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ORIGINAL ARTICLE

Validation study of the use of the HRVCAM software for the evaluation of heart rate and heart rate variability at rest

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Aims The existing instruments for assessing heart rate (HR) and heart rate variability (HRV) require contact area. This is difficult to obtain from specific groups of patients and from those moving. The aim of this study was to validate the use of the HRVCam software for measuring HR and HRV in healthy adults.

Methods and results The HR and HRV variables were evaluated in terms of time and frequency using a webcam and Polar® S810i. The Shapiro–Wilk test was used to test the normality of the data, and the Pearson's correlation coefficient (*r*) was used to identify the possible correlation between the two instruments. The size of the effect was calculated based on a generalized linear model, and the Bland–Altman plots were used to analyse the agreement between the methods. The level of significance for all analyses was set at $P < 0.05$. We evaluated 102 participants, of whom 52% were men; 83.3% were aged between 18 and 29.9 years; and 84.3% were single.

Conclusion There was a good agreement and moderate to strong correlations among all analysed variables. The biases were low, except for the low frequency/high frequency measures. Moreover, the difference between the samples was small to moderate. The results of this study corroborate the use of HRVCam for measuring HR and HRV.

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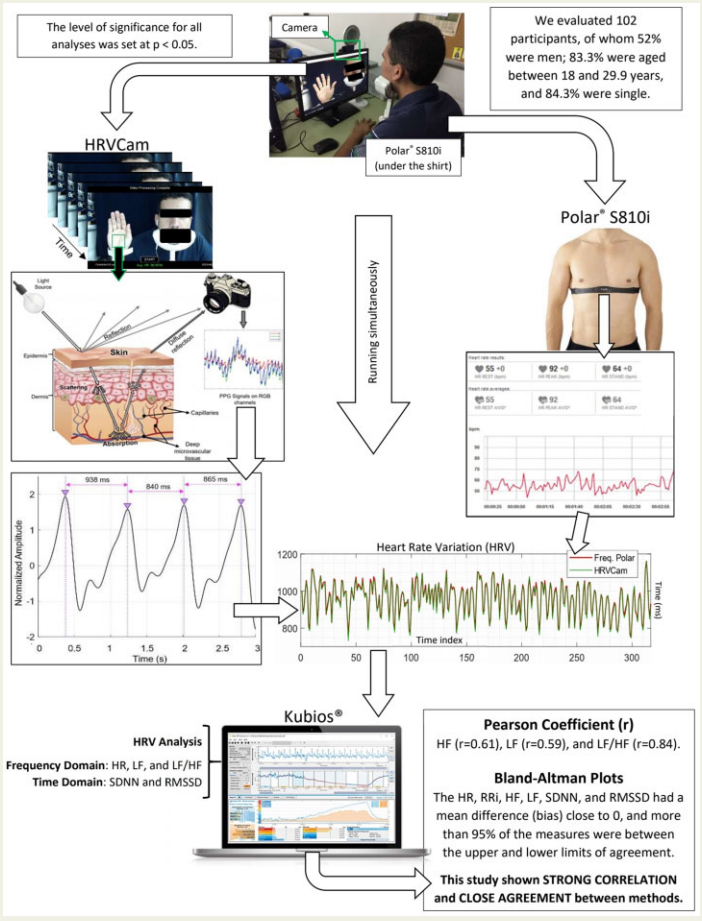
Graphical Abstract



Keywords Validation study • Heart rate • Photoplethysmography

Introduction

Heart rate (HR) is defined as the number of heartbeats per minute with physiological oscillations at rest due to the action of the autonomic nervous system.[1] Heart rate variability (HRV) is a quantitative marker used to evaluate cardiac autonomic activity and its possible oscillations using RR intervals (RRis). A high HRV indicates good cardiac adaptation, while a low HRV indicates cardiovascular problems.[2–4]

The most commonly used equipment for determining HR and HRV are HR monitors, which can be photoplethysmographic sensors and electrocardiogram (ECG).[5] The former is widely used because it is practical and non-invasive. Moreover, it enables proper recording outside the outpatient environment and during sports practice.[6]

In general, systems that record HR and HRV require a contact area for the installation and positioning of electrodes, which create restrictions and even limitations to the patient's movements.[7] Furthermore, methods that require physical contact between the user's body and the computer system, despite being accurate and efficient, are becoming obsolete because they may cause pain and irritation during prolonged examinations. Moreover, they may be contraindicated for some patients, such as burn victims, premature newborns, and elderly patients with fragile skin.[8]

Therefore, there has been an increasing interest in technology that can measure vital signs without the need for physical contact but can provide similar accuracy as that of the gold standard.

The HRVCam is a photoplethysmographic sensor developed in the software for capturing HR and HRV. These measures were obtained without physical contact using a camera.[9] It can be used on digital platforms, where it stores and/or extracts information from available data in the cloud. It allows processing of data *a posteriori* (offline) without the need to maintain an active Internet connection.

Furthermore, it enables the use of video files posted on social networks, regardless of their publication date. In the future, these functionalities may be incorporated into everyday objects, such as televisions, car multimedia centres, bathroom mirrors, and smart glasses.

These functionalities enable the expansion of the current scenarios for the use of this technology since it provides decentralization of the provision of health services from the hospital medical environment towards the user's home. In other words, they enable monitoring of physiological variables anywhere and anytime. Other situations that favour its use are associated with the location of resources in rural areas, prisons, asylums, or space stations. Furthermore, it can be used in the presence of geographical obstacles (e.g. islands, mountains, or deserts) and situations of war or natural disasters. This concept is called telemedicine.[10]

Thus, this technology actively supports the control of chronic heart diseases and enables monitoring of physical exercises for training and treatment purposes because it is readily available and easy to use.

The aim of this study was to validate the use of the HRVCam software for measuring HR and HRV by comparing it with the Polar® S810i heart rate monitor.

Methods

Type and location of the study

This was a validation study performed in a laboratory at a Brazilian higher education institution (HEI) with controlled light (200 cd). The ambient temperature was maintained between 22°C and 24°C, and the relative humidity was maintained between 40% and 60%.

Population and sample

This study included 102 volunteers of both sexes aged ≥18 years. They were either students or professors at a Brazilian HEI. The inclusion criteria were as follows: healthy condition, enrolment (student) or employment (professor) at the selected HEI, and age of ≥18 years.

Data collection

The participants were instructed to prepare themselves for the evaluation by doing the following: (i) avoiding strenuous physical activity and consumption of caffeinated and alcoholic beverages within 24 h before the laboratory session, (ii) not having a heavy meal within 3 h before the laboratory session, (iii) sleeping at least 6 h the night before, and (iv) avoiding sexual intercourse the night before.

A data collection instrument was used to evaluate the participants. It was comprised of two parts: the identification and analysis of the exclusion criteria and the evaluation of HR and HRV using the HRVCam and the Polar® S810i heart rate monitor.

The evaluation form contained demographic data, such as age, sex, marital status, presence or absence of diseases, use of medications, and exclusion criteria. The following exclusion criteria were identified in the participants' reports and were used in this study[11]: current smoking status; history of acute myocardial infarction in the previous 6 months, coronary artery bypass grafting, unstable angina, hypertension above stage 1,[12] obstructive pulmonary disease, insulin-dependent diabetes, neoplasia, renal failure, sequelae of stroke, liver failure, or uncontrolled hypothyroidism; the presence of pacemakers, as reported by the participant; and use of antiarrhythmic drugs and/or beta-blockers.

Heart rate and HRV were evaluated using the HRVCam with the participants seated and at rest. Initially, the Polar® S810i heart rate monitor tape was positioned in the thoracic region at the 5th intercostal space. Subsequently, the volunteers supported the chin and palm of their hand on the orthoses. They were then positioned 50 cm from the computer screen. Subsequently, they were instructed to adjust the position of their face and palm within the region of interest presented by the system on the video monitor in front of them (*Figure 1*). At the same time, the Polar® S810i heart rate monitor recorded both HR and HRV.

Thus, HR and HRV were obtained using two devices simultaneously: the HRVCam (test) and the Polar® S810i heart rate monitor. This enabled comparison between the two devices.

The Polar® S810i heart rate monitor recorded the RRis from a belt with a coded transmitter, which was transmitted to an interface connected to a compatible computer for storing and processing the signals.

In this study, the HRVCam captured data from the palm because this area was minimally influenced by melanin. Melanin's light absorption properties might affect the result due to the phototype of each participant.

HRVCam is a software that non-invasively measures HR and HRV without requiring physical contact with the user's body. The photoplethysmographic principle was applied, including the detection of the variation in blood volume through the intensity of the light reflected in the microvascular bed of the tissue caused by the difference arising from the heartbeat.[13]

HRVCam captures the photoplethysmographic signal by determining the variation in the amount of light reflected by the haemoglobin. Thus, when configured to use the green channel, the cardiac cycle peaks used to calculate HR and HRV correspond to the moments of diastole when the minimum amount of light is reflected since the green light is absorbed by haemoglobin. This method is called the fixed-colour channel.[14]

The HRVCam can also be configured using an independent component analysis (ICA) algorithm to obtain HR.[9] However, this setting is only recommended for obtaining HR from black individuals. It is difficult to obtain the photoplethysmographic signal and other measures derived from it, such as HRV, if the ICA algorithm is used.[15] In this study, the data were obtained using a fixed-colour channel configured for green colour. The computer running the application was equipped with an Intel Core i7

Source: Researcher's archive

Figure 1 The positioning of the participants during the measurement of heart rate and heart rate variability.

4710HQ 2.5-GHz processor with 16 GB of RAM. A Logitech Brio 4k Ultra HD webcam was attached to the computer.

The following HRV-derived variables were collected: HR; RRi; root mean square successive difference between the RRis (RMSSD); standard deviation of all normal RRis recorded in a time interval shown in m/s (SDNN); low frequency power in normalized units (LF, ranging from 0.04 Hz to 0.15 Hz); high frequency power in normalized units (HF, ranging from 0.15 Hz to 0.4 Hz); and ratio of absolute LF power to HF power (LF/HF). The RMSSD and SDNN were used in the analysis of HRV in terms of time, LF, and HF in the study of HRV regarding HR.

Data were independently entered into the EPIDATA software by two team members for subsequent analysis of consistency and quality assurance (validation).

The variables were stored using the HRVCam and Polar® S810i heart rate monitor. Subsequently, the distribution of the RRis (ms) was visually inspected to eliminate the tracings with noise to select an RRi of the ECG with excellent tracing stability. The Kubios® HRV software was used to analyse the HRV.

Statistical analyses

Exploratory statistics with determination of the measures of central tendency and variability were used to test the assumptions of normality of the data. Normality of the data was tested using the Shapiro–Wilk test. The Pearson's correlation coefficient (*r*) was used to identify possible correlations between HR and HRV obtained using the different methods. The effect size (ES) was calculated based on the Cohen's *D*. The differences were considered small if the ES was ≤0.2, moderate if the ES ≤0.5, and large if the ES >0.8.[16] The analysis was performed using the Stata 13.0 statistical package.

The upper and lower agreement limits and the bias between the means of the measurements used to analyse the agreement between the Bland–Altman methods[17] were identified using Excel 2010 for MacBook. The level of significance used in all analyses was set at $P < 0.05$.

Ethical approval

This study was approved by the Research Ethics Committee of the Pontifical Catholic University of Goiás (opinion number 2,287,991). All participants read and signed the consent form before data collection, and all procedures of the study followed Brazilian and International ethical rules.

Results

A total of 102 participants were evaluated, of whom 52 were men, and 50 were women. None of the participants were excluded from the study. Most of the participants were aged between 18 and 30 years and were single (*Table 1*).

The Bland–Altman plots for HR, RRi, HF, and LF (*Figure 2*) showed a mean difference (bias) of 0, thus suggesting good agreement between the instruments used to measure these variables. The SDNN and RMSSD had a low bias. They were determined by the small distance from the dots to the line corresponding to the mean of the measurements. More than 95% of the measurements were between the upper and lower limits of the agreement, which suggests good agreement between the HRVCam and the Polar® S810i heart rate monitor. The variable with the lowest agreement between the instruments was the LF/HF, which had a high standard deviation, with 7.8% of the measurements having values lying outside the standard deviations (*Figure 2*).

Table 1 General characteristics of the sample (*n* = 102; Goiânia, Goiás, 2018)

Variables	*n*	%
Sex		
Male	52	52.0
Female	50	48.0
Age group		
18–29.9 years	85	83.3
30–66 years	17	16.7
Marital status		
In a relationship	16	15.7
Single	86	84.3

The means of the measurements obtained using the HRVCam and Polar® S810i heart rate monitor were the same for the HR, HF, and LF. The methods obtained using the HRVCam were higher for the RRi, SDNN, and RMSSD and lower for the LF/HF. There was a significant correlation between all the measurements obtained using the Polar® S810i heart rate monitor and HRVCam. The biases were low, except for the LF/HF measurements. The difference between the measurements was small, except for the RMSSD, LF, and LF/HF, which showed moderate differences (*Table 2*).

Discussion

This study found that the measurements obtained using the HRVCam were consistent with those obtained using the Polar® S810i heart rate monitor for HR and HRV in terms of rate (HR, LF, and LF/HF) and time (SDNN and RMSSD).

These results agreed with those of a study that evaluated HRV regarding time and rate and found a strong correlation and close agreement between an imaging plethysmographic and a photoplethysmography (PPG) contact sensor.[18] In this case, the authors used instruments that process the same biopotential (PPG), whose origin was mechanical rather than electrical.

This study found a close agreement between the HR and RRi, showing that the HRVCam software exhibited functional characteristics comparable to those of the Polar® S810i heart rate monitor, thereby allowing the evaluation of HR. From a clinical point of view, the term 'comparable' means that measurements obtained using different instruments must be sufficiently similar to one another to avoid altering actions and decisions regarding patient treatment.[19]

There was no significant difference between the HR and RRi obtained using the HRVCam and Polar® S810i heart rate monitor in this study. This finding agrees with those of previous studies that used a webcam-based system to measure these physiological parameters.[7,18,20–22]

In the present study, the correlations with SDNN, RMSSD, and LF/HF were stronger; those with RRi were the same; and those with HF and LF were weaker than those in a study that also analysed data obtained using a webcam and the Polar® heart rate monitor. The biases for RRi, SDNN, and HF were lower in the present study, while

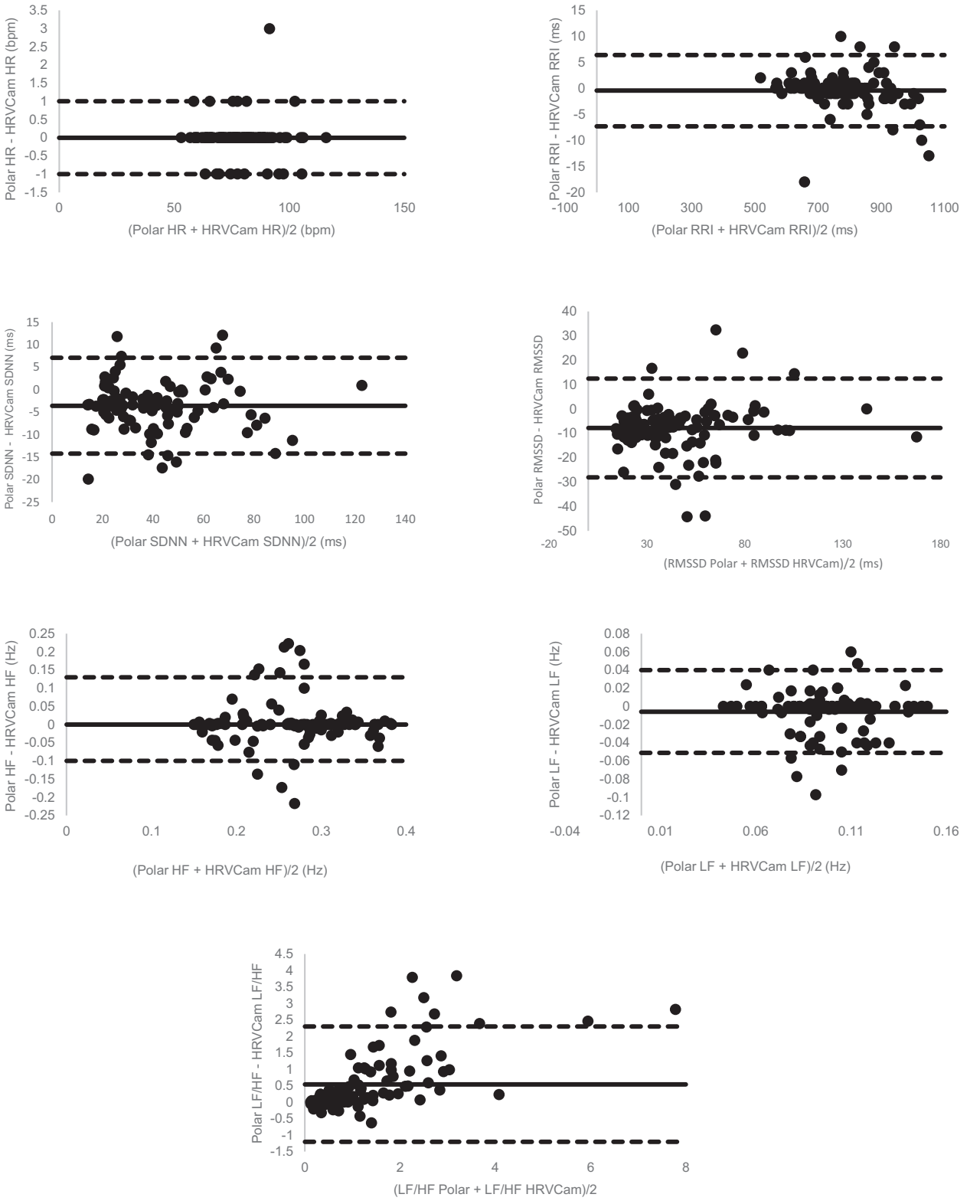


Figure 2 Bland–Altman plots comparing the measurements of heart rate and heart rate variability obtained using the Polar® S810i heart rate monitor and HRVCam. The dotted lines indicate the upper and lower agreement limits, and the continuous lines indicate the difference in the means. HF, high frequency; HR, heart rate; HRV, HR variability; LF, low frequency; RMSSD, square root of the mean of the squared differences between adjacent normal RRis in a time interval expressed in m/s; RRi, RR interval; SDNN, standard deviation of all normal RRis recorded in a time interval expressed in m/s.

Table 2 Means of the measurements obtained using the Polar® S810i heart rate monitor and the HRVCam, correlation between the Polar® S810i heart rate monitor and HRVCam data, bias, bias magnitude, and agreement limits (lower and upper)

Variables	Polar® S810i (mean ± SD)	HRVCam (mean ± SD)	Cor[a]	Bias	Agreement limit (lower–upper)	Bias magnitude	
						Effect size	Interp.
HR (b.p.m.)	78.4 ± 12.0	78.4 ± 12.0	0.99	0	-1.00 to 1.00	0.0008	Small
RRi (ms)	782.5 ± 119.4	782.9 ± 120.1	0.99	-0.4	-7.30 to 6.43	0.003	Small
SDNN (ms)	38.1 ± 20.1	42.5 ± 20.2	0.96	-3.6	-14.25 to 7.05	0.178	Small
RMSSD (ms)	41.1 ± 28.0	49.4 ± 26.1	0.93	-7.74	-27.98 to 12.49	0.282	Moderate
HF (Hz)	0.3 ± 0.1	0.3 ± 0.1	0.61	0	-0.12 to 0.13	0.059	Small
LF (Hz)	0.1 ± 0.0	0.1 ± 0.0	0.59	0	0 to 0.04	0.214	Moderate
LF/HF (Hz)	1.5 ± 1.5	0.1 ± 0.1	0.84	0.55	-1.20 to 2.29	0.427	Moderate

HF, high frequency; HR, heart rate; LF, low frequency; RMSSD, square root of the mean of the squared differences between adjacent normal RRis in a time interval expressed in m/s; RRi, RR interval; SD, standard deviation; SDNN, standard deviation of all normal RRis recorded in a time interval expressed in m/s
[a]All correlations had *P*-values of <0.001.

those for the RMSSD, LF, and LF/HF were moderate in both studies.[23]

The correlations between data obtained using a webcam and a PPG sensor placed on the finger were very strong for HR and HRV with respect to time and rate.[24] The HRV variables regarding rate had a strong correlation when data obtained using a webcam were compared with those collected using ECG.[25]

We also found correlations between the Polar® S810i heart rate monitor and HRVCam with respect to the rate of HF ($r = 0.61$), LF ($r = 0.59$), and LF/HF ($r = 0.84$). This result differs from that of a study that captured HR and HRV in terms of rate. This study found robust correlations for the same variables when comparing data obtained using a webcam and using a contact PPG placed on the finger.[26] This finding reinforces the need to compare the results obtained using systems considering the PPG acquired using a non-contact camera and instruments with results close to those that are considered the gold standard for the measurement of HR and HRV.

A study compared data obtained using a PPG application embedded in a smartphone with ECG and evaluated HRV only with respect to time. The study found a small mean of absolute errors in participants who were at rest.[27]

The size of the sample evaluated in this study differs from those in previous studies. Our sample was composed of 102 healthy participants of both sexes. The other studies that also used a webcam to determine HR and/or HRV had smaller sample sizes: 6[27], 9[20], 10[18], 10[26], 12[7], 12[25], 15[8], 20[23], and 40[22] participants. The only study that evaluated a sample larger than ours (117 participants) investigated only HR-related variables.[21]

Almost all studies found in the literature, including ours, used reference instruments whose origin of biopotentials was electrical. However, the biopotential source of PPG sensors was mechanical. This implies divergences due to the propagation time, which may become more evident when considering the rate, a situation in which the delay and the variation of the delay are more noticeable. Thus, this work raises the need for a calibration protocol that promotes the necessary adjustments to avoid exceeding the tolerance limits required for each application.

Thus, validation studies for specific applications, such as validation of HRVCam for monitoring in neonatal intensive care units, are currently in progress. Another limitation of the study is that the analysis of individuals with diseases, especially those who alter the HR that were not evaluated because they were not the objective of the study. The evaluation of people with diseases continues, thus, not yet elucidated.

The HRVCam software is still currently in its developmental stage. Therefore, new features derived from the photoplethysmographic signal, such as pulse transit time measurement, pulse wave speed assessment, and oximetry, are being included. Moreover, a version for Android platforms is developed, while other programming technologies are tested to increase platform independence and system speed. Furthermore, algorithms are improved to minimize the effects of motions and variations in ambient light. Thus, further validation studies can be conducted in highly dynamic situations, such as in monitoring athletes.

This study proposed a validation methodology for an HR and HRV measurement instrument with consistent results that support the use of HRVCam for measuring HR and HRV even without the exclusion of outliers.

The measures obtained using the proposed instrument (HRVCam) and the Polar® S810i heart rate monitor showed a good agreement, a moderate to strong correlation, and a small to moderate bias magnitude.

Acknowledgements

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Conflict of interest: none declared.

Data availability

The data underlying this article cannot be shared publicly due to the privacy of individuals that participated in the study. The data will be shared on reasonable request to the corresponding author.

References

1. Hall JE. *Guyton e Hall tratado de fisiologia médica*. Brazil: Elsevier; 2011.
2. Carvalho JLA. *Ferramenta Para análise tempofreqüencial da variabilidade da freqüência cardíaca*. Brasilia: University of Brasilia; 2003.
3. Lopes PFF, Oliveira M, André S, et al. Aplicabilidade clínica da variabilidade da frequência cardíaca. *Rev Neurocienc* 2013;**21**:600–603.
4. Vanderlei LCM, Pastre CM, Hoshi RA, Carvalho TD, Godoy MF. Noções básicas de variabilidade da frequência cardíaca e sua aplicabilidade clínica. *Braz J Cardiovasc Surg* 2009;**24**:205–217.
5. van Vonderen JJ, Hooper SB, Kroese JK, et al. Pulse oximetry measures a lower heart rate at birth compared with electrocardiography. *J Pediatr* 2015;**166**:49–53.
6. Pimentel AS, Alves EDS, Alvim RDO, et al. Polar S810 como recurso alternativo ao eletrocardiograma no teste de exercício de 4 segundos. *Arq Bras Cardiol* 2010; **94**:580–584.
7. Poh M-Z, McDuff DJ, Picard RW. Advancements in noncontact, multiparameter physiological measurements using a webcam. *IEEE Trans Biomed Eng* 2011;**58**:7–11.
8. Rodrigues KAS, Pereira MHR, Pádua FLC. Detecção em tempo real da frequência cardíaca de pessoas por meio da análise de variações temporais em vídeos. *e-xacta* 2016;**9**:49.
9. Souza PH, Ferreira JO, Barbosa TA, Rocha AF. HRVCam: A software for real-time feedback of heart rate and HRV. In: *2016 IEEE 6th International Conference on Computational Advances in Bio and Medical Sciences (ICCABS)*. IEEE; 2016, p1–6.
10. Soirefmann M, Blom MB, Leopoldo LR, Cestari TF. Telemedicina: uma revisão da literatura. *Rev HCPA* 2008;**28**:116–119.
11. Malachias MVB, Souza W, Plavnik F, Rodrigues C, Brandão A, Neves M. 7ª Diretriz brasileira de hipertensão arterial. *Arq Bras Cardiol* 2016;**107**:1–103.
12. Reboussin DM, Allen NB, Griswold ME, et al. Systematic review for the 2017 ACC/AHA/AAPA/ABC/ACPM/AGS/APhA/ASH/ASPC/NMA/PCNA Guideline for the prevention, detection, evaluation, and management of high blood pressure in adults: a report of the American College of Cardiology/American Heart Association Task Force on Clinical Practice Guidelines. *J Am Coll Cardiol* 2018;**71**: 2176–2198.
13. Challoner A, Ramsay C. A photoelectric plethysmograph for the measurement of cutaneous blood flow. *PhysMed Biol* 1974;**19**:317–328.
14. Souza PHB, Souza IMB, Sacramento TP, et al. Contributions to the acquisition of heart rate and photoplethysmography signal using a real-time software. In: *2018 IEEE International Conference on Healthcare Informatics (ICHI)*. IEEE; 2018, p332–337.
15. Sacramento TP, Souza IMB, Vitorino PVO, Barbosa TMGA. A real-time software to the acquisition of heart rate and photoplethysmography signal using two region of interest simultaneously via webcam. In: *2017 IEEE MIT Undergraduate Research Technology Conference (URTC)*. IEEE; 2017, p1–4.
16. Lindenau JD-R, Guimarães LSP. Calculando o tamanho de efeito no SPSS. *Rev HCPA* 2012;**32**:363–381.
17. Hirakata VN, Camey SA. Análise de concordância entre métodos de Bland-Altman. *Rev HCPA* 2009;**29**:261–268.
18. Sun Y, Hu S, Azorin-Peris V, Kalawsky R, Greenwald S. Noncontact imaging photoplethysmography to effectively access pulse rate variability. *J Biomed Opt* 2013; **18**:061205.
19. Humphreys K, Ward T, Markham C. Noncontact simultaneous dual wavelength photoplethysmography: a further step toward noncontact pulse oximetry. *Rev Sci Instrum* 2007;**78**:044304.
20. Bal U. Non-contact estimation of heart rate and oxygen saturation using ambient light. *Biomed Opt Express* 2015;**6**:86–97.
21. Haan G, Jeanne V. Robust pulse rate from chrominance-based rPPG. *IEEE Trans Biomed Eng* 2013;**60**:2878–2886.
22. Yan BP, Chan CK, Li CK, et al. Resting and postexercise heart rate detection from fingertip and facial photoplethysmography using a smartphone camera: a validation study. *JMIR Mhealth Uhealth* 2017;**5**:e33.
23. Moreno J, Ramos-Castro J, Movellan J, Parrado E, Rodas G, Capdevila L. Facial video-based photoplethysmography to detect HRV at rest. *Int J Sports Exerc Med* 2015;**36**:474–480.
24. Melchor Rodríguez A, Ramos-Castro J. Video pulse rate variability analysis in stationary and motion conditions. *Biomed Eng Online* 2018;**17**:11.
25. Alghoul K, Alharthi S, Al Osman H, El Saddik A. Heart rate variability extraction from videos signals: ICA vs. EVM comparison. *IEEE Access* 2017;**5**: 4711–4719.
26. McDuff D, Gontarek S, Picard R. Remote measurement of cognitive stress via heart rate variability. In: *2014 36th Annual International Conference of the IEEE Engineering in Medicine and Biology Society*. IEEE; 2014, p2957–2960.
27. Huang R-Y, Dung L-R. Measurement of heart rate variability using off-the-shelf smart phones. *Biomed Eng Online* 2016;**15**:11.