Reliability of the Heartbeat Tracking Task to Assess Interoception

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Abstract

Interoception refers to the competence in perceiving and interpreting internal sensations emerging from the body. The most common approach to assess interoception is through cardiac interoceptive tests like the heartbeat tracking task (HTT), which measures the accuracy on perceive and counting heartbeats during a period. However, the literature is scarce in providing adequate reliability evidence for this measure so that the interoception assessment may be threaten. In addition to HTT accuracy, it is possible to determine sensibility (self-reported confidence) and interoceptive awareness (correspondence between accuracy and sensibility). Thus, we measured the test-retest reliability of HTT and also investigated the behavior of HTT outcomes along the task. Therefore, 31 healthy adults (16 males) with 27.8 (9.4) years old performed two consecutive HTT interspersed by one day. Intraclass correlation coefficient (ICC), standard error of measurement (SEM) and minimal detectable difference (MD) analyzes showed 'Good' relative reliability for interoceptive accuracy (ICC = 0.880; SEM = 0.263; MD = 0.728; $p < 0.001$) and 'Moderate' for sensibility (ICC = 0.617; SEM = 0.648; MD = 1.797; $p < 0.001$) and awareness (ICC = 0.593; SEM = 0.227; MD = 0.628; $p < 0.001$). The absolute reliability shows low threshold values for observing true effects in HTT outcomes. The results also showed that reducing the number of HTT blocks did not impact the outcomes. The HTT showed to be reliable in determine the interoceptive competences in healthy adults.

Introduction

Interoception may be defined as the competence in perceiving and interpreting body-derived sensations such as beats, pain and temperature (Quadt et al., 2018). Usually, these sensations are related to the activity of body signals arising from heart, lungs, thermoregulation, pain sensation and physical effort (Craig, 2002; Marcora, 2009). According to a conceptual framework developed by Garfinkel et al. (2015), interoception is composed of three different dimensions such as accuracy, sensibility and awareness. In this regard, interoceptive accuracy (IAcc) is the objective representation of perceived internal sensations, while interoceptive sensibility (ISen) is the individual subjective evaluation regarding the confidence in your own perception of bodily signals (Garfinkel et al., 2015). The metacognitive correspondence between IAcc and ISen is the interoceptive awareness (IAwa), thus referring to how adequate is the conscious comprehension of what has been happening internally in the body (Garfinkel et al., 2015).

The literature has shown that detecting and interpreting internal bodily signals may play a fundamental role in physical and mental health (Khalsa et al., 2018; Machado et al., 2019; Paolucci et al., 2017). Indeed, variations in health conditions have been suggested to be involved in different profiles of perceiving and reporting signs and symptoms (Murphy et al., 2017; Quadt et al., 2018) as well as behavior (Critchley & Garfinkel, 2017). Is well established that different psychiatric disorders affect individuals interoceptive skills in specific ways (Khalsa et al., 2018). Therefore, psychological and/or emotional impaired individuals are impacted by interoceptive mechanisms that can act to minimize or attenuate the symptoms of disorders, such as depression, anxiety, alexithymia, autism, panic and others (Brewer et al., 2016; Dunn et al., 2010; Ehlers & Breuer, 1992; Pollatos, Herbert, et al., 2007; Schauder et al., 2015). In addition, interoceptive processing may be linked to fatigue mechanisms that arise from signals provided by physical exercise (McMorris, 2020). Given this, it seems relevant to investigate whether the measures used to access interoceptive competences are in fact reliable maintaining stability and consistency over multiple trials.

Approaches to access interoception have used cardiac responses (Brener & Ring, 2016). For example, as originally suggested by Schandry (1981), the Heartbeat Tracking Task (HTT) indicates interoceptive competences through the mental counting of heartbeats during a period of time. Although slight changes such as blocks number and duration (Brener & Ring, 2016; Garfinkel et al., 2015), the HTT have been used as originally based on the proximity between measured and perceived heartbeats (Schandry, 1981). For example, individuals accurately counting the beats of the heart are considered as having a higher IAcc. In order to minimize individuals' attempts to predict the counted beat based on time, self-report measures were used for assessing the counting confidence. This was incorporated into the performance of the HTT through the use of scales or questionnaires to evaluate the confidence of individuals in relation to counting (Garfinkel et al., 2015; Porges, 1993). This confidence variable allows the determination of ISen as well as IAwa, providing more robust interpretation of interoceptive competences.

The HTT present a few criticism in literature regarding its ability to reflect interoception as an overarching concept (Zamariola et al., 2018) and whether heartbeat counting is fully related to cardiac detection (Ring & Brener, 2018). Despite the conceptual limitations of the HTT, it has been suggested that this test is capable of adequately determining interoceptive competences based on cardiac signals. Some of the studies that have dedicated themselves to investigating the psychometric qualities of the HTT (Ehlers & Breuer, 1992; Ferentzi et al., 2018; Herbert et al., 2011; Larsson et al., 2021; Pollatos, Traut-Mattausch, et al., 2007; Ring & Brener, 2018; Stevens et al., 2011; Van der Does et al., 1997; Wittkamp et al., 2018) usually guarantee the reliability of the test. However, most of these studies use statistical methods or experimental designs that may threaten results reported previously due to errors.

Reliability refers to the reproducibility of a test or a measure performed several times (Hopkins, 2000) between (e.g. inter-rater) and within examiners (e.g. intra-rater) (e.g. test-retest) (Koo & Li, 2016). In this regard, reliability analysis is important to provide information about the error of the measurement and the power of analysis, thereby being essential to estimate sample size in scientific investigations as well as parameters for interpreting measurements in clinical scenarios. Therefore, the aim of the present study was to determine the test-retest reliability of HTT. In addition, we observed the behavior of IAcc, ISen and IAwa along the blocks, given that different HTT variations (i.e. number and duration of blocks) have been used by previous studies.

Methods

Participants

Thirty-one healthy adult males (n = 16) and females (n = 15) ranging from 20 to 53 yrs old voluntarily agreed to participate in this study after been invited through posts on social media (i.e. Instagram and Whatsapp). They were included if: 1) attended the age range limit between 18 and 59 yrs; and 2) have no clinical diagnosis of neurological disorders that could impact the performance in HTT. Importantly, all participants completed the research protocols so that no dropout was registered. This research was approved by the institutional Ethics Committee in Research with human beings under registration number 4.606.418 (National Health Council number 466/12), being conducted according to the Helsinki declaration.

Study Design

This is a test-retest reliability study performed in two visits interspersed by 24 h between them. In the first visit, participants signed an informed consent form before assessment of body mass, height, level of physical activity, profession, illness history and heartbeat perception. Afterward, they completed the Multidimensional Assessment of Interoceptive Awareness (MAIA) (Mehling et al., 2012). In the first visit, participants were familiarized with the HTT (3 to 5 blocks) before performing the full task with 60 blocks 5 min later. In the second visit, they repeated the HTT as in the first visit. The characteristics of the study were reported following the recommendations of Guidelines for Reporting Reliability and Agreement Studies (GRRAS) (Kottner et al., 2011).

The sample size (n = 29) was estimated through the web calculator (https://wnarifin.github.io/ssc_web.html) provided by Arifin (2021). The sample size was estimated considering a design having two replicate observations, 80% statistical power and 95% statistical significance. The minimum acceptable reliability (ρ0) was set at 0.76 while the expected reliability (ρ1) at 0.91, as according to ratings by Koo and Li (2016) to ensure that the intraclass correlation coefficient (ICC) was rated as ‘Good’ and ‘Excellent’. It is important to emphasize that ‘Moderate’ ICC values (0.50 - 0.75) would not represent insufficient reliability. However, the range between ‘Good’ and ‘Excellent’ was used to ensure that even in the worst-case scenario, the desired ICC remains around the ‘Good’ rating.

Heartbeat Tracking Task (HTT)

Briefly, the HTT assesses the individual's accuracy through measuring the difference between perceived heartbeat and actual heartbeat (Garfinkel et al., 2015). The closer the count is to actual beats, greater is the accuracy. Participants were seated in a comfortable position having the arms extended over a comfortable holding so that the oximeter (Nonim OEM, Xpod 3012LP, Minnesota, US) was placed on the right-hand middle finger. The participants performed the HTT as recommended by Larsson et al. (2021). The following instructions were given based on the aforementioned authors: “You should keep your eyes closed and try to perceive and silently count your heartbeat without manually or electronically checking your pulse. A software will give a 'Start' and 'Stop' signal so that you initiate and end your count. At the

'Stop' signal, you will be asked to report how many heartbeats you counted during that period, as well as self-report your confidence in the count”.

To access the IAcc the task was performed with a total of 60 blocks of different durations. The blocks lasting 18 s (n = 6), 20 s (n = 48) and 22 s (n = 6), and were randomly presented to participants, as suggested by Larsson et al. (2021). Participants were oriented to mentally estimate the heartbeat to access the ISen, so that at the end of each block they reported their level of confidence in estimating the heartbeat (i.e. perceived heartbeat). They rated their ISen in a scale ranging from 1 to 4, having items corresponding to: 1) I did not sense my heartbeats; I am completely guessing about the number of beats; 2) I sensed something about my heart, but I had no idea what I was counting, and I have no confidence at all in my counting; 3) I sporadically or faintly picked up on my heartbeat; my counting is based on something, but it may be off by a small margin; and 4) I clearly sensed my heartbeat, and have full confidence in my count (Larsson et al., 2021). The IAwa was accessed through the correspondence between IAcc and ISen.

Statistical Analysis

A two-way mixed effects ICC analysis ($ICC_{3,1}$) assessed the relative reliability between of interoceptive measures such as accuracy, sensibility and awareness, being interpreted as 'Poor' (< 0.5), 'Moderate' (> 0.5 and < 0.75), 'Good' (> 0.75 and < 0.9), and 'Excellent' (> 0.9) (Koo and Li (2016). The absolute reliability was calculated using the standard error of the measurement (SEM) and the minimal difference (MD) (Brietzke et al., 2021; Weir, 2005). Importantly, the SEM represents the minimal difference necessary to identify a true effect so that pre-to-post differences higher than the MD are interpreted as a real and clinical relevant change (Weir (2005).

The IAcc was calculated (Equation 1) as proposed by Schandry (1981), while ISen was assessed as the participant’s averaged in the confidence scale. The IAwa was accessed through a Pearson correlation coefficient between IAcc and ISen scores as suggested elsewhere (Garfinkel et al. (2015). A one-way repeated measures ANOVA verified whether the number of blocks of HTT interfered in the test performance, having the HTT blocks grouped in three different moments such as 1-20, 21-40 and 41-60. The Bonferroni’s correction was used in multiple comparisons if F-values were significant. Moreover, a paired t-test was performed to compare 1-30 vs 31-60 HTT blocks. The Bland-Altman analysis was performed to determine the data dispersion.

$$IAcc = 1 - \frac{actual\ heartbeats - counted\ heartbeats}{actual\ heartbeats} \qquad \text{Equation 1}$$

Where:

IAcc - Interoceptive Accuracy

actual heartbeats - Real number of heartbeats

counted heartbeats - Reported number of heartbeats

Results were expressed as mean, standard deviation (SD) and 95% of confidence interval ($CI_{95\%}$). All analyzes were performed using the SPSS software (v.23, IBM, New York, US) and the graphs were produced on GraphPad Prism (v.6, GraphPad Software, San Diego, US).

Results

Table 1 presents the participants' characteristics such as body mass, height, and MAIA scores. For example, 83.9% of them had already noticed changes in HR at some moment in their lives. The mean (± SD) HR during the task was 74.5 (10.1) bpm for trial 1 and 77.0 (8.7) bpm for trial 2. In addition, the actual and counted beats were respectively 24.8 (3.4) and 16.6 (5.3) beats for trial 1, and 25.7 (2.9) and 18.9 (6.2) for trial 2. Importantly, there were no significant differences when the HTT was divided into three parts with 20 blocks in each ($F_{(1.820;\ 111)} = 0.005$; $p = 0.991$) or into two parts with 30 blocks ($t_{(61)} = 0.436$; $p = 0.664$), thus indicating that the HTT did not promote changes in the behavior of the IAcc, ISen and IAwa variables throughout the task.

Table 1

Personal characteristics of participants (n = 31)

Variables	Mean (SD)
Age (yrs)	27.8 (9.4)
Weight (kg)	71.1 (14.1)
Height (m)	1.68 (0.10)
Total Physical Activity Frequency (d/week)	4.7 (1.2)
Total Physical Activity Time (min/week)	70.6 (24.3)
MAIA Responses	
Noticing (a.u.)	3.7 (0.9)
Attention Regulation (a.u.)	2.7 (1.0)
Overall (a.u.)	2.6 (0.5)

Note: SD = standard deviation; MAIA = Multidimensional Assessment of Interoceptive Awareness; a.u. = arbitrary units.

Analysis of ICC revealed 'Good' relative reliability for IAcc (ICC = 0.880; $CI_{95\%}$ = 0.684; 0.949; $p < 0.001$), with values ranging from 'Moderate' to 'Excellent' relative reliability. In contrast, 'Moderate' reliability was observed in ISen (ICC = 0.617; $CI_{95\%}$ = 0.345; 0.794; $p < 0.001$) and IAwa indexes (ICC = 0.593; $CI_{95\%}$ = 0.310; 0.780; $p < 0.001$), having individual values ranging from 'Poor' to 'Good' reliability.

Absolute reliability analysis indicated that IAcc, ISen and IAwa variables showed a SEM of 0.263, 0.648 and 0.227, respectively, thereby indicating the threshold values for observing true effects in HTT outcomes. Furthermore, MD results indicated that true effects in pre-to-post HTT outcomes may be detected with changes from 0.728, 1.797 and 0.628 in IAcc, ISen and IAwa variables, respectively. Table 2 presents relative and absolute reliability values.

Table 2

Relative and absolute reliability of HTT

Variables	Mean (SD)		Relative Values			Absolute Values	
	Trial 1	Trial 2	$ICC_{(3,1)}$ ($CI_{95\%}$)	p	Rating[1]	SEM	MD
IAcc (a.u.)	0.67 (0.21)	0.73 (0.22)	0.880 (0.684; 0.949)	< 0.001	Good (M - E)	0.263	0.728
ISen (a.u.)	2.62 (0.58)	2.77 (0.51)	0.617 (0.345; 0.794)	< 0.001	Moderate (P - G)	0.648	1.797
IAwa (a.u.)	0.40 (0.25)	0.36 (0.26)	0.593 (0.310; 0.780)	< 0.001	Moderate (P - G)	0.227	0.628

Note: HTT = heartbeat tracking task; IAcc = interoceptive accuracy; ISen = interoceptive sensibility; IAwa = interoceptive awareness; SD = standard deviation; ICC = intraclass correlation coefficient; $CI_{95\%}$ = 95% confidence interval; SEM = standard error of measurement; MD = minimal difference; a.u. = arbitrary units; M = Moderate; E = Excellent; P = Poor; G = Good; 1 = Koo, T. K., & Li, M. Y. (2016). A Guideline of Selecting and Reporting Intraclass Correlation Coefficients for Reliability Research. *J Chiropr Med*, 15(2), 155-163. https://doi.org/10.1016/j.jcm.2016.02.012.

Bland-Altman analysis suggested no bias in IAcc, ISen and IAwa variables, given the roughly random data dispersion. Figure 1 depicts Bland-Altman results for IAcc, ISen and IAwa respectively.

Discussion

The aim of the present study was to determine the reliability and the influence of the total number of blocks on HTT outcomes. Together with non-significant differences in HTT outcomes between trials, we observed a moderate-to-good relative reliability in interoceptive competences such as IAcc, ISen and IAwa, thereby suggesting that HTT can yield stable and consistent responses. Furthermore, we showed that reducing the number of blocks in task did not impact HTT outcomes.

Relative reliability index as expressed as ICC may be considered adequate to reflect the stability and consistency of repeated measures (Koo & Li, 2016). Indeed, alternative relative reliability methods such as Pearson correlation and split tests have concerns as errors due to small samples-derived bias and inappropriate divisions of single trials may impact the interpretation of results (Hopkins, 2000; Weir, 2005). In this regard, caution is necessary when interpreting results of previous studies assessing relative reliability in HTT outcomes through approaches such as Pearson or Spearman correlation coefficient (Ferentzi et al., 2018; Herbert et al., 2011; Larsson et al., 2021; Pollatos, Traut-Mattausch, et al., 2007; Ring & Brener, 2018; Stevens et al., 2011; Van der Does et al., 1997), given that high and significant correlation coefficients do not necessarily indicate strong reliability, but rather a proportionality between trials.

According to Weir (2005), Pearson correlation coefficient is not adequate for test-retest reliability as it cannot handle systematic errors derived from instrumentation and procedures. To the best of our knowledge, the study by Wittkamp et al. (2018) was the first to use ICC measurements to determine the reliability of the HTT. The authors found lower reliability (ICC = 0.42; $CI_{95\%}$ = 0.27, 0.58) compared to the present study (ICC = 0.880; $CI_{95\%}$ = 0.684, 0.949) for the IAcc. The difference between the ICC values found here in relation to the study of Wittkamp et al. (2018), can be explained by the fact that our study presents a design exclusively dedicated to testing the reliability of the HTT. In addition, we highlight the use of a more robust protocol (e.g. with 60 blocks) and, in an original way, the measurement of reliability for measures of sensibility and awareness. Using ICC results, we observed that interoception assessed through HTT accuracy showed a good reliability, although sensibility and awareness have been moderate.

It is worth highlighting that absolute reliability may play as a complement to relative reliability, as absolute measures may more applicable than ICC as it reflects the measurement error while maintaining the accessed variables as originally acquainted (Weir, 2005). In our results, all participants presented SEM and MD for IAcc lowest than 0.263 and 0.728 respectively, thus representing untrue change in HTT performance. Since there were no values higher than SEM and MD scores it may be suggested a relevant absolute reliability between trials. Moreover, ISen results showed that 7 individuals presented SEM and MD scores higher than 0.648 and 1.797 respectively, thus suggesting true changes on absolute reliability for this variable. Considering that IAwa corresponding to IAcc and ISen changes, its values were impacted by the moderate stability and consistency demonstrated by ISen. Therefore, one may recommend HTT to assess IAcc with certain level of confidence, although ISen and IAwa variables may be less consistent. Future studies are required to investigate if SEM and MD thresholds can be used as cutoff points to separate individuals with low and high interoception, and if they remain similar in different populations (i.e. athletes, elderly, sedentary, emotional impaired, psychiatric impaired).

Establishing cut-off points for the level of interoception is a very common strategy, but it still lacks more substantial evidence. The way individuals are stratified, according to their level of perception of internal signals (e.g. good or bad perceivers), does not seem to have sufficient theoretical robustness, since different cutoff points were used in the literature (i.e. 0.4; 0.6; 0.65; 0.66; 0.69; 0.7; 0.8; 0.85; 0.86) to divide the sample into groups of low and high interoception (Filippetti & Tsakiris, 2017; Garfinkel et al., 2015; Herbert et al., 2012; Hill et al., 2017; Machado et al., 2019; Zamariola et al., 2018). Another concern is regarding the equations used to determine the levels of IAcc, that according to our observation it was possible to identify four different formulas being used in the studies (Chick et al., 2020; Garfinkel et al., 2015; Machado et al., 2019; Schandry, 1981). Although these equations produce similar results, it is necessary to establish better defined criteria to determine the IAcc, especially that consider the measurement error and not just the average difference between the counted and actual beats.

A relevant point to be highlighted from the results of the present study is that it does not seem necessary to carry out very extensive HTT protocols. Originally popularized with three blocks and durations of 25 s, 35 s and 45 s (Schandry, 1981), the HTT has been changed over the years either with different total number of blocks (i.e. 4, 5, 6 and 60) or durations (i.e. 25 s; 30 s; 35 s ; 40 s; 45 s; 50 s; 55 s) (Garfinkel et al., 2015; Herbert et al., 2012; Larsson et al., 2021; Ueno et al., 2020). Our results suggest that performing the test with 20 or 30 blocks does not imply in reduced performance. In the present study some participants reported tiredness, sleep, loss of concentration, loss of attention and mental fatigue during the HTT with 60 blocks. It is then suggested to perform the HTT with fewer blocks to minimize possible effects of loss of cognition due to sustained attention for a very long time.

From the applicability viewpoint, some aspects and limitations need to be considered. First, it is questionable whether HTT measures reflect the concept of interoception in its entirety. The simple representation through the perception of cardiac signals can generate limited interpretations, since interoception is a capacity that includes other aspects such as visceral, breathing, pain, thirst, hunger and several other sensations (Craig, 2002). The study by Zamariola et al. (2018) criticized the theoretical concept behind cardiac signal perception tests, suggesting that they are not capable of providing sensitive data regarding global interoception. However, a few studies (Herbert et al., 2012; Ketai et al., 2021; van Dyck et al., 2016) have investigated the relationship between the perception of cardiac signals and other internal signals (i.e. gastric and urinary). Other studies have also investigated the relevance of interoceptive signals on exercise (Hill et al., 2017; Kósa et al., 2021; Machado et al., 2019).

Secondly, as highlighted in previous studies (Brener & Ring, 2016; Larsson et al., 2021), it is possible that factors such as the individual's general intelligence, temporal perception capacity and prior knowledge of their heart rate may impact the HTT results. However, a well-organized protocol reduces the possibility of bias during the performance of the HTT, including the confidence scale used (Larsson et al., 2021), which predicts possible situations that may occur during the perception and counting of heartbeats. Third, the Bland-Altman analysis offer an observation of the dispersion of data that corroborate the results of relative and absolute reliability, showing that the individuals remained in an area of concentration with low inter-individual variation. Finally, it is possible that occurrences in the participants' lives (i.e. emotional stress, anxiety, poor sleep) as well as external environmental factors (i.e. noise, cold, heat) may impact performance during the HTT test. However, all the procedures used, and the guidelines given to the participants were made to minimize these effects.

Conclusion

HTT outcomes were reliable in determining the interoceptive competences in healthy adults. While IAcc results showed stable (i.e. not changing within days) and consistent (i.e. not changing within hours) results in relative and absolute reliability analyses, ISen and IAwa showed lower reliability levels, thus requiring caution in their application.

Declarations

Competing Interests and funding:

The authors declare that there is no financial or non-financial interest, as well as no funding related to this research.

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CONFLICT-OF-INTEREST STATEMENT

The authors declare that they have no conflict of interest.

DATA AVAILABILITY STATEMENTS

The datasets generated during and/or analyzed during the current study are not publicly available due to they are part of ongoing research but are available from the corresponding author on reasonable request.

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Figures

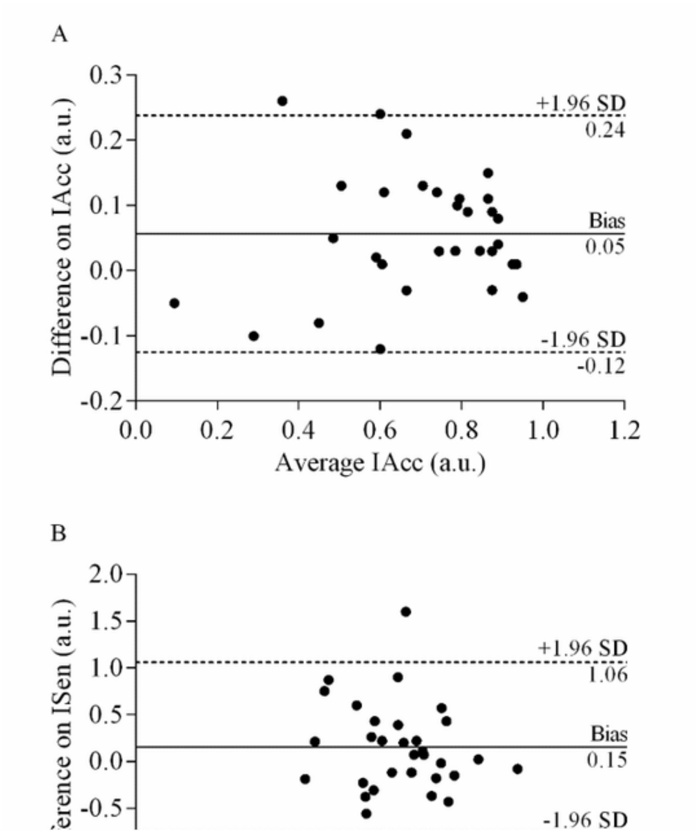

Figure 1

Bland-Altman analysis of HTT outcomes. IAcc - interoceptive accuracy; ISen - interoceptive sensibility; IAwa - interoceptive awareness; a.u. - arbitrary units; SD - standard deviation