Journal of Pharmaceutical and Sciences
Electronic ISSN: 2656-3088 DOI: https://doi.org/10.36490/journal-jps.com
Homepage: https://journal-jps.com
ORIGINAL ARTICLE JPS. 2026, 9(4), 3275-3283

Agreement Between a Smart Ring and Manual Pulse Palpation for Heart Rate Measurement After the Six-Minute Walk Test in Male Hajj Pilgrims: A Cross-Sectional Agreement Study

Kesepakatan antara Smart Ring dan Palpasi Nadi Manual dalam Pengukuran Denyut Jantung setelah Tes Jalan Enam Menit pada Jemaah Haji Laki-laki: Studi Kesepakatan Potong Lintang

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Abstract

This cross-sectional method-comparison study assessed the agreement between heart rate measured by a smart ring and by manual pulse palpation after the six-minute walk test in Hajj pilgrims, and the consistency of repeated smart-ring readings. The study was conducted at the Pondok Gede Hajj Dormitory, East Jakarta, in April 2026. We enrolled 108 healthy male special Hajj pilgrims aged 18–60 years using on-site random sampling. Consistency was assessed in 10 participants, each with 10 consecutive smart-ring readings. Immediately after the six-minute walk test, trained staff recorded heart rate with the smart ring and, at the same time, by palpation of the radial artery for 60 s. We assessed agreement using the paired t-test, Pearson's correlation, and Bland–Altman analysis. The comparator was manual palpation, not electrocardiography. The 10 repeated smart-ring readings were highly consistent as an average (Cronbach's alpha 0.962; intraclass correlation coefficient for average measures 0.959, 95% confidence interval 0.908–0.988; P <0.001), whereas the consistency of a single reading was moderate (intraclass correlation coefficient 0.702). Mean heart rate after the test was 86.42 ± 6.54 beats/min with the smart ring and 86.25 ± 6.68 beats/min with palpation, a mean difference of 0.17 beats/min that was not significant (P = 0.120); the two methods were closely correlated (r = 0.986; P <0.001). The 95% limits of agreement were −2.04 to 2.38 beats/min, within a clinically acceptable margin of ±5 beats/min, with no proportional bias. In healthy male pilgrims, smart-ring heart rate agreed closely with manual palpation, supporting the smart ring as a practical, non-invasive option for fitness screening.

Keywords*: *smart ring, heart rate, six-minute walk test, Hajj pilgrims, photoplethysmography

Abstrak

Studi perbandingan metode dengan desain potong lintang ini menilai kesepakatan antara denyut jantung yang diukur menggunakan smart ring dan palpasi nadi manual setelah tes jalan enam menit pada jemaah haji, serta konsistensi pembacaan smart ring saat diulang. Penelitian dilakukan di Asrama Haji Pondok Gede, Jakarta Timur, pada 1–30 April 2026. Sebanyak 108 jemaah haji laki-laki sehat berusia 18–60 tahun direkrut melalui pengambilan sampel acak di lokasi. Segera setelah tes jalan enam menit, denyut jantung dicatat menggunakan smart ring dan, pada saat yang sama, dengan palpasi arteri radialis selama 60 detik oleh petugas terlatih. Kesepakatan dinilai dengan uji-t berpasangan, korelasi Pearson, dan analisis Bland–Altman; pembanding yang digunakan adalah palpasi manual, bukan elektrokardiografi. Konsistensi dinilai pada 10 partisipan yang masing-masing menjalani 10 kali pembacaan smart ring secara berturut-turut dalam kondisi yang sama. Rerata dari 10 pembacaan berulang sangat konsisten (alfa Cronbach 0,962; koefisien korelasi intrakelas untuk rerata pengukuran 0,959; interval kepercayaan 95% 0,908–0,988; P <0,001), sedangkan konsistensi pada satu kali pembacaan tergolong sedang (koefisien korelasi intrakelas 0,702). Rerata denyut jantung setelah tes adalah 86,42 ± 6,54 kali/menit dengan smart ring dan 86,25 ± 6,68 kali/menit dengan palpasi, dengan selisih rerata 0,17 kali/menit yang tidak bermakna (P = 0,120); kedua metode berkorelasi sangat kuat (r = 0,986; P <0,001). Batas kesepakatan 95% adalah −2,04 hingga 2,38 kali/menit, masih dalam batas yang dapat diterima secara klinis (±5 kali/menit), tanpa bias proporsional. Pada jemaah haji laki-laki yang sehat, denyut jantung yang diukur dengan smart ring setelah tes jalan enam menit menunjukkan kesesuaian yang erat dengan palpasi manual, sehingga smart ring berpotensi menjadi pilihan yang praktis dan non-invasif untuk skrining kebugaran jemaah haji.

***Kata Kunci:** smart ring, denyut jantung, tes jalan enam menit, jemaah haji, fotopletismografi*

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https://doi.org/10.36490/journal-jps.com.v9i4.1921

Article History:
Received: 18/07/2026,
Revised: 02/10/2026,
Accepted: 02/10/2026,
Available Online: 14/10/2026.

QR access to this Article

Introduction

Cardiorespiratory fitness reflects how well the body can sustain physical activity. Heart rate is one of the simplest measures of how circulation responds to exercise because it shows how hard the heart works to deliver oxygen to tissues [1]. It rises quickly as exercise becomes harder; it is easy to measure and closely linked to aerobic capacity and exercise tolerance. Heart rate matters greatly for Hajj pilgrims. The rituals involve repeated activity, long walks, heat, humidity, and dense crowds, all of which increase the heart's workload [2]. An excessive or unusually flat response may indicate poor fitness. It may also signal a greater risk of a cardiac event during the pilgrimage, particularly in older pilgrims and in those with other illnesses; cardiovascular disease is the leading recorded cause of death among Indonesian pilgrims, and classical cardiovascular risk factors are associated with higher rates of hospitalisation and death during the Hajj [3,4].

The six-minute walk test (6MWT) is a submaximal exercise test used widely in clinical practice to measure functional capacity [5]. Walking distance is the main result, but heart rate before, during, and after the test also shows how the circulation copes with the workload and how quickly it recovers. Staff usually count heart rate during the test by hand at the pulse or read it from a simple monitor. Manual counting takes staff time and depends on the person doing it. Digital health technology now offers another route. Smartwatches, fitness trackers and similar devices use photoplethysmography (PPG), an optical method that senses changes in blood volume beneath the skin, and allow continuous, non-invasive monitoring [6,7]. Recent work shows that these devices measure heart rate reasonably well at rest and during submaximal activity, although accuracy varies with the device, the algorithm, the exercise intensity, and the user [8]. Most of this work has focused on the general population or athletes, and data on special groups such as Hajj pilgrims remain scarce.

Evidence from Asian populations is more limited. In Taiwan, two wrist-worn trackers tested against a chest-strap monitor in young adults and in adults aged 65 years and older showed acceptable average error during sedentary and moderate aerobic activity. Still, one device fell below the acceptable threshold, and both produced occasional large errors [9]. Agreement also tends to weaken as exercise intensity rises. During maximal treadmill testing, a smartwatch showed a mean bias of −2.7 beats/min but 95% limits of agreement of about −17 to 12 beats/min, adequate for group comparisons but not for decisions about individuals [10]. To our knowledge, no published study has assessed a smart ring's agreement with any comparator in Hajj pilgrims or after a field-based fitness test such as the 6MWT, and no validation of the device used in this study has been reported.

The smart ring is a newer wearable that places a PPG sensor and an accelerometer in a ring. It is small, comfortable, and unobtrusive, which may suit older users. A ring could therefore track heart rate during light or submaximal activity such as the 6MWT. However, evidence that ring readings agree with hand-counted readings during field fitness testing remains limited, especially in Indonesian healthcare facilities. The 2024 Hajj health readiness (istithaah) guideline of the Indonesian Ministry of Health calls for a thorough assessment of pilgrims' health and fitness to reduce illness and death during the pilgrimage [2]. Simple, easy-to-use wearables could support that screening. Before they are adopted widely, though, their readings need to be checked against the manual method used now. We chose manual palpation as the comparator because it is the method currently used in istithaah fitness screening and is feasible in a busy field setting where electrocardiography is not routinely available. Electrocardiography remains the reference standard, and the implications of this choice are considered in the Discussion.

The aim of this study was therefore to assess agreement between heart rate measured by a smart ring and manual palpation immediately after the 6MWT in male special Hajj pilgrims in Jakarta, Indonesia, and to assess the consistency of repeated smart-ring readings. The research question was whether the smart ring

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provides acceptable agreement with manual palpation at the individual level, not only at the group level. We hypothesised that (H1) heart rate measured by the smart ring would not differ significantly from that obtained by manual palpation, and (H2) repeated smart-ring readings would show high consistency.

Methods

Study design, setting and population

This cross-sectional method-comparison study was carried out at the Pondok Gede Hajj Dormitory, East Jakarta, between 1 and 30 April 2026. The accessible population was healthy male special Hajj pilgrims aged 18-60 years who attended a health examination at the dormitory during that period. We randomly selected eligible pilgrims present at the site. The study period fell within the final weeks before departure for the 2026 Hajj season, when pilgrims undergo pre-departure health examinations, so seasonal and preparatory conditions were similar for all participants.

Ethical considerations

The study followed the Declaration of Helsinki and the International Council for Harmonisation's good clinical practice guidelines. Ethical approval was granted by the Health Research Ethics Committee of the Faculty of Medicine, Universitas Islam Negeri Syarif Hidayatullah (approval no. 005/F12/KEPK/TL.00/03/2026, granted on 30 March 2026). All participants, or their legal representatives, gave written informed consent, and confidentiality was maintained throughout.

Eligibility criteria

Pilgrims were eligible if they were male, aged 18-60 years, in good health, and willing to give written informed consent. They were excluded if they had a musculoskeletal or neurological disorder that limited walking, unstable heart or lung disease at the time of examination, or were unable to complete the full 6MWT. We counted participants with incomplete measurements and those who withdrew during the study as drop-outs. Only participants with complete paired readings were analysed (per-protocol analysis), and no missing values were imputed.

Instrument

The main instrument was the SHL-AFIAT smart ring (PT Afiat Karsa Teknologi, Tangerang, Indonesia), a ring-shaped wearable for non-invasive physiological monitoring. An optical sensor (VC30F bio-optical sensor) set into the inner surface of the ring uses PPG to estimate heart rate and oxygen saturation in real time, and readings are transferred to a paired device via Bluetooth Low Energy. Details of signal acquisition and processing, including the PPG sampling rate, LED wavelength, firmware version, and heart-rate algorithm, are proprietary and are not publicly disclosed by the manufacturer. No previous validation study of this device has been published, so this study is, to our knowledge, its first reported evaluation against a comparator method. In this study, the ring was used to measure each participant's heart rate immediately after the 6MWT.

Procedure and data collection

We carried out the 6MWT according to the American Thoracic Society standard protocol [11]. Immediately after each participant finished the test, trained staff recorded heart rate at the same time using the smart ring and by palpation of the radial artery for 60 s. All readings were recorded in beats/min. Age and sex were also recorded. To assess the device's consistency, 10 participants each had 10 consecutive smart-ring readings taken under the same resting conditions. We used consecutive readings within a single session to estimate the device's short-term repeatability while minimizing physiological changes in heart rate; we did not assess between-day stability.

Data management and analysis

Data were checked, coded and entered in Microsoft Excel 2020 (Microsoft Corp., Redmond, Washington, USA) and analysed with IBM SPSS Statistics for Windows, version 26.0 (IBM Corp., Armonk, New York, USA). Heart rate readings from the smart ring and from palpation were summarised as mean ± standard deviation. The consistency of the 10 repeated smart-ring readings was assessed with Cronbach's

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alpha and the intraclass correlation coefficient (ICC), using a two-way mixed-effects model with absolute agreement; ICCs were reported for single and average measures and interpreted as poor (<0.50), moderate (0.50–0.75), good (0.75–0.90) or excellent (>0.90) [12]. To express the variability of a single reading in beats/min, the standard error of measurement (SEM = pooled standard deviation × √[1 − single-measure ICC]) and the minimal detectable change at 95% confidence (MDC95 = 1.96 × √2 × SEM) were calculated, and the mean readings were examined for a linear trend across the 10 readings to detect learning or fatigue effects. We checked normality with the Shapiro-Wilk test. We compared the mean heart rates obtained by the two methods using a paired-samples t-test and examined their relationship using Pearson's correlation coefficient. Because a high correlation and a non-significant mean difference do not by themselves show agreement, Bland–Altman analysis was also performed [13]. We defined bias as the mean of the paired differences (smart ring minus palpation) and the 95% limits of agreement as the bias ± 1.96 × the standard deviation of the differences, each with its 95% confidence interval. Proportional bias was examined by regressing the paired difference on the mean of the two methods [14]. We regarded a difference within ±5 beats/min as clinically acceptable, consistent with the accuracy requirement commonly applied to heart rate meters [15]. The adequacy of the sample size was checked for the main comparison: assuming a standard deviation of the paired differences of 6 beats/min, 71 participants are needed to detect a mean difference of 2 beats/min with a two-sided α of 0.05 and 80% power, and a sample of 108 gives 95% confidence intervals of about ±0.33 standard deviations for each limit of agreement [13]. A P value below 0.05 was taken as significant.

Results and Discussion

A total of 108 male special Hajj pilgrims met the inclusion criteria. All 108 had complete paired readings and were included in the analysis. This section presents participants' age characteristics, the consistency of repeated smart-ring readings, and agreement between the smart ring and manual palpation after the six-minute walk test, along with their interpretation in light of previous reports.

Participant characteristics

The mean age of the 108 participants was 46.6 ± 9.4 years (median 48 years; range 19-60 years). Most were aged 41-50 years (49 participants, 45.4%), followed by 51-60 years (41 participants, 38.0%). The 18-30-year and 31-40-year groups included 10 (9.3%) and 8 (7.4%) participants, respectively [Table 1]. This study did not record characteristics other than age and sex, such as body mass index, blood pressure, oxygen saturation, smoking status, physical activity, and comorbidity.

Table 1. Age characteristics of the male special Hajj pilgrims (N = 108).

Characteristic	Value	Percentage (%)
Age in years, mean ± standard deviation	46.6 ± 9.4	–
Age in years, median (range)	48 (19–60)	–
Age group in years		
18–30	10	9.3
31–40	8	7.4
41–50	49	45.4
51–60	41	38.0

Consistency of smart-ring heart rate readings

Ten participants each had 10 consecutive heart rate readings taken with the SHL-AFIAT smart ring under the same conditions. The mean reading ranged from 74.1 to 76.1 beats/min, with standard deviations of 1.52-3.30 beats/min [Table 2]. The narrow spread of means indicates stable readings across repetitions. Linear regression of the mean reading on reading order showed no systematic trend (slope −0.07 beats/min per reading; P = 0.27), so there was no evidence of a learning or fatigue effect across the 10 readings.

Table 2. Mean heart rate across 10 consecutive smart-ring readings taken in 10 participants.

Reading	Mean ± standard deviation (beats/min)
1	75.0 ± 2.45

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2	75.5 ± 2.12
3	76.1 ± 2.69
4	75.7 ± 2.26
5	74.9 ± 2.03
6	75.6 ± 3.24
7	75.7 ± 3.30
8	75.2 ± 2.90
9	75.5 ± 2.88
10	74.1 ± 1.52

Cronbach's alpha was 0.962, and the ICC for average measures was 0.959 (95% confidence interval: 0.908-0.988; P <0.001). The ICC for a single measure was 0.702 [Table 3]. According to the criteria of Koo and Li, these values indicate excellent consistency for the average of repeated readings but only moderate consistency for a single reading [12]. Based on the pooled standard deviation of the readings (2.60 beats/min), the SEM of a single reading was 1.4 beats/min and the MDC95 was 3.9 beats/min [Table 3].

Table 3. Consistency of smart-ring heart rate readings across 10 consecutive readings.

Parameter	Value
Cronbach's alpha	0.962
Intraclass correlation coefficient, single measures	0.702
Intraclass correlation coefficient, average measures	0.959
95% confidence interval, average measures	0.908–0.988
Standard error of measurement (beats/min)	1.4
Minimal detectable change, 95% (beats/min)	3.9
P value, intraclass correlation coefficient	<0.001

Intraclass correlation coefficient: two-way mixed-effects model, absolute agreement. Standard error of measurement = pooled standard deviation × √(1 − single-measure intraclass correlation coefficient); minimal detectable change = 1.96 × √2 × standard error of measurement. We considered p-values below 0.05 significant.

These findings agree with Cao et al., who compared a commercial smart ring with electrocardiography and reported that PPG-based rings provide stable heart rate readings that align well with the reference standard, supporting their use for long-term monitoring [16]. Kinnunen et al. reached a similar conclusion for nocturnal readings, reporting that ring PPG can track heart rate accurately against medical-grade electrocardiography under resting conditions comparable to the controlled repeated readings taken here [17]. The consistency assessment included only 10 participants, so it did not fully capture individual variation; it was high mainly for the average of repeated readings. For a single reading, the ICC was more modest, and in practice a single reading is taken, so some measurement variation should be expected. In practical terms, an MDC95 of about 4 beats/min means that a change between two single readings smaller than this cannot be distinguished from measurement error. A single reading is therefore adequate for group-level screening or detecting large deviations, whereas taking two or three readings and averaging them would make individual assessment more reliable.

Comparison of smart-ring and manual palpation after the six-minute walk test

After the 6MWT, the mean heart rate was 86.42 ± 6.54 beats/min with the smart ring and 86.25 ± 6.68 beats/min with manual palpation, giving a mean difference of 0.17 beats/min [Table 4]. Readings ranged from 72 to 108 beats/min with both methods, and the modest spread shows that most values clustered near the mean. The data met the normality assumption (Shapiro–Wilk test, P = 0.366), so parametric tests were applied. The paired-samples t-test gave t = 1.565 and P = 0.120, so the difference between the two methods was not significant, and there was no evidence of a systematic difference at the group level. Correlation analysis showed a close relationship between the methods (r = 0.986; P < 0.001), meaning higher hand-counted readings matched higher ring readings. Correlation, however, measures association rather than agreement [13], so agreement was assessed with Bland–Altman analysis.

Table **4.** Heart rate after the six-minute walk test measured by smart ring and by manual palpation (N = 108).

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Measurement method	Mean ± standard deviation (beats/min)	Minimum (beats/min)	Maximum (beats/min)
Smart ring	86.42 ± 6.54	72	108
Manual palpation	86.25 ± 6.68	72	108
Mean difference	0.17	–	–

Bland–Altman analysis showed a bias of 0.17 beats/min (95% confidence interval −0.05 to 0.39), with 95% limits of agreement of −2.04 to 2.38 beats/min [Table 5]. Even the outer confidence bounds of the limits (−2.42 and 2.76 beats/min) lay within the ±5 beats/min margin regarded as clinically acceptable, so for about 95% of participants the ring reading would be expected to fall within roughly 2.4 beats/min of the palpated value. The difference between methods was not related to the level of heart rate (slope of the difference on the mean −0.02; r = −0.13; P = 0.20), indicating no proportional bias across the observed range of 72–108 beats/min.

Table 5. Bland–Altman agreement between smart-ring and manual palpation heart rate after the six-minute walk test (N = 108).

Parameter	Value (beats/min)	95% confidence interval
Bias (smart ring − manual palpation)	0.17	−0.05 to 0.39
Standard deviation of the differences	1.13	–
Lower limit of agreement	−2.04	−2.42 to −1.67
Upper limit of agreement	2.38	2.01 to 2.76
Width of the limits of agreement	4.42	–
Proportional bias, slope (P value)	−0.02 (0.20)	–

Bias = mean of the paired differences (smart ring minus manual palpation). Limits of agreement = bias ± 1.96 × standard deviation of the differences. Proportional bias was assessed by regressing the paired difference on the mean of the two methods.

Both values fall within the range expected after submaximal activity such as the 6MWT. During exercise, rising oxygen demand in the tissues increases sympathetic activity, which raises heart rate so that cardiac output can meet metabolic needs; the rise seen after the 6MWT is therefore a normal response [18]. The close agreement between the two methods is consistent with the work of Parak and Korhonen, who reported that PPG-based wearables estimate heart rate well at rest and during light to submaximal activity, and with that of Bent et al., who found that modern wearables are reasonably accurate at low to moderate intensity but are affected by signal quality, sensor position and movement [6,8].

The mean difference of 0.17 beats/min is too small to matter for routine heart rate monitoring. The paired t-test showed no significant difference; the 95% limits of agreement were narrow, and the two methods were closely correlated. This suggests the ring provides heart rate readings comparable to the manual method, a widely used bedside technique, while also being easier to use and enabling continuous monitoring. These results align with Düking et al., who validated wrist-worn wearables for heart rate during sitting and light to vigorous activity, and with their earlier recommendation that wearables should be used for physiological monitoring only after they have shown adequate reliability and validity against a comparator [19,20]. Taken together, the narrow limits of agreement and the absence of a meaningful mean difference suggest that the smart ring could serve as a practical alternative to manual palpation for heart rate measurement immediately after submaximal activity such as the 6MWT. The smart ring therefore shows promise as a practical, non-invasive, easy-to-use tool for heart rate monitoring during fitness screening of Hajj pilgrims and, once validated against electrocardiography, could contribute to the istithaah health readiness assessment.

The limits of agreement in this study were much narrower than those reported for wrist-worn devices during more demanding exercise. During maximal treadmill testing, a smartwatch showed limits of agreement spanning about 28 beats/min [10], and in Taiwanese young and older adults, wrist-worn trackers had acceptable average error but occasional large outlying values during moderate aerobic exercise [9]. Several features of the present design probably favoured agreement: readings were taken after participants had stopped walking, heart rates were moderate (72–108 beats/min), and the comparator was a 60-s count, which averages out beat-to-beat variation. Agreement under these conditions should therefore not be extrapolated to readings taken while walking or at higher intensities.

Conditions during the Hajj itself also differ from those in a dormitory examination room. Motion is a major source of error for wearable optical sensors [6], and heat, high humidity, sweating, dehydration and changes in skin perfusion may further degrade the PPG signal. Pilgrims in Mecca, Mina, and Arafat walk long distances in dense crowds, often in high ambient temperatures, so the agreement found here may overstate

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the ring's accuracy during the pilgrimage itself. Validation under these field conditions, ideally against continuous electrocardiographic recording, is needed before the ring is used for in-pilgrimage monitoring.

Operationally, a ring reading is obtained within seconds, requires little training, frees staff from manual counting during high-volume istithaah screening, and electronic transfer of readings could reduce transcription errors. Wider adoption, however, will depend on device cost and supply, battery life, staff training, data protection, and integration with the existing Hajj health information system, none of which were evaluated in this study.

This study has several limitations. Participants were healthy men aged 18-60 years, which limits how far the findings can be generalised to women, to older pilgrims, and to people with chronic disease; because PPG accuracy tends to be lower in people with poor peripheral perfusion or arrhythmia, this selection is more likely to overestimate than to underestimate agreement. The on-site sampling procedure was not documented in enough detail to show that every eligible pilgrim had an equal chance of selection, and the numbers screened, ineligible, and declining were not recorded, so a participant flow diagram and response rate cannot be reported, and selection bias cannot be excluded. The comparator was manual pulse counting rather than electrocardiography, the reference standard, so agreement with a true reference remains untested. Finally, readings were taken immediately after the test rather than continuously during it, so the performance of the ring during walking itself is unknown; in addition, the details of the 6MWT course, the exact interval between the end of the walk and the start of recording, and the finger on which the ring was worn were not recorded in detail. The consistency subsample was small (10 participants), the resting conditions for the repeated readings (posture, rest duration, room temperature) were not formally specified, and between-day test–retest stability was not assessed; the single-measure ICC of 0.702 shows that one reading carries appreciable variability. Despite these limitations, the study provides useful evidence of the smart ring's consistency and its agreement with the manual method. Further studies with larger, more diverse samples; a defined sampling frame; blinded observers; continuous recording during the walk; between-day repeat measurements; and a reference standard such as electrocardiography are needed before its validity for wider clinical use can be confirmed.

Conclusions

In this sample of healthy male pilgrims, smart-ring heart rate measured immediately after the 6MWT did not differ significantly from manual palpation (86.42 ± 6.54 vs 86.25 ± 6.68 beats/min; mean difference 0.17 beats/min), and the 95% limits of agreement (−2.04 to 2.38 beats/min) lay within a clinically acceptable margin of ±5 beats/min. The average of repeated smart-ring readings was highly consistent, but a single reading showed only moderate consistency. The smart ring is therefore a promising, practical option to support heart rate measurement during fitness screening of Hajj pilgrims; however, its validity against electrocardiography during walking, under Hajj field conditions, and in women, older, and unwell pilgrims must be established before widespread adoption.

Conflict of Interest

The authors declare that there is no conflict of interest. None of the authors has any financial or non-financial relationship with PT Afiat Karsa Teknologi, the manufacturer of the SHL-AFIAT smart ring, and the manufacturer had no role in the study design, data collection, analysis, interpretation of the data, or the decision to publish.

Acknowledgment

This work received no external funding. The authors thank the Indonesian Hajj Medicine Association (Perhimpunan Kedokteran Haji Indonesia), the staff of the Pondok Gede Hajj Dormitory, East Jakarta, and all the Hajj pilgrims who participated in this study for their support during data collection.

Author Contribution

SHL: Conceptualization, Methodology, Resources, Data Curation, and Writing - Original Draft. AF: Conceptualization, Methodology, Supervision, Formal Analysis, and Investigation. AR: Conceptualization,

Electronic ISSN : 2656-3088
Homepage: https://www.journal-jps.com

Supervision, Writing - Original Draft, and Writing - Review & Editing. MAA: Methodology, Supervision, Investigation, and Writing - Review & Editing. LSR: Resources, Data Curation, and Formal Analysis.

Data Availability

The data supporting the findings of this study are available from the corresponding author upon reasonable request.

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