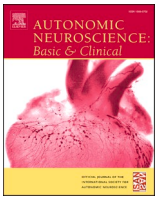
Autonomic Neuroscience: Basic and Clinical 266 (2026) 103447

Contents lists available at ScienceDirect

Autonomic Neuroscience: Basic and Clinical

journal homepage: www.elsevier.com/locate/autneu



Validity of the Polar H10 for heart rate variability and cardiac autonomic reflex tests☆

Ann Claire E. Blalock [a], Bryan L. Riemann [a], Andrew A. Flatt [a,*]

[a] Biodynamics and Human Performance Center, Department of Health Sciences and Kinesiology, Georgia Southern University - Armstrong Campus, Savannah, GA, United States

ARTICLE INFO

Keywords:
Parasympathetic
Cardiovascular
Electrocardiography
Wearable technology
Physiological measurement

ABSTRACT

We tested the validity of the Polar H10 chest strap against criterion electrocardiography (ECG) for heart rate variability (HRV) and cardiac autonomic reflex assessment in young adults and examined associations between supine HRV and other cardiovagal markers. Forty-three healthy adults (18–39 years, 44% male) completed an 8-min protocol: 3 min supine rest (HRV assessed in minute 2 after 1-min stabilization), 1 min paced deep breathing (minute 4; 0.1 Hz), 1 min supine washout, and 3 min active standing (30:15 ratio assessed post-transition; HRV assessed in minute 6 after 1-min post-transition stabilization). Simultaneous RR intervals were recorded via ECG and H10. Agreement was evaluated for time-domain HRV (mean RR interval, root-mean square of successive differences [RMSSD], and standard deviation of normal RR intervals) and reflex tests (deep breathing expiratory [E] to inspiratory [I] ratio, E − I difference, heart rate response; orthostatic 30:15 ratio). Excellent agreement was observed between devices for all metrics (concordance correlation ≥0.99; mean absolute percentage error < 1%; and narrow 95% limits of agreement (widest = −1.5 to 1.7 ms). Supine RMSSD shared 39–53% of variance with deep breathing outcomes, 34% with standing RMSSD, and < 1% with the 30:15 ratio. The H10 provides measurements effectively interchangeable with laboratory ECG for time-domain HRV and standard cardiovagal reflex tests in healthy young adults. Supine RMSSD shares approximately half or less of the variance with other cardiovagal markers, reinforcing the importance of incorporating complementary reflex and orthostatic tests for comprehensive cardiac autonomic assessment.

1. Introduction

Cardiovagal outflow confers numerous protective health effects, whereas its hypoactivity and dysfunction is implicated in various pathological conditions (He et al., 2015; Thayer and Lane, 2007). Since direct measurement of vagal nerve activity is invasive and impractical, indirect assessment methods are more common (Freeman, 2006). Beat-to-beat heart rate fluctuations primarily reflect phasic parasympathetic influence on the sinus node, making electrocardiograph (ECG)-derived heart rate variability (HRV) the preferred non-invasive index of cardiovagal modulation (Freeman, 2006). The ease of measurement and broad applicability of HRV in clinical, athletic, and general populations have driven its widespread adoption and a growing body of research examining its diagnostic, prognostic, and monitoring utility (Buchheit, 2014; Franca da Silva et al., 2016; Lahiri et al., 2008; Zhou et al., 2016).

A more comprehensive assessment of cardiovagal function involves standardized cardiac reflex tests that elicit measurable heart rate responses to specific provocations (Ewing and Clarke, 1982). For instance, the 1-min deep breathing reflex test (DBT) maximizes respiratory sinus arrhythmia through paced deep breathing at 0.1 Hz, producing large phasic RR interval fluctuations (Ewing et al., 1985). Additionally, the orthostatic reflex test, via the 30:15 ratio (longest RR interval near beat 30 divided by shortest near beat 15 after active standing), captures initial parasympathetic withdrawal due to unloading of carotid and cardiopulmonary baroreceptors, followed by reflex bradycardia (Ewing et al., 1985). These tests are quick and easy to administer, and aid in the early detection, staging, and prognostic evaluation of cardiac autonomic neuropathy in various conditions (Katz et al., 1999; Maser et al., 2003). Reflex tests have also been used to evaluate exercise adaptation (Oksanen et al., 2019; Uusitalo et al., 2000) and future risk of

☆ This article is part of a Special issue entitled: 'Wearables and the ANS' published in Autonomic Neuroscience: Basic and Clinical.

* Corresponding author at: Georgia Southern University - Armstrong Campus, Department of Health Sciences and Kinesiology, Biodynamics and Human Performance Center, 11935 Abercorn St., Savannah, GA, 31419, United States.

E-mail addresses: ab55227@georgiasouthern.edu (A.C.E. Blalock), briemann@georgiasouthern.edu (B.L. Riemann), aflatt@georgiasouthern.edu (A.A. Flatt).

https://doi.org/10.1016/j.autneu.2026.103447
Received 18 February 2026; Received in revised form 1 April 2026; Accepted 8 June 2026
Available online 9 June 2026

cardiovascular (Engström et al., 2022) and neurological disorders (Chou et al., 2023). The availability of age-adjusted clinical cutoffs further enhances their interpretive and diagnostic utility (Wieling et al., 1982).

Although supine short-term HRV (5-min recording after ~5 min stabilization) tends to be the predominant metric of cardiac autonomic modulation in research studies (Shaffer and Ginsberg, 2017), it shares less than half of the variance with standard reflex measures in middle aged and patient populations (Ewing et al., 1981; Kwon et al., 2022; McCraty et al., 2018), and is susceptible to parasympathetic saturation effects (Kiviniemi et al., 2004), limiting its utility as a standalone index. Ultra-short, time domain HRV markers following brief stabilization (e.g., 1-min recording after 1 min stabilization) (Flatt and Esco, 2016) serve as valid surrogates for traditional short-term HRV (Esco et al., 2018; Munoz et al., 2015; Politi et al., 2020), while standing measurements provide unique insight regarding autonomic function (Gronwald et al., 2024). Thus, combining ultra-short supine and standing HRV with standardized reflex tests enables a more thorough and efficient evaluation of cardiac autonomic status that can be completed in less time than the typical ~10 min required for short-term HRV.

The Polar H10 chest-strap is a wearable ECG-based heart rate monitor that offers greater affordability and convenience than traditional laboratory-grade ECG systems (Krummenacher et al., 2023). Thus, it is well-suited for remote monitoring and use by non-experts (Grosicki et al., 2022). Although it has demonstrated strong agreement with criterion ECG-derived RR intervals at rest and during exercise, prior validation studies are limited by small samples (n = 10–25) and lack of time domain HRV and cardiac reflex assessment (Gilgen-Ammann et al., 2019; Schaffarczyk et al., 2022). Many other comparisons have focused on smartphone applications that apply proprietary artifact filtering algorithms rather than evaluating the H10's raw RR interval accuracy directly (Moya-Ramon et al., 2022; Stone et al., 2021; Vondrasek et al., 2023). Therefore, we aimed to test the validity of the Polar H10 against simultaneous laboratory-grade ECG for time-domain HRV and standardized cardiovagal reflex tests in a time-efficient protocol. Additionally, since associations between supine HRV and other cardiovagal markers (deep breathing outcomes, 30:15 ratio, standing HRV) lack investigation in young adults, our secondary aim was to examine their shared variance in this population. We hypothesized excellent agreement between H10 and ECG for all tests, and that supine HRV would incompletely reflect other cardiovagal metrics.

2. Methods

2.1. Study design

This cross-sectional study compared the H10 with ECG during a cardiac autonomic assessment protocol in healthy young adults. Participants arrived at the laboratory in the morning after fasting for ≥2 h and abstaining from strenuous exercise, alcohol, and caffeine for the preceding 24 h. They were familiarized with the protocol and performed at least one DBT practice attempt in the laboratory before data collection. Initially, subjects rested in a supine position on an examination table and were prepped for simultaneous ECG and H10 recording. Then, brachial blood pressure was assessed using automated oscillometry. Next, the continuous cardiac autonomic assessment protocol commenced as follows: 3 min of supine rest with spontaneous breathing, 1-min of paced deep breathing (DBT), 1 min supine spontaneous breathing (washout), 3 min of active standing. Associations between traditional supine HRV and other markers of cardiovagal function were subsequently quantified. An example comparison protocol is displayed in Fig. 1.

2.2. Participants

Healthy males and females aged 18 to 39 years were recruited for this study. To participate, individuals needed to be free from known cardiovascular, metabolic, and neurological disorders. Subjects with an abnormal heart rhythm or that were on any heart rate altering medications were excluded. Prior to data collection, volunteers were informed of the risks and benefits of the study and were given the opportunity to ask questions before signing a consent form. All procedures involving human participants were conducted in accordance with relevant laws, institutional guidelines, and the ethical standards of the Georgia Southern University Institutional Review Board, which approved the study (Protocol H24038, September 2023).

Sample size was determined using guidelines by Lu et al. (2016) for

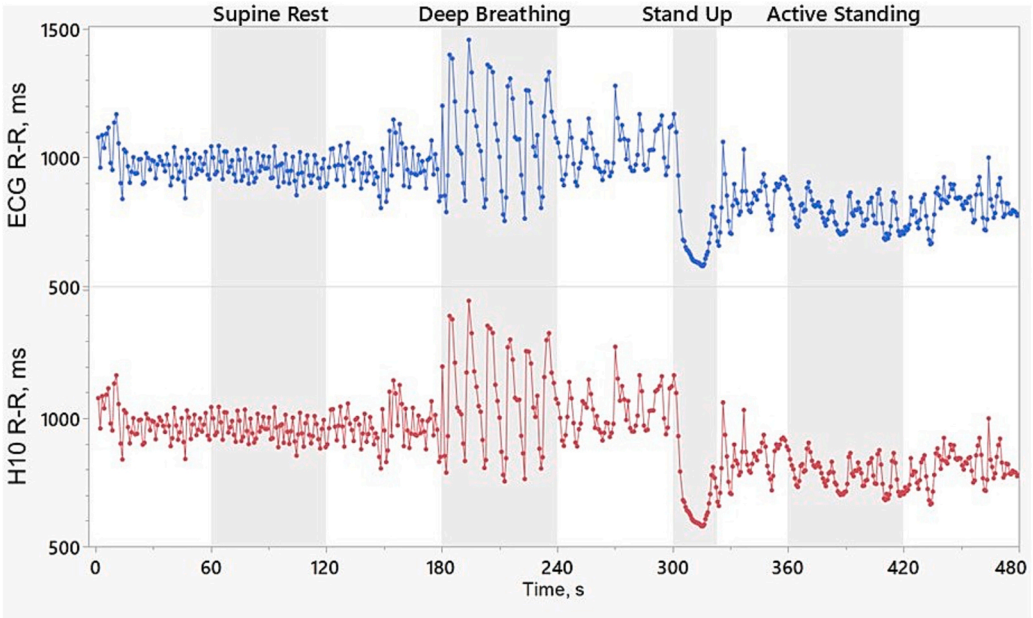


Fig. 1. Representative RR-interval tachograms from simultaneous electrocardiogram (ECG; top) and Polar H10 (bottom) recordings during the ~8-min cardiac autonomic protocol in a healthy young adult. Vertical shaded regions demarcate the protocol phases: supine rest with spontaneous breathing (HRV assessed in min 2 after 1-min stabilization), paced deep breathing test (DBT; min 4, 0.1 Hz), supine washout, transition to standing (Stand Up), and active standing (HRV assessed in min 6 after 1-min post-transition stabilization).

Bland–Altman agreement assessment. Based on a prior H10 validation study ($n = 10$) reporting a mean bias <0.1 ms and 95% limits of agreement ±2.3 ms (corresponding to a standard deviation of differences of ~1.2 ms) during seated reading (Gilgen-Ammann et al., 2019), we anticipated near-zero bias and low variability. Under these conditions, the sample-size tables of Lu et al. (2016) indicate that 40 participants is sufficient to obtain narrow 95% limits of agreement with conventional power and confidence assumptions (≥80% power at $\alpha = 0.05$).

2.3. Electrocardiogram

Criterion ECG was obtained from wireless recordings via the BioNomadix amplifier interfaced with the MP160 data acquisition system (Biopac Systems Inc., Goleta, CA, USA). Disposable Ag-AgCl electrodes were placed on the skin of the trunk in a modified lead II configuration and sampling frequency was set at 1000 Hz. Real-time cardiac cycles were displayed on a laptop computer running AcqKnowledge 5.0 software (Biopac Systems Inc. Goleta, CA, USA) which facilitated manual marking of the ECG at the onset and completion of simultaneous ~8-min recordings with the H10.

2.4. H10

The H10 chest-strap (Polar Electro Oy, Kempele, Finland, 1000 Hz sampling rate) was moistened for conductivity and fastened around the trunk at the level of the xiphoid process. It was then paired via Bluetooth to a tablet device running Heart Rate Variability Logger (v5.1.2; A.S.M. A. B.V., Amsterdam, Netherlands), a mobile application that visualizes and stores continuous RR interval data. RR interval corrections by the application were disabled for all measurements. H10 recordings were initiated at the same time as ECG and were subsequently exported for download as a .CSV spreadsheet.

2.5. Heart rate variability

Minutes 2 and 6 of the protocol were selected as the primary analysis windows for supine and standing ultra-short HRV, respectively, with each preceded by a 1-min stabilization period (Flatt and Esco, 2016; Holmes et al., 2020). One-min samples after a 1-min stabilization period in supine and standing positions have previously been associated with various health and lifestyle metrics in young adults (Grosicki et al., 2022). If an ectopic beat was detected within the chosen minute, the sample window was shifted to the nearest artifact-free segment within minutes 2–4 (supine) and 6–8 (standing). The root-mean-square of successive differences (RMSSD) served as the primary index of cardiac parasympathetic activity (Penttilä et al., 2001) because of its suitability for ultra-short recordings (Esco et al., 2018; Munoz et al., 2015; Politi et al., 2020), established clinical relevance (Jarczok et al., 2022; Kang et al., 2022), and widespread use in consumer mobile applications (Grosicki et al., 2022; Natarajan et al., 2020). The mean RR interval (RRi) and the standard deviation of normal-to-normal RR intervals (SDNN; reflecting overall autonomic influence) were also reported for clinical completeness. RR intervals were detrended using the smoothness priors method (Tarvainen et al., 2002) prior to HRV calculation using Kubios HRV Scientific software (v4.2.0, University of Kuopio, Kuopio, Finland). Only segments containing 100% normal sinus beats were included in the analysis. No correction of ectopic beats was performed to avoid introducing additional error variance from editing procedures.

2.6. Cardiac autonomic reflexes

The DBT and orthostatic reflex test were included in the protocol because they are valid non-invasive reflex tests of cardiovagal function that can be performed without additional equipment, are easy for subjects to perform, are non-HR-dependent (Agelink et al., 2001; Ewing and Clarke, 1982), and have established clinical and practical relevance across patient (Ewing et al., 1985; Katz et al., 1999), athletic (Oksanen et al., 2019; Uusitalo et al., 2000), and healthy populations (Chou et al., 2023; Engström et al., 2022). The DBT occurred at minute 4 of the protocol. Breathing was supervised by the investigator and visually paced at 6 breaths·min^{-1} (5 s inhale, 5 s exhale) using a separate tablet running the BreathPacer (v2.0.7, Vagus Labs LLC) application. Subjects were instructed to inhale deeply and exhale each breathing cycle without pausing. From at least 5 breathing cycles, the longest RR interval during expiration and the shortest RR interval during inspiration were identified and averaged to determine the expiratory to inspiratory ratio (E:I) and the absolute difference (E − I) (Freeman, 2006). The corresponding maximum and minimum HR per cycle were used to determine the HR response to deep breathing (HRDB) (Ewing et al., 1985).

The orthostatic reflex test began at minute 6 of the protocol with an active transition from supine to standing. The 30:15 ratio was calculated as the longest RR interval occurring around the 30th beat after standing divided by the shortest RR interval around the 15th beat after standing (Ewing et al., 1985). Results for the DBT and orthostatic test were obtained using the Kubios software.

2.7. Statistical analysis

Agreement between H10- and ECG-derived metrics was evaluated using Bland-Altman methods with appropriate extensions when assumptions were violated (Bland and Altman, 1999; Ludbrook, 2010). Normality of difference scores (H10 − ECG) were evaluated using Shapiro–Wilk tests, normal probability plots, and skewness/kurtosis statistics, with particular emphasis on inspection for skewed distributions (Bland and Altman, 1999). Absence of proportional bias was tested by regressing difference scores on the mean of the two methods. A statistically significant slope ($p < 0.05$) indicated proportional bias. Heteroscedasticity was evaluated by regressing absolute residuals from the proportional-bias model against the mean of the two methods. A significant slope indicated increasing variance with magnitude (heteroscedasticity). Systematic bias was assessed with a paired t-test and reported as mean ± standard deviation (SD) or regression-based equation (intercept + slope × mean) when proportional bias was detected. Limits of agreement (LoA) were calculated as mean difference ± 1.96 × SD. When proportional bias was present but homoscedastic, LOA were calculated as bias ±1.96 × standard error of the estimate from the regression model (Bland and Altman, 1999). Relative agreement was quantified with Lin's concordance correlation coefficient (CCC), interpreted as poor (<0.90), moderate (0.90–0.95), substantial (0.95–0.99), and near-perfect (≥0.99) (Lawrence and Lin, 1989). Absolute agreement was expressed as mean absolute error (MAE) and mean absolute percentage error (MAPE). Pearson correlations were used to quantify bivariate associations between supine RMSSD and other metrics of cardiovagal function. Sex-adjusted (partial) correlations were derived from multiple linear regression models controlling for sex. Statistical analyses were performed using JMP Pro 17 (SAS Institute, Cary, NC, USA) and Excel (Microsoft Corporation, Redmond, WA, USA).

3. Results

A total of 43 subjects participated in the study. Descriptive statistics are presented in Table 1. After excluding samples with unavoidable ectopic beats, final sample sizes for the assessment of supine HRV, the DBT, the orthostatic reflex test, and standing HRV were 40, 42, 41, and 40, respectively.

3.1. Supine and standing HRV

Assumption checks confirmed that difference scores for supine RRi,

Table 1
Descriptive characteristics of the study participants (mean ± standard deviation).

Descriptor	Males ($n = 19$)	Females ($n = 24$)	Total ($n = 43$)
Age, years	25.5 ± 5.4	22.8 ± 4.2	23.0 ± 4.9
Height, cm	178.8 ± 6.8	164.2 ± 7.0	170.7 ± 10.1
Body Weight, kg	86.3 ± 15.7	68.2 ± 16.1	76.2 ± 18.1
Systolic Blood Pressure, mmHg	129.9 ± 8.5	111.0 ± 9.4	119.6 ± 13.0
Diastolic Blood Pressure, mmHg	70.9 ± 8.9	65.0 ± 7.2	67.7 ± 8.5

RMSSD, and SDNN were normally distributed, with no evidence of proportional bias (β = −0.095–0.045, p values >0.05) or heteroscedasticity (β = −0.074–0.166, p values >0.05). Fixed bias was negligible (−0.1 to 0.0 ms; all $p > 0.05$), and 95% LoA were very narrow (each within −1.3 to 1.1 ms). Additionally, absolute agreement was excellent (MAPE <1% for all metrics) and relative agreement was near-perfect (CCC ≥ 0.99 for all metrics). Detailed comparison statistics are presented in Table 2 and Bland-Altman plots are displayed in Fig. 2.

Assumption checks confirmed that difference scores for standing RRi and RMSSD were normally distributed, with no evidence of proportional bias (β = −0.157–0.153, p values >0.05) or heteroscedasticity (β = 0.021–0.031, p values >0.05). A statistically significant but clinically negligible fixed bias was observed for RRi (−0.2 ms, $p < 0.001$), whereas bias for RMSSD was non-significant (0.0 ms, $p > 0.05$), and the 95% LoA were very narrow (each within −0.7 to 0.9 ms). Additionally, absolute agreement was excellent (MAPE <1% for all metrics) and relative agreement was near-perfect (CCC ≥ 0.99 for all metrics).

Despite a negligible fixed bias (−0.03 ms, p > 0.05), regression analysis revealed proportional bias for standing SDNN (β = −0.390, slope = −0.0075, 95% CI [−0.013 to −0.002], $p = 0.011$). This corresponds to a trivial underestimation of only 0.075 ms for every 10 ms increase in standing SDNN (or ~ 0.4 ms at the upper end of observed values near 130 ms). Absolute agreement remained excellent (MAPE <1%) and relative agreement near-perfect (CCC = 0.99).

3.2. Cardiac autonomic reflex tests

Assumption checks confirmed that difference scores for the DBT and orthostatic reflex test metrics were normally distributed, with no evidence of proportional bias (β = −0.269 to −0.031, p values >0.05) or heteroscedasticity (β = −0.289–0.114, p values >0.05). Fixed bias was negligible (≤ 0.1 in respective units, all p > 0.05), and 95% LoA were very narrow (−0.5 to 0.7 across metrics). Additionally, absolute agreement was excellent (MAPE <0.3% for all metrics), while relative agreement was near-perfect (CCC ≥ 0.99 for all metrics). Detailed comparison statistics are presented in Table 2 and Bland-Altman plots are displayed in Fig. 3.

3.3. Associations between metrics of cardiovagal function

Bivariate analyses showed that supine RMSSD accounted for ~53% of the variance in the DBT E − I difference and E/I ratio (both r values = 0.73, p values <0.0001), ~39% in the HRDB ($r = 0.63$, $p < 0.0001$), ~34% in standing RMSSD ($r = 0.59$, $p < 0.0001$), and < 1% in the orthostatic 30:15 ratio ($r = -0.04$, $p = 0.82$). After adjusting for sex, the associations were similar with supine RMSSD accounting for ~52% of the variance in the DBT E − I difference and E/I ratio (both r values = 0.72, p values <0.0001), ~42% in the HRDB ($r = 0.65$, $p < 0.0001$), ~28% in standing RMSSD ($r = 0.53$, $p < 0.001$), and < 1% in the orthostatic 30:15 ratio ($r = -0.06$, $p = 0.73$).

4. Discussion

This study examined whether the H10 can serve as a valid alternative to laboratory ECG for time-efficient cardiac autonomic assessment in healthy young adults and the extent to which supine RMSSD captures variability in other markers of cardiovagal function. We found that the H10 provided measurements that are effectively interchangeable with simultaneous laboratory ECG for both time-domain HRV and standard cardiac autonomic reflex tests. Additionally, supine RMSSD explained between approximately none and half of the variance in markers of cardiovagal function from separate assessments. Together, these findings support the use of the H10 as a low-cost and portable alternative to laboratory ECG for cardiac autonomic testing and provide an easily reproducible assessment protocol from which distinct markers of

Table 2
Agreement statistics between the H10 and criterion electrocardiogram (ECG) for time-domain heart rate variability and cardiac autonomic reflex metrics (mean ± standard deviation; n = 40–42 per metric after exclusions).

Metric	Device	Mean ± SD	Systematic bias	LoA (95%)	MAE	MAPE%	CCC
Supine RRi, ms	H10	1006.1 ± 147.4	−0.1 ± 0.5	−1.1 to 0.8	0.4 ± 0.3	0.04 ± 0.03	1.0
	ECG	1006.3 ± 147.3					
Supine RMSSD, ms	H10	63.6 ± 36.4	−0.1 ± 0.6	−1.3 to 1.1	0.4 ± 0.5	0.8 ± 0.8	0.99
	ECG	63.7 ± 36.4					
Supine SDNN, ms	H10	55.2 ± 28.8	0.0 ± 0.5	−1.0 to 0.9	0.3 ± 0.3	0.8 ± 0.8	0.99
	ECG	55.2 ± 28.9					
DBT E–I difference, ms	H10	286.7 ± 129.0	0.1 ± 0.8	−1.5 to 1.7	0.5 ± 0.6	0.2 ± 0.3	1.0
	ECG	286.6 ± 129.2					
DBT E:I ratio	H10	1.36 ± 0.16	0.0 ± 0.0	−0.007 to 007	0.001 ± 0.003	0.1 ± 0.3	0.99
	ECG	1.36 ± 0.17					
DBT HR difference, bpm	H10	18.9 ± 7.1	0.0 ± 0.1	−0.1 to 0.2	0.03 ± 0.07	0.2 ± 0.4	0.99
	ECG	18.9 ± 7.1					
Orthostatic 30/15 Ratio	H10	1.41 ± 0.16	0.0 ± 0.0	−0.002 to 0.002	0.001 ± 0.001	0.05 ± 0.05	1.0
	ECG	1.41 ± 0.16					
Standing RRi, ms	H10	831.2 ± 117.9	−0.2 ± 0.5**	−1.2 to 0.7	0.4 ± 0.3	0.05 ± 0.04	1.0
	ECG	831.4 ± 118.0					
Standing RMSSD, ms	H10	40.2 ± 24.7	0.0 ± 0.3	−0.6 to 0.6	0.2 ± 0.2	0.7 ± 0.9	0.99
	ECG	40.2 ± 24.7					
Standing SDNN, ms	H10	53.8 ± 28.5	0.375–0.0075 * A	Bias ±1.96 * 0.512	0.4 ± 0.4	0.9 ± 1.2	0.99
	ECG	53.8 ± 28.7					

RRi = mean RR interval; RMSSD = root-mean-square of successive differences; SDNN = standard deviation of normal-to-normal intervals; DBT = deep breathing test; E = expiration; I = inspiration; HR = heart rate; MAE = mean absolute error; MAPE = mean absolute percentage error; CCC = concordance correlation coefficient; β = beta coefficient from regression; LoA = limits of agreement; *P < 0.05; **P < 0.001.

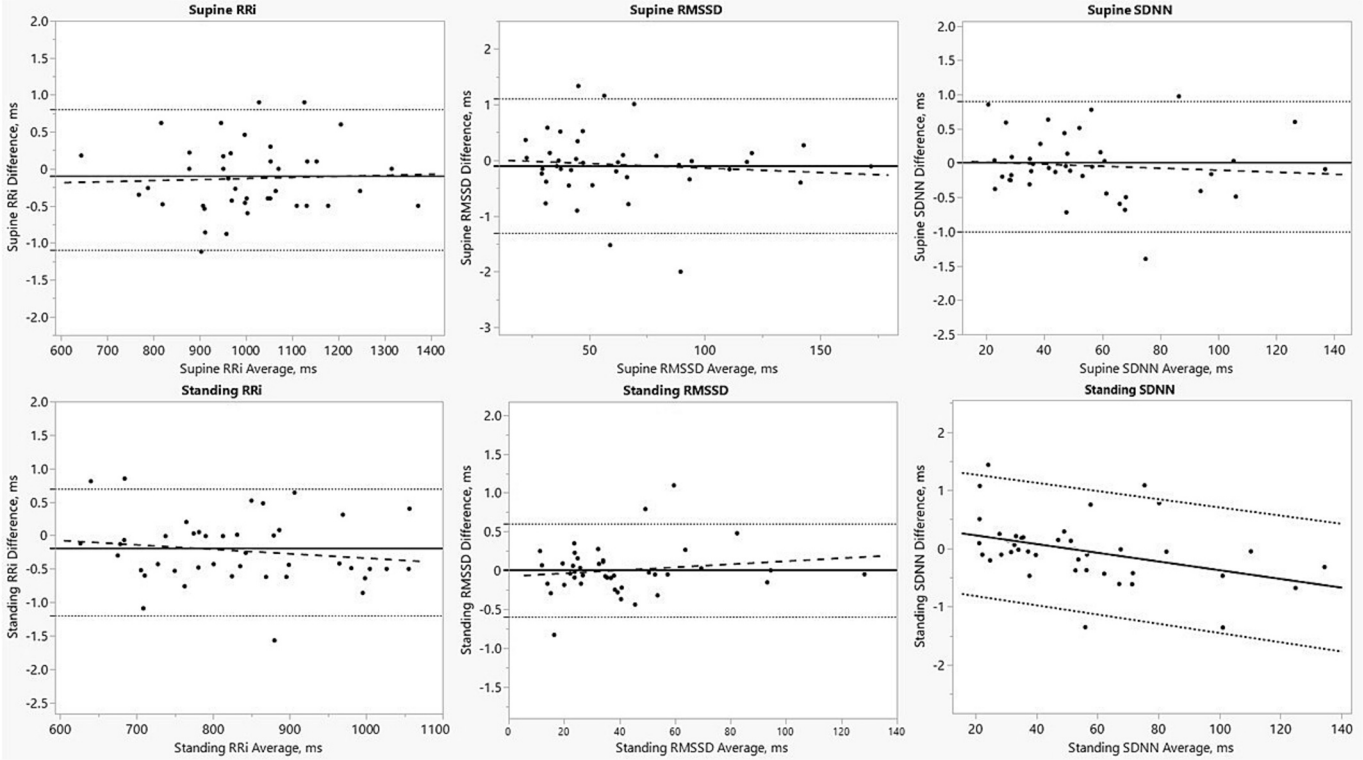


Fig. 2. Bland–Altman plots illustrating agreement between simultaneous electrocardiogram (ECG) and H10 measurements for time-domain heart rate variability metrics in supine rest and active standing positions ($n = 40$ per metric after exclusions). Each panel shows the difference (H10 – ECG) plotted against the average of the two methods. Solid line = mean difference (bias); dotted lines = 95% upper and lower limits of agreement; dashed line = best fit line from linear regression. A statistically significant but clinically trivial fixed bias was observed for standing RRi (mean difference = −0.2 ms, $p < 0.001$). Additionally, a statistically significant but clinically trivial proportional bias was observed for standing SDNN (slope = −0.0075, $p = 0.011$), reflected in a diagonal bias line and regression-based limits of agreement.

cardiovagal function can be derived.

For all supine and standing HRV metrics, fixed biases were trivial (all ≤0.3 ms) and both relative (CCC ≥ 0.99) and absolute agreement (MAPE <1%) were excellent. Although a fixed bias was observed for standing RRi (−0.2 ms, p < 0.001) and proportional bias for standing SDNN (slope = −0.0075, $p = 0.011$), magnitudes were clinically negligible. For example, the proportional bias in SDNN resulted in a maximum underestimation of ~0.4 ms at the upper end of the observed range (~130 ms). While several studies have compared H10 to ECG at rest for HRV, prior work primarily relied on third-party mobile applications that apply proprietary artifact-detection and filtering algorithms (Moya-Ramon et al., 2022; Vondrasek et al., 2023). This shifts the focus from the accuracy of the H10 sensor to the mobile application. In contrast, we disabled all automatic corrections and analyzed raw RR intervals, eliminating this confounding factor. Previous studies that applied matched filtering methods when comparing H10- and ECG-derived RRi at rest reported comparably excellent agreement (no significant fixed bias, mean difference < 0.2 ms, LoA within −2.6–2.4 ms), though sample sizes (n = 10–25) were small and RMSSD and SDNN were not evaluated (Gilgen-Ammann et al., 2019; Schaffarczyk et al., 2022).

For the DBT and orthostatic reflex test results, fixed biases were trivial (all ≤0.1 in respective units) and both relative (CCC ≥ 0.99) and absolute agreement (MAPE <1%) were excellent. The DBT findings are particularly noteworthy because this reflex maneuver elicits larger and more abrupt RR-interval fluctuations than those observed during quiet rest or exercise. For example, several participants displayed HRDB scores ≥30 bpm between peak inspiration and expiration (within ~5 s), yet agreement between H10 and ECG remained strong. Regarding lower scores, normal HRDB values during the DBT are ≥12 and 14 bpm for 10–29 year olds and 30–39 year olds, respectively (Novak, 2011), and values ≤10 bpm are considered abnormal regardless of age (Ewing et al., 1985). In the current study, 11 subjects exhibited values <14 bpm and 4 with <10 bpm as measured with H10 and ECG (between-device differences ≤0.1 bpm), indicating that their corresponding clinical classification would be identical. This provides preliminary evidence that the H10 can detect clinically reduced or abnormal DBT results, supporting its potential utility as a low-cost, portable screening tool in settings where laboratory ECG is impractical.

Regarding our secondary aim, RMSSD explained between <1 and 53% of the variance in the other indicators of cardiovagal function, with the greatest shared variance in DBT outcomes. Previous work in predominantly middle aged adults (n = 805; mean age = 50.1 years) reported weaker correlations relative to current findings between supine RMSSD and DBT outcomes (E:I ratio: $r = 0.42$; HRDB: $r = 0.27$; both $p <$ 0.01) (McCraty et al., 2018). In 61 diabetics (mean age = ~43 years), mean square of successive differences in the supine position correlated with the HRDB ($r = 0.51$, $p < 0.001$) but not the orthostatic 30:15 ratio ($r = 0.19$, $p > 0.05$) (Ewing et al., 1981). Another investigation in a cohort with various comorbidities (mean age = 50 years) found that the HRDB shared 27% of the variance with supine RMSSD among participants with normal-range responses, whereas no linear association was evident in those with abnormal values (Kwon et al., 2022). Taken together, it seems that the association between supine RMSSD and the HRDB may weaken with age and diseases affecting autonomic function. In contrast, the consistent lack of association between supine RMSSD and the 30:15 ratio suggests that resting parasympathetic modulation shares minimal common variance with parasympathetic reactivity to active standing.

One explanation for instances of dissociation between supine and standing measures of cardiovagal function is parasympathetic saturation. This is a well-documented but underappreciated effect in which supine HRV is reduced at low resting HR, attributed to very high vagal

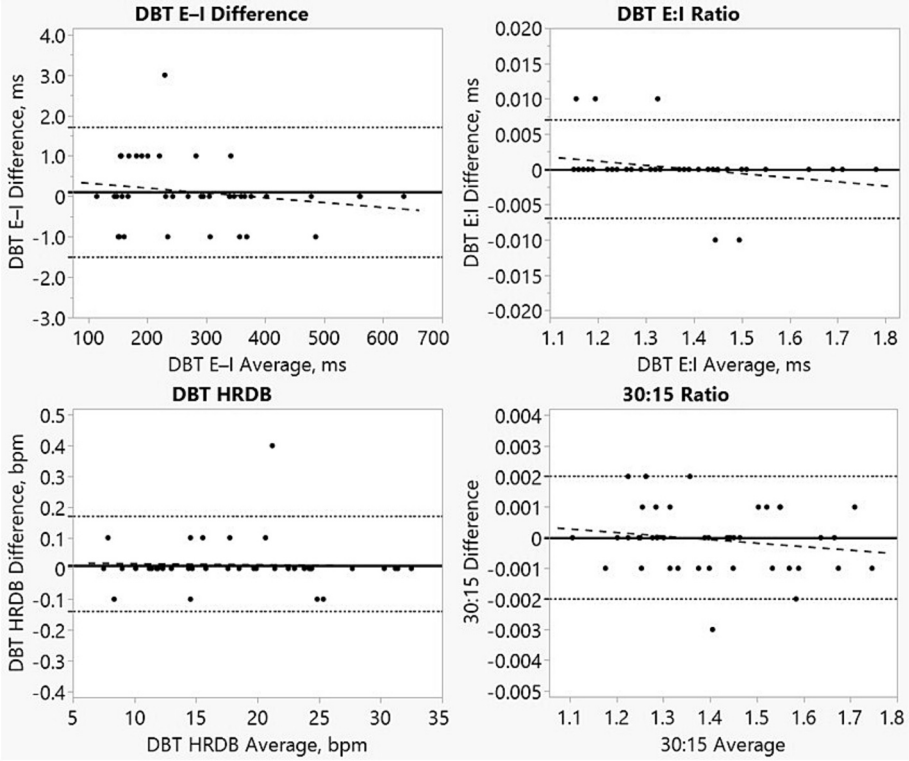


Fig. 3. Bland–Altman plots demonstrating agreement between simultaneous electrocardiogram (ECG) and H10 measurements for cardiac autonomic reflex test metrics during the paced deep breathing test and orthostatic 30:15 ratio (n = 41–42 per metric after exclusions). Each panel shows the difference (H10 – ECG) against the average of the two methods. Solid line = mean difference (bias); dotted lines = 95% upper and lower limits of agreement; dashed line = best fit line from linear regression.

outflow and M2 muscarinic acetylcholine receptor saturation, which attenuates phasic beat-to-beat modulation (Goldberger et al., 2001; Kiviniemi et al., 2004; van Lien et al., 2011). This effect results in a quadratic rather than linear association between RRi and RMSSD. Although thresholds vary inter-individually, parasympathetic saturation tends to occur when HR is <55 bpm, corresponding to a RRi >1090 ms (Goldberger et al., 2001; Kiviniemi et al., 2004), with one study finding it in nearly half of young adults (35/76) during 24-h ambulatory monitoring (Kiviniemi et al., 2004). In the current sample, 10 of 43 participants exceeded this RRi threshold. An implication of saturation is the underestimation of resting cardiac parasympathetic modulation, which may have affected the strength of associations between supine RMSSD and other cardiovagal metrics in the present study, and could similarly confound associations reported in other studies that rely primarily on supine assessment. Parasympathetic saturation may also obscure enhanced cardiovagal outflow following an intervention (e.g., exercise training) when associated changes in HR or RRi exceed saturation thresholds. Conversely, blunted parasympathetic reactivity to standing, reflected in persistent elevations in HR (e.g., >20 bpm) and reduced RMSSD within 3 min, may reveal abnormalities in cardiac parasympathetic regulation often not evident in the supine position (Gronwald et al., 2024; Juraschek et al., 2018). Depending on magnitude and context, this presentation may reflect autonomic dysfunction associated with various underlying conditions (Sánchez-Manso et al., 2023) or greater sensitivity of standing HRV to transient influences such as excessive mental stress (Hynynen et al., 2011), incomplete exercise recovery (Mourot et al., 2004), viral infection (Hottenrott et al., 2021), or sleep deprivation (Bourdillon et al., 2021). An implication of this is the underestimation of parasympathetic responsiveness. Potential parasympathetic saturation (based on supine HR <55 bpm and elevated standing RMSSD) and blunted parasympathetic reactivity (based on HR >20 bpm above supine value) are exemplified in Fig. 4 and further illustrate the value of incorporating standing-based assessments for a more comprehensive evaluation of cardiovagal function.

The primary applied value of validating the H10 beyond laboratory testing lies in enabling scalable remote data collection of cardiovagal function. The simple chest-strap design requires no specialized expertise and can be self-applied by non-expert users, thereby supporting repeated home-based assessments. Remote cardiovagal testing has numerous applications, including monitoring training adaptation and recovery in athletes (Flatt and Howells, 2022), prolonged symptom surveillance following concussion (Nabasny et al., 2022) or viral illness (Corrado et al., 2024), evaluation of autonomic status in occupational contexts (LeBlanc et al., 2025), and longitudinal health tracking and optimization in general populations (Grosicki et al., 2022). For remote monitoring applications, chest-strap ECG assessment should be prioritized over optical wearable sensors such as wristbands and smartwatches, which remain susceptible to substantial error in HRV estimation (Flatt et al., 2025). Another important application is home-based HRV biofeedback which involves slow-paced breathing with real-time visual feedback to enhance respiratory HRV. This is used as a therapeutic intervention for the management of chronic diseases, with demonstrated positive effects on mental health and stress management, sleep quality, baroreflex sensitivity and blood pressure regulation, and cognitive performance (Fournié et al., 2021). Finally, validated wearable ECG devices like the H10 can enhance the feasibility of research protocols that would otherwise rely on more expensive or resource-intensive instrumentation (e.g., clinical-grade ambulatory ECG with expendable electrodes) that are provided to subjects for home-based self-assessment (Friedberg et al., 2022).

The present study has several limitations. First, the sample comprised exclusively healthy young adults. Although some participants exhibited DBT responses below age-adjusted clinical cutoffs, no abnormal 30:15 ratios were observed. Accordingly, evaluating the

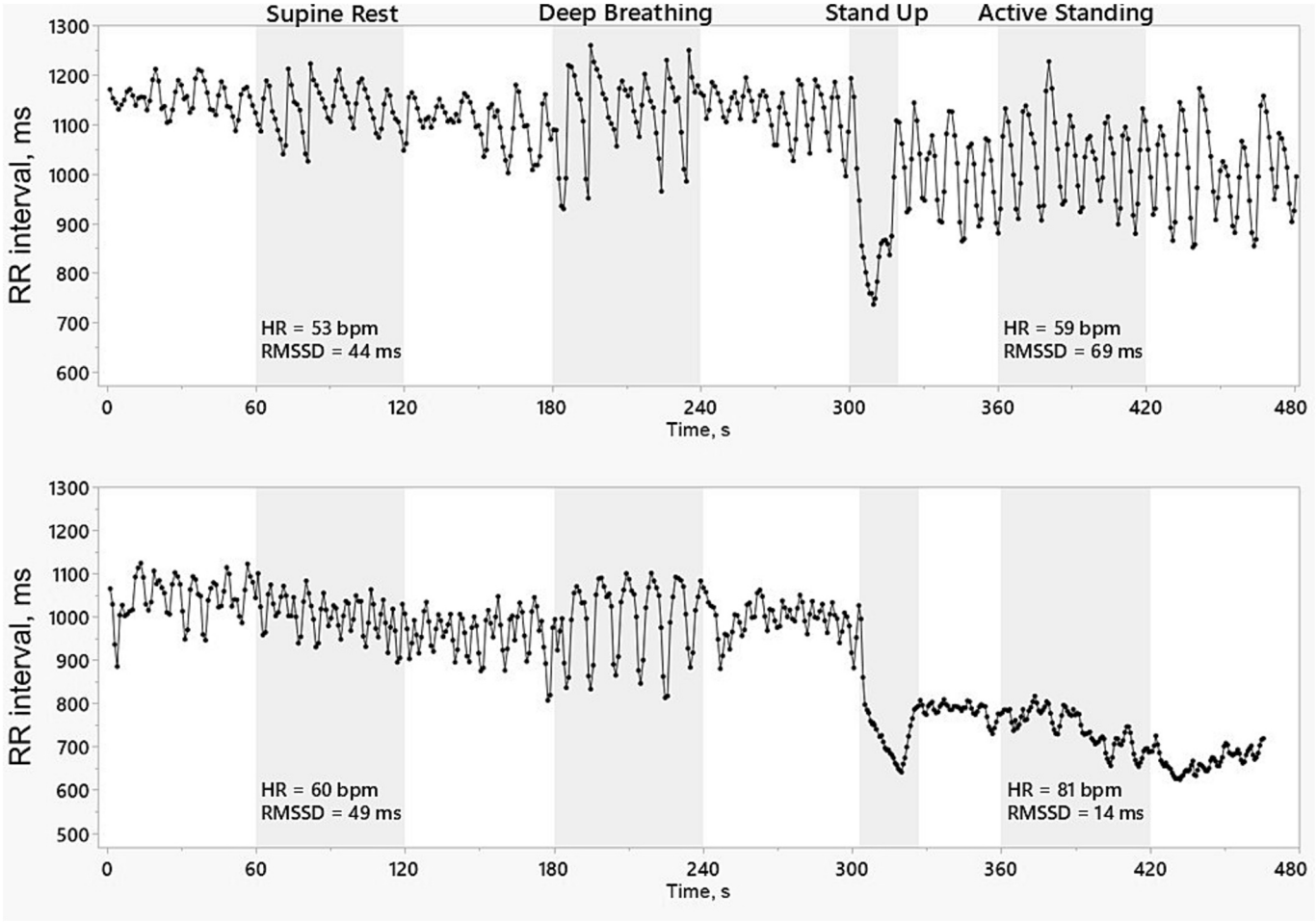


Fig. 4. Representative RR-interval tachograms illustrating two distinct patterns of cardiovagal function during the ~8-min assessment protocol in healthy young adults. Vertical shaded regions demarcate protocol phases. The top panel exemplifies potential parasympathetic saturation during supine rest based on a resting heart rate (HR) <53 bpm with relatively attenuated RMSSD (44 ms) compared to the elevated RMSSD (69 ms) during active standing. The bottom panel demonstrates blunted parasympathetic reactivity to orthostatic challenge based on persistent HR elevation (>20 bpm increase from 60 to 81 bpm) with substantial RMSSD reduction (49 to 14 ms) during active standing. Annotated metrics include mean heart rate (HR) and root-mean-square of successive differences (RMSSD) for key phases. These examples highlight abnormal or dissociated responses that may not be apparent from supine measures alone.

clinical utility of the H10 for detecting impaired cardiac autonomic reflexes in patient populations represents an important direction for future research. Second, although the H10 and Biopac ECG systems sample at 1000 Hz, subtle differences in R-wave detection algorithms, as well as minor beat-to-beat variability in atrioventricular conduction time, could theoretically influence RR-interval measurements. This may be more relevant in clinical populations with altered QRS morphology, atrioventricular conduction disturbances, or higher ectopic burden, reinforcing the need for future validation in clinical subjects. Third, the Valsalva maneuver was omitted because it requires additional equipment (e.g., a manometer for pressure feedback) and more complex identification of RR interval phases, making it less practical for field-based assessments (Wieling et al., 1982). Forth, HRV analysis was restricted to time-domain metrics (RRi, RMSSD, and SDNN). Frequency domain measures were not included, as they typically require longer (≥2-min) stable segments and controlled respiration (Penttilä et al., 2001). Moreover, although sympathetic activity contributes to HR dynamics, there is no accepted HRV metric that selectively quantifies sympathetic modulation, and the widespread interpretation of low-frequency power as an index of sympathetic activity has been largely discredited (Billman, 2013). Fifth, the H10 does not directly measure rate or depth of breathing. However, respiration metrics are not always measured during the DBT in clinical settings (Engström et al., 2022). Sixth, analyses related to the secondary aim may have been limited by sample size and the lack of control for menstrual cycle phase and hormonal contraceptive use among female participants. Seventh, the proposed continuous measurement protocol that combined supine, standing, and reflex measurements has not yet undergone formal reliability testing. Finally, the present agreement findings are specific to the H10. Given potential variability in hardware design, signal processing, and data handling across devices, future research is needed to independently validate other commercially available chest-strap ECG systems for HRV and cardiac autonomic reflexes.

5. Conclusion

The Polar H10 chest-strap provided measurements that are effectively interchangeable with laboratory-grade ECG for time-domain HRV and standard cardiac autonomic reflex tests in healthy young adults. Relative agreement was near-perfect across all metrics, with negligible bias, narrow 95% limits of agreement, and MAPE consistently <1%. The H10's ease of use, low cost, and lack of disposable electrodes make it well-suited for remote monitoring and field-based testing, while its high measurement accuracy supports its use in laboratory or clinical settings when traditional ECG is impractical or unavailable. Furthermore, the current protocol involving four distinct autonomic assessments (supine HRV, DBT, orthostatic reflex test, and standing HRV) was completed in 8 min, undercutting the typical 10-min duration often used for short-

term HRV. This time-efficient, multi-assessment approach is particularly relevant given that supine RMSSD explained only a portion of the variance (ranging from <1% to approximately 53%) in other indicators of cardiac parasympathetic function, highlighting limitations of supine HRV as a standalone index. Collectively, these results support the Polar H10 as a valid tool for cardiac autonomic assessment while emphasizing the added value of a multi-assessment protocol for a more comprehensive evaluation of cardiovagal function.

CRediT authorship contribution statement

Ann Claire E. Blalock: Writing – original draft, Investigation, Data curation. **Bryan L. Riemann:** Writing – review & editing. **Andrew A. Flatt:** Writing – original draft, Supervision, Formal analysis, Conceptualization.

Declaration of Generative AI and AI-assisted technologies in the writing process

We used Microsoft Copilot for refining sentences and formatting references. After using this tool, we reviewed and edited the content as needed and take full responsibility for the content of the published article.

Declaration of competing interest

The authors declare no conflicts of interest and no specific funding for this work.

Acknowledgements

The authors thank volunteers for participating in this investigation.

Data availability

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

References

Agelink, M.W., Malessa, R., Baumann, B., Majewski, T., Akila, F., Zeit, T., Ziegler, D., 2001. Standardized tests of heart rate variability: normal ranges obtained from 309 healthy humans, and effects of age, gender, and heart rate. Clin. Auton. Res. 11, 99–108.

Billman, G.E., 2013. The LF/HF ratio does not accurately measure cardiac sympatho-vagal balance. Front. Physiol. 4, 26.

Bland, J.M., Altman, D.G., 1999. Measuring agreement in method comparison studies. Stat. Methods Med. Res. 8, 135–160.

Bourdillon, N., Jeanneret, F., Nilchian, M., Albertoni, P., Ha, P., Millet, G.P., 2021. Sleep deprivation deteriorates heart rate variability and photoplethysmography. Front. Neurosci. 15, 642548.

Buchheit, M., 2014. Monitoring training status with HR measures: do all roads lead to Rome? Front. Physiol. 5, 73.

Chou, Y.-T., Sun, Z.-J., Shao, S.-C., Yang, Y.-C., Lu, F.-H., Chang, C.-J., Liao, T.-C., Li, C.-Y., Chen, T.H.-H., Wu, J.-S., 2023. Autonomic modulation and the risk of dementia in a middle-aged cohort: a 17-year follow-up study. Biom. J. 46, 100576.

Corrado, J., Iftekhar, N., Halpin, S., Li, M., Tarrant, R., Grimaldi, J., Simms, A., O'Connor, R.J., Casson, A., Sivan, M., 2024. HEART rate variability biofeedback for LOng COVID dysautonomia (HEARTLOC): results of a feasibility study. Adv. Rehabil. Sci. Pract. 13, 27536351241227261.

Engström, G., Hamrefors, V., Fedorowski, A., Persson, A., Johansson, M.E., Ostenfeld, E., Goncalves, I., Markstad, H., Johnson, L.S., Persson, M., 2022. Cardiovagal function measured by the deep breathing test: relationships with coronary atherosclerosis. J. Am. Heart Assoc. 11, e024053.

Esco, M.R., Williford, H.N., Flatt, A.A., Freeborn, T.J., Nakamura, F.Y., 2018. Ultra-shortened time-domain HRV parameters at rest and following exercise in athletes. Eur. J. Appl. Physiol. 118, 175–184.

Ewing, D., Clarke, B., 1982. Diagnosis and management of diabetic autonomic neuropathy. Br. Med. J. (Clin. Res. Ed.) 285, 916.

Ewing, D., Borsey, D., Bellavere, F., Clarke, B., 1981. Cardiac autonomic neuropathy in diabetes. Diabetologia 21, 18–24.

Ewing, D.J., Martyn, C.N., Young, R.J., Clarke, B.F., 1985. The value of cardiovascular autonomic function tests. Diabetes Care 8, 491–498.

Flatt, A.A., Esco, M.R., 2016. Heart rate variability stabilization in athletes. Clin. Physiol. Funct. Imaging 36, 331–336.

Flatt, A.A., Howells, D., 2022. Effects of long-haul travel and the Olympic games on heart-rate variability. Int. J. Sports Physiol. Perform. 17, 951–960.

Flatt, A.A., Blalock, A.C.E., Wade, A.N., Riemann, B.L., 2025. Biostrap Kairos wristband versus electrocardiography for resting heart rate variability assessment. Sensors 25, 3165.

Fournié, C., Chouchou, F., Dalleau, G., Caderby, T., Cabrera, Q., Verkindt, C., 2021. Heart rate variability biofeedback in chronic disease management. Complement. Ther. Med. 60, 102750.

Franca da Silva, A.K., da Costa, Penachini, de Rezende Barbosa, M., Marques Vanderlei, F., Destro Christofaro, D.G., Marques Vanderlei, L.C., 2016. Application of heart rate variability in diabetes mellitus. Ann. Noninvasive Electrocardiol. 21, 223–235.

Freeman, R., 2006. Assessment of cardiovascular autonomic function. Clin. Neurophysiol. 117, 716–730.

Friedberg, F., Adamowicz, J.L., Bruckenthal, P., Milazzo, M., Ramjan, S., Quintana, D., 2022. Nonimprovement in chronic fatigue syndrome: relation to activity patterns, uplifts and hassles, and autonomic dysfunction. Biopsychosoc. Sci. Med. 84, 669–678.

Gilgen-Ammann, R., Schweizer, T., Wyss, T., 2019. RR interval signal quality of a heart rate monitor. Eur. J. Appl. Physiol. 119, 1525–1532.

Goldberger, J.J., Challapalli, S., Tung, R., Parker, M.A., Kadish, A.H., 2001. Relationship of heart rate variability to parasympathetic effect. Circulation 103, 1977–1983.

Gronwald, T., Schaffarczyk, M., Hoos, O., 2024. Orthostatic testing for heart rate monitoring. Eur. J. Appl. Physiol. 124, 3495–3510.

Grosicki, G.J., Culver, M.N., McMillan, N.K., Cross, B.L., Montoye, A.H., Riemann, B.L., Flatt, A.A., 2022. Self-recorded heart rate variability profiles. Clin. Auton. Res. 32, 507–518.

He, X., Zhao, M., Bi, X., Sun, L., Yu, X., Zhao, M., Zang, W., 2015. Novel strategies of modulation of vagal activity. Br. J. Pharmacol. 172, 5489–5500.

Holmes, C.J., Fedewa, M.V., Dobbs, W.C., Liu, Y., Flatt, A.A., Nakamura, F.Y., Esco, M.R., 2020. Effects of body position on ultra-short-term HRV. J. High Technol. Manag. Res. 31, 100375.

Hottenrott, L., Gronwald, T., Hottenrott, K., Wiewelhove, T., Ferrauti, A., 2021. Utilizing heart rate variability after viral infection. Front. Sports Act. Living 3, 612782.

Hynynen, E., Konttinen, N., Kinnunen, U., Kyröläinen, H., Rusko, H., 2011. The incidence of stress symptoms and heart rate variability during sleep and orthostatic test. Eur. J. Appl. Physiol. 111, 733–741.

Jarczok, M.N., Weimer, K., Braun, C., Williams, D.P., Thayer, J.F., Guendel, H.O., Balint, E.M., 2022. Heart rate variability in the prediction of mortality. Neurosci. Biobehav. Rev. 143, 104907.

Juraschek, S.P., Appel, L.J., Miller III, E.R., Mukamal, K.J., Lipsitz, L.A., 2018. Hypertension treatment effects on orthostatic hypotension. Hypertension 72, 986–993.

Kang, J., Chang, Y., Kim, Y., Shin, H., Ryu, S., 2022. Ten-second heart rate variability, its changes over time, and the development of hypertension. Hypertension 79, 1308–1318.

Katz, A., Liberty, I.F., Porath, A., Ovsyshcher, I., Prystowsky, E.N., 1999. A simple bedside 1-minute HRV test. Am. Heart J. 138, 32–38.

Kiviniemi, A.M., Hautala, A.J., Seppanen, T., Makikallio, T.H., Huikuri, H.V., Tulppo, M. P., 2004. Saturation of high-frequency oscillations. Am. J. Physiol. Heart Circ. Physiol. 287, H1921–H1927.

Krummenacher, M., Tarvainen, M., Montet, E., Turner, M.C., Canu, I.G., 2023. Which device is most suitable for measuring heart rate variability in the field? A comparative evaluation of two leading options. J. Occup. Environ. Med. 10–1097.

Kwon, P.M., Lawrence, S., Mueller, B.R., Thayer, J.F., Benn, E.K., Robinson-Papp, J., 2022. Interpreting resting heart rate variability in complex populations: the role of autonomic reflexes and comorbidities. Clin. Auton. Res. 32, 175–184.

Lahiri, M.K., Kannankeril, P.J., Goldberger, J.J., 2008. Assessment of autonomic function in cardiovascular disease: physiological basis and prognostic implications. J. Am. Coll. Cardiol. 51, 1725–1733.

Lawrence, I., Lin, K., 1989. A concordance correlation coefficient to evaluate reproducibility. Biometrics 45, 255–268.

LeBlanc, V.R., Mastoras, G., Hicks, C., MacGregor, P., O'Rielly, C., Petrosoniak, A., Tavares, W., 2025. The stressed heart: validity evidence supporting mobile heart rate variability applications to detect psychological stress in healthcare learners. Med. Educ. 59, 729–738.

van Lien, R., Goedhart, A., Kupper, N., Boomsma, D., Willemsen, G., de Geus, E.J., 2011. Underestimation of cardiac vagal control. Int. J. Psychophysiol. 81, 169–176.

Lu, M.-J., Zhong, W.-H., Liu, Y.-X., Miao, H.-Z., Li, Y.-C., Ji, M.-H., 2016. Sample size for assessing agreement. Int. J. Biostat. 12, 20150039.

Ludbrook, J., 2010. Confidence in Altman–Bland plots. Clin. Exp. Pharmacol. Physiol. 37, 143–149.

Maser, R.E., Mitchell, B.D., Vinik, A.I., Freeman, R., 2003. Cardiovascular autonomic neuropathy and mortality. Diabetes Care 26, 1895–1901.

McCraty, R., Atkinson, M., Dispenza, J., 2018. One-minute deep breathing assessment. Heart Mind 2, 70–77.

Mourot, L., Bouhaddi, M., Tordi, N., Rouillon, J.-D., Regnard, J., 2004. Effects of exercise on HRV. Eur. J. Appl. Physiol. 92, 508–517.

Moya-Ramon, M., Mateo-March, M., Peña-González, I., Zabala, M., Javaloyes, A., 2022. Validity and reliability of different smartphone applications to measure HRV during short and ultra-short measurements in elite athletes. Comput. Methods Prog. Biomed. 217, 106696.

Munoz, M.L., Van Roon, A., Riese, H., Thio, C., Oostenbroek, E., Westrik, I., de Geus, E.J., Gansevoort, R., Lefrandt, J., Nolte, I.M., 2015. Validity of ultra-short HRV recordings. PLoS One 10, e0138921.
Nabasny, A., Rabinowitz, A., Wright, B., Wang, J., Preminger, S., Terhorst, L., Juengst, S. B., 2022. Neurobehavioral symptoms and heart rate variability: feasibility of remote collection using mobile health technology. J. Head Trauma Rehabil. 37, 178–188.
Natarajan, A., Pantelopoulos, A., Emir-Farinas, H., Natarajan, P., 2020. Heart rate variability with photoplethysmography in 8 million individuals: a cross-sectional study. Lancet Digit. Health 2, e650–e657.
Novak, P., 2011. Quantitative autonomic testing. J. Vis. Exp. 53, 2502.
Oksanen, P., Tulppo, M.P., Auvinen, J., Niemelä, M., Jämsä, T., Puukka, K., Huikuri, H. V., Korpelainen, R., Venojärvi, M., Kiviniemi, A.M., 2019. Associations of fitness and physical activity with orthostatic responses of heart rate and blood pressure at midlife. Scand. J. Med. Sci. Sports 29, 874–885.
Penttilä, J., Helminen, A., Jartti, T., Kuusela, T., Huikuri, H.V., Tulppo, M.P., Coffeng, R., Scheinin, H., 2001. Time-domain analysis of cardiac vagal outflow. Clin. Physiol. 21, 365–376.
Politi, K., Kaminer, K., Nussinovitch, U., 2020. Reliability of ultrashort electrocardiographic indices in hypertension: the quest for a clinically applicable prognostic marker. J. Investig. Med. 68 (2), 364–370.
Sánchez-Manso, J.C., Gujarathi, R., Varacallo, M.A., 2023. Autonomic Dysfunction. StatPearls [Internet]. StatPearls Publishing, Treasure Island (FL).
Schaffarczyk, M., Rogers, B., Reer, R., Gronwald, T., 2022. Validity of the Polar H10 sensor for heart rate variability analysis during resting state and incremental exercise in recreational men and women. Sensors 22, 6536.
Shaffer, F., Ginsberg, J.P., 2017. An overview of heart rate variability metrics and norms. Front. Public Health 5, 258.
Stone, J.D., Ulman, H.K., Tran, K., Thompson, A.G., Halter, M.D., Ramadan, J.H., Stephenson, M., Finomore Jr., V.S., Galster, S.M., Rezai, A.R., 2021. Accuracy of commercial technologies. Front. Sports Act. Living 3, 585870.
Tarvainen, M.P., Ranta-Aho, P.O., Karjalainen, P.A., 2002. Advanced detrending method for HRV. IEEE Trans. Biomed. Eng. 49, 172–175.
Thayer, J.F., Lane, R.D., 2007. Role of vagal function in cardiovascular disease. Biol. Psychol. 74, 224–242.
Uusitalo, A.L.T., Uusitalo, A.J., Rusko, H.K., 2000. Heart rate and blood pressure variability during heavy training and overtraining in the female athlete. Int. J. Sports Med. 21, 45–53.
Vondrasek, J.D., Riemann, B.L., Grosicki, G.J., Flatt, A.A., 2023. Validity and efficacy of the Elite HRV smartphone application during slow-paced breathing. Sensors 23, 9496.
Wieling, W., Van Brederode, J., De Rijk, L., Borst, C., Dunning, A., 1982. Reflex control of heart rate. Diabetologia 22, 163–166.
Zhou, X., Ma, Z., Zhang, L., Zhou, S., Wang, J., Wang, B., Fu, W., 2016. Heart rate variability in the prediction of survival. J. Psychosom. Res. 89, 20–25.