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Measurement properties of the Xiaomi Mi Band 7 for measuring heart rate in resistance exercises: a concurrent validity study

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Abstract
Introduction. **Moderate to high-intensity resistance exercises result in rapid changes and high values of heart rate, which may impact the accuracy of measurements in devices utilizing photoplethysmography technology. Nevertheless, the validity and reliability of the Mi Band 7 (MB7) have not yet been subjected to analysis, particularly in the context of resistance exercise programs.** Aim of Study. **The aim of this study was to analyze the validity and reliability of the MB7 device for measuring heart rate during resistance exercises in young male adults.** Material and Methods. **In a concurrent validity study design, 15 participants performed 3 × 12-15 repetitions (60% 1-RM) of bench press and low pulley seated row exercises, with a 1-minute interval between sets. Heart rate was simultaneously recorded by electrocardiogram (Polar H10) and two MB7 worn randomly on the right and left forearms. A Bland–Altman analysis was used to assess the systematic error. In addition, reliability was determined using the intraclass correlation coefficient (ICC) and the accuracy was also quantified as the mean absolute percentage error (MAPE).** Results. **Heart rate underestimation increased with higher exercise intensity regardless of which forearm the device was on. The mean MB7 error was 15-25 bpm in the bench press (MAPE = −18.5 to −12.5%), and 14-40 bpm in the low pulley seated row (MAPE = −24.4 to −10.1%). Moreover, the forearm on which the MB7 was worn seemed to have no impact on the reliability of the device for measuring heart rate during these exercises.** Conclusions. **The MB7 device demonstrated inadequate indexes of validity and reliability for the measurement of HR during bench press and low pulley seated row exercises.**

KEYWORDS: wearable electronic devices, resistance training, photoplethysmography, data accuracy.

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Introduction

The development of wearable electronic devices for monitoring physical activity parameters has attracted significant critical attention [1, 2]. The most popular wearable devices currently available on the market include the Xiaomi wristbands. One such device is the Mi Band 7 (MB7), which was released on a global scale in June 2022. This smart device is notable for its low cost (less than $30) and convenient design, and is equipped with a photoplethysmography (PPG) sensor. The MB7 offers a comprehensive array of features for the measurement of health parameters across a range of disciplines, including running, swimming, cycling, rowing, and resistance training. This development signifies a substantial enhancement over previous versions [3].

Previous studies have analyzed the measurement properties of different versions of Mi Band wristbands for monitoring parameters related to health and physical activity [4-6]. For instance, the validity and reliability of the Mi Band 2 for measuring heart rate (HR) while cycling may not meet the criteria for clinical or research purposes, as it has been observed to underestimate HR [4]. In turn, convergent measurement properties of the Mi Band 4 in relation to the Firstbeat Bodyguard 2 monitor have been demonstrated both at rest and during walking [5]. However, the validity and reliability of the MB7 have not yet been subjected to analysis, primarily in the context of resistance exercise programs.

It is hypothesized that the nature of the exercise may have a significant influence on the accuracy of the device, particularly in the case of resistance exercises that require recurrent handgrip and elbow flexion and extension movements [7-10]. Consequently, upper limb resistance exercises are of particular interest (e.g., bench press and low pulley seated row), as they result in the devices undergoing constant oscillation. In addition, resistance exercises of moderate to high intensity have been shown to result in rapid changes and elevated HR values. This may have a consequential impact on the accuracy of measurements obtained by devices utilizing PPG technology [7, 11].

Monitoring HR during resistance training is essential to optimize the benefits of the workout and ensure the safety of the user. Despite efforts to enhance the precision of PPG-based devices in estimating HR during physical exertion, there remains a paucity of evidence concerning their measurement properties in resistance exercises [1]. In view of the characteristics of this type of exercise, the hypothesis is that the MB7 device is not valid and reliable for measuring HR in young male adults during resistance exercises. The present investigation also evaluated the use of MB7 on the right and left wrists, with the potential to provide scientific and practical insights for end users in the acquisition of these devices.

Aim of Study

This study analyzed the validity and reliability of the MB7 device for measuring HR during resistance exercises in young male adults.

Material and Methods

Study design

This study used a concurrent validity study design to assess the scientific authenticity of the MB7 wearable device in measuring HR against a reference standard. Concurrent validity was determined using an electrocardiography (ECG) sensor, while reliability was established by wearing the MB7 device on the right and left forearms in a counterbalanced order. This study adheres to the guidelines set forth by the Guidelines for Reporting Reliability and Agreement Studies – GRRAS [12].

The present study was approved by the local ethics committee (CAAE: 56334722.0.0000.5179) and was conducted in accordance with the ethical standards of the Declaration of Helsinki and the Brazilian Health Council. Written informed consent was obtained from each participant prior to their involvement in the study.

Participants

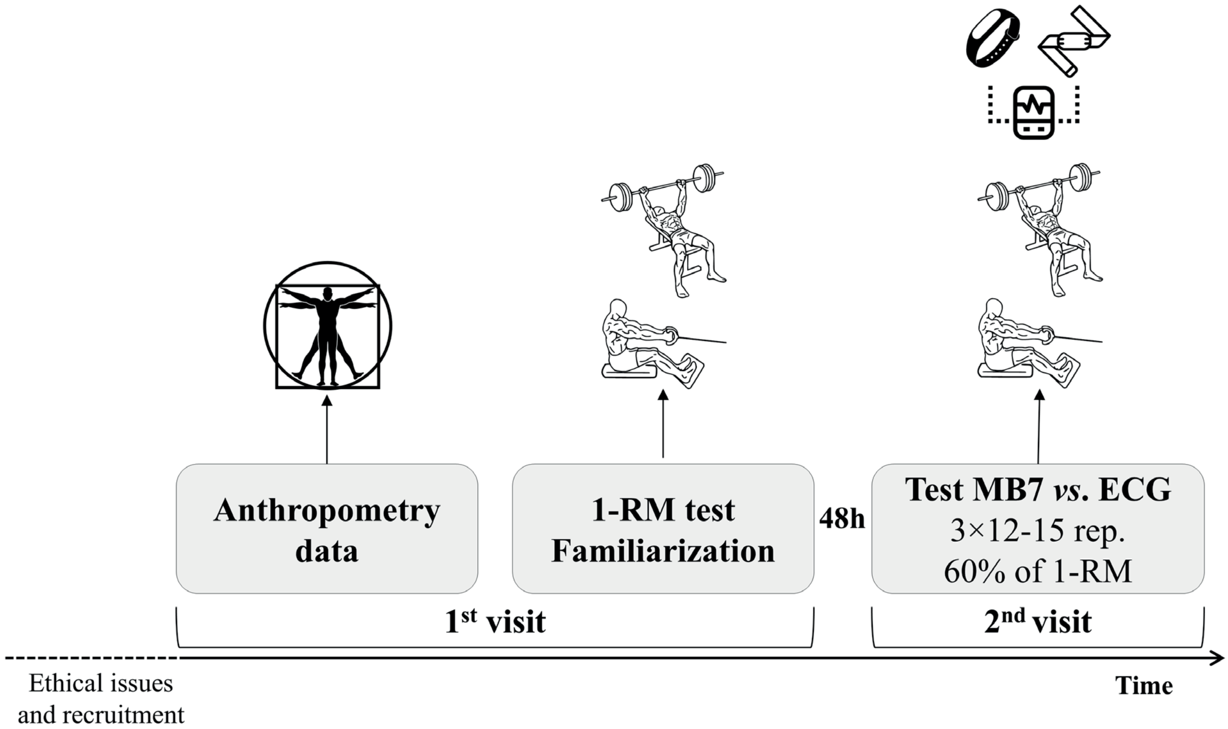
A total of 17 young male adults participated in the study. Participants were recruited through social media (Instagram and WhatsApp) and through the word-of-mouth approach. Inclusion criteria were as follows: male adults aged 18 to 32, a minimum of one year's experience in strength training, non-Caucasian (skin tone III to V on the Fitzpatrick scale) [13], and physically active (≥150 minutes/week of moderate or vigorous physical activity). The exclusion criterion was not having complete and valid data from the devices. Two participants were excluded from further analysis due to incomplete data.

The sample size calculation, *a priori*, estimated 14 participants, for an intraclass correlation coefficient (ICC) between the MB7 and the reference standard measures, given ICC = 0.8 ± 0.2, confidence level = 95% (1 − α), and number of repetitions per subject, $k = 2$ [14].

Procedures

Participants who met the eligibility criteria were invited to visit a gym on two occasions to take part in the following activities: 1st visit – anthropometric measurements, test of maximum repetitions of bench press and low pulley seated row, and familiarization with the experimental protocols; and 2nd visit – test protocol (Figure 1). Given that the time of day appears to have an effect on resistance exercise performance and HR responses [15], the participants were scheduled to visit at consistent times.

Age, height, and body mass were recorded in a data collection form. Additionally, the participants completed the Physical Activity Readiness Questionnaire (PAR-Q) to check their physical readiness for the study. On the day preceding the scheduled visits, participants were asked to refrain from engaging in vigorous physical exercise and from consuming beverages that could affect their



1-RM – test of maximum repetitions, MB7 – Mi Band 7 device, ECG – electrocardiography sensor chest trap

Figure 1. Study protocol

HR (e.g., coffee, alcoholic beverages, energy drinks). Moreover, the participants were asked to maintain their usual diet and daily activities during the study.

All participants had experience with strength exercises and received verbal instructions regarding the protocol, and were familiarized with the devices and exercises. The maximum load (1-RM) was estimated using a test of maximum repetitions of flat barbell bench press and low pulley seated row (Lion Fitness, Brazil) exercises, in a single, randomized session, with a 5-minute interval between exercises. For the purpose of determining the 1-RM, participants were required to lift a satisfactory weight (up to 10 repetitions) and the Brzycki equation [16] was applied.

In order to assess the validity of the MB7 (2nd visit), participants performed three sets of 12-15 repetitions (60% of 1-RM) of the bench press and the low pulley seated row (neutral grip) exercises, in a randomized order. The interval between the sets was 1 minute and between the exercises 5 minutes. HR was monitored continuously, but for the purpose of statistical analysis, recording on both devices was performed immediately after the fifth, tenth, and last repetition of each exercise. On all occasions, participants wore the global version of the MB7 device (Xiaomi, China), randomly positioned in counterbalanced order on the right (MB7-R) and left (MB7-L) forearms, and a validated ECG chest strap (Polar H10, Polar Electro Oy, Finland) [17]. The sampling frequency of the Polar H10 and MB7 devices is 130 Hz (beat-by-beat HR patterns) and 50 Hz (beat-to-beat pulsatile patterns), respectively. The MB7 and ECG were synchronized via Bluetooth to Zepp Life and Polar Flow apps, respectively. All measurements were obtained by three trained evaluators, who were independent of each other.

Data analysis

The data presented normal distribution (Shapiro–Francia test) and were reported as mean and standard deviation (SD). The paired *t*-test was used to compare HR between the devices (MB7-L, MB7-R, ECG) in different conditions. Reliability was determined using the intraclass correlation coefficient ($ICC_{3,1}$, consistency, two-way mixed-effects model), and interpreted as: <0.50 (poor), 0.51-0.74 (moderate), 0.75-0.90 (good), and >0.90 (excellent) [18]. Accuracy was also quantified as the mean absolute percentage error (MAPE) between the MB7 and reference standard (ECG) [100*(MB7−ECG)/ECG] and reported as mean and 95% confidence interval (95% CI). A Bland–

Altman analysis was used to assess the systematic error. Furthermore, the concordance correlation coefficient (ρ_c) was calculated, and the magnitude of agreement was interpreted as follows: <0.90 (poor), 0.90-0.95 (moderate), 0.95-0.99 (substantial), and >0.90 (almost perfect) [19]. The statistical analysis was conducted using IBM Statistical Package for the Social Sciences (SPSS) 27.0 (IBM Corp., Armonk, New York, USA), and MedCalc® Statistical Software 23.2.8 (MedCalc Software Ltd., Ostend, Belgium). A *p*-value was considered statistically significant if it was less than 5%. Validity was assessed using three criteria: MAPE < 10.0% [20], ICC > 0.80 [21], and equivalence between MB7 and the ECG chest strap (nonsignificant difference in the t-test).

Results

Data from 15 young male adults were analyzed. The mean (SD) age, body mass, height and BMI of the participants were 24 (4) years, 78.8 (11.2) kg, 1.75 (0.1) m and 25.5 (2.8) kg/m², respectively. Moreover, the mean (SD) estimated maximum load was 49.5 (11.7) kg and 58.8 (11.9) kg in the flat barbell bench press and low pulley seated row, respectively.

Both in the bench press and low pulley seated row exercise, the MB7 (right and left) underestimated HR when compared to the reference standard (Table 1). The MB7-R and MB7-L devices did not demonstrate any significant differences ($P > 0.05$). As the 3rd set demonstrated the best validity compared to the others (Tables S1 and S2, Supplementary Materials), the following analyses of measurement properties were only carried out for the MB7-R in this set.

Table 2 provides a summary of measurement properties for measuring HR in the bench press exercise – the MB7-R in comparison with the Polar H10. The reliability was interpreted as moderate (ICC < 0.59), and the magnitude of agreement was interpreted as poor ($\rho_c < 0.36$). Furthermore, the Bland–Altman analysis revealed a bias (mean error) ranging from 15 bpm (repetition 5) to 25 bpm (last repetition). For bench press exercise, MAPE values do not provide evidence of validity (>10%).

As illustrated in Table 3, a comprehensive overview of measurement properties is provided for the measurement of HR during the low pulley seated row exercise – the MB7-R in comparison with the Polar H10. The reliability was interpreted as moderate (ICC < 0.66), and the magnitude of agreement was interpreted as poor ($\rho_c < 0.10$). Additionally, the Bland–Altman analysis revealed a bias (mean error) ranging from 14 bpm (repetition 5) to 40 bpm (last repetition). For low pulley seated row exercise, MAPE values do not provide evidence of validity (>10%).

Table 4 shows the reliability and concordance indexes between MB7-R and MB7-L. In bench press exercise, the 3rd set presented better reliability and concordance based on ICC and ρ_c. In low pulley seated row exercise, the 1st set demonstrated better reliability and concordance based on ICC and ρ_c.

Table 1. Comparison of heart rate (bpm) during the bench press and low pulley seated row exercises measured by the Polar H10 and the MB7 (*n* = 15)

Bench press									
Set	1st			2nd			3rd		
Repetition	5	10	Last	5	10	Last	5	10	Last
Polar H10	111 (13)	120 (12)	128 (13)	116 (13)	123 (18)	132 (16)	118 (13)	126 (14)	130 (16)
MB7-R	99 (11)*	98 (10)*	95 (11)*	101 (13)*	101 (14)*	99 (14)*	103 (15)*	104 (15)*	105 (14)*
MB7-L	100 (17)*	100 (17)*	97 (13)*	100 (13)*	101 (14)*	100 (14)*	102 (14)*	102 (16)*	102 (14)*
Low pulley seated row									
Polar H10	121 (11)	135 (14)	143 (14)	125 (11)	140 (12)	149 (12)	128 (13)	145 (12)	152 (12)
MB7-R	102 (14)*	105 (16)*	107 (17)*	108 (16)*	107 (17)*	109 (19)*	114 (9)*	112 (12)*	113 (14)*
MB7-L	101 (13)*	100 (13)*	101 (13)*	105 (12)*	106 (14)*	103 (14)*	108 (11)*	110 (11)*	108 (13)*

Note: MB7-R – Mi Band 7 (right forearm), MB7-L – Mi Band 7 (left forearm)
Data presented as mean (SD).
* Significant difference from Polar H10 ($P < 0.05$)

Table 2. Measurement properties of the MB7-R device (right forearm) vs Polar H10 for measuring heart rate (bpm) during bench press exercise (n = 15)

Condition*	ICC (95% CI)	Bland–Altman analysis		ρ_c	MAPE (%)
		Bias (95% CI)	LOA		
Set 3 Repetition 5	0.598 [0.13 to 0.84]	15.1 [8.1 to 22.0]	−9.6 to 39.8	0.361	−12.5 [−7.0 to −18.1]
Set 3 Repetition 10	0.446 [−0.06 to 0.77]	21.9 [13.6 to 30.3]	−7.6 to 51.4	0.197	−17.1 [−11.2 to −22.9]
Set 3 Last repetition	0.299 [−0.23 to 0.69]	24.9 [15.1 to 34.8]	−9.8 to 59.7	0.120	−18.5 [−11.6 to −25.3]

Note: ICC – intraclass correlation coefficient, LOA – limits of agreement, ρ_c – concordance correlation coefficient, 95% CI – 95% confidence interval
* The 3rd set showed the best validity compared to the others.

Table 3. Measurement properties of the MB7-R device (right forearm) vs Polar H10 for measuring heart rate (bpm) during low pulley seated row exercise (n = 15)

Condition*	ICC (95% CI)	Bland–Altman analysis		ρ_c	MAPE (%)
		Bias (95% CI)	LOA		
Set 3 Repetition 5	0.268 [−0.26 to 0.67]	13.6 [8.7 to 18.5]	−3.9 to 31.1	0.091	−10.1 [−15.0 to −5.2]
Set 3 Repetition 10	0.480 [−0.02 to 0.78]	33.7 [27.0 to 40.4]	10.0 to 57.4	0.080	−22.5 [−29.8 to −15.2]
Set 3 Last repetition	0.666 [−0.25 to 0.87]	39.7 [30.8 to 48.7]	8.0 to 71.4	0.031	−24.4 [−31.2 to −17.6]

Note: ICC – intraclass correlation coefficient, LOA – limits of agreement, ρ_c – concordance correlation coefficient, 95% CI – 95% confidence interval
* The 3rd set showed the best validity compared to the others.

Table 4. Measurement properties of the MB7-R device (right forearm) vs MB7-L device (left forearm) for measuring heart rate (bpm) during the bench press and low-pulley seated row exercises (n = 15)

Bench press									
Set	1st			2nd			3rd		
Repetition	5	10	Last	5	10	Last	5	10	Last
ICC (95% CI)	0.652 [0.23 to 0.87]	0.405 [−0.11 to 0.75]	0.442 [−0.06 to 0.77]	0.654 [0.23 to 0.87]	0.579 [0.12 to 0.84]	0.352 [−0.22 to 0.71]	0.673 [0.26 to 0.87]	0.606 [0.16 to 0.85]	0.526 [0.03 to 0.81]
ρ_c	0.650	0.440	0.375	0.654	0.579	0.324	0.669	0.598	0.513
Low pulley seated row									
ICC (95% CI)	0.959 [0.87 to 0.98]	0.921 [0.78 to 0.97]	0.825 [0.56 to 0.93]	0.744 [0.39 to 0.90]	0.762 [0.42 to 0.91]	0.749 [0.40 to 0.90]	0.681 [0.28 to 0.88]	0.527 [0.04 to 0.81]	0.581 [0.12 to 0.83]
ρ_c	0.942	0.877	0.762	0.718	0.757	0.707	0.564	0.521	0.554

Note: ICC – intraclass correlation coefficient, ρ_c – concordance correlation coefficient, 95% CI – 95% confidence interval

Discussion

This study analyzed the measurement properties of the MB7 device for measuring HR during resistance exercises in young male adults. The hypothesis that the MB7 device is not valid and reliable for measuring HR in young male adults during resistance exercises was supported. The main findings of this study were as follows: (i) irrespective of the forearm used, as the exercise intensity increased, there was a greater underestimation of HR; (ii) the MB7 device presented inadequate validity indexes for measuring HR during bench press and low pulley seated row exercises; and (iii) the forearm on which the MB7 was worn seemed to have no impact on the reliability of the device for measuring HR during these exercises. Consequently, using the MB7 device for the measurement of heart rate during upper limb resistance exercises of moderate to high intensity is not recommended.

Data analysis indicated that as HR increased with exertion, the MB7 devices demonstrated a higher mean error relative to the reference standard, with MAPE exceeding 10%. This pattern was particularly evident in both exercises, when the participants were performing at or near their maximum effort (at the end of the sets). This phenomenon has also been observed in other studies conducted during running, cycling and resistance exercises [7, 8, 22]. In devices using PPG technology, the estimation of HR is highly dependent on the detectability of the arterial pulse wave [11, 22]. Thus, a possible explanation for these discrepancies is that the devices use different technologies (ECG vs. PPG), which may result in a delay (latency) in obtaining the HR reading using the PPG method [4, 7, 23].

The magnitude of HR underestimation observed in this study (ranging from 15 to 40 bpm) is of practical relevance in both clinical and training contexts. For instance, exercise prescription in cardiac rehabilitation or for patients with cardiovascular conditions often relies on narrow HR ranges (e.g., 60-70% of maximum HR), where a 20-25 bpm error could result in exercise being performed at subtherapeutic intensities, potentially compromising health outcomes. In resistance exercise programs, discrepancies of this magnitude may result in misclassification of training intensity, inadequate recovery assessments, or incorrect feedback on session exertion [8].

In general, the chest strap is considered the more accurate method for measuring HR when compared with the wrist-based measurement. Although the Polar H10 is recommended as a reference device for HR measurements during resistance exercises [17], there are few comparative studies between the Polar chest strap and wristbands. A recent investigation reveals a very good agreement between wrist-worn Polar Vantage V2 and Polar H10 devices in a supine position during spontaneous breathing [24]. Another study shows that the Polar OH1 (PPG technology) underestimated HR by 1 beat·min^{-1} (MAPE: −0.8 to 0.6%) compared to the Polar H10 device, and there was a very good correlation between the devices (r = 0.957) in cycle ergometer and treadmill exercises [25].

In our study, participants performed flat barbell bench press and low pulley seated row exercises at moderate intensity, which differs from previous published studies [7, 9, 10]. At higher levels of intensity, isometric contractions in the forearm muscles are more intense, suggesting that there is a decrease in contact between the PPG sensor of the device and skin, which in turn reduces signal quality [11, 22]. Based on these statements, the findings of this study indicate that wristbands may be more susceptible to low accuracy during upper limb resistance exercises, regardless of the forearm used. Consequently, when a more precise real-time measurement of HR is imperative (e.g., evaluation of special groups), using ECG sensors is advised.

The validity and reliability of HR measurement in resistance exercises were evaluated for some PPG-based wristbands [7-10]. For instance, during three sets of four resistance exercises at a 10-RM load, the values obtained from the TomTom Touch (MAPE: 19.1%), the Fitbit Blaze (MAPE: 13.7%), and the Garmin Vivosmart HR (MAPE: 10.7%) exhibited substantial variability and were found to be lower than those derived from the ECG, suggesting low validity [8]. Conversely, the Mio Alpha device exhibited a tendency to underestimate HR during a biceps curl to overhead press exercise involving a small barbell at a low intensity [7]. Thus, our research provides further evidence to support the preliminary observation that the mean difference observed in HR measurements for resistance exercise programs is larger than the criterion measure [26], which does not provide evidence of validity.

The utilization of wearable devices for HR measurements has been demonstrated to facilitate the estimation of caloric expenditure, which can be beneficial for the control of intensity during physical activities [1, 27]. Furthermore, these devices are suitable for HR monitoring in specific populations, such as those with heart disease [28], since it is crucial to ensure that the appropriate intensities are maintained when carrying out activities in this population. However, the findings of this study suggest that the MB7 is not a suitable tool for estimating caloric expenditure from HR for special groups (e.g., athletes or patients) during resistance exercises with moderate or high intensities.

It is widely acknowledged that the optimal wearable device for end users must be affordable, user-friendly, and accurate in measuring physical activity [27]. Some studies have indicated that devices from the Mi Band line are valid and reliable for reading HR in conditions of rest or low-intensity exercise [4, 5]. However, previous versions of the Mi Band have been found to underestimate HR in exercises of moderate to high intensity (e.g., running and cycling) [7]. In light of these considerations, it has been suggested that users should be cautious when relying on device readings to indicate exercise intensities, as certain devices may produce erroneous readings that infer incorrect intensities in real time [23].

Despite the numerous proposals for wearable devices to monitor physical training, especially to control intensity, inadequate reading patterns must be observed depending on the modality and intensity of the exercise. Consequently, the necessity for validating devices at varying levels of intensity and for diverse exercises is emphasized, ensuring enhanced safety for both the end user and the researcher. In this regard, other authors have proposed that enhanced transparency in the development and validation of wearable device reviews would contribute to an enhancement in their validity and reliability [29]. As new devices are produced, it becomes necessary to ascertain whether there has been a genuine improvement in reading standards, or whether the improvement is merely a marketing strategy designed to persuade consumers to purchase the product [30].

Notwithstanding the practical applicability of the study, there are certain limitations that must be acknowledged. Initially, only two resistance exercises focused on the upper limbs were analyzed. The exploration of other multi-joint exercises, or those with an emphasis on the lower limbs, could be a valuable way of analyzing the response of the PPG reader under conditions that do not require constant forearm movement. Furthermore, it is important to consider that lighter intensities were not analyzed and may present a better reading pattern. In the Bland–Altman analysis, smaller samples may result in wider confidence intervals for the limits of agreement. As a result, the limits of agreement estimates may be compromised. Finally, although the sample size met the statistical requirements for detecting reliability indexes, it comprised only 15 young, physically active, non-Caucasian male adults. This limits the generalizability of our findings to broader populations. Thus, further validation studies should aim to include larger and more diverse cohorts, encompassing different sexes, age groups, training status and ethnic backgrounds to verify the reproducibility of these results.

Conclusions

The MB7 device demonstrated inadequate indexes of validity and reliability for the measurement of HR during flat barbell bench press and low pulley seated row exercises. Consequently, using the MB7 device is not endorsed for the assessment of HR in male adults during upper limb resistance exercises of moderate or high intensity.

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Conflict of Interest
The authors declare no conflict of interest.

Supplementary Materials
Supplementary data to this article can be found online at: https://tss.awf.poznan.pl/SuppFile/209601/1/

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