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Human Kinetics
ORIGINAL RESEARCH REPORT

Concurrent Validity of Resting Pulse-Rate Measurements: A Comparison of 2 Smartphone Applications, the Polar H7 Belt Monitor, and a Pulse Oximeter With Bluetooth

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Context: Pulse rate is commonly measured manually or with commercial wrist or belt monitors. More recently, pulse-rate monitoring has become convenient with the use of mobile technology that allows monitoring through a smartphone camera. This optical technology offers many benefits, although the clinimetric properties have not been extensively studied. ***Design:*** Observational study of reliability ***Setting:*** University kinesiology laboratory. ***Participants:*** 30 healthy, recreationally active adults. ***Intervention:*** Concurrent measurement of pulse rate using 2 smartphone applications (fingertip, face-scan,) with the Polar H7 belt and pulse oximeter. ***Main Outcome Measure:*** Average resting pulse rate for 5 min in 3 positions (supine, sitting, and prone). ***Results:*** Concurrent validity in supine and standing was good between the 2 applications and the Polar H7 (intraclass correlation coefficient [ICC] .80–.98) and pulse oximeter (ICC .82–.98). For sitting, the validity was good between the fingertip application, Polar H7 (ICC .97), and pulse oximeter (ICC .97). The face-scan application had moderate validity with the Polar H7 (ICC .74) and pulse oximeter (ICC .69). The minimal detectable change (MDC_{90}) between the fingertip application and Polar H7 ranged from 1.38 to 4.36 beats/min (BPM) and from 0.69 to 2.97 BPM for the pulse oximeter with both positions. The MDC_{90} between the face-scan application and Polar H7 ranged from 11.88 to 12.83 BPM and from 0.59 to 17.72 BPM for the pulse oximeter. The 95% limits of agreement suggest that the fingertip application may vary between 2.40 and 3.59 BPM with the Polar H7 and between 3.40 and 3.42 BPM with the pulse oximeter. The face-scan application may vary between 3.46 and 3.52 BPM with the Polar H7 and between 2.54 and 3.46 BPM with the pulse oximeter. ***Conclusion:*** Pulse-rate measurements may be effective using a fingertip application, belt monitor, and pulse oximeter. The fingertip scanner showed superior results compared with the face scanner, which only demonstrated modest validity compared with the Polar H7 and pulse oximeter.

Keywords: mobile technology, heart, smartphone apps

Pulse rate has traditionally been measured manually using radial pulse for a 30- or 60-second time interval.[1] The advent of commercial wrist and belt monitors has enhanced the convenience of measuring pulse rate. These commercial monitors have eliminated the need for manual monitoring and have been reported as a valid measure of pulse rate during rest and activity.[2–4]

More recently, pulse-rate monitoring has become convenient and portable with the use of mobile smartphone technology. The company Polar has created the Polar H6 and H7 belt monitors that communicate with an Apple mobile device by combining their Polar WearLink wireless technology with Bluetooth technology. Data are recorded through their accompanying Polar Beats smartphone application. The manufacturer has not reported any research on the clinimetrics of this smartphone technology.

Several new smartphone applications have also been developed that measure a person's pulse rate by a fingertip touch to the smartphone camera or scanning of the face by the camera.[5,6] The smartphone camera uses an optical pulse sensor, or photoplethysmography, to measure pulse rate by sensing the subtle changes in a person's skin color as the capillaries expand and contract with each heartbeat.[7,8] This technology can be used with mobile devices such as smartphones, media players, or tablets that use the Apple or Android operating system. This smartphone optical technology has shown a high correlation with electrocardiography (ECG) and pulse oximetry with laboratory testing.[9–11] The current research examining the utility of this technology beyond the preliminary investigations has been limited to studies with small samples sizes in the field of psychology.[5,12] To date there has been no cohort or population-based research that assessed the validity of this smartphone technology. This

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lack of scientific research creates a void in knowing how accurate this technology is compared with other popular measures of pulse monitoring.

The new mobile smartphone technology has become popular for health and wellness and in various medical settings.[5,7] The utility of such technology may provide an efficient way of data collection and communication in many settings including prehospital care, cardiopulmonary rehabilitation, daily monitoring by patients, and monitoring athletes. Since this technology is widely used, there is a need to further validate its clinimetric properties. Thus, the purpose of this study was to assess the concurrent validity of 2 commercial smartphone applications (fingertip, face-scan) with the Polar H7 commercial belt monitor and pulse oximeter using Bluetooth in measuring short-term resting pulse rate in healthy individuals.

Methods

Participants

Participants included 30 healthy, recreationally active adults (Table 1). Exclusion criteria consisted of previously diagnosed cardiac problems or systemic diseases, reporting of medications that would affect cardiorespiratory function, having an electrical implant device, or being a smoker. This study was conducted at a university kinesiology laboratory and was approved by the institutional review board. All participants who qualified were informed of the study requirements and signed an approved consent form once they agreed to participate.

Instruments

One Polar H7 belt monitor with the WearLink wireless technology was used with its accompanying Polar Beat smartphone application designed for the Apple operating system (Figure 1). Currently, the manufacturer has not reported any research on this smartphone technology. Other Polar belt monitors that use the WearLink wireless technology, such as the S810, have been validated with ECG in prior investigations.[3,4,13] Data were recorded using 1 iPad Mini.

Table 1 Participant Demographics

Item	Measure
Participants	N = 30
male	n = 18
female	n = 12
Age	26 ± 5 y
Height	170 ± 9.51 cm
Body mass	76 ± 19.33 kg

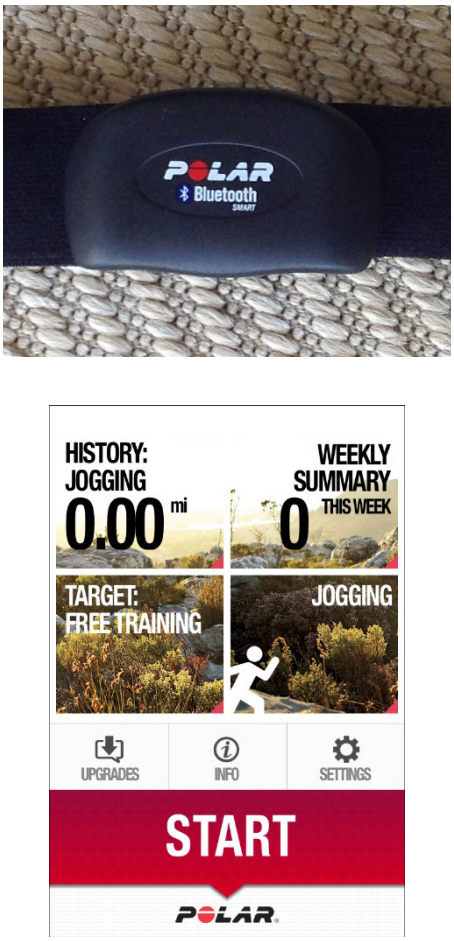
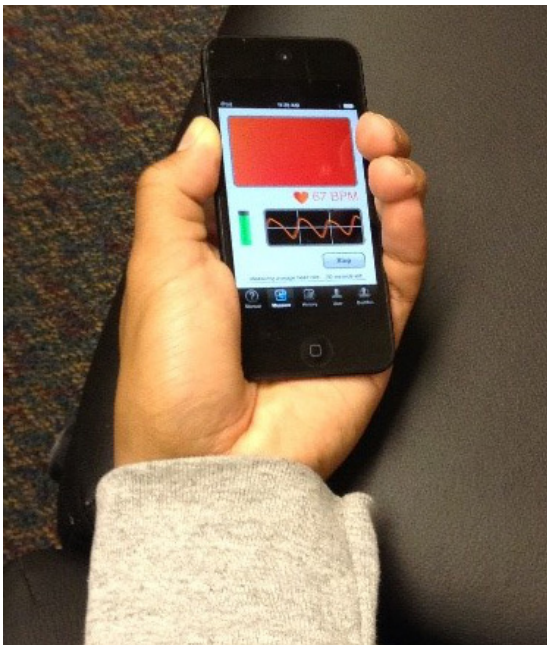


Figure 1 — (a) Polar H7 monitor and (b) Polar Beats application.

Two commercial smartphone applications designed for the Apple operating system were used in this investigation. The first smartphone application was the SensCare fingertip pulse-rate monitor by SensCare (Figure 2). The second smartphone application was the Cardio Buddy pulse-rate face scanner by Azumio (Figure 3). Currently, both manufacturers have reported no information on the clinimetric properties of their smartphone applications. One Apple fifth-generation iPod Touch was used for each smartphone application during data collection.

A clip-type pulse oximeter (Figure 4[a]) (Model CMS-50E Contec; Qinhuangdao, Hebei Province, China) with Bluetooth technology was used with its accompanying Windows software (SpO_2 Assistant v 2.4) (Figure 4[b]). Prior studies have shown a clip-type sensor on the finger to be more accurate than earlobe placement.[14] The manufacturer reported pulse-rate accuracy to be within the range of 30 to 240 beats/min. In addition, the manufacturer reported that accuracy is ±2 beats/min, or 2%.[15]



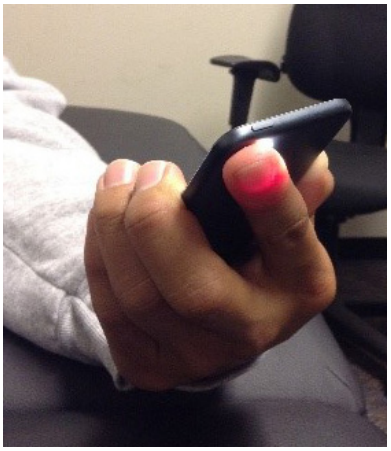


Figure 2 — SensCare fingertip application.

The pulse oximeter was considered the gold standard for the purpose of this study and has been validated in prior investigations with ECG.[14,16–19]

Before data collection, 3 training session were conducted among 4 investigators: the principal investigator, a board-certified orthopedic physical therapist with 12 years of clinical experience, a doctoral-level kinesiology professor with 20 years of research experience, and 2 senior undergraduate students. The principal investigator measured resting pulse rate using both smartphone applications via the iPods and was the only investigator to use the iPods throughout the investigation. The other 3 investigators practiced data collection for the Polar H7 and pulse oximeter using the iPad mini and laptop computer. After the training sessions, a pilot test was

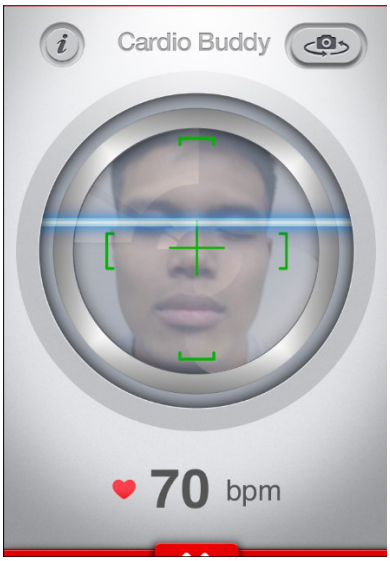
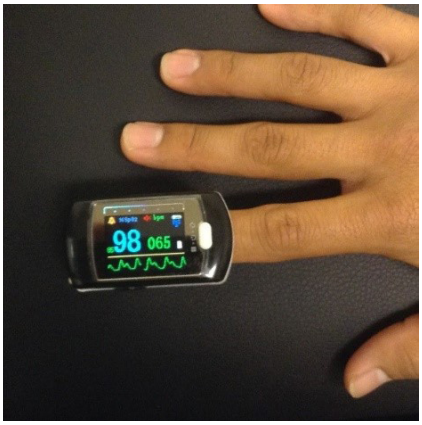


Figure 3 — Cardio Buddy face-scan application.

(a)



(b)

Figure 4 — (a) Pulse oximeter and (b) SpO_2 software.

conducted with 10 participants and yielded an interrater reliability value of 94% agreement among all examiners. This exceeded the recommended minimal reliability of 90% agreement for clinical measurements.[20] Data were collected with 2 raters at a time, which included the principal investigator and 1 other trained investigator.

Protocol

For each participant, concurrent validity testing was completed on the same day between 11 AM and 1 PM by 2 investigators. Participants avoided exercise, caffeine, energy drinks, and heavy eating 4 hours before testing and refrained from wearing nail polish and acrylic nails on the right and left index fingers. Nail polish and acrylic nails have been shown to affect the accuracy of pulse oximetry in prior investigations.[21,22] Participants also refrained from having any electronic devices (eg, cell phone) on or near them during testing.

Participants' resting pulse rate was concurrently tested with all instruments after a 5-minute time interval in 3 positions: supine lying on a plinth, sitting in a chair, and standing. Before testing, a rater cleaned the skin with a disinfectant wipe where the belt monitor was positioned and the right index finger where the pulse oximeter was placed. Each position was timed with an electronic timer. Fifteen seconds before the end of each interval the primary investigator placed the iPod with the SensCare fingertip monitor in the participant's left hand and index finger over the camera and positioned the iPod with the Cardio Buddy face scanner above the participant's face accordingly. The second investigator monitored the iPad mini, which was wirelessly linked to the Polar H7 belt and a laptop computer linked to the pulse oximeter via Bluetooth. At the end of the time interval both raters recorded resting pulse rate. This sequence was conducted in all 3 positions, which followed similar protocols used in prior investigations.[4,23,24]

Statistical Analysis

Statistical analysis was performed using SPSS version 22.0 for Windows (IBM SPSS, Chicago, IL). Participant descriptive data were calculated and reported as mean ± SD. Concurrent validity for all instruments was determined by the intraclass correlation coefficient (ICC) model 3,k using the average measures. ICC values above .75 were considered good reliability, whereas value of .50 to .75 were considered moderate, and values below .50 poor.[25] The ICC values may be influenced by intersubject variability because a large ICC value may be reported despite poor trial-to-trial consistency if the intersubject variability is too high.[25] The standard error of measurement (SEM) was used in conjunction with the ICC since it is not affected by intersubject variability.[25] The minimal detectable change ($MDC_{90} = 1.65 \times SEM \times$ the square root of 2) was used to determine the magnitude of change that would exceed the threshold of measurement error at a 90% confidence level.[26] Therefore, clinicians can be 90% certain that the difference between devices is not due to intertrial variability or measurement error. The 95% limits of agreement (LoA = mean difference ± 2SD) were also calculated.[25]

Results

The concurrent validity, mean difference, MDC_{90}, and 95% LoA for all devices are summarized in Tables 2 and 3.

SensCare and Cardio Buddy Smartphone Applications

The concurrent validity between the 2 smartphone applications was good for measuring resting heart rate in supine ($ICC_{3,k}$ = .84, SEM = 6.59) and standing ($ICC_{3,k}$ = .88, SEM = 2.05) but moderate in sitting ($ICC_{3,k}$ = .73, SEM = 6.04). The MDC_{90} for both applications was 21.74 beats/min for supine, 19.93 beats/min for sitting, and 6.76 beats/min for standing. The 95% LoA for measuring pulse rate suggests that both smartphone applications may vary by 0.26 beats/min (–1.87, –2.13) for supine, 2.4 beats/min (–0.7, –3.1) for sitting, and 0.26 beats/min (–1.87, 2.13) for standing.

SensCare and Polar H7

The concurrent validity between the fingertip application and the Polar H7 was good for measuring resting heart rate in supine ($ICC_{3,k}$ = .98, SEM = 0.42), sitting ($ICC_{3,k}$ = .97, SEM = 0.60), and standing ($ICC_{3,k}$ = .94, SEM = 1.32). The MDC_{90} for both devices was 1.39 beats/min for supine, 1.98 beats/min for sitting, and 4.35 beats/min for standing. The 95% LoA for measuring pulse rate suggests that both devices may vary by 3.59 beats/min (–.027, –3.73) for supine, 2.4 beats/min (–1.16, –2.76) for sitting, and 3.44 beats/min (–0.31, –3.75) for standing.

Cardio Buddy and Polar H7

The concurrent validity between the face-scan application and Polar H7 was good for measuring resting heart rate in supine ($ICC_{3,k}$ = .80, SEM = 3.60) and standing ($ICC_{3,k}$ = .81, SEM = 3.89) but moderate in sitting ($ICC_{3,k}$ = .74, SEM = 4.34).

The MDC_{90} for both devices was 11.88 beats/min for supine, 14.32 beats/min for sitting, and 12.84 beats/min for standing. The 95% LoA for measuring pulse rate suggests that both devices may vary by 3.52 beats/min (–0.14, –3.66) for supine, 3.46 beats/min (–0.27, –3.73) for sitting, and 3.52 beats/min (–0.14, –3.66) for standing.

SensCare and Pulse Oximeter

The concurrent validity between the fingertip application and the pulse oximeter was good for measuring resting heart rate in supine ($ICC_{3,k}$ = .99, SEM = 0.21), sitting ($ICC_{3,k}$ = .97, SEM = 0.63), and standing ($ICC_{3,k}$ = .96,

Table 2 Concurrent Validity of All Devices, ICC (95% CI)

Position	SensCare & Cardio Buddy	SensCare & Polar H7	Cardio Buddy & Polar H7	SensCare & pulse oximeter	Cardio Buddy & pulse oximeter	Polar H7 & pulse oximeter	All instruments
Supine	.84* (.66–.92)	.98* (.97–.99)	.80* (.58–.90)	.98* (.97–.99)	.82* (.61–.91)	.98* (.97–.99)	.96* (.92–.97)
Sitting	.73† (.43–.87)	.97* (.93–.98)	.74† (.46–.88)	.97* (.95–.99)	.69† (.35–.85)	.97* (.94–.99)	.95* (.91–.97)
Standing	.88* (.75–.94)	.94* (.88–.97)	.81* (.60–.91)	.96* (.92–.98)	.82* (.63–.92)	.98* (.96–.99)	.95* (.91–.97)

Abbreviations: ICC, intraclass correlation coefficient (3,k); CI, confidence interval.

*Good validity. †Moderate validity.

Table 3 Mean Difference, 95% Limits of Agreement (LoA), and Minimal Detectable Change (MDC) for All Instruments

Position		SensCare and Cardio Buddy	SensCare and Polar H7	Cardio Buddy and Polar H7	SensCare and pulse oximeter	Cardio Buddy and pulse oximeter	Polar H7 and pulse oximeter
Supine	mean difference (95% CI)	1.10 (–3.88, 1.68)	0.56 (–1.53, 0.40)	1.67 (–4.68, 1.34)	2.00 (–2.93, –1.06)	3.10 (–6.00, –0.16)	1.43 (–2.32, –0.54)
	LoA	(–1.87, –2.13)	(–.027, –3.73)	(–0.14, –3.66)	(–0.43, –3.83)	(–0.27, –3.73)	(–1.80, –1.90)
	MDC_{90}	21.74	1.38	11.88	0.69	0.59	0.69
Sitting	mean difference (95%CI)	1.17 (–4.50, 2.17)	0.80 (–2.12, 0.52)	1.97 (–5.14, 1.20)	2.13 (–3.31, –0.95)	3.30 (–6.89, 0.29)	1.33 (0.06, 2.61)
	LoA	(–0.70, –3.10)	(–1.16, –2.76)	(–0.27, –3.73)	(–0.39, –3.81)	(–2.03, –4.57)	(–0.59, –3.19)
	MDC_{90}	19.93	1.98	14.32	2.08	17.72	3.20
Standing	mean difference (95%CI)	0.13 (–3.03, 2.77)	2.03 (–4.00, –0.07)	1.90 (–5.21, 1.41)	2.14 (–3.78, –0.50)	2.0 (–5.28, 1.27)	0.11 (–1.26, 1.04)
	LoA	(–1.87, 2.13)	(–0.31, –3.75)	(–0.14, –3.66)	(–0.43, –3.83)	(–0.27, –3.73)	(–1.90, 2.10)
	MDC_{90}	6.76	4.36	12.83	2.97	12.41	1.39

Abbreviations: CI, confidence interval; LoA, limits of agreement (mean difference ± 2SD); $MDC_{90} = 1.65 \times SEM \times$ the square root of 2).

SEM = 0.90). The MDC_{90} for both devices was 0.69 beats/min for supine, 2.08 beats/min for sitting, and 2.97 beats/min for standing. The 95% LoA for measuring pulse rate suggests that both devices may vary by 3.40 beats/min (–0.43, –3.83) for supine, 3.42 beats/min (–0.39, –3.81) for sitting, and 3.40 beats/min (–0.43, –3.83) for standing.

Cardio Buddy and Pulse Oximeter

The concurrent validity between the face-scan application and pulse oximeter was good for measuring resting heart rate in supine ($ICC_{3,k}$ = .82, SEM = 0.18) and standing ($ICC_{3,k}$ = .82, SEM = 3.76) but moderate in sitting ($ICC_{3,k}$ = .69, SEM = 5.37). The MDC_{90} for both devices was 0.59 beats/min for supine, 17.72 beats/min for sitting, and 12.41 beats/min for standing. The 95% LoA for measuring pulse rate suggests that both devices may vary by 3.46 beats/min (–0.27, –3.73) for supine, 2.54 beats/min (–2.03, –4.57) for sitting, and 3.46 beats/min (–0.27, –3.73) for standing.

Polar H7 and Pulse Oximeter

The concurrent validity between the Polar H7 belt and pulse oximeter was good for measuring resting heart rate in supine ($ICC_{3,k}$ = .99, SEM = 0.21), sitting ($ICC_{3,k}$ = .97, SEM = 0.61), and standing ($ICC_{3,k}$ = .98, SEM = 0.42). The MDC_{90} for both devices was 0.69 beats/min for supine, 2.01 beats/min for sitting, and 1.38 beats/min for standing. The 95% LoA for measuring pulse rate suggests that both devices may vary by 0.10 beats/min (–1.8, –1.9) for supine, 2.6 beats/min (–0.59, –3.19) for sitting, and 1.39 beats/min (–1.90, 2.10) for standing.

Discussion

The advent of mobile technology has provided a convenient method of measuring pulse rate for clinicians and consumers using smartphones, tablets, and laptops. Despite the utility of such technology, the clinimetric properties must be validated to ensure accuracy in measurements. In this study, we sought to assess the concurrent validity of 2 smartphone applications (fingertip, face-scan) with the Polar H7 belt monitor and pulse oximeter with Bluetooth measuring short-term resting pulse rate in 3 different positions.

Supine

Both smartphone applications demonstrated good concurrent validity with the Polar H7 and pulse oximeter. The Polar H7 also demonstrated good validity when compared with the pulse oximeter. The MDC_{90} for the fingertip application was much smaller than that for the face-scan application when measured against the Polar H7. The WearLink wireless technology has been validated in prior studies but not with the Polar Beat smartphone application.[2,3] This variability supports the need to further study their clinimetric properties to ensure accurate measures. Consequently, all 3 applications demonstrated similar MDC_{90} values when measured against the pulse oximeter. This consistency may be expected since the pulse oximeter was the gold standard and has been previously validated.[27–29]

Seated and Standing

The fingertip application demonstrated good concurrent validity with both the Polar H7 and pulse oximeter, but the face-scan application demonstrated moderate validity in sitting and standing. The Polar H7 demonstrated good validity when compared with the pulse oximeter in sitting and standing. The MDC_{90} for the fingertip application was smaller than that for the face-scan application when measured with the Polar H7 in both positions. Both the fingertip application and Polar H7 had close MDC_{90} values when compared with the pulse oximeter in both positions.

Clinical Application

Our findings suggest that short-term pulse-rate measurements with the fingertip smartphone application, Polar H7 belt monitor, and pulse oximeter may have the best results. The variability in performance of the face-scan application in all 3 positions makes its use questionable. The highest variability of the face-scan application was seen in the sitting and standing position, which questions the accuracy of this optical technology during possible body motions. This is supported by prior optical pulse-sensor studies that have shown inconsistent results when participants demonstrated minor body movements in sitting or standing.[23,30] The standardized use of 1 measurement tool is recommended to provide accurate, consistent measurements. The interchangeability between devices and their reliability with repeated measures is questionable and needs further research.

Limitations and Future Research

A limitation of this study is that participants were tested at rest and not during physical activity. A second limitation is that measurements were obtained from healthy adult participants, which limits the generalizability of our findings. A third limitation is that this new technology was not compared with direct measurements of pulse rate, such as ECG. We did use pulse oximetry as our reference standard as it has been validated with ECG; however, it must be recognized that it an indirect measurement of pulse rate.[17,20]

As mobile technology develops, other commercial products are emerging, such as watch-based and wristband pulse monitors, which offer other ways of portable pulse monitoring. A review of the literature revealed no independent investigations for these new instruments. The overall lack of known clinimetrics makes this technology questionable in many situations such as prehospital

care, cardiovascular rehabilitation, and fitness endeavors. Future research should focus on further validating this mobile technology with larger sample sizes, standardized procedures, and comparing these instruments with direct measures of pulse rate. Future research should also focus on testing participants with pathology, repeated measures, and during physical activity.

Conclusion

For clinicians and consumers, the use of smartphone-application-based devices may offer convenience and portability, but limitations exist. Our findings suggest that short-term pulse-rate measurements may be effectively captured using a fingertip scanning smartphone application, belt monitor, and pulse oximeter. The fingertip scanner showed superior results compared with the face-scan application, which only demonstrated modest concurrent validity when compared with the Polar H7 and pulse oximeter. The interchangeability of this technology is still questionable due to the lack of known clinimetric properties, validation with different populations, and standardized procedures. These variables need to be considered before using this technology in clinical practice.

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