Association between individual differences in interoception and cardiac coherence during heart rate variability biofeedback

Ryuji Saito[1], Kazuki Yoshida[2], Daisuke Sawamura[2]

1. Graduate School of Health Sciences, Hokkaido University, Sapporo, Japan
2. Department of Rehabilitation Science, Faculty of Health Sciences, Hokkaido University, Sapporo, Japan

Corresponding Author

Kazuki Yoshida, Ph.D.

Address: N12, W5, Kita-ku, Sapporo, Hokkaido, 060-0812, Japan

Phone/Fax number: +81-11-706-3414

Email: ot-k-yoshida@huhp.hokudai.ac.jp

ORCID ID

Ryuji Saito: https://orcid.org/0000-0003-1925-7044

Kazuki Yoshida: https://orcid.org/0000-0002-1701-6274

Daisuke Sawamura: https://orcid.org/0000-0003-3180-3474

Highlights

- We tested the relationship between interoception and the effects of HRVBF.
- Interoception parameters and vmHRV parameters were related to HRVBF effects.
- Our study may contribute to predicting HRVBF effects and participant selection.

Abstract

Heart rate variability biofeedback (HRVBF) is the training to increase vagally-mediated heart rate variability (vmHRV), accompanied by slow-paced breathing and feedback of heart rhythm. It has been reported to be effective for emotion and cognition. In recent years, increased attention has turned toward participant characteristics as factors affecting HRVBF training effects. Focusing on neural basis commonalities between the mechanisms of HRVBF training effects and processing interoception, this study comprehensively measured interoception and examined the relationship between interoception and cardiac coherence reflecting HRVBF effects. Fifty-four healthy young participants were recruited, and subjective interoception was measured using the Japanese version of Multidimensional Assessment of Interoceptive Awareness (MAIA-J) and the Japanese version of the Body Perception Questionnaire-Body Awareness Very Short Form (BPQ-BAVSF-J), objective interoception using heartbeat counting task (HCT), heart rate variability (HRV), visual exteroception, and the coherence score achieved by HRVBF. We conducted a multiple regression analysis with interoception, HRV, and visual exteroception parameters as explanatory variables and the coherence score as the objective variable. Some subjective interoception and HRV parameters were found to be associated with the coherence score. Our results were consistent with previous studies, showing that higher vmHRV was related to high cardiac coherence. Interoception effects on cardiac coherence may be limited because of the low adjusted coefficient of determination and less selected explanatory variables in the multiple regression analysis. Our results may contribute toward predicting HRVBF training effects and the screening of those who are likely to benefit from the training from the perspective of interoception and vmHRV.

Keywords

interoception, heart rate variability, biofeedback, cardiac coherence, vagus nerve

1. Introduction

Heart rate variability biofeedback (HRVBF) is a breathing training for increasing vagally-mediated heart rate variability (vmHRV), which is a combination of slow-paced breathing and feedback on heart rate variability (HRV) waveform [1]. Recent studies, including a meta-analysis and a systematic review [2,3], have shown that HRVBF is an effective psychophysiological intervention that improves physical, emotional, and cognitive functions. As to the mechanism of the HRVBF training effects, many reviews [4–6] integrate anatomical, physiological, and behavioral studies and postulate that the nucleus tractus solitarii projects to brain regions such as medial prefrontal cortex, insula, anterior cingulate cortex, and amygdala via vagus nerve, and that the action on these brain regions may be involved in the effects of HRVBF. Recent meta-analyses have reported the therapeutic effects of HRVBF on self-reported anxiety and stress [7], depressive symptoms [8], and post-traumatic stress disorder (PTSD) [9]. Conversely, HRVBF effects are inconsistent, and scattered studies are showing no effectiveness of behaviorally assessed anxiety [10], cognitive function [11,12], and brain activity measured by electroencephalography (EEG) [10,13]. Previous studies have pointed to a lack of active-controlled studies [14] and consistent training protocols [15], which may cause an inappropriate evaluation of HRVBF training effects. Furthermore, as an essential factor, recent studies [10,16,17] have focused on participant characteristics, and there is a possibility that high vmHRV before HRVBF training may affect the training effects. The HRVBF effects can be affected by other various factors, yet the findings regarding factors affecting the training effects have been limited to vmHRV and are lacking. Therefore, in order to pursue greater effectiveness for HRVBF training, it is important to investigate additional factors that may be affecting the training effects from the perspective of participant characteristics.

Previous behavioral and physiological studies [18–20] have shown that vmHRV at baseline and changes in vmHRV were positively correlated with interoception measured by the behavioral tasks. Also, a previous *in vivo* study has shown that mice that had tachycardia due to manipulation of their heart rate activated the posterior insular cortex, which is a hub for processing interoception [21]. Thus, interoception is one of the potential factors affecting HRVBF training effects from the relationship between vmHRV and interoception. Interoception is the sensing of internal bodily sensations and refers to the processing of signals from inside the internal body; it includes heartbeat, breathing, visceral sensations, hunger, and so on, contributing to adaptative behaviors and emotional control [22,23]. Interoception can be divided into three aspects: interoceptive sensibility (IS), interoceptive accuracy (IAc), and interoceptive awareness (IAw) [24]. IS, IAc, and IAw are measured by subjective parameters such as questionnaires, objective parameters using behavioral tasks, and the confidence rating for the accuracy of the tasks, respectively. Regarding the neural basis for processing interoception, the signals are transmitted in subcortical regions such as the nucleus tractus solitarii and hypothalamus and integrated and interpreted in cortical regions such as the insula and anterior cingulate cortex [25]. Thus, the neural bases of processing of interoception and the mechanism related to the HRVBF training effect may be common. Our previous study [10] has focused on the commonality of the above neural basis and referred to the possibility that interoception may be one of the factors affecting HRVBF training. Furthermore, a previous study [26] has reported that IAc increased after slow-paced breathing, similar to the breathing pace in HRVBF, and a favorable outcome of the HRVBF training may be reflected by an increase in interoception. Moreover, previous studies have reported that the amplitude of the heart-rate-evoked potential (HEP), an electroencephalographic component reflecting the transmission of afferent signals from the heart to the brain, increased by HRVBF training [27,28]. High interoception may improve the HRVBF training effects due to the enhanced afferent pathways from subcortical to higher brain regions via the vagus nerve. Moreover, focusing on the fact that breathing is one of interoception, HRVBF may also be related to interoception through breathing [26–28]. Integrating these findings, participants with highly interoceptive individuals may be more likely to be proficient in HRVBF training and benefit from the training effects. However, previous studies have not examined the direct relationship between interoception and HRVBF training effects. By clarifying their relationship, HRVBF training effects can be better predicted along with improved screening of those who are more likely to benefit from the training effects. This would be possible from the perspectives of vmHRV and interoception.

The effectiveness of HRVBF training is related to high cardiac coherence [10,29,30]. Cardiac coherence is reflected in a sine wave-like pattern in the HRV waveform and can be quantified as scores (see "HRVBF" in the Methods section for details) [31–33]. This study aimed to comprehensively measure interoception using questionnaires and tasks and examine the association between interoception and cardiac coherence reflecting the HRVBF training effects using multiple regression analysis. We hypothesized that each of the high IS, IAc, and IAw would be associated with high cardiac coherence.

2. Methods

2.1 Participants

The required sample size was calculated using G*power 3.1 [34]. We determined a correlation coefficient (r = 0.379) based on previous studies [18,19] and calculated the sample size with significance probability (α = 0.05) and statistical power (1-β = 0.80), resulting in the required sample size of 49 participants. Considering a 10% dropout rate and outliers, we estimated the final sample size to be 54 participants.

Healthy undergraduate and graduate students were recruited. Considering the effects of age on HRV [35] and interoception [36], we recruited participants aged 18 to 30 years. The exclusion criteria were as follows: 1) medical history of psychiatric disorder or brain, heart, or respiratory diseases; 2) history of dizziness and consciousness disorder due to controlled respiratory rates; 3) consumption of drugs affecting the autonomic nervous system; and 4) neurological or visual disability that interferes with behavioral tasks. The study was approved by the Ethics Committee of the Faculty of Health Sciences, Hokkaido University (approval number: 23-70). Written informed consent was obtained from all participants.

2.2 Interoception measurement and analysis

IS was measured using the Japanese version of the Multidimensional Assessment of Interoceptive Awareness (MAIA-J) [37] and the Japanese version of the Body Perception Questionnaire-Body Awareness Very Short Form (BPQ-BAVSF-J) [38]. The MAIA-J comprises 25 items and six subscales (“Noticing”, “Not-Distracting”, “Attention Regulation”, “Emotional Awareness”, “Body Listening”, and “Trusting”) and BPQ-BAVSF-J is a one-factor scale comprising of 12 items.

IAc was measured using the heartbeat counting task (HCT) [39]. The timeline of one trial in HCT is shown in **Figure 1A**. Participants counted their own heartbeats without speaking out over a series of time intervals (20 s, 25 s, 30 s, 35 s, 40 s, and 45 s, twice and each at random) between the audibly presented start cue and the end cue. After that, they rated their confidence in the accuracy of counted heartbeats from 0 (low confidence) to 10 (high confidence) on a visual analog scale (VAS). Auditory cues and VAS in the HCT were created using PsychoPy [40]. Referring to previous studies [41,42], participants were instructed to perform the task in an upright posture, not to move the body, not to touch the wrists, neck, or other parts of the body, to perform the task with open eyes, to count heartbeats with attention on the body, and not to estimate based on the time perception or knowledge of heart rate. During the HCT, participants were fitted with the pulse wave sensor attached to the emWave Pro (HeartMath LLC, Boulder Creek, CA, USA) to measure heartbeats. Based on the previous study [43], the IAc score was calculated using the following **Formula 1**. To examine the influence of time perception on heartbeat counting [41,42], participants conducted time estimation task (TET). TET was performed similarly to HCT, but with seconds counting instead of heartbeat counting. The TET score was calculated using the same analysis as HCT.

$$\text{IAc score} = \frac{1}{12}\sum\left(1-\frac{|\text{Actual heartbeats - Counted heartbeats}|}{|\text{Actual heartbeats + Counted heartbeats}|/2}\right) - (1)$$

IAw was measured using the correlation coefficient between the HCT score and the VAS rating for each time interval. Based on the previous study [24], the IAw score was calculated by averaging correlation coefficients for each time interval per participant.

Participants with any interoceptive parameters exceeding the mean ± 3 standard deviations within all participants were excluded from the analysis.

2.3 Exteroception measurement and analysis

Referring to previous studies [44–46], we measured vision-based exteroception using a continuous performance test (CPT). The timeline of one trial in CPT is shown in **Figure 1B**. A, B, C, D, E, F, G, H, and I were defined as target stimuli and X as a non-target stimulus. Participants were instructed to press the space key when target stimuli were presented and not to press the space key when a non-target stimulus was presented. In the CPT, fixation was randomly presented for 1000, 1500, and 2000 ms, followed by stimuli for 500 ms. Reaction time (RT) was calculated from the beginning of the stimuli presentation to 1000 ms, and the interstimulus interval (ISI) was 1500, 2000, or 2500 ms. Incidence of stimuli was 90% for target stimuli and 10% for a non-target stimulus. In total, 150 trials were included, comprised of 135 trials of target stimuli and 15 trials of non-target stimuli.

A key press to target stimuli was defined as a correct response, a key press to a non-target stimulus as a commission error, and no response to target stimuli as an omission error. The mean RT was calculated for correct response and the commission and omission error rate, respectively.

2.4 HRV recording and analysis

Pulse wave data was measured using an infrared pulse plethysmograph ear sensor supplied with emWave Pro (HeartMath LLC, Boulder Creek, CA, USA). Pulse wave data were recorded for 5 min in the baseline measurement and 15 min during HRVBF. In the 15 min data during HRVBF, to make the data length consistent at 5 min, the data from the 5 min after the start of measurement and the 5 min before the end of measurement were excluded. The RR interval data were extracted at a sampling frequency of 370 Hz and analyzed using Kubios HRV Premium version 3.4.2 (Kubios Oy, Kuopio, Finland). In the pre-processing, the RR interval data were detrended by the smoothness priors method (λ = 500) and artifact-corrected by an automatic correction algorithm. The RR interval data with a percentage of corrected beats exceeding 5% were defined as invalid, and participants with invalid data were excluded from the analysis. Subsequently, the RR interval data were re-sampled at 4 Hz, and Fast Fourier Transform (FFT) was applied, with a window width of 300 s and a window overlap of 50%. Thus, the root mean square of successive differences (RMSSD) (ms) was calculated as a time-domain parameter and natural logarithmic transformation of low frequency (LF; 0.04-0.15Hz), lnLF (ms^2) as a frequency-domain parameter. The RMSSD reflects cardiac vagal activity [47], and the LF reflects baroreflex activity by HRVBF [1,48].

2.5 HRVBF

The 15 min HRVBF was performed according to a previously published protocol [1]. First, the resonance frequency, which is the respiratory cycle that maximizes LF, was determined from the range of 6.5, 6.0, 5.5, 5.0, and 4.5 breaths per minute. Subsequently, participants performed inhalations and exhalations based on resonance frequency with the guidance of a breathing pacer. While receiving visual feedback on the waveform, they adjusted the HRV waveform to achieve a sine wave-like pattern. Participants were instructed to perform pursed-lip breathing, abdominal breathing, inhalation through the nose, and exhalation through the mouth, with the aim of achieving higher coherence scores. The coherence score is calculated as “Peak power/(Total power - Peak power)” [33]. Peak power is determined by identifying the highest peak in the 0.04–0.26 Hz range and calculating the integral in a window of 0.030 Hz width, centered on the highest peak in that region. Total power is calculated for the 0.0033–0.4 Hz range. In this study, we adopted the averaged coherence score during HRVBF for the analysis.

2.6 *Procedure*

The measurements were conducted according to the procedure shown in **Figure 1C**. Referring to a previous study on the effects of time of day on autonomic nervous activity [49] and a previous study on HCT [18], the measurements were conducted between 9:00 and 18:00 hours. Participants were asked to get sufficient sleep the day before the measurement, to participate in the measurement at least two hours after eating, not to consume alcohol or caffeine on the day of the measurements, and not to engage in strenuous exercise. In the measurements, we conducted a demographic information questionnaire regarding gender, age, height (cm), and weight (kg) and calculated Body Mass Index (BMI). It has been reported that higher BMI is associated with lower interoceptive sensation [50].

2.7 *Statistical analysis*

To confirm the change in HRV by HRVBF, we applied a paired *t*-test for HRV parameters (i.e., RMSSD, lnLF) at baseline and during HRVBF.

To confirm the influence of exteroception and BMI on interoception, a Pearson's correlation analysis was conducted among CPT parameters (i.e., mean RT for correct response, commission error rate, and omission error rate), BMI, IS (i.e., each MAIA-J subscale score, BPQ-BAVSF-J score), IAc, and IAw. Additionally, to confirm the influence of time perception on interoception, a Pearson's correlation analysis was conducted between TET score and IAc.

The extent to which interoception, exteroception, and HRV are associated with the coherence score was examined using the following steps. First, we conducted a multiple regression analysis using the forced entry method, which included the IS, IAc, and IAw parameters, RMSSD, and lnLF at baseline, along with CPT parameters as explanatory variables and the coherence score as the objective variable. Second, to construct the appropriate model and avoid overfitting in the regression model [51], a multiple regression analysis was conducted using the backward stepwise method. All statistical analyses were performed using SPSS version 26.0 (IBM Corp., Armonk, NY, USA). The statistical significance level was set at $p < 0.05$.

3. Results

Fifty-four participants were recruited in this study, and five participants were excluded: invalid HRV data (n = 3), MAIA-J "Awareness" score exceeding the mean ± 3 standard deviations (n = 1), and IAc exceeding the mean ± 3 standard deviations (n = 1). Finally, we included 49 participants (mean age = 21.8 ± 2.0 years, 25 females) in the analysis.

3.1 Participant characteristic

Demographic data, interoceptive parameters, and the coherence score are shown in **Table 1**.

3.2 HRV changes from baseline to during HRVBF

The RMSSD (47.10 ± 19.72 at baseline, 57.80 ± 30.00 during HRVBF; $t(48) = -3.27$, $p = 0.002$) and lnLF (6.33 ± 0.92 at baseline, 8.72 ± 0.80 during HRVBF; $t(48) = -16.81$, $p = 0.000$) were significantly increased during HRVBF compared to baseline.

3.3 *Factors affecting interoception*

The TET score showed a significant positive correlation with IAc ($r = 0.318$, $p = 0.026$). This result indicated that the more accurate the time perception, the higher the IAc. The CPT parameters and BMI showed no significant correlation with any interoceptive parameters ($p > 0.05$). These results indicated that exteroception and BMI did not affect interoception.

3.4 *Relationship between interoception, HRV, and coherence scores*

Table 2 shows the results of the multiple regression analysis using the forced entry method. The standardized partial regression coefficient (β) was significantly positive for MAIA-J "Noticing" ($\beta = -0.616$, $p = 0.007$). The regression equation was not significant ($p = 0.228$). The adjusted coefficient of determination (R^2) was 0.094. The variance inflation factor (VIF) was less than five for all explanatory variables, which confirmed there were no explanatory variables with multicollinearity. The Durbin-Watson ratio was 1.727, which confirmed the normality of the residuals.

Table 3 shows the results of multiple regression analysis using the backward stepwise method. The finally selected explanatory variables were MAIA-J "Noticing," MAIA-J "Emotional Awareness," RMSSD and lnLF at baseline, and the omission error rate in CPT. The regression equation was significant ($p = 0.021$), and the R^2 coefficient was 0.172. The β coefficient was significantly positive for MAIA-J "Emotional Awareness" ($\beta = 0.497$, $p = 0.007$) and RMSSD ($\beta = 0.349$, $p = 0.030$) and significantly negative for MAIA-J "Noticing" ($\beta = -0.047$, $p = 0.014$) and lnLF ($\beta = -0.339$, $p = 0.034$). The VIF was less than five for all explanatory variables, which confirmed that there were no explanatory variables with multicollinearity. The Durbin-Watson ratio was 1.942, which confirmed the normality of the residuals.

3.5 *Effects of changes in LF on coherence scores*

To examine if an increase in lnLF before and after HRVBF was related to high coherence score, we calculated the changes in lnLF from baseline to during HRVBF, that is, lnLF(Δ) and applied a Pearson's correlation analysis among lnLF at baseline, lnLF(Δ) and the coherence score as an additional analysis. The results showed a significant negative correlation (r = -0.650, p = 0.000) between lnLF at baseline and lnLF (Δ) and a significant positive correlation (r = 0.475, p = 0.001) between lnLF(Δ) and the coherence score. These results indicated that the lower the lnLF at baseline, the larger the lnLF (Δ); furthermore, the larger the lnLF (Δ) then the higher the coherence score.

4. Discussion

Interoception was comprehensively measured using questionnaires and behavioral tasks, and whether interoception is associated with the coherence score in HRVBF was examined using a multiple regression analysis. We tested our hypothesis that each of the high IS, IAc, and IAw parameters would be associated with a high coherence score. Our results showed that some of the subjective interoception and HRV parameters were associated with the coherence score. Moreover, we reproduced previous studies showing the relationship between vmHRV and HRVBF training effects. Although we assumed that various aspects of interoception would be associated with the coherence score, the association between interoception and the coherence score may be limited because the R^2 coefficient was low, and only some of the subjective interoception parameters were selected as explanatory variables in the multiple regression analysis.

Thus, we suggest the importance of participant characteristics on HRVBF training effects from the perspective of interoception and vmHRV.

Regarding the relationship between HRV and the coherence score, RMSSD at baseline predicted the coherence score in the positive direction, and lnLF at baseline predicted the score in the negative direction. Our result shows a positive relationship between RMSSD at baseline and the coherence score reproduced in recent previous studies reporting the contribution of vmHRV at baseline to the training proficiency and training effects [10,16,17]. Our result shows a negative relationship between lnLF at baseline and the coherence score, which may be due to an increase in lnLF during HRVBF. Additional analysis suggested that the low lnLF at baseline contributed to the increase in lnLF during HRVBF, which was related to the high coherence score. Regarding the contribution of lnLF to the coherence score, previous studies have suggested that high cardiac coherence is likely to be caused by high amplitude and peak in the LF power spectrum [52,53]. The LF is a complex autonomic nervous system indicator, including sympathetic and vagal activity, and primarily reflects baroreflex activity [1,48]. Thus, our results may be related to an increase in baroreflex activity associated with an increase in lnLF from the baseline by HRVBF.

For the relationship between interoception and the coherence score, MAIA-J "Emotional Awareness" predicted the coherence score in the positive direction, and MAIA-J "Noticing" predicted the score in the negative direction. The higher the MAIA-J "Emotional Awareness" score, the easier it is to perceive physical sensations related to positive emotion [54], and MAIA-J "Emotional Awareness" may be particularly related to positive emotion. Also, a previous study [55] has reported that a positive emotional state brought about high cardiac coherence. Therefore, those who have high MAIA-J

"Emotional Awareness" scores may tend to perceive interoception related to positive emotion and achieve higher coherence scores. MAIA-J "Noticing" is positively correlated with pain catastrophizing, assessed by the Pain Catastrophizing Scale (PCS) [37]. The stronger the pain catastrophizing, then the more negative emotional stimuli were prioritized for processing [56]. Thus, MAIA-J "Noticing" may be particularly related to negative emotions. In addition, a previous study [57] reported that low cardiac coherence was found in negative emotional states such as stress. Therefore, those who have high MAIA-J "Noticing" scores may tend to perceive interoception related to negative emotion and achieve lower coherence scores.

We suggest that some of the subjective interoception and vmHRV at baseline can predict HRVBF training effects. However, as mentioned above, since the R^2 coefficient was low and only some of the subjective interoception parameters were selected as explanatory variables in the multiple regression analysis, our results may not be robust. Therefore, there is a relationship between subjective interoception and HRVBF training effects, but it is not a very strong association. However, there is room for discussion as to whether only subjective interoception is a factor affecting the effects. Further research is needed to carefully examine the relationship between interoception and HRVBF training effects by measuring objective interoception using other methods besides HCT used in our study, such as heartbeat discrimination task (HDT) and HEP. Overall, our study emphasizes the importance of the impact of participant characteristics such as vmHRV and interoception on HRVBF training effects. Our results may be similar to a systematic review by Tinello et al. [3], which suggested that HRVBF training can be more effective in clinical populations and individuals with particular profiles (e.g., those exposed to stressful environments).

Regarding exteroception, the multiple regression analysis using the backward stepwise method revealed that the omission error rate in CPT was selected as an explanatory variable, and it predicted the coherence score in the negative direction. The omission error is an indicator of visual attention, and the more omission error there is, the less sensitive visual exteroception [46]. Considering the nature of HRVBF training, which involves continuously focusing attention on the HRV waveform, it may be possible that the more sensitive the visual exteroception is, then the easier it would be to achieve a high coherence score. However, as no significant coefficient was found in the omission error rate, the effect of exteroception on the coherence score might be more limited than that of interoception and vmHRV.

Our study has a few limitations. The first relates to IAc measured by the HCT. A significant positive correlation was found between the TET score and IAc, suggesting that time perception may affect IAc. Thus, we cannot deny the possibility that the detection power of interoception decreased and the relationship between the coherence score and IAc and its associated IAw was masked. However, referring to a previous study [41], the HCT was conducted by instructing the participants to count their heartbeats by focusing their attention on their bodies and reporting the actual heartbeats they could feel without estimating their heartbeats based on counting seconds. Therefore, it is thought that the effect of time perception on counting heartbeats was eliminated as much as possible. The second relates to participants. Previous studies have reported that interoception declines with age [36] and decreases in functional syndromes [58]. Further studies will be necessary to examine the generalizability to a broader population, such as older adults and patients with psychosomatic disease.

5. Conclusions

This study measured interoception from multiple perspectives and examined the association between interoception and coherence score achieved by HRVBF using multiple regression analysis. Our results showed that some subjective interoception measured by the MAIA-J and vmHRV at baseline were associated with the coherence score, but the association between interoception and the coherence score may be limited because of the low R^2 coefficient and less selected explanatory variables. We suggest that the higher the sensitivity to interoception related to positive emotion, the higher the coherence score; meanwhile, the higher the sensitivity to interoception related to negative emotion, the lower the coherence score. Our results may help predict HRVBF training effects and screen those who are more likely to benefit from the training effects, as determined from the perspectives of interoception and vmHRV.

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CRediT authorship contribution statement

Ryuji Saito: Conceptualization; Data curation; Formal analysis; Funding acquisition; Investigation; Methodology; Project administration; Visualization; Writing – original draft. **Kazuki Yoshida**: Conceptualization; Formal analysis; Methodology; Project administration; Resources; Visualization; Writing – review & editing. **Daisuke Sawamura**: Methodology; Supervision; Resources; Writing – review & editing.

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

The authors declare that they did not use generative AI technologies for the preparation of this paper.

Data availability

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

Conflict of interest disclosure

The authors declare that they have no conflict of interest.

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Figure

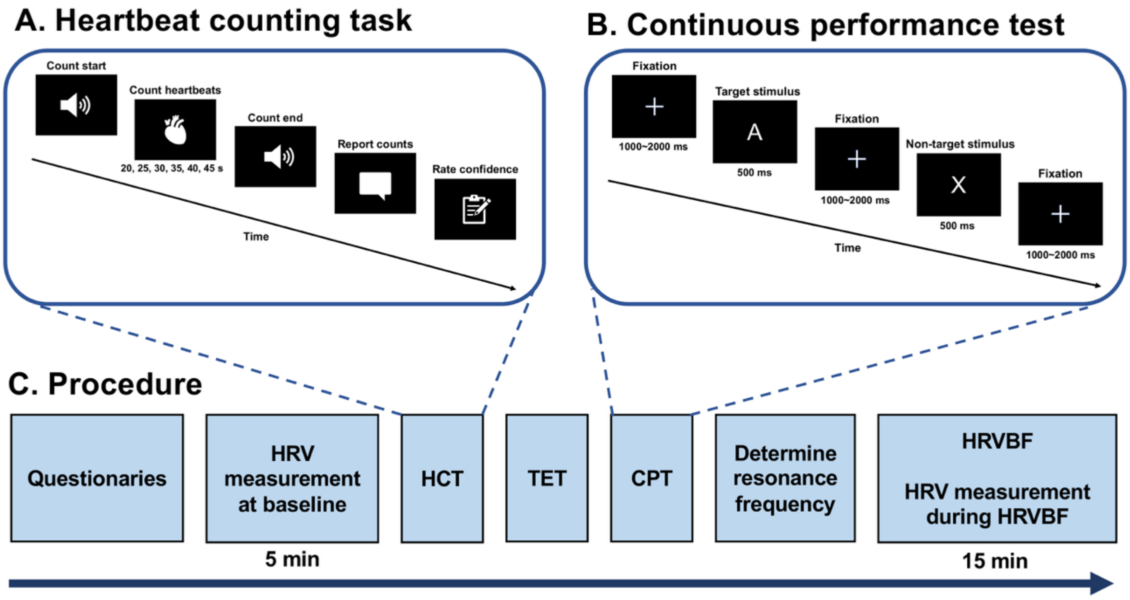

Figure 1. Behavioral tasks and measurement procedure.

A. Timeline of one trial in the HCT. B. Timeline of one trial in the CPT. C. Procedure.

CPT, continuous performance test; HCT, heartbeat counting task; HRV, heart rate variability; HRVBF, heart rate variability biofeedback; TET, time estimation task.

Table 1. Demographic data, interoceptive parameters, and the coherence score.

Parameters	Mean (SD)
Demographic data	
Age (years)	21.8 (2.0)
BMI (kg/m^2)	21.3 (2.6)
Interoceptive parameters	
MAIA-J “Noticing”	2.74 (0.79)
MAIA-J “Not-Distracting”	2.73 (1.04)
MAIA-J “Attention Regulation”	2.72 (0.80)
MAIA-J “Emotional Awareness”	2.78 (0.92)
MAIA-J “Body Listening”	1.99 (0.90)
MAIA-J “Trusting”	2.97 (0.90)
BPQ-BAVSF-J	37.45 (6.02)
IAc	0.53 (0.22)
IAw	0.28 (0.27)
Coherence score	4.6 (1.2)

BMI, body mass index; BPQ-BAVSF-J, Japanese version of the Body Perception Questionnaire-Body Awareness Very Short Form; IAc, interoceptive accuracy; IAw, interoceptive awareness; MAIA-J, Japanese version of Multidimensional Assessment of Interoceptive Awareness; SD, standard deviation.

Table 2. The results of multiple regression analysis (forced entry method).

	Partial regression coefficient	Standardized partial regression coefficient (β)	*P*	95% confidence interval	
				Lower bound	Upper bound
Intercept	6.165		0.061	-0.299	12.629
MAIA-J “Noticing”	-0.922	-0.616*	0.007	-1.579	-0.266
MAIA-J “Not-Distracting”	-0.204	-0.178	0.302	-0.599	0.191
MAIA-J “Attention Regulation”	0.098	0.067	0.706	-0.428	0.625
MAIA-J “Emotional Awareness”	0.430	0.333	0.236	-0.294	1.154
MAIA-J “Body Listening”	0.096	0.073	0.684	-0.381	0.574
MAIA-J “Trusting”	0.305	0.229	0.210	-0.180	0.790
BPQ-BAVSF-J	0.040	0.201	0.339	-0.043	0.123
IAc	1.081	0.199	0.230	-0.716	2.878
IAw	0.246	0.055	0.759	-1.371	1.863
CPT mean RT	-0.001	-0.029	0.870	-0.014	0.012
CPT commission error rate	-0.191	-0.204	0.227	-0.508	0.125
CPT omission error rate	-0.483	-0.260	0.087	-1.039	0.073
RMSSD at baseline	0.017	0.287	0.118	-0.005	0.039
lnLF at baseline	-0.448	-0.346	0.073	-0.940	0.044

BPQ-BAVSF-J, Japanese version of the Body Perception Questionnaire-Body Awareness Very Short Form; CPT, continuous performance test; IAc, interoceptive accuracy; IAw, interoceptive awareness; LF, low frequency; MAIA-J, Japanese version of

Multidimensional Assessment of Interoceptive Awareness; RMSSD, root mean square of successive differences; RT, reaction time.

$^{*}p < 0.01$.

Table 3. The results of multiple regression analysis (backward stepwise method).

	Partial regression coefficient	Standardized partial regression coefficient (β)	*P*	95% confidence interval Lower bound	95% confidence interval Upper bound
	6.675		0.000	4.118	9.232
MAIA-J "Noticing"	-0.669	-0.047*	0.014	-1.198	-0.140
MAIA-J "Emotional Awareness"	0.641	0.497**	0.007	0.186	1.097
CPT omission error rate	-0.480	-0.259	0.063	-0.987	0.027
RMSSD at baseline	0.021	0.349*	0.030	0.002	0.040
lnLF at baseline	-0.440	-0.339*	0.034	-0.845	-0.035

CPT, continuous performance test; LF, low frequency; MAIA-J, Japanese version of Multidimensional Assessment of Interoceptive Awareness; RMSSD, root mean square of successive differences.

*$p < 0.05$; **$p < 0.01$.