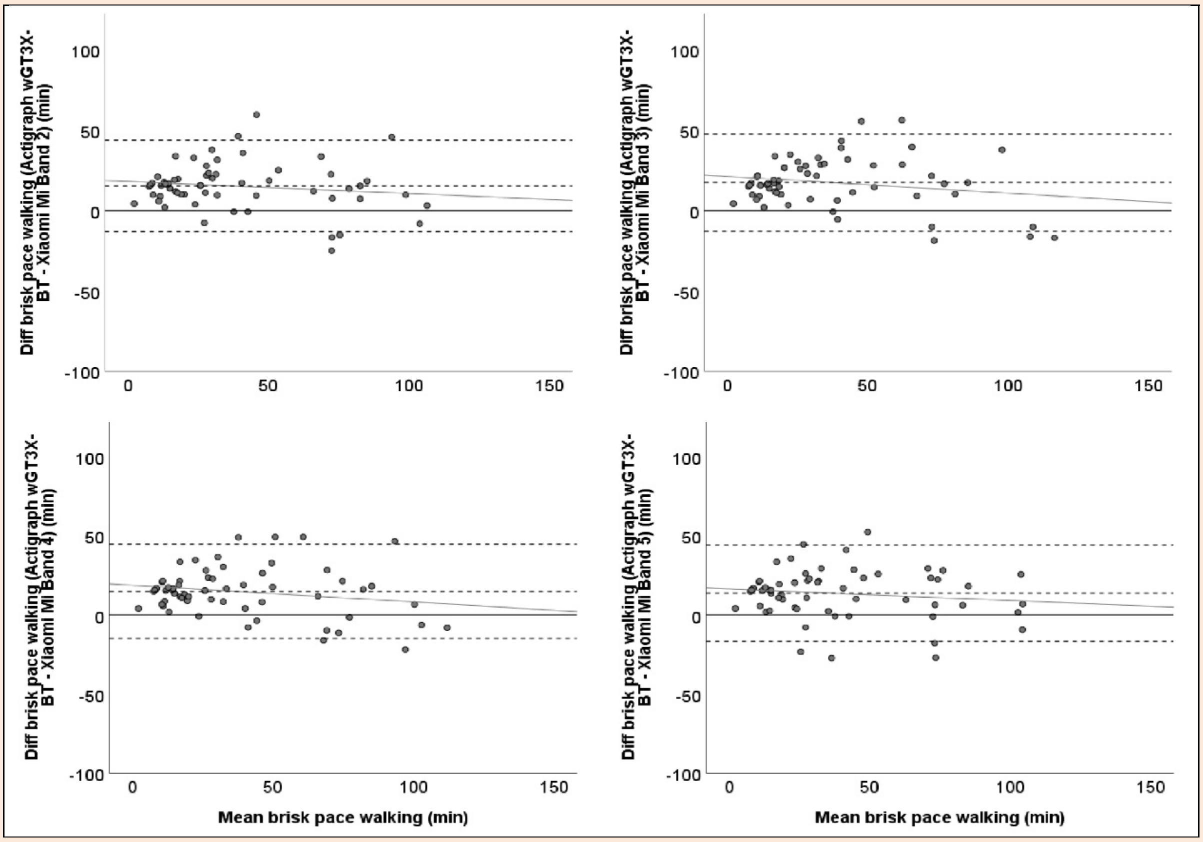


Figure 4. Bland-Altman plots of the four devices for measuring brisk walking (i.e., moderate-to-vigorous physical activity) under free-living conditions. The middle line shows the mean difference between the measurements of brisk walking (i.e., moderate-to-vigorous physical activity) of the four Xiaomi Mi Band trackers and the ActiGraph, and the dashed lines indicate the limits of agreement.

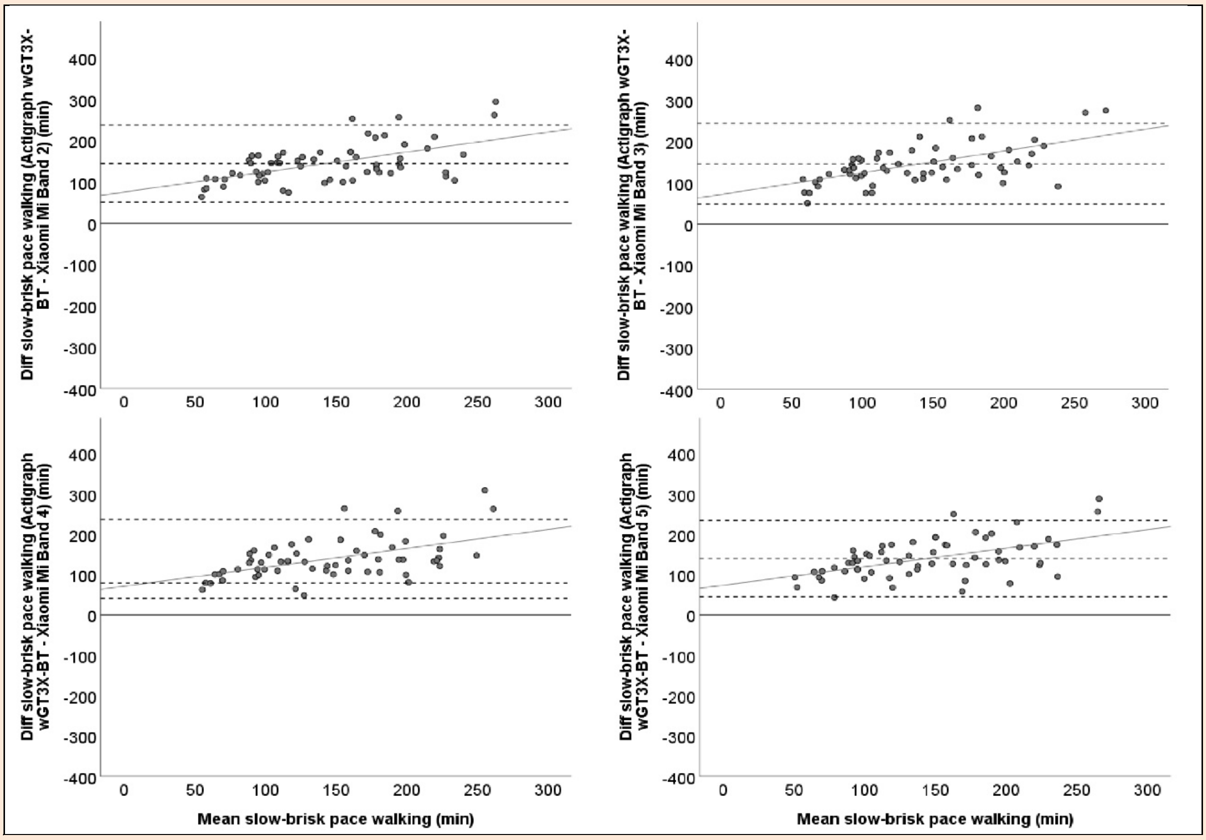


Figure 5. Bland-Altman plots of the four devices for measuring slow-brisk walking (i.e., total physical activity) under free-living conditions. The middle line shows the mean difference between the measurements of slow-brisk walking (i.e., total physical activity) of the four Xiaomi Mi Band trackers and the ActiGraph, and the dashed lines indicate the limits of agreement.

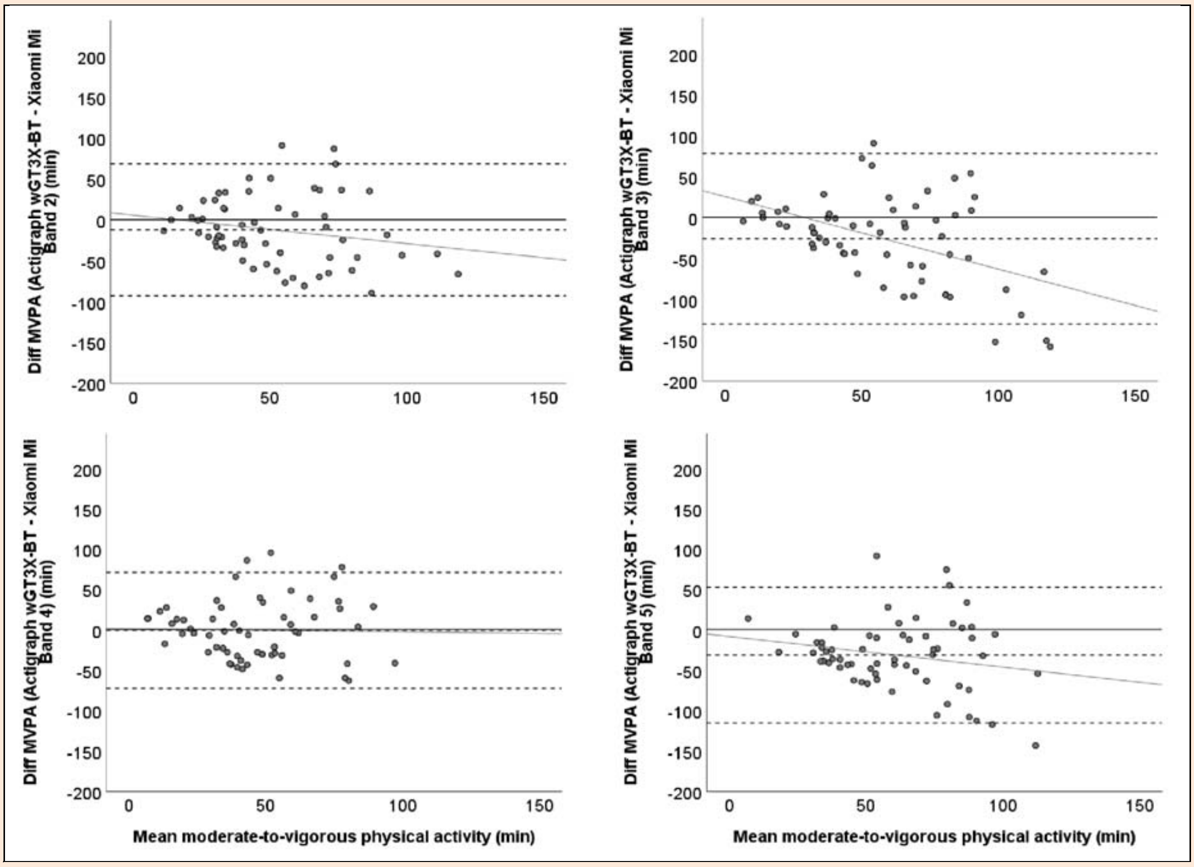


Figure 6. Bland-Altman plots of the four devices for measuring moderate-to-vigorous physical activity under free-living conditions. The middle line shows the mean difference between the measurements of moderate-to-vigorous physical activity of the four Xiaomi Mi Band trackers and the ActiGraph, and the dashed lines indicate the limits of agreement.

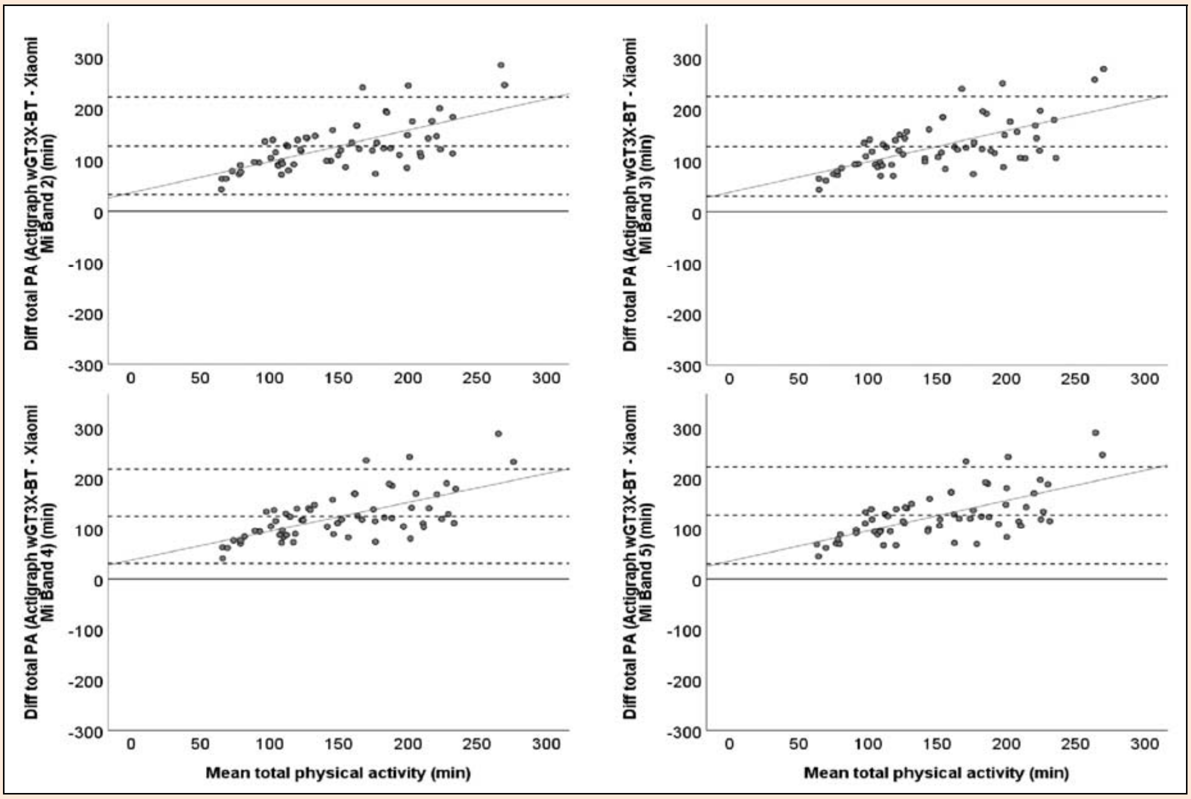


Figure 7. Bland-Altman plots of the four devices for measuring total physical activity under free-living conditions. The middle line shows the mean difference between the measurements of total physical activity of the four Xiaomi Mi Band trackers and the ActiGraph, and the dashed lines indicate the limits of agreement.

Table 5. Comparability of the Xiaomi Mi Band wristbands for estimating daily physical activity (*n* = 62).

Instrument	Equivalence test (90% CI)	LOA (95% CI)	MAE	MAPE	ICC (95% CI)
Steps (n)	-1,060.0, 1060.0				
Xiaomi Mi Band 2-3	4.1, 182.0	93.0 (-728.6, 914.6)	295.0	0.0	0.99 (0.99, 1.00)
Xiaomi Mi Band 2-4	-319.4, -194.5	-257.0 (-834.0, 320.0)	293.4	0.0	1.00 (0.97, 1.00)
Xiaomi Mi Band 2-5	-212.2, -97.5	-154.9 (-684.7, 374.9)	231.5	0.0	1.00 (0.99, 1.00)
Xiaomi Mi Band 3-4	-449.0, -251.1	-350.0 (-1264.5, 564.5)	404.3	0.1	0.99 (0.96, 1.00)
Xiaomi Mi Band 3-5	-335.7, -160.1	-247.9 (-1058.9, 563.1)	345.0	0.1	0.99 (0.98, 1.00)
Xiaomi Mi Band 4-5	36.1, 168.1	102.1 (-507.7, 711.9)	246.7	0.0	1.00 (0.99, 1.00)
Slow pace walking (min)	-25.4, 25.4				
Xiaomi Mi Band 2-3	-4.4, 3.4	-0.5 (-36.8, 35.8)	14.0	0.5a	0.82 (0.72, 0.89)
Xiaomi Mi Band 2-4	-8.9, -1.2	-5.0 (-40.7, 30.7)	14.9	0.5	0.81 (0.70, 0.88)
Xiaomi Mi Band 2-5	-7.4, 1.3	-3.0 (-43.0, 37.0)	15.8	0.5	0.77 (0.65, 0.85)
Xiaomi Mi Band 3-4	-8.6, -0.5	-4.5 (-42.1, 33.1)	14.4	0.5	0.80 (0.69, 0.88)
Xiaomi Mi Band 3-5	-6.7, 1.7	-2.5 (-41.3, 36.3)	13.7	0.4	0.79 (0.68, 0.87)
Xiaomi Mi Band 4-5	-2.1, 6.1	2.0 (-36.0, 40.0)	14.1	0.4a	0.80 (0.69, 0.87)
Brisk pace walking (min)	-6.8, 6.8				
Xiaomi Mi Band 2-3	-0.2, 4.7	2.2 (-20.3, 24.7)	5.7	0.3b	0.93 (0.88, 0.96)
Xiaomi Mi Band 2-4	-2.0, 1.5	-0.3 (-16.8, 16.2)	4.5	0.2b	0.96 (0.94, 0.98)
Xiaomi Mi Band 2-5	-3.4, 0.6	-1.4 (-19.4, 16.6)	4.8	0.3b	0.95 (0.92, 0.97)
Xiaomi Mi Band 3-4	-5.2, 0.3	-2.5 (-27.8, 22.8)	7.2	0.3c	0.91 (0.86, 0.95)
Xiaomi Mi Band 3-5	-6.4, -0.8	-3.6 (-29.7, 22.5)	7.5	0.3c	0.90 (0.84, 0.94)
Xiaomi Mi Band 4-5	-3.5, 1.2	-1.1 (-22.5, 20.3)	6.5	0.3b	0.94 (0.90, 0.96)
Slow-brisk pace walking (min)	-32.1, 32.1				
Xiaomi Mi Band 2-3	-1.9, 5.3	1.7 (-31.8, 35.2)	12.5	0.2	0.93 (0.89, 0.96)
Xiaomi Mi Band 2-4	-9.0, -1.6	-5.3 (-39.8, 29.2)	14.3	0.3	0.92 (0.87, 0.95)
Xiaomi Mi Band 2-5	-8.7, -0.2	-4.4 (-43.6, 34.8)	15.7	0.3	0.91 (0.85, 0.94)
Xiaomi Mi Band 3-4	-11.1, -3.0	-7.0 (-44.4, 30.4)	14.5	0.3	0.91 (0.83, 0.94)
Xiaomi Mi Band 3-5	-9.9, -2.4	-6.1 (-41.0, 28.8)	13.7	0.2	0.92 (0.86, 0.95)
Xiaomi Mi Band 4-5	-3.2, 5.0	0.9 (-37.1, 38.9)	14.4	0.2	0.92 (0.87, 0.95)
Moderate-to-vigorous physical activity (min)	-6.8, 6.8				
Xiaomi Mi Band 2-3	-22.7, -4.6	-13.6 (-97.3, 70.1)	34.4	0.6	0.46 (0.23, 0.63)
Xiaomi Mi Band 2-4	5.2, 18.1	11.6 (-48.0, 71.2)	25.0	0.6	0.52 (0.30, 0.68)
Xiaomi Mi Band 2-5	-27.6, -10.8	-19.2 (-97.0, 58.6)	32.4	0.5	0.31 (0.07, 0.52)
Xiaomi Mi Band 3-4	16.4, 34.1	25.2 (-56.5, 106.9)	36.0	0.8	0.37 (0.09, 0.58)
Xiaomi Mi Band 3-5	-14.6, 3.4	-5.6 (-88.5, 77.3)	31.8	0.5	0.49 (0.27, 0.65)
Xiaomi Mi Band 4-5	-38.8, -22.9	-30.8 (-104.1, 42.5)	35.9	0.7a	0.22 (0.00, 0.46)
Total physical activity (min)	-32.1, 32.1				
Xiaomi Mi Band 2-3	-0.4, 2.0	0.8 (-10.4, 12.0)	4.0	0.1	0.99 (0.98, 0.99)
Xiaomi Mi Band 2-4	-3.7, -2.0	-2.9 (-10.7, 4.9)	3.6	0.0	0.99 (0.97, 1.00)
Xiaomi Mi Band 2-5	-2.0, -0.1	-1.1 (-9.9, 7.7)	3.4	0.0	0.99 (0.99, 1.00)
Xiaomi Mi Band 3-4	-5.0, -2.4	-3.7 (-15.9, 8.5)	5.1	0.1	0.99 (0.96, 0.99)
Xiaomi Mi Band 3-5	-3.0, -0.7	-1.9 (-12.5, 8.7)	4.3	0.1	0.99 (0.98, 1.00)
Xiaomi Mi Band 4-5	0.8, 2.7	1.8 (-7.0, 10.6)	3.8	0.0	0.99 (0.99, 1.00)

SD = Standard deviation; LOA = Limits of agreement; 90%/95% CI = 90%/95% confident interval; MAE = Mean absolute error; MAPE = Mean absolute percentage error; ICC = Intraclass correlation coefficient. Due to zero values in the denominator in some cases, the sample size was as follow: a61, b54, c53.

Table 6. Pearson's correlation coefficient (*r*) between the absolute differences and the individual means (*n* = 62).

Variable	Xiaomi Mi Band 2-3	Xiaomi Mi Band 2-4	Xiaomi Mi Band 2-5	Xiaomi Mi Band 3-4	Xiaomi Mi Band 3-5	Xiaomi Mi Band 4-5
Steps (n)	0.18	0.44†	0.32*	0.24	0.25	0.30*
Slow pace walking (min)	0.37‡	0.36‡	0.39‡	0.22	0.37‡	0.29*
Brisk pace walking (min)	0.38‡	0.40‡	0.22	0.49†	0.36‡	0.40‡
Slow-brisk pace walking (min)	0.27*	0.28*	0.18	0.24	0.28*	0.25
MVPA (min)	0.54†	0.23	0.26*	0.62†	0.21	0.31*
Total physical activity (min)	0.21	0.40‡	0.03	0.31*	0.42‡	0.25

MVPA = Moderate-to-vigorous physical activity. * $p < 0.05$, ‡ $p < 0.01$, and † $p < 0.001$

Table 7. Comparability of the Xiaomi Mi Band wristbands for estimating daily physical activity recommendations (n = 62).

Instrument	10,000 steps		60 min of brisk pace walking		60 min of MVPA	
	P	***k***	***P***	***k***	***P***	***k***
Xiaomi Mi Band 2-3	0.97	0.92†	0.95	0.85†	0.66	0.33‡
Xiaomi Mi Band 2-4	0.97	0.92†	0.95	0.86†	0.69	0.35‡
Xiaomi Mi Band 2-5	0.98	0.96†	0.95	0.86†	0.55	0.15
Xiaomi Mi Band 3-4	0.94	0.84†	0.90	0.69†	0.68	0.37‡
Xiaomi Mi Band 3-5	0.95	0.88†	0.90	0.69†	0.69	0.38‡
Xiaomi Mi Band 4-5	0.95	0.88†	0.97	0.90†	0.60	0.25*

MVPA = Moderate-to-vigorous physical activity; P = Proportion of agreement; k = Kappa coefficient. * $p < 0.05$, ‡ $p < 0.01$ and † $p < 0.001$

Table 7 shows the comparability of the Xiaomi MB wristbands for estimating daily PA recommendations. The comparability results of the daily step- and brisk pace walking-based recommendations assessed by the Xiaomi MB wristbands were excellent. However, based on the MVPA score of the Xiaomi MB wristbands, the comparability results of the daily MVPA-based recommendations were poor.

Discussion

The main purpose of the present study was to assess the validity of four generations of Xiaomi MB wristbands (i.e., MB 2, 3, 4, and 5) for the assessment of step count and PA levels among adolescents aged 12-18 years under free-living conditions. Firstly, although the findings of the present study showed that the Xiaomi MB wristband trackers were inside the equivalence region of the reference standard and they have between acceptable to excellent validity results for step count in comparison with the wGT3X-BT accelerometer, validity results for levels of PA were not within this range. These results are of great importance due to the main wristbands PA output being total daily step count, which is considered a simple, easier-to-understand, and credible indicator of daily PA (Mayorga-Vega et al., 2021; Parra-Saldías et al., 2018; Tudor-Locke et al., 2011). Furthermore, users highlight step count as the most useful feature on their activity trackers (Maher et al., 2017), its importance is also reflected in the fact that most consumer-wearable activity tracker-based interventions to promote PA in adolescents used step count per day as the most appropriate goal (Casado-Robles et al., 2022; Strath and Rowley, 2018).

Regarding previous research about the validity of Xiaomi MB wristbands for measuring adolescents' step count, the results of the present study agree with those carried out by Campos-Meirinhos et al. (2019) about the excellent validity of the Xiaomi MB 2 under free-living conditions (i.e., MAPE = 12.3% vs. 12.7%; ICC = 0.95 vs. 0.90). Moreover, the present results also agree with those obtained by the Yang et al. (2019) study about the Xiaomi MB 2 wristband validity for measuring step count among children and adolescents (i.e., MAPE = 12.2-13.6% vs. 14.5%). However, comparing the results from the Bland-Altman plots, the present results seem greatly better than those by Yang et al. (2019) for the Xiaomi MB 2 (LOA; 95% CI = -220.2; -2,462 - 2,021 vs. -633.5; -6,981 - 5,714, respectively). Furthermore, the present study also seems to have slightly better results than those obtained by Hao et al. (2021) to assess validity of the Xiaomi MB 2 for step count under simulated free-living conditions (i.e., MAPE = 12.3% vs. 21.3%). These differences may be due to methodological decisions such as ActiGraph accelerometer placement. Specifically, the study carried out by Hao et al. (2021) adjusted the accelerometer on the adolescents' non-dominant wrist, while the previous studies (Campos-Meirinhos et al., 2019; Yang et al., 2019) and the present one placed it on their hip. In this line, previous empirical studies have found that wrist- and hip-worn accelerometer step count outputs are not always comparable (Evenson et al., 2015; Tudor-Locke et al., 2015). However, hip-worn accelerometers as in the present study are considered the reference placement for assessing PA through accelerometry (Migueles et al., 2017).

Unfortunately, although the validity results depend on the population and context and should not be generalized, due to the lack of research on the validity of the other Xiaomi MB generations (i.e., 3, 4, and 5) among adolescents to measure step count, the present results have been also compared with available literature in other populations and settings. Even so, no previous studies have been found about the validity of the Xiaomi MB 5 for measuring step count. Regarding studies under free-living conditions among healthy adults, DeGroote et al. (2020), Topalidis et al. (2021) and de la Casa Pérez et al. (2022) carried out validity studies of the Xiaomi MB wristbands for measuring step count (i.e., MB 2, 3 and 4, respectively). Comparing the results from the Bland-Altman plots, the present results seem greatly better than those by DeGroote et al. (2020) for the Xiaomi MB 2 (LOA; 95% CI = -220.2; -2,462 - 2,021 vs. 1,011; -2,713 - 4,737, respectively), as well as those by Topalidis et al. (2021) for the Xiaomi MB 3 (LOA; 95% CI = -127.2; -2,575 - 2,320 vs. -4,050; -8,350 - 275, respectively) and de la Casa Pérez et al. (2022) for the Xiaomi MB 4 (LOA; 95% CI = -477.2; -2,927 - 1,973 vs. 924.3; -5,214.2 - 7.062.7, respectively). Moreover, considering the ICC and MAPE results obtained by DeGroote et al. (2020), they seem similar although slightly worse than the present ones showing good validity of the Xiaomi MB 2 for measuring step count under free-living conditions (i.e., ICC, 95% CI = 0.90, 0.77 - 0.95 vs. 0.95, 0.93 - 0.97; MAPE = 17.1% vs. 12.3%). Nevertheless, despite the fact that MAPE results from DeGroote et al. (2020) slightly exceed the acceptable cut-off point (i.e., 15.0%) proposed by Johnston et al. (2021), it is important to highlight that the Xiaomi MB 2 obtained the highest validity for the measurement of step count in comparison with the other 6 wristband brands in that study, including a high-cost wristband (i.e., Fitbit Charge 2; ≈ 125 €). Differences between previous studies and the present one could be due, for instance, to differences in the movement and PA patterns of the populations studied. That is, the stride amplitude, as well as the speed and frequency of arm movements, might be different in the adult population in comparison to the adolescent population.

Regarding studies carried out under structured conditions among adults (among adolescents, previous studies were not found), agreement between step count by the Xiaomi MB 2 and reference standards were found (DeGroote et al., 2020; Stamm and Hartanto 2018; Tam and Cheung, 2018). Moreover, these previous studies highlighted Xiaomi MB wristbands as the best model in comparison with other studied wearables from a wide price range (e.g., Fitbit or Samsung). Likewise, Hartung et al. (2020) found excellent results (i.e., MAPE = 4.9%) under walking conditions with the Xiaomi MB 3 wristbands against manually observed step count under structured activity protocols among adults. Moreover, de la Casa Pérez et al. (2022) also found no significant differences between Xiaomi MB 4 wristbands and step count by video recording under laboratory conditions among adults. Lastly, Pino-Ortega et al. (2021) carried out a similar study to the present one assessing the validity of the Xiaomi MB 2, 3, and 4 against the WIMU PRO inertial device, obtaining a nearly perfect agreement with the standard reference measure for the three generations of Xiaomi MB as the present study (ICC, 95% CI = 0.99, 0.98 - 1.00 vs. 0.94 - 0.95, 0.90 - 0.97). Nevertheless, although the results obtained by Pino-Ortega et al. (2021) under continuous walking conditions seem slightly better than those of the present study, the differences in settings are crucial. Specifically, it should be considered that while in the studies carried out in laboratory conditions participants were constrained to a predefined path with stable gait patterns, the present study was carried out under a greater variability of motor patterns including a wide range of adolescents' daily life behaviors which could increase the bias in measurement (Johnston et al., 2021). Therefore, studies focused solely on controlled and structured conditions, may fail in the ecological validation of wearables under free-living conditions (Johnston et al., 2021). Moreover, due to the main goal of consumer-wearable activity trackers being to assess adolescents' daily PA levels or to use them as a motivating tool to increase adolescents' PA practice, the results obtained from free-living conditions are closer to reality and, therefore, they are more meaningful and useful (Duncan et al., 2018).

However, despite the good results obtained for the step count, the findings of the present study showed poor validity for light PA, MVPA and total PA minutes between the Xiaomi MB wristbands and the wGT3X-BT accelerometer. Regarding previous research about the validity of Xiaomi MB devices for measuring adolescents' PA levels, only the study by Yang et al. (2019) was found assessing the validity of Xiaomi MB 2. Similar to the present study, they also showed poor validity much like the present study for measuring MVPA (LOA, 95% CI = 42.6, -56.1–141.3; vs. -12.4, -93.2 - 68.4), MVPA based on the brisk pace walking (LOA, 95% CI = 42.6, -56.1 - 141.3; vs. 15.2, -13.2 - 43.6) and total PA (LOA, 95% CI = 21.4, -129.1 - 171.9 vs. 144.2, 51.1 - 237.3). Furthermore, the study by DeGroote et al. (2020) also investigated the validity of the Xiaomi MB 2 for measuring MVPA minutes obtaining similarly poor results as the present study for minutes involved in MVPA (ICC, 95% CI = 0.15, -0.08 - 0.39 vs. 0.15, 0.00 - 0.37; MAPE = 293.29% vs. 110.8%), although it was carried out with an adult population. However, comparing the previous MVPA results by DeGroote et al. (2020) with the present study, but based on the brisk pace walking score, the present ones seem slightly better ranging from poor (MAPE = 50.1%) to acceptable validity (ICC, 95% CI = 0.78, 0.18 - 0.92). Meanwhile, both the previous and present study (only if minutes in brisk pace walking is considered) showed that the Xiaomi MB wristbands overestimated the time spent on MVPA in comparison with the accelerometer. Unfortunately, no previous studies have been found on the validity of the other Xiaomi MB generations (i.e., 3, 4, and 5) to measure PA levels in any population or setting in order to compare with the present results.

Nevertheless, these results are also consistent with other previous studies that found the consumer-wearable activity trackers from different brands and models valid to measure step count but not to measure PA at different intensities, even with high-cost trackers (e.g., DeGroote et al., 2020; Evenson et al., 2015; Feehan et al., 2018; Fuller et al., 2020; Voss et al., 2017). However, these discrepancies between the wristbands and research-grade accelerometers may arise not only for measurement bias but also from the specific algorithmic equation used (i.e., the accelerometer-based cut-points used for classifying PA intensity; Ferguson et al., 2015). Therefore, regarding the research-grade accelerometer as the reference measure, although the best available literature has been considered in the present study, there is still no strong evidence-based consensus about methodological issues (e.g., the best MVPA cut-point among adolescents or device placement; Migueles et al., 2017).

Besides that, the present study assessed the validity of the Xiaomi MB wristbands for correctly classifying adolescents as meeting or not meeting the international PA recommendations. The findings of the present study showed that the Xiaomi MB wristbands have good to excellent validity for correctly classifying adolescents as meeting or not meeting the recommendation of 10,000 steps per day (P = 0.89 - 0.95, k = 0.71 - 0.87) and the recommendation of 60 minutes of MVPA per day (based on the brisk pace walking score; P = 0.89 - 0.94, k = 0.69 - 0.83). Therefore, although the Xiaomi MB wristbands present low validity for assessing intensity-related PA outputs, these results are promising for public health policies, in order to set daily targets and receive feedback on their achievement. Specifically, they allow for knowing if adolescents are achieving the minimum PA levels recommended and, therefore, its consequent health benefits (WHO, 2020). Moreover, these results can help physical education teachers or policymakers to set goals within Xiaomi MB-based PA promotion programs among adolescents, establishing a minimum of 10,000 daily steps and/or 60 minutes of brisk pace walking per day to ensure the accomplishment with the international recommendations (Viciana et al., 2022). However, it should be noted that based on the MVPA score of the Xiaomi MB wristbands, the validity results were poor.

Regarding the secondary aim of this study focused on assessing the comparability of the four generations of Xiaomi MB wristbands for estimating daily PA, different results were obtained and different conclusions could be deduced. Firstly, step count, brisk pace walking, slow-brisk pace walking, and total PA outputs obtained the best comparability result; followed by the slow pace walking output; and finally, the MVPA output. To our knowledge, unfortunately, there are no previous studies focused on comparing the validity of different generations of Xiaomi MB wristbands with which to compare our results. Therefore, considering that the different generations achieve comparable results for measuring step count, brisk pace walking, slow-brisk pace walking and total PA outputs, options offered by the different generations of Xiaomi wristbands also could be an important reason to select one or another for a particular research context (Viciana et al., 2022). For instance, the color screen for display data could provide more motivation and attraction for children and adolescents, the type of alerts, or the data registered in the application and other options could be essential. Apart from that, these results are so valuable during health promotion programs, since many times, adolescents have their own wristbands that are usually of different generations depending on the time of acquisition of the wristband. Therefore, it would not be necessary to buy more wearables of the same generation for all schoolchildren, thus being a very feasible way to promote PA among this population and in Physical Education classes with their own bracelets and without spending money (Viciana et al., 2022).

An important strength of the present study was being, to our knowledge, the first one to examine the validity of four generations of Xiaomi MB wristbands (i.e., 2, 3, 4, and 5) among adolescents for measuring different PA variables (i.e., step count and time spent on PA at different intensities). Moreover, the validity of the Xiaomi MB wristbands in correctly classifying adolescents according to whether or not they met the daily PA recommendations was also assessed, which is very relevant for those responsible for PA promotion programs to evaluate and set targets. Thus, the present study allows for addressing an important gap in the scientific literature to date, due to most previous studies being carried out with adults and older people, and/or only using the oldest Xiaomi MB generations (i.e., Xiaomi MB 2, 3, and 4), and/or only assessing their validity for measuring step count. Furthermore, the evaluation in free-living conditions better reflects the validity of the wristband for measuring actual PA behavior of adolescents during their daily life (Duncan et al., 2018). Therefore, it provides more useful information for monitoring adolescents' PA levels during health promotion programs, PA surveillance studies, or for the provision of feedback in behavior change programs (Casado-Robles et al., 2022; Duncan et al., 2018; Strath and Rowley, 2018).

However, the present study is not without limitations. Firstly, a non-probability and relatively small sample has been used, which limits the generalizability of the obtained outcomes to the particular studied setting (i.e., adolescents with similar characteristics and PA patterns). However, due to the human and material resource restrictions, a probability and larger sample could not be examined. Moreover, although ActiGraph accelerometers have been highlighted as the most common and valid method for objectively assessing adolescents' PA levels during free-living conditions (e.g., Romanzini et al., 2014; Trost et al., 2011), today there is no strong evidence-based consensus about many methodological issues (Migueles et al., 2017). Therefore, it may contribute to the variability of the Xiaomi MB wristbands validity results, although the best current evidence-based decisions were adopted in the present study (Migueles et al., 2017). Due to these aforementioned limitations, further studies should be performed to improve the knowledge about the validity of these Xiaomi MB wristbands and new models for the recording of PA parameters. Moreover, it would be interesting if future studies showed a comparison between males and females, as well as, between children and adolescents.

Conclusion

The Xiaomi MB 2, 3, 4, and 5 wristbands presented good validity with the ActiGraph wGT3X-BT accelerometer for measuring adolescents' step count. Furthermore, although validity for the measurement of PA at different intensities was poor, they accurately classified adolescents as meeting or not meeting the recommendation of 10,000 steps and the recommendation of 60 minutes of MVPA per day (based on the brisk pace walking score). This highlights the potential of Xiaomi MB wristbands for monitoring adolescents' PA levels and obtaining accurate information about compliance with international PA recommendations, offering a feasible alternative, for most people, to the research-grade accelerometers. Furthermore, they could be used during health promotion programs to provide accurate feedback to adolescents (especially for step count output), as well as to set specific daily goals based on 10,000 steps and/or 60 minutes of brisk pace walking per day to ensure their accomplishment with the international recommendations. Lastly, if there are economic constraints to carrying out these intervention programs, different generations of Xiaomi MB wristbands could be mixed to carry it out (e.g., schoolchildren's own wristbands or previous models already purchased), as they have been found to be comparable for measuring step count, brisk pace walking, slow-brisk pace walking and total PA.

Acknowledgements

Authors thank Aliisa Hatten for the English revision. This study is part of the doctoral thesis of Carolina Casado-Robles, as well as of the I + D + i Fit-Person project (Reference: PID2019-110179GB-100), funded by the MCIN/AEI/10.13039/501100011033. There is no conflict of interest. The funder had no role in study design, data collection and analysis, decision to publish, or preparation of the manuscript. The present study complies with the current laws of the country in which it was performed. The datasets generated and analyzed during the current study are not publicly available but are available from the corresponding author, who was an organizer of the study.

References

ActiGraph Corporation,. (2021) *Activity monitors comparisons*. http://actigraphcorp.com

Alley, S., Schoeppe, S., Guertler, D., Jennings, C., Duncan, M. J. and Vandelanotte, C. (2016) Interest and preferences for using advanced physical activity tracking devices: results of a national cross-sectional survey. *BMJ Open* **6**, e011243. https://doi.org/10.1136/bmjopen-2016-011243

Arifin, W. (2018) A web-based sample size calculator for reliability studies. *Education in Medicine Journal* **10**, 67-76. https://doi.org/10.21315/eimj2018.10.3.8

Atkinson, G. and Nevill, A. M. (1998) Statistical methods for assessing measurement error (reliability) in variables relevant to sports medicine. *Sports Medicine* **26**, 217-238. https://doi.org/10.2165/00007256-199826040-00002

Bland, J. and Altman, D. (1986) Statistical methods for assessing agreement between two methods of clinical measurement. *Lancet* **1**, 307-310. https://doi.org/10.1016/S0140-6736(86)90837-8

Brickwood, K. J., Watson, G., O'Brien, J. and Williams, A. D. (2019) Consumer-based wearable activity trackers increase physical activity participation: Systematic review and meta-analysis. *JMIR mHealth and uHealth* **7**, e11819. https://doi.org/10.2196/11819

Brooke, H. L., Corder, K., Atkin, A. J. and van Sluijs, E. M. (2014) A systematic literature review with meta-analyses of within- and between-day differences in objectively measured physical activity in school-aged children. *Sports medicine* **44**, 1427-1438. https://doi.org/10.1007/s40279-014-0215-5

Butte, N., Watson, K., Ridley, K., Zakeri, I., McMurray, R., Pfeiffer, K., Crouter, S., Herrmann, S., Bassett, D., Long, A., Berhane, Z., Trost, S., Ainsworth, B., Berrigan, D. and Fulton, J. (2018) A youth compendium of physical activities: Activity codes and metabolic intensities. *Medicine and Science in Sports and Exercise*, **50**, 246-256. https://doi.org/10.1249/MSS.0000000000001430

Campos-Meirinhos, E. J., Mayorga-Vega, D., Casado-Robles, C., Guijarro-Romero, S. and Viciana, J. (2019) Are activity wristbands valid to estimate moderate-to-vigorous physical activity in adolescents during free-living conditions? *Motricidade* **15**, 18.

Casado-Robles, C., Viciana, J., Guijarro-Romero, S. and Mayorga-Vega, D. (2022) Effects of consumer-wearable activity tracker-based programs on objectively measured daily physical activity and sedentary behavior among school-aged children: A systematic review and meta-analysis. *Sports Medicine-Open* **8**, 18. https://doi.org/10.1186/s40798-021-00407-6

Cicchetti, D. (2001) The precision of reliability and validity estimates revisited: Distinguishing between clinical and statistical significance of sample size requirements. *Journal of Clinical and Experimental Neuropsychology* **23**, 695-700. https://doi.org/10.1076/jcen.23.5.695.1249

Cohen, J. (1992) A power primer. *Psychological Bulletin* **112**, 155-159. https://doi.org/10.1037/0033-2909.112.1.155

Cole, T. J., Bellizzi, M. C., Flegal, K. M. and Dietz, W. H. (2000) Establishing a standard definition for child overweight and obesity worldwide: International survey. *BMJ* **320**, 1240-1243. https://doi.org/10.1136/bmj.320.7244.1240

De la Casa Pérez, A., Latorre Román, P. Á., Muñoz Jiménez, M., Lucena Zurita, M., Laredo Aguilera, J. A., Párraga Montilla, J. A. and Cabrera Linares, J. C. (2022) Is the Xiaomi Mi Band 4 an accuracy tool for measuring health-related parameters in adults and older People? An original validation study. *International Journal of Environmental Research and Public Health* **19**, 1593. https://doi.org/10.3390/ijerph19031593

Degroote, L., Hamerlinck, G., Poels, K., Maher, C., Crombez, G., De Bourdeaudhuij, I., Vandendriessche, A., Curtis, R. G. and DeSmet, A. (2020) Low-cost consumer-based trackers to measure physical activity and sleep duration among adults in free-living conditions: Validation study. *JMIR mHealth and uHealth* **8**, e16674. https://doi.org/10.2196/16674

Dhurandhar, N. V., Schoeller, D., Brown, A. W., Heymsfield, S. B., Thomas, D., Sørensen, T. I., Speakman, J. R., Jeansonne, M., Allison, D. B. and Energy Balance Measurement Working Group. (2015) Energy balance measurement: when something is not better than nothing. *International Journal of Obesity* **39**, 1109-1113. https://doi.org/10.1038/ijo.2015.81

Dixon, P. M., Saint-Maurice, P. F., Kim, Y., Hibbing, P., Bai, Y. and Welk, G. J. (2018) A primer on the use of equivalence testing for evaluating measurement agreement. *Medicine & Science in Sports & Exercise* **50**, 837-845. https://doi.org/10.1249/MSS.0000000000001481

Duncan, M. J., Wunderlich, K., Zhao, Y. and Faulkner, G. (2018) Walk this way: Validity evidence of iPhone health application step count in laboratory and free-living conditions. *Journal of Sports Sciences* **36**, 1695-1704. https://doi.org/10.1080/02640414.2017.1409855

Evenson, K. R., Catellier, D. J., Gill, K., Ondrak, K. S. and McMurray, R. G. (2008) Calibration of two objective measures of physical activity for children. *Journal of Sports Sciences* **26**, 1557-1565. https://doi.org/10.1080/02640410802334196

Evenson, K. R., Goto, M. M. and Furberg, R. D. (2015) Systematic review of the validity and reliability of consumer-wearable activity trackers. *International Journal of Behavioral Nutrition and Physical Activity* **12**, 159. https://doi.org/10.1186/s12966-015-0314-1

Feehan, L. M., Geldman, J., Sayre, E. C., Park, C., Ezzat, A. M., Yoo, J. Y., Hamilton, C. B. and Li, L. C. (2018) Accuracy of Fitbit devices: Systematic review and narrative syntheses of quantitative data. *JMIR mHealth and uHealth* **6,** e10527. https://doi.org/10.2196/10527

Ferguson, T., Rowlands, A. V., Olds, T. and Maher, C. (2015) The validity of consumer-level, activity monitors in healthy adults worn in free-living conditions: a cross-sectional study. *The International Journal of Behavioral Nutrition and Physical Activity* **12**, 42. https://doi.org/10.1186/s12966-015-0201-9

Franssen, W., Franssen, G., Spaas, J., Solmi, F. and Eijnde, B. O. (2020) Can consumer wearable activity tracker-based interventions improve physical activity and cardiometabolic health in patients with chronic diseases? A systematic review and meta-analysis of randomised controlled trials. *The International Journal of Behavioral Nutrition and Physical Activity* **17**, 57. https://doi.org/10.1186/s12966-020-00955-2

Fuller, D., Colwell, E., Low, J., Orychock, K., Tobin, M. A., Simango, B., Buote, R., Van Heerden, D., Luan, H., Cullen, K., Slade, L. and Taylor, N. (2020) Reliability and validity of commercially available wearable devices for measuring steps, energy expenditure, and heart rate: Systematic review. *JMIR mHealth and uHealth* **8**, e18694. https://doi.org/10.2196/18694

Gorzelitz, J., Farber, C., Gangnon, R. and Cadmus-Bertram, L. (2020) Accuracy of wearable trackers for measuring moderate- to vigorous-intensity physical activity: A systematic review and meta-analysis. *Journal for the Measurement of Physical Behaviour* **3**, 346-357. https://doi.org/10.1123/jmpb.2019-0072

Guthold, R., Stevens, G. A., Riley, L. M. and Bull, F. C. (2020) Global trends in insufficient physical activity among adolescents: a pooled analysis of 298 population-based surveys with 1.6 million participants. *The Lancet Child and Adolescent Health* **4**, 23-35. https://doi.org/10.1016/S2352-4642(19)30323-2

Hao, Y., Ma, X. K., Zhu, Z. and Cao, Z. B. (2021) Validity of Wrist-wearable activity devices for estimating physical activity in adolescents: Comparative study. *JMIR mHealth and uHealth* **9**, e18320. https://doi.org/10.2196/18320

Hartung, V., Sarshar, M., Karle, V., Shammas, L., Rashid, A., Roullier, P., Eilers, C., Mäurer, M., Flachenecker, P., Pfeifer, K. and Tallner, A. (2020) Validity of consumer activity monitors and an algorithm using smartphone data for measuring steps during different activity types. *International Journal of Environmental Research and Public Health* **17**, 9314. https://doi.org/10.3390/ijerph17249314

Henriksen, A., Haugen Mikalsen, M., Woldaregay, A. Z., Muzny, M., Hartvigsen, G., Hopstock, L. A. and Grimsgaard, S. (2018) Using fitness trackers and smartwatches to measure physical activity in research: Analysis of consumer wrist-worn wearables. *Journal of Medical Internet Research* **20**, e110. https://doi.org/10.2196/jmir.9157

Hernaez, R. (2015) Reliability and agreement studies: A guide for clinical investigators. *Gut* **64**, 1018-1027. https://doi.org/10.1136/gutjnl-2014-308619

Howie, E. K. and Straker, L. M. (2016) Rates of attrition, non-compliance and missingness in randomized controlled trials of child physical activity interventions using accelerometers: A brief methodological review. *Journal of Science and Medicine in Sport* **19**, 830-836. https://doi.org/10.1016/j.jsams.2015.12.520

International Data Corporation. (2020) Shipments of Wearable Devices Leap to 125 Million Units, Up 35.1% in the Third Quarter, According to IDC. Available at: https://www.idc.com/getdoc.jsp?containerId=prUS47067820 (Accessed: 15 September 2022).

Jia, Y., Wang, W., Wen, D., Liang, L., Gao, L. and Lei, J. (2018) Perceived user preferences and usability evaluation of mainstream wearable devices for health monitoring. *PeerJ* **6**, e5350. https://doi.org/10.7717/peerj.5350

Johnston, W., Judice, P. B., Molina García, P., Mühlen, J. M., Lykke

Skovgaard, E., Stang, J., Schumann, M., Cheng, S., Bloch, W., Brønd, J. C., Ekelund, U., Grøntved, A., Caulfield, B., Ortega, F. B. and Sardinha, L. B. (2021) Recommendations for determining the validity of consumer wearable and smartphone step count: expert statement and checklist of the INTERLIVE network. *British Journal of Sports Medicine* **55**, 780-793. https://doi.org/10.1136/bjsports-2020-103147

Koo, T. and Li, M. (2016) A guideline of selecting and reporting intraclass correlation coefficients for reliability research. *Journal of Chiropractic Medicine* **15**, 155-163. https://doi.org/10.1016/j.jcm.2016.02.012

Kottner, J., Audigé, L., Brorson, S., Donner, A., Gajewski, B. J., Hróbjartsson, A., Roberts, C., Shoukri, M. and Streiner, D. L. (2011) Guidelines for reporting reliability and agreement studies (GRRAS) were proposed. *Journal of Clinical Epidemiology* **64**, 96-106. https://doi.org/10.1016/j.jclinepi.2010.03.002

Maher, C., Ryan, J., Ambrosi, C. and Edney, S. (2017) Users' experiences of wearable activity trackers: a cross-sectional study. *BMC Public Health* **17**, 880. https://doi.org/10.1186/s12889-017-4888-1

Martínez-Gómez, D., Martínez-De-Haro, V., Del-Campo, J., Zapatera, B., Welk, G. J., Villagra, A., Marcos, A. and Veiga, O. L. (2009) Validity of four questionnaires to assess physical activity in Spanish adolescents. *Gaceta sanitaria* **23**, 512-517. https://doi.org/10.1016/j.gaceta.2009.02.013

Mayorga-Vega, D., Casado-Robles, C., López-Fernández, I. and Viciana, J. (2021) A comparison of the utility of different step-indices to translate the physical activity recommendation in adolescents. *Journal of Sports Sciences* **39**, 469-479. https://doi.org/10.1080/02640414.2020.1826667

Metcalf, B., Henley, W. and Wilkin, T. (2012) Effectiveness of intervention on physical activity of children: systematic review and meta-analysis of controlled trials with objectively measured outcomes. *BMJ* **345**, e5888. https://doi.org/10.1136/bmj.e5888

Michie, S., Richardson, M., Johnston, M., Abraham, C., Francis, J., Hardeman, W., Eccles, M. P., Cane, J. and Wood, C. E. (2013) The behavior change technique taxonomy (v1) of 93 hierarchically clustered techniques: building an international consensus for the reporting of behavior change interventions. *Annals of Behavioral Medicine* **46**, 81-95. https://doi.org/10.1007/s12160-013-9486-6

Migueles, J. H., Cadenas-Sanchez, C., Ekelund, U., Delisle Nyström, C., Mora-Gonzalez, J., Löf, M., Labayen, I., Ruiz, J. R. and Ortega, F. B. (2017) Accelerometer data collection and processing criteria to assess physical activity and other outcomes: A systematic review and practical considerations. *Sports Medicine* **47**, 1821-1845. https://doi.org/10.1007/s40279-017-0716-0

Nunnally, J. (1978) Psychometric theory. 2nd edition. New york: McGraw-Hill.

Oliver, M., Badland, H. M., Schofield, G. M. and Shepherd, J. (2011) Identification of accelerometer nonwear time and sedentary behavior. *Research Quarterly for Exercise and Sport* **82**, 779-783. https://doi.org/10.5641/027013611X13275192112186

Parra Saldías, M., Mayorga-Vega, D., López-Fernández, I. and Viciana, J. (2018) How many daily steps are really enough for adolescents? A cross-validation study. *Retos* **33**, 241-246. https://doi.org/10.47197/retos.v0i33.55504

Pino-Ortega, J., Gómez-Carmona, C. D. and Rico-González, M. (2021) 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. *Gait & Posture* **87**, 6-10. https://doi.org/10.1016/j.gaitpost.2021.04.015

Poitras, V. J., Gray, C. E., Borghese, M. M., Carson, V., Chaput, J. P., Janssen, I., Katzmarzyk, P. T., Pate, R. R., Connor Gorber, S., Kho, M. E., Sampson, M. and Tremblay, M. S. (2016) Systematic review of the relationships between objectively measured physical activity and health indicators in school-aged children and youth. *Applied Physiology, Nutrition, and Metabolism* **41**, 197-239. https://doi.org/10.1139/apnm-2015-0663

Rich, E. and Miah, A. (2016) Mobile, wearable and ingestible health technologies: towards a critical research agenda. *Health Sociology Review* **26**, 84-97. https://doi.org/10.1080/14461242.2016.1211486

Romanzini, M., Petroski, E. L., Ohara, D., Dourado, A. C. and Reichert, F. F. (2014) Calibration of ActiGraph GT3X, Actical and RT3 accelerometers in adolescents. *European Journal of Sport Science* **14**, 91-99. https://doi.org/10.1080/17461391.2012.732614

Ruiz, D. C. and Goransson, A. (2015) Professional Android Wearables. New York: John Wiley & Sons.

Šimůnek, A., Dygrýn, J., Jakubec, L., Neuls, F., Frömel, K. and Welk, G. J. (2019) Validity of Garmin Vívofit 1 and Garmin Vívofit 3 for school-based physical activity monitoring. *Pediatric Exercise Science* **31**, 130-136. https://doi.org/10.1123/pes.2018-0019

Stamm, A. and Hartanto, R. (2018) Feature extraction from mems accelerometer and motion tracking measurements in comparison with smart bands during running. *Proceedings* **2**, 197-202. https://doi.org/10.3390/proceedings2060197

Stewart, A., Marfell-Jones, M., Olds, T. and De Ridder, J. (2011) International standards for anthropometric assessment. New Zealand: International Society for the Advancement of Kinanthropometry.

Strath, S. J. and Rowley, T. W. (2018) Wearables for Promoting Physical Activity. *Clinical Chemistry* **64**, 53-63. https://doi.org/10.1373/clinchem.2017.272369

Tam, K. M. and Cheung, S. Y. (2018) Validation of Electronic Activity Monitor Devices During Treadmill Walking. *Telemedicine Journal and e-Health : the Official Journal of the American Telemedicine Association* **24**, 782-789. https://doi.org/10.1089/tmj.2017.0263

Topalidis, P., Florea, C., Eigl, E. S., Kurapov, A., Leon, C. and Schabus, M. (2021) Evaluation of a Low-Cost Commercial Actigraph and Its Potential Use in Detecting Cultural Variations in Physical Activity and Sleep. *Sensors* **21**, 3774. https://doi.org/10.3390/s21113774

Trost, S. G., Loprinzi, P. D., Moore, R. and Pfeiffer, K. A. (2011) Comparison of accelerometer cut points for predicting activity intensity in youth. *Medicine and Science in Sports and Exercise* **43**, 1360-1368. https://doi.org/10.1249/MSS.0b013e318206476e

Tudor-Locke, C., Barreira, T. V. and Schuna, J. M. (2015) Comparison of step outputs for waist and wrist accelerometer attachment sites. *Medicine and Science in Sports and Exercise* **47**, 839-842. https://doi.org/10.1249/MSS.0000000000000476

Tudor-Locke, C., Craig, C. L., Beets, M. W., Belton, S., Cardon, G. M., Duncan, S., Hatano, Y., Lubans, D. R., Olds, T. S., Raustorp, A., Rowe, D. A., Spence, J. C., Tanaka, S. and Blair, S. N. (2011) How many steps/day are enough? for children and adolescents. *International Journal of Behavioral Nutrition and Physical Activity* **8**, 78. https://doi.org/10.1186/1479-5868-8-79

Van Hecke, L., Loyen, A., Verloigne, M., van der Ploeg, H. P., Lakerveld, J., Brug, J., De Bourdeaudhuij, I., Ekelund, U., Donnelly, A., Hendriksen, I. and Deforche, B. (2016) Variation in population levels of physical activity in European children and adolescents according to cross-European studies: a systematic literature review within DEDIPAC. *International Journal of Behavioral Nutrition and Physical Activity* **13**, 70. https://doi.org/10.1186/s12966-016-0396-4

Viciana, J., Casado-Robles, C., Guijarro-Romero, S. and Mayorga-Vega, D. (2022) Are wrist-worn activity trackers and mobile applications valid for assessing physical activity in high school students? Wearfit Study. *Journal of Sports Science and Medicine* **21**, 356 - 375. https://doi.org/10.52082/jssm.2022.356

Voss, C., Gardner, R. F., Dean, P. H. and Harris, K. C. (2017) Validity of commercial activity trackers in children with congenital heart disease. *Canadian Journal of Cardiology* **33**, 799-805. https://doi.org/10.1016/j.cjca.2016.11.024

Willmott, C. and Matsuura, K. (2005) Advantages of the mean absolute error (MAE) over the root mean square error (RMSE) in assessing average model performance. *Climate Research* **30**, 79-82. https://doi.org/10.3354/cr030079

WHO, World Health Organization (2018) Physical Activity Factsheets for the 28 European Union Member States of the Who European Region. Geneva: World Health Organization

WHO, World Health Organization. (2020) WHO guidelines on physical activity and sedentary behaviour. Geneva: World Health Organization.

Yang, X., Jago, R., Zhang, Q., Wang, Y. Y., Zhang, J. and Zhao, W. H. (2019) Validity and reliability of the wristband activity monitor in free-living children aged 10-17 years. *Biomedical and Environmental Sciences* **32**, 812-822.

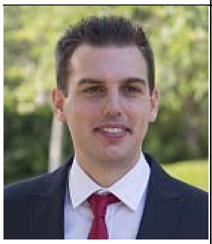
Key points

- The Xiaomi Mi Band 2, 3, 4, and 5 wristbands were valid for measuring adolescents' step count under unstructured free-living conditions.
- The Xiaomi Mi Band 2, 3, 4, and 5 wristbands accurately classified adolescents as meeting or not meeting the recommendations of 10,000 steps and the recommendation of 60 minutes of moderate-to-vigorous physical activity per day (based on the brisk pace walking score) under unstructured free-living conditions.
- The different generations of Xiaomi Mi Band wristbands achieve comparable results for measuring adolescents' step count, time involved in brisk pace walking, slow-brisk pace walking, and total physical activity; however, results were poor for measuring time involved in moderate-to-vigorous physical activity.
- Options offered by the different generations could be an important reason to select one or another for a particular research context, as well as, they could be mixed during intervention programs.

✉ **Santiago Guijarro-Romero**
Department of Didactic of Musical, Plastic and Corporal Expression, Faculty of Education and Social Work, University of Valladolid, Paseo de Belén, 1, 47011, Valladolid, Spain.

AUTHOR BIOGRAPHY

Carolina CASADO-ROBLES
Employment
Department of Physical Education and Sport, University of Granada, Spain.
Degree
PhD
Research interests
Measurement and evaluation, health-enhancing physical activity, sedentary behavior, Physical Education-based interventions, motivation toward physical activity.
E-mail: ccasado@ugr.es



Daniel MAYORGA-VEGA
Employment
Departamento de Didáctica de las Lenguas, las Artes y el Deporte, Facultad de Ciencias de la Educación, Universidad de Málaga, Málaga, España.
Degree
PhD
Research interests
Measurement and evaluation, health-enhancing physical activity, sedentary behavior, health-related physical fitness, Physical Education-based interventions, motivation toward physical activity.
E-mail: dmayorgavega@uma.es

Santiago GUIJARRO-ROMERO
Employment
Department of Didactic of Musical, Plastic and Corporal Expression, University of Valladolid, Valladolid, Spain
Degree
PhD
Research interests
Measurement and evaluation, health-enhancing physical activity, sedentary behavior, Physical Education-based interventions, motivation toward physical activity.
E-mail: santigr93@gmail.com

Jesús VICIANA
Employment
Department of Physical Education and Sport, University of Granada, Spain.
Degree
PhD
Research interests
Measurement and evaluation, health-enhancing physical activity, sedentary behavior, Physical Education-based interventions, motivation toward physical activity.
E-mail: jviciana@ugr.es