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Accuracy of the Garmin Venu for measuring heart rate, respiratory rate, and peripheral oxygen saturation in patients hospitalized in a respiratory ward: a validation study

Ruben Knevels
Hasselt University
Elise Baert
Hasselt University
Jelle Schils
Hasselt University
Christophe Smeets
Hasselt University
Zoë Pieters
Hasselt University
Louis Van Slambrouck
KU Leuven KULAK
Julie Vranken
Hasselt University
Chris Burtin
Hasselt University
Femke Wouters
Hasselt University
David Ruttens
david.ruttens@zol.be
Hasselt University

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Abstract

Introduction –

Commercially available smartwatches, such as the Garmin Venu, hold the ability to measure physiological parameters such as heart rate (HR), respiratory rate (RR), and peripheral oxygen saturation (SpO_2). However, little is known about their accuracy relative to the reference method and clinical reliability in a pulmonology patient population.

Methods –

Individuals hospitalized at the pulmonology ward at Ziekenhuis Oost-Limburg were asked to wear a Garmin Venu 3 or Venu 4 while connected to a hospital-grade patient monitor for at least one night. A minute-to-minute comparison was made for HR, RR, and SpO2 between the two measuring methods. At the end of the measurement period, patients completed the Smartwatch Rating Scale questionnaire.

Results –

Out of 30 included patients, 29 were included in the data analysis. The mean absolute error (MAE) for HR was 2.71 beats per minute (bpm), 4.21 breaths per minute for RR, and 2.96% for SpO_2. Overall, 85.0% of HR, 47.1% of RR measurements, and 61.7% of SpO_2 measurements fell within the clinically acceptable range of ± 5 bpm, ± 3 breaths per minute and, ± 3%, respectively. Taffé analysis indicated that both HR and SpO_2 had acceptable error margins across the measured best linear unbiased predictor (BLUP) range, whereas RR remained within the clinically acceptable range only up to 22 breaths per minute.

Conclusion –

Compared with a hospital monitor, the Garmin Venu performs well in measuring HR and SpO_2 within an acceptable error margin in hospitalized patients. The RR measurements from the smartwatch should be interpreted with caution, especially at higher breathing rates.

Introduction

Over the past decade, the use of wearables (e.g., smartwatches, smart rings) has increased rapidly [1]. These devices, which can be classified as Mobile Health (mHealth) technologies, offer promising opportunities for remote patient monitoring (RPM), enabling early detection of physiological deterioration and supporting more personalized healthcare delivery at the patients' homes [2]. Advances in sensor technology, together with an expanded range of monitored physiological parameters, make them increasingly attractive to be adopted in various healthcare domains [1]. As healthcare shifts toward

more decentralized models of care, wearables may help reduce hospital burden while enabling continuous observation outside traditional clinical environments [3].

Many wearables rely on photoplethysmography (PPG), a non-invasive optical technique that detects changes in blood volume in the vascular bed beneath the sensor. Using this method, wearables can estimate multiple physiological parameters, including heart rate (HR), respiratory rate (RR), and peripheral oxygen saturation (SpO_2) [4]. By connecting to smartphones and cloud-based platforms, these devices enable near-real-time data transmission, making them remotely accessible to both patients and healthcare providers [5].

Despite their widespread availability and technological advancements in sensor design and signal processing algorithms, concerns remain regarding the accuracy and reliability of wearable-derived measurements. Many available devices are not certified as medical-grade equipment, and their performance may be influenced by factors such as motion artifacts, skin tone, perfusion status, and environmental conditions [6,7]. Furthermore, accuracy studies are often scarce, and when available, may not reflect the specific population or setting in which devices could be useful. This raises important questions about whether such measurements are sufficiently accurate to inform clinical decision-making [8].

The Garmin Venu smartwatch is a commercially available wearable device equipped with multi-wavelength PPG sensors. These allow for HR, RR, and SpO_2 to be estimated at a minute-based interval. Although such (non-medical) devices hold considerable potential for RPM applications, independent validation against hospital-grade monitoring systems remains necessary to determine their clinical accuracy. Particularly, in patients experiencing physiological parameters falling outside population-based normal ranges, accurate determination of parameters is of great clinical importance [9]. Therefore, the aim of the current study was to evaluate the accuracy of HR, RR, and SpO_2 measurements obtained from the Garmin Venu 3 and Garmin Venu 4 smartwatches, using a hospital-grade patient monitoring system as the reference standard, in hospitalized patients.

Methods

Study design and participants

This prospective, observational, monocentric study evaluated the accuracy of the Garmin Venu 3 and 4 for measuring HR, RR, and SpO_2. Patients hospitalized at the pulmonology ward of a single tertiary care center, Ziekenhuis Oost-Limburg, Genk, Belgium, were included between October 2025 and April 2026. Eligible patients were aged 18 or older, able to read and understand the informed consent form, and expected to be hospitalized for at least another 24 hours. Patients receiving palliative care or patients hospitalized in isolation due to infection control were excluded to reduce patient burden and ensure the safe implementation of study procedures, respectively. Due to logistical reasons, only one patient could

be monitored at a time, introducing the risk of selection bias. To minimize this risk, patients were approached in order of screening.

Patients were asked to wear the Garmin Venu smartwatch while simultaneously being monitored with a Philips IntelliVue MP50 hospital monitor. The watch was consistently worn on the same arm as the SpO_2 sensor of the monitor throughout all measurements. Monitoring lasted for a minimum of one night (8 hours) and up to 24 hours. At the end of the monitoring period, patients completed the Smartwatch Rating Scale (SRS) to assess their user experience with the smartwatch [10].

This study protocol was in accordance with the Declaration of Helsinki and was approved by the Belgian Federal Agency of Medicine and Health Products (FAMHP) and an independent Belgian medical ethics committee (CIV-25-07-053536). The study was registered at clinicaltrials.gov (NCT07360678).

Data collection

At the start of the study, sociodemographic and clinical data information was collected from the electronic patient files (HIX, Chipsoft, The Netherlands. This data was collected in the electronic case report form (Castor EDC, The Netherlands).

Garmin Venu smartwatch

The Garmin Venu smartwatch (Garmin, United States of America) is a commercially available smartwatch that can be connected to a smartphone via Bluetooth. While the smartwatch is capable of measuring a wide range of parameters, this study focused on HR, RR, and SpO_2, obtained via PPG-derived measurements, as these are the only continuously monitored physiological parameters. HR was measured at a 15-second interval, while RR and SpO_2 were measured at a 1-minute interval. The obtained measurements were extracted for each patient separately from the Garmin Connect web platform.

This study used the Garmin Venu 3 and Venu 4 smartwatches. For each smartwatch model, the same individual device was used for all participants assigned to that model. The watches were reset to factory settings between participants and synchronized with the reference patient monitor to a common reference time using an internet-based world clock to allow proper data comparison .

Philips Intellivue MP50

The Philips IntelliVue MP50 (Koninklijke Philips N.V., The Netherlands) is a medical-grade, multiparameter bedside monitor capable of objectively measuring multiple vital parameters, including HR, RR, and SpO_2. The monitor was connected to the patient using a 5-lead ECG for HR and RR measurements, and a finger PPG sensor for SpO_2 measurements. Data were recorded at a 1-second

interval for all parameters. HR was derived from both ECG signals, RR from transthoracic impedance, and SpO_2 from transmissive PPG. Data were extracted using ixTrend express software version 2.1.0 (ixellence GmbH, Wildau, Germany). The computer software clock was synchronized to the same internet-based time reference as the Garmin watch.

Data analysis

Data processing and statistical analysis were done using R (version 4.6.0; R Foundation for Statistical Computing, Vienna, Austria). Descriptive statistics are presented as median [Q1 – Q3] or as number (%). Prior to analysis, the Philips monitor data were aggregated by calculating mean values over intervals corresponding to the Garmin watch sampling period to align the sampling frequencies of the two devices (1 Hz vs. 0.0167 Hz, respectively). Next, data were matched by timestamp to allow minute-to-minute comparison between the two devices. Data processing was done using R packages 'dplyr', 'purrr', and 'lubridate'.

Before formal data analysis, data visualization was performed using the 'ggplot2' package to identify visual outliers. Next, the mean absolute error (MAE) between the monitor and Garmin watch was calculated for HR, RR, and SpO_2 using the minute-to-minute measurements of both devices. Acceptable error margins were, in line with similar research, defined as ±5 bpm for HR, ±3 breaths per minute for RR, and ±3% for SpO_2 [11]. Data were analyzed using the Taffé method through the 'MethodCompare' package [12,13].

Post-hoc analysis was performed to calculate the percentage of Garmin watch measurements that fell within predefined acceptable error margins for each parameter.

Results

Patient demographics

Between October 2025 and April 2026, 337 patients were screened, and 38 were approached for participation. This resulted in the inclusion of 30 patients. After data collection, 1 patient was excluded from the analysis due to outlier measurements caused by atrial fibrillation with rapid ventricular response (Supplemental Figure 1). Therefore, 29 patients were included in the final data analysis (Figure 1).

Patients had a median age of 71 years, were predominantly male (62.1%), and had a median BMI of 26.3 kg/m². Most patients were hospitalized due to pneumonia (58.6%), followed by a Chronic Obstructive Pulmonary Disease (COPD) exacerbation (20.6%) Table 1.

Table 1: Patient demographics.

Characteristic	*n* = 29
Age (years), median (Q1-Q3)	71 (63 – 75)
Sex (male), n (%)	18 (62.1%)
BMI (kg/m²), median (Q1-Q3)	26.3 (21.1 – 28.0)
Cardiovascular disease, n (%)	21 (72.4%)
Arterial hypertension, n (%)	16 (55.2%)
Diabetes, n (%)	5 (17.2%)
Current smokers, n (%)	9 (31.0%)
Medication use	
β-blockers, n(%)	10 (34.5%)
Bronchodilators, n (%)	15 (21.7%)
Supplemental oxygen in hospital, n (%)	6 (20.7%)
Supplemental oxygen at home, n (%)	7 (24.1%)
Antiarrhythmics, n (%)	5 (17.2%)
Reason for hospitalization	
Pneumonia, n (%)	17 (58.6%)
COPD exacerbation, n (%)	6 (20.7%)
Lung cancer related, n (%)	2 (6.9%)
Other, n (%)	4 (13.8%)

BMI: Body Mass Index, COPD: Chronic Obstructive Pulmonary Disease

Physiological measurements

After data sampling, a total of 21,718 HR measurements were available from the monitor, compared with 22,126 measurements from the Garmin watch. For RR, 18,782 measurements were available from the monitor and 21,417 from the Garmin watch. For SpO_2, 18,945 were obtained from the monitor and 20,202 from the Garmin watch. After matching the measurements to their corresponding timestamps, 20,260 pairs were available for HR, 16,821 for RR, and 16,113 for SpO_2.

For all parameters, MAE's were calculated, yielding values of 2.71 bpm for HR, 4.21 breaths per minute for RR, and 2.96% for SpO_2. At the minute-to-minute level, 85.0% of HR, 47.1% of RR measurements, and

61.7% of SpO_2 measurements fell within the predefined acceptable error margins. The distribution of errors across parameters is shown in Supplemental Figure 2.

Next, bias and precision were determined using the Taffé method, which allows both to depend on the latent true value of the parameter under investigation. The unobserved true values are predicted using Best Linear Unbiased Predictors (BLUP) within the estimation procedure. The Garmin watch systematically underestimates HR, with a bias of −0.2 to −1.4 bpm. This is also showcased by the presence of differential bias (0.99, 95% confidence interval (CI) [−0.46 – 2.44]) and proportional bias (0.98, 95% CI [0.96 – 1.00]). Precision for both the monitor and the Garmin watch was almost identical, with a lower standard deviation of the measurement errors at lower HR and a small increase towards higher HR (Figure 2).

For RR, differential (10.80, 95% CI [6.55 – 15.05]) and proportional (0.37, 95% CI [0.18 – 0.56]) biases are present, resulting in a general underestimation of RR, with greater underestimation at higher breathing rates. However, at a RR just below 18 breaths per minute, bias is zero, indicating there is no bias between the Garmin watch and the monitor. Measurements performed with the Garmin watch are less precise than those with the monitor, with a higher, though constant, overall standard deviation of measurement error (Figure 3).

For SpO_2, in comparison with the hospital monitor, the Garmin watch overestimates SpO_2 up to a value of 92%, after which the smartwatch underestimates SpO_2. The acceptable 3% deviation is situated around an SpO_2 of 86%. This is illustrated by the presence of differential (45.73, 95% CI [23.60 – 67.87]) and proportional (0.50, 95% CI [0.27 – 0.74]) bias. Measurements performed with the Garmin watch are less precise, with an overall higher standard deviation of the measurement error (Figure 4). However, this decreases with increasing values, similar to the trend observed with the monitor.

Smartwatch rating scale

Of 29 patients, 27 completed the SRS questionnaire. One patient declined to complete the questionnaire, and one was discharged before it could be administered. Questions were categorized into one of three topics: display, material, and usability.

Overall likability was high across all domains. Responses rated with at least ‘good’ accounted for 92.3% for display, 96.0% for material, and 93.9% for usability. Negative ratings were uncommon, with 4.0% of responses for display rated as ‘very bad’, and 1.4% of responses for usability being ‘bad’ (Figure 5).

Discussion

This prospective validation study evaluated the accuracy of the Garmin Venu for measuring HR, RR, and SpO_2 compared with a hospital-grade monitor in hospitalized patients. Both HR and SpO_2 met the predefined accuracy criteria, whereas RR did not. With an MAE of 2.71 bpm for HR and 2.96% for SpO_2,

the Garmin Venu smartwatch measured these parameters within the predefined error ranges of ± 5 bpm and ± 3%, respectively. Accordingly, 85.0% of HR measurements and 61.7% of SpO_2 measurements fell within these limits. For RR, an MAE of 4.21 breaths per minute was found, which exceeds the predefined error range of ± 3 breaths per minute. Only 47.1% of RR measurements fell within the predefined error range.

Although the Bland-Altman analysis remains the dominant approach in validation studies, its assumptions are violated when repeated (semi-)continuous measurements are present. Regression-based agreement methods, such as those proposed by Taffé, have therefore been recommended for longitudinal vital-sign studies [14]. However, no other studies using the Taffé analysis on physiological wearable-derived measurements were identified, so no direct comparison could be made.

The findings of this study contribute to a growing body of literature on the validation of mHealth devices for measuring physiological parameters. Existing literature highlights discrepancies between validation studies on such devices, especially in a clinical setting [8,11]. While traditional medical devices are typically evaluated under established regulatory standards, wearable non-medical PPG systems sit in a hybrid space between consumer electronics and clinical monitoring, where these are absent. As a result, studies often employ different methodologies, sample sizes, and statistical approaches. In contrast to most previous validation studies, our study evaluated the accuracy of the Garmin Venu in a clinically relevant population, being patients hospitalized in a respiratory ward.

When comparing our results with previous research on Garmin devices, our findings match those for HR, which reported an average accuracy of ± 3% [8]. This accuracy is to be expected, as PPG is a validated method for estimating HR [4]. RR measurements showed lower agreement with the reference monitor. While RR is estimated using the same PPG signals used to derive HR, it is derived through more advanced algorithmic processing. These algorithms generally rely on subtle respiratory-induced variations in pulse amplitude and heart rate variability. These secondary signals are more susceptible to motion artifacts and physiological variability. This might explain the less accurate results compared to the hospital monitor, and why RR measurements through wearables are often considered inherently more challenging [15]. The Garmin watch showed an acceptable bias up to a BLUP of 22 breaths per minute, which is slightly above the upper limit of 20 breaths per minute in a normal resting adult. At higher values, the Garmin underestimated RR compared with the hospital monitor. The increased breathing frequency observed in this study can be explained by the fact that all included patients were hospitalized for a respiratory condition at the time of participation [16].

For SpO_2, previous studies reported mean absolute errors ranging from 4.27% to 9.77%. This is considerably higher compared with our findings, and might be explained by differences in study design, population, and sample size [17,18]. The Garmin Venu uses reflective PPG technology, whereas most clinical pulse oximeters use transmissive PPG. The first is more sensitive to motion artifacts, ambient light interference, and variations in contact pressure to the skin [19]. Despite these challenges, the MAE

observed in this study was still within the error range of ± 3%, with the bias increasing below 86%. From a clinical perspective, overestimation at lower SpO_2 is particularly relevant, as it could delay recognition of clinically significant hypoxemia. The observed BLUP range in this study can be explained through the study population's reason for hospitalization.

Prior to formal analysis, one patient was excluded due to substantial differences between HR measurements obtained by the smartwatch and the monitor, ranging from 43 bpm to 102 bpm. This patient was diagnosed with AF with rapid ventricular response. Previous studies have demonstrated a higher proportion of out-of-threshold measurements in PPG-based HR measurements in AF patients [20,21]. This can be attributed to a reduction in stroke volume, leading to changes in skin color that fall below the PPG sensor's detection limit [21]. While no literature was found on the influence of AF on RR or SpO_2 measurements, none of the AF patient's measurements were included in the data analysis to maintain uniformity.

Limitations

The most important limitation of this study is that patients were in a controlled hospital environment. The findings cannot be directly extrapolated to real-world daily-life conditions, and results are primarily representative of measurements in a sedentary phase. In addition, the full physiological range of each parameter was not assessed. Because participants were hospitalized and did not engage in physical exercise, higher heart and respiratory rates associated with increased physical activity were not captured. Lastly, skin tone was not considered because the screened population showed insufficient variation to allow meaningful analysis.

Conclusion

Our findings indicate that the Garmin Venu 3 and 4 measure both HR and SpO_2 within the predefined ranges of ±5bpm and ± 3% relative to the reference method, respectively, in hospitalized patients. RR measurements were systematically underestimated in a population characterized by elevated RR, with only 47.7% of measurements within the acceptable range, and should therefore be interpreted with caution.

Abbreviations

AF: Atrial Fibrillation

BLUP: Best Linear Unbiased Predictor

BMI: Body Mass Index

CI: Confidence Interval

COPD: Chronic Obstructive Pulmonary Disease

FAMHP: Federal Agency of Medicine and Health Products

HR: Heart Rate

IP: Impedance Pneumography

MAE: Mean Absolute Error

PPG: Photoplethysmography

RR: Respiratory Rate

RPM: Remote Patient Monitoring

SpO_2: Peripheral Oxygen Saturation

SRS: Smartwatch Rating Scaleμ

Declarations

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Conflicts of interest

None declared.

Data availability

The datasets generated and/or analyzed during the current study are not publicly available due to the need for a data transfer agreement, but are available from the corresponding author on reasonable request.

Code availability

The underlying code for this study is not publicly available but may be made available to qualified researchers on reasonable request from the corresponding author.

Authors' contributions

RK: Designed the study, study execution, wrote the first draft of the manuscript, EB: study execution, critically revised the manuscript, JS: critically revised the manuscript, CS: critically revised the manuscript, ZP: provided statistical support, critically revised the manuscript, LVS: critically revised the manuscript, JV: helped design the study, critically revised the manuscript, CB: critically revised the manuscript, FW: helped design the study critically revised the manuscript, DR: supervised the project, critically revised the manuscript.

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Figures

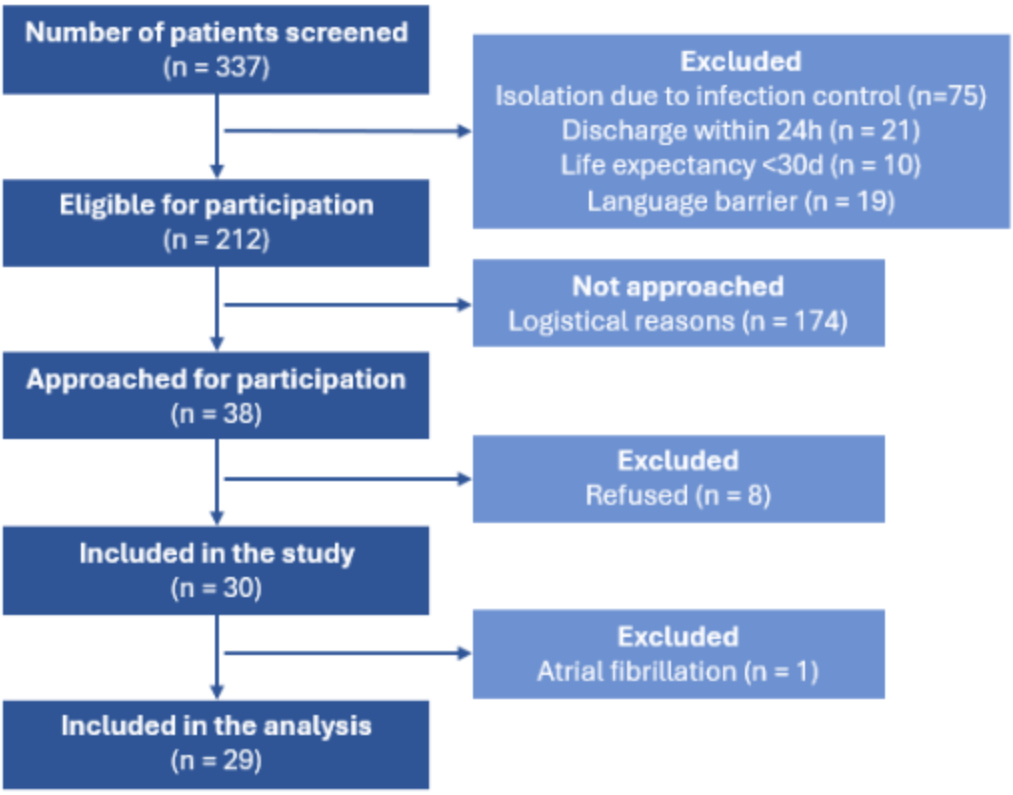


Figure 1

Flow chart presenting patient inclusion.

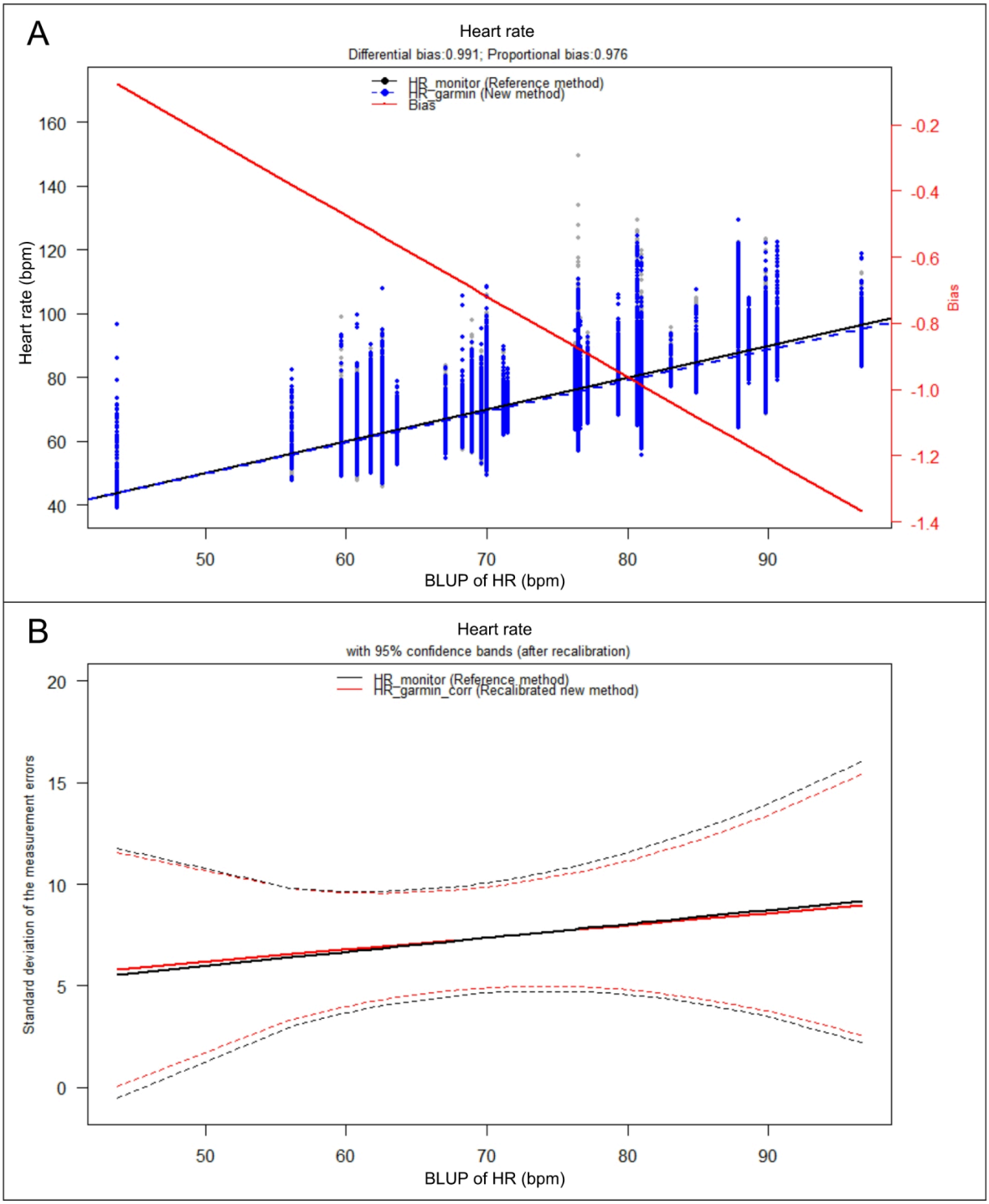


Figure 2

Bias and precision plots for HR according to the Taffé method. (A) Bias plot for HR. The x-axis represents BLUP of the true value of HR. Smartwatch measurements (blue dashed line) are compared with monitor measurements (solid black line). Both values are read from the left y-axis. Bias (the difference between smartwatch and monitor measurements) is shown as a solid red line. The value is read from the right y-axis. (B) Precision plot for HR. The x-axis represents BLUP of the true value of HR. The standard deviation of

measurement errors for the monitor are shown in black, those for the Garmin watch are shown in red. BLUP, best linear unbiased prediction; bpm, beats per minute; HR, heart rate.

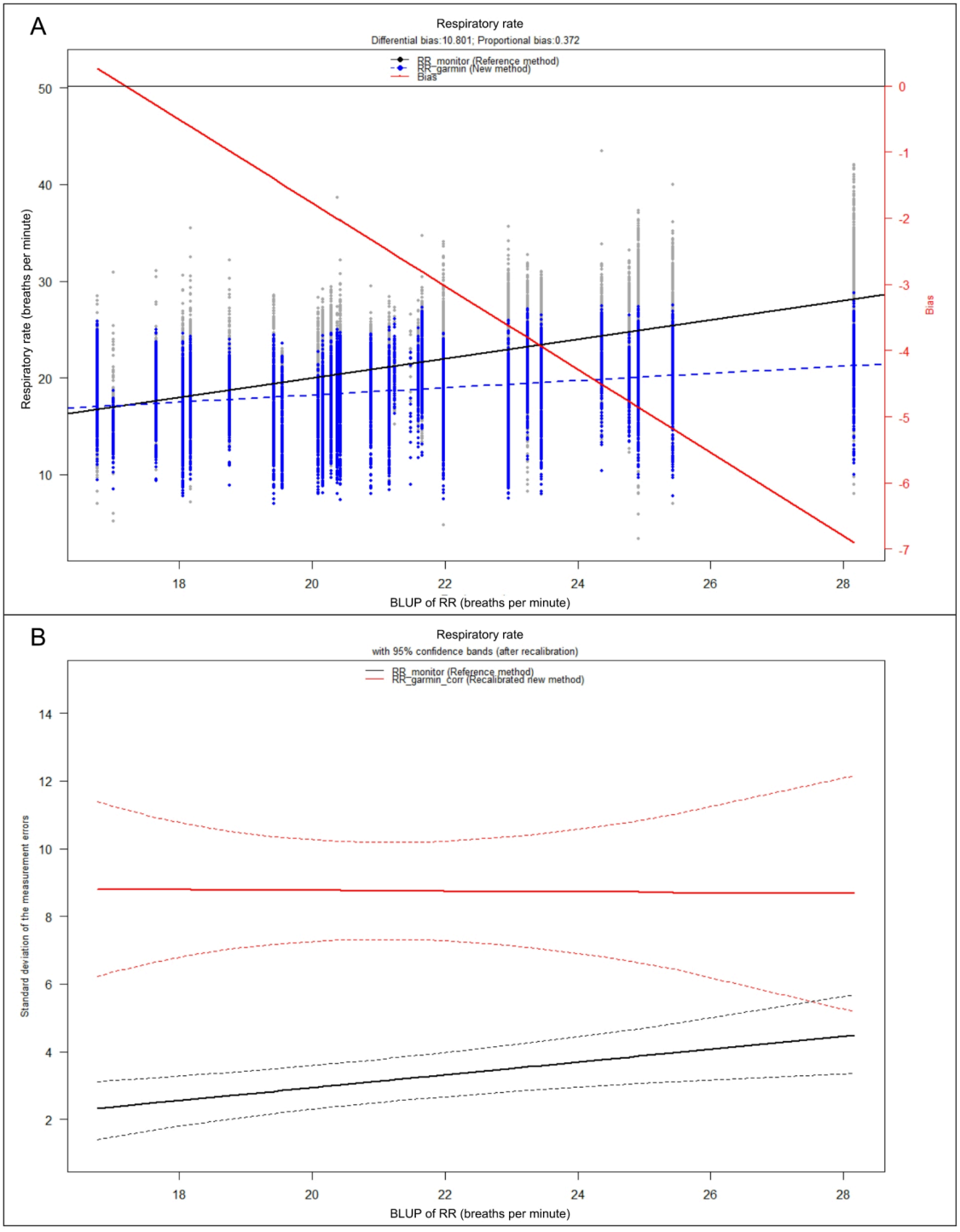


Figure 3

Bias and precision plots for RR according to the Taffé method. (A) Bias plot for RR. The x-axis represents BLUP of the true value of RR. Smartwatch measurements (blue dashed line) are compared with monitor

measurements (solid black line). Both values are read from the left y-axis. Bias (the difference between smartwatch and monitor measurements) is shown as a solid red line. The value is read from the right y-axis. (B) Precision plot for RR. The x-axis represents BLUP of the true value of RR. The standard deviation of measurement errors for the monitor are shown in black, those for the Garmin watch are shown in red. BLUP, best linear unbiased prediction; RR, respiratory rate.

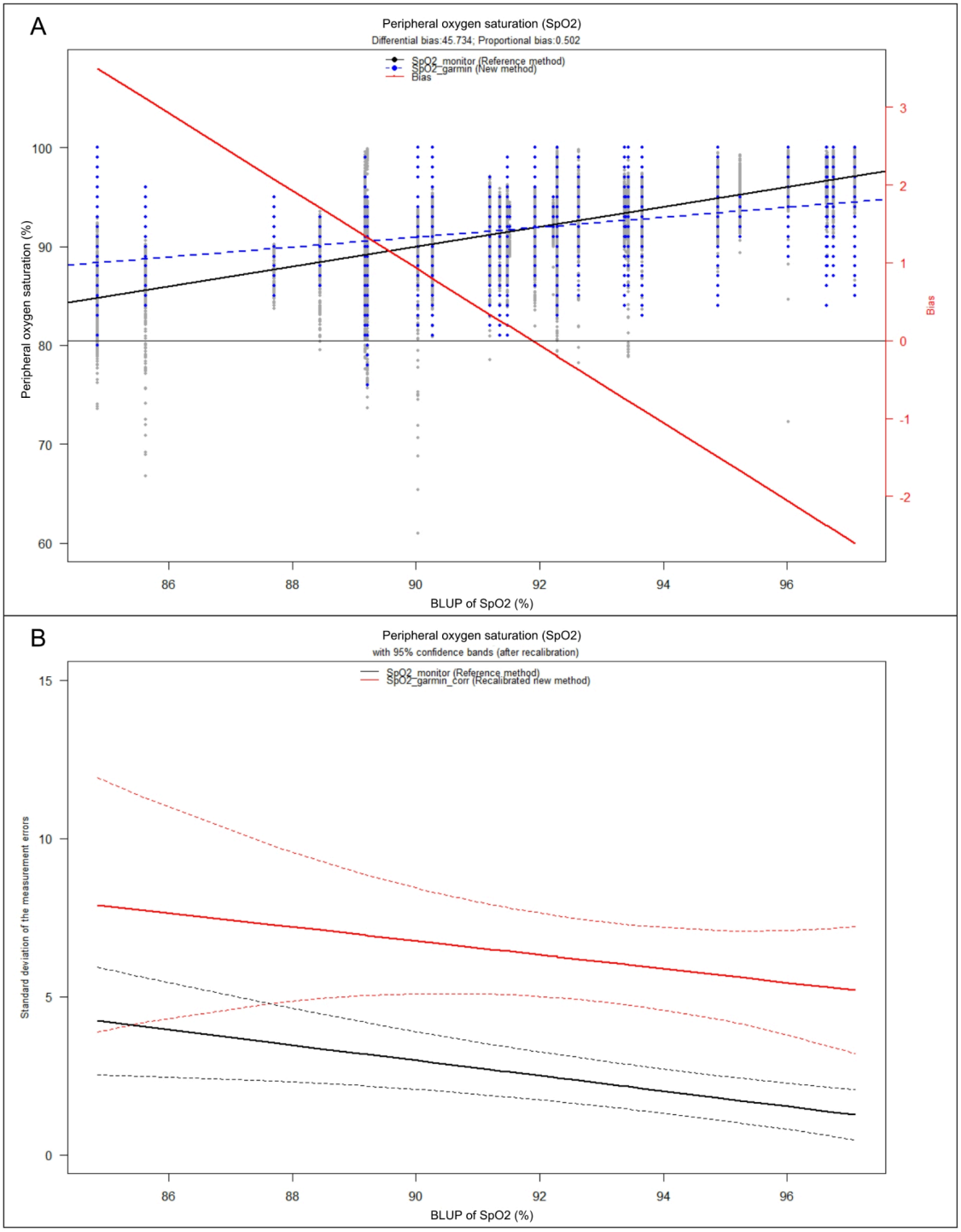


Figure 4

Bias and precision plots for SpO_2 according to the Taffé method. (A) Bias plot for SpO_2. The x-axis represents BLUP of the true value of SpO_2. Smartwatch measurements (blue dashed line) are compared with monitor measurements (black solid line). Both values are read from the left y-axis. Bias (the difference between smartwatch and monitor measurements) is shown as a solid red line. The value is read from the right y-axis. (B) Precision plot for SpO_2. The x-axis represents BLUP of the true value of SpO_2. The standard deviation of measurement errors for the monitor are shown in black, those for the Garmin watch are shown in red. BLUP, best linear unbiased prediction; SpO_2, peripheral oxygen saturation.

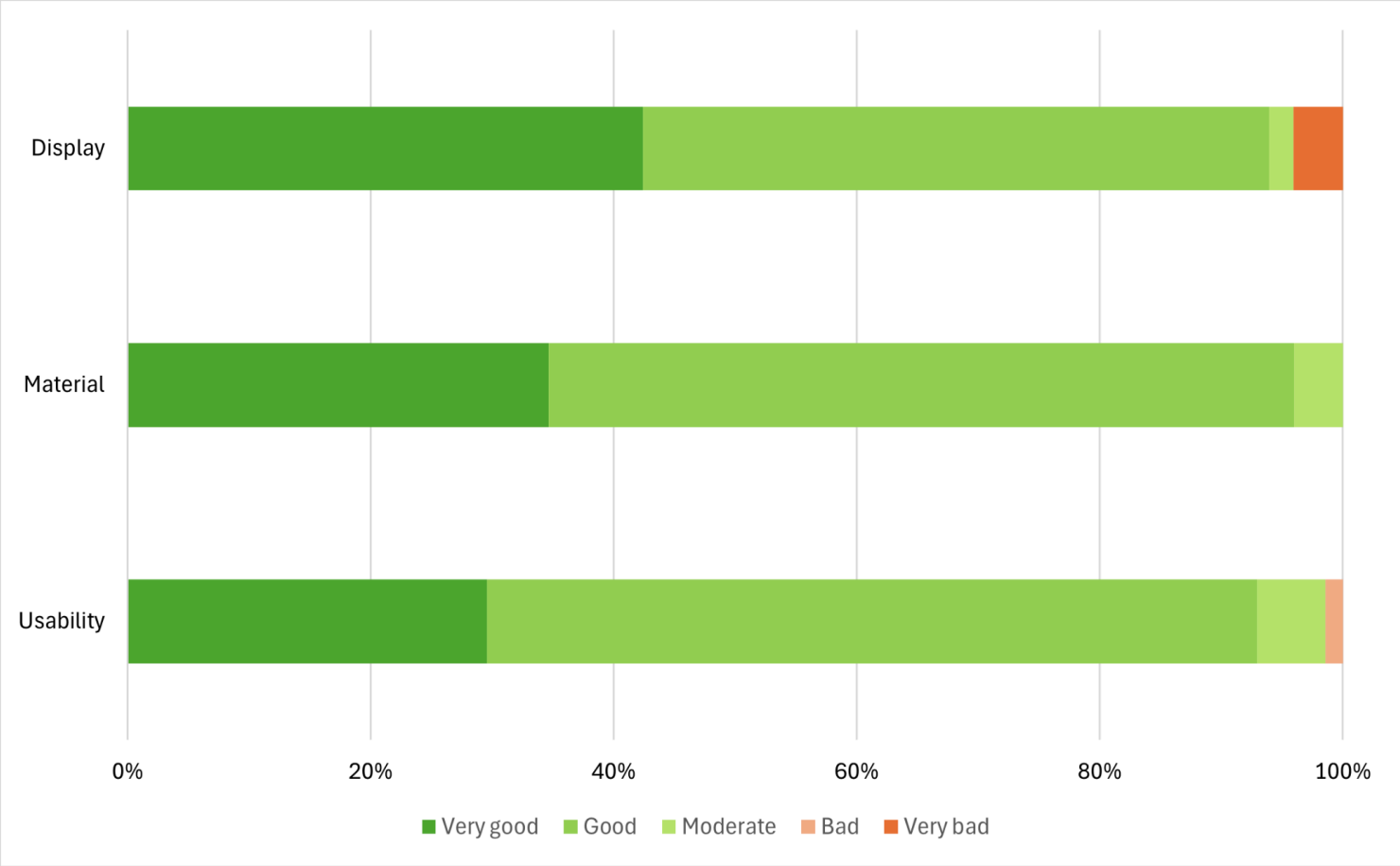


Figure 5

Results of the SRS questionnaire.

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- Supplements.docx