

UNIVERSITY OF BIRMINGHAM

Research at Birmingham

Heartbeat Counting is Unrelated to Heartbeat Detection:

Ring, Christopher; Brener, Jasper

DOI:

[10.1111/psyp.13084](https://doi.org/10.1111/psyp.13084)

License:

Other (please specify with Rights Statement)

Document Version

Peer reviewed version

Citation for published version (Harvard):

Ring, C & Brener, J 2018, 'Heartbeat Counting is Unrelated to Heartbeat Detection: A Comparison of Methods to Quantify Interoception' *Psychophysiology*. <https://doi.org/10.1111/psyp.13084>

[Link to publication on Research at Birmingham portal](#)

Publisher Rights Statement:

This is the peer reviewed version of the following article: Ring C, Brener J. Heartbeat counting is unrelated to heartbeat detection: A comparison of methods to quantify interoception. *Psychophysiology*. 2018;e13084, which has been published in final form at: <https://doi.org/10.1111/psyp.13084>. This article may be used for non-commercial purposes in accordance with Wiley Terms and Conditions for Self-Archiving.

General rights

Unless a licence is specified above, all rights (including copyright and moral rights) in this document are retained by the authors and/or the copyright holders. The express permission of the copyright holder must be obtained for any use of this material other than for purposes permitted by law.

- Users may freely distribute the URL that is used to identify this publication.
- Users may download and/or print one copy of the publication from the University of Birmingham research portal for the purpose of private study or non-commercial research.
- User may use extracts from the document in line with the concept of 'fair dealing' under the Copyright, Designs and Patents Act 1988 (?)
- Users may not further distribute the material nor use it for the purposes of commercial gain.

Where a licence is displayed above, please note the terms and conditions of the licence govern your use of this document.

When citing, please reference the published version.

Take down policy

While the University of Birmingham exercises care and attention in making items available there are rare occasions when an item has been uploaded in error or has been deemed to be commercially or otherwise sensitive.

If you believe that this is the case for this document, please contact UBIRA@lists.bham.ac.uk providing details and we will remove access to the work immediately and investigate.

1

2

Heartbeat Counting is Unrelated to Heartbeat Detection:

3

A Comparison of Methods to Quantify Interoception

4

5

6

Christopher Ring^a & Jasper Brener^b

7

8

^a School of Sport, Exercise & Rehabilitation Sciences, University of

9

Birmingham, UK

10

^b Department of Psychology, SUNY at Stony Brook, USA

11

12

13

14

Correspondence should be addressed to: Christopher Ring, School of Sport,

15

Exercise and Rehabilitation Sciences, University of Birmingham, Edgbaston,

16

Birmingham, B15 2TT, UK. c.m.ring@bham.ac.uk

17

HEARTBEAT COUNTING VERSUS DETECTION

1

Abstract

2 Recent research has identified individual differences in interoceptive sensitivity as a key
3 source of variation in action, cognition and emotion. This research has relied heavily on a
4 single method for assessing interoceptive sensitivity: the accuracy of counting heartbeats
5 while at rest. The validity of this method was assessed here by comparing the Heartbeat
6 Counting (HBC) performance of 48 individuals with their Heartbeat Detection (HBD)
7 performance. The Heartbeat Counting (HBC) task required participants to report the
8 numbers of heartbeats counted during brief signaled periods and indexed cardioceptive
9 accuracy based on the difference between the numbers of reported and actual heartbeats. In
10 the Heartbeat Detection (HBD) task, participants indicated the temporal location of
11 heartbeat sensations relative to the onset of ventricular contraction. On each trial they
12 judged whether heartbeat sensations were or were not simultaneous with brief tones
13 presented at one of six fixed delays following R-waves of the ECG. In this method,
14 cardioceptive accuracy or precision was indexed by variability in the temporal location,
15 relative to the R-wave, of tones judged to be simultaneous with heartbeat sensations.
16 Although intra-task correlations indicated that each method yielded reliable scores,
17 inter-task correlations showed that HBC scores were unrelated to HBD scores. These
18 results, which indicate that heartbeat detection and heartbeat counting are distinct
19 processes, raise important questions about the assessment of interoceptive sensitivity and
20 the involvement of this attribute in the psychological processes that have been associated
21 with it on the basis of their correlations with HBC performance.

22

HEARTBEAT COUNTING VERSUS DETECTION

1 **Heartbeat Counting is Unrelated to Heartbeat Detection:**

2 **A Comparison of Methods to Quantify Interoception**

3 A rapidly-growing body of research has identified individual differences in interoceptive
4 sensitivity as a key source of variation in a wide range of affective, cognitive, conative and
5 clinical processes (Shivkumar, *et al.*, 2016; Tsakiris & Critchley, 2016). This research has
6 relied heavily on measuring sensitivity to heartbeat sensations as a means of assessing
7 interoceptive sensitivity, presumably because of the simplicity and unintrusiveness of the
8 associated methods. While several techniques for measuring sensitivity to heartbeat
9 sensations are no longer used because of flawed methodology and/or poor psychometrics,
10 others have survived despite their apparent flaws (Brener & Ring, 2016). With this issue in
11 mind, the current study evaluated and compared two different methods for assessing
12 sensitivity to heartbeat sensations – Heartbeat Counting (HBC) and Heartbeat Detection
13 (HBD). According to Garfinkel *et al* (2015) these two methods, which are claimed by their
14 proponents to yield valid objective measures of cardioceptive accuracy, are “*founded on*
15 *distinct (as well as potentially shared) underlying processes*”.

16 **Heartbeat Counting**

17 In the Heartbeat Counting (HBC) task participants are instructed to report the
18 number of counted *or estimated* heartbeats during several signaled periods, each generally
19 lasting less than a minute (Dale & Anderson, 1978; Schandry, 1981). Sensitivity to heartbeat
20 sensations is indexed by a perception score calculated from the difference between the
21 numbers of actual and reported heartbeats. Evidence shows that the accuracy of heartbeat
22 counting is unrelated to the abilities to estimate time (Antony, *et al.*, 1994) or to count

HEARTBEAT COUNTING VERSUS DETECTION

1 accurately (Ring & Brener, 1996), leaving open the possibility that individual differences in the
2 accuracy of heartbeat counting are due to individual differences in sensitivity to stimuli
3 produced by the beating of the heart.

4 Mechanoreceptors in the heart, the pericardium, and other parts of the body
5 generate afferent signals on each heartbeat (see Ring & Brener, 1992). Hence, it seems
6 plausible that individuals, particularly those with high mechanoreceptive sensitivity, will
7 develop an ability to recognize and count their heartbeats and to estimate their heart rates
8 accurately. As research on interoceptive processes has grown (Shivkumar, et al., 2016;
9 Tsakiris & Critchley, 2016), the Schandry (1981) heartbeat counting procedure, which is
10 simple to implement and quick to execute, has become the main method used to assess
11 individual differences in interoceptive sensitivity¹.

12 However, the face validity of the counting task has been challenged repeatedly on the
13 grounds that individuals may perform accurately by counting at a rate that approximates their
14 heart rates but without actually detecting any heartbeat sensations (Flynn & Clemens, 1988;
15 Jones, 1994; Katkin & Reed, 1988 ; Kleckner, et al., 2015; Weisz, et al., 1988; Yates, et al.,
16 1985). This criticism has been supported by the publication of a series of experimental
17 findings showing that counts are based more on beliefs about heart rate than on sensations
18 generated by heartbeats (Pennebaker, 1981; Pennebaker & Hoover, 1984; Phillips, et al.,
19 1999; Ring & Brener, 1996; Ring, et al., 2015; Windmann, et al., 1999). For example, the
20 numbers of reported heartbeats change little despite substantial changes in heart rates
21 elicited by postural (Ring & Brener, 1996) and pacemaker (Windmann, et al., 1999)
22 manipulations.

HEARTBEAT COUNTING VERSUS DETECTION

1 These data indicate that high scores on the heartbeat counting task may be earned by
2 a combination of accurate knowledge of heart rate and inaccurate perception of cardiac
3 activity (Brenner & Ring, 2016). Nevertheless, the “Predictive Coding”, “Bayesian Inference”
4 viewpoint that has been adopted by several researchers in the field (Ainley, *et al.*, 2016;
5 Barrett, *et al.*, 2016; Seth & Friston, 2016) appears to accommodate the possibility that while
6 beliefs about heart rate can be experimentally manipulated (e.g. Ring *et al.*, 2015), the “prior”
7 content of such beliefs reflects knowledge based on a life time’s experience of heartbeat
8 sensations. Hence, individuals who are more sensitive to heartbeat sensations will develop
9 more accurate implicit and/or explicit knowledge of their cardiac activity from which they
10 can generate more accurate counts of heart beats as well as better estimates of heart rate
11 and hence, higher perception scores on the Schandry HBC task.

12 In addition, proponents of the HBC method point to a number of heart evoked
13 potential (HEP) studies that purport to show significant differences in heart-related neural
14 activity between accurate and inaccurate heartbeat counters (Canales-Johnson, *et al.*, 2015;
15 Katkin, *et al.*, 1991; Pollatos, *et al.*, 2005; Pollatos & Schandry, 2004; Schandry, *et al.*, 1986;
16 Yuan, *et al.*, 2007). These data appear to support the validity of the counting method by
17 showing that the accuracy of heartbeat perception as measured by the Schandry HBC
18 method taps neural processes associated with heartbeat sensations. An fMRI study (Pollatos,
19 *et al.*, 2007) also purports to show a significant relationship between heartbeat counting
20 accuracy and the BOLD signal in the right insula. [Another fMRI study has shown specificity in](#)
21 [insula activity from interoceptive versus exteroceptive information \(Simmons, Avery,](#)
22 [Barcalow, Bodurka, Drevets, & Bellgowan, 2013\).](#) However, a more recent report, using an

HEARTBEAT COUNTING VERSUS DETECTION

1 arguably more completely-balanced control design (Pfleiderer, *et al.*, 2014), failed to find a
2 significantly greater BOLD signal in the right insula when attention was directed to
3 interoceptive stimuli (heartbeats) rather than exteroceptive stimuli (tones): both types of
4 stimuli giving rise to similar right insula activation.

5 Furthermore, it is possible that variations in HEP amplitude that have been attributed
6 to individual differences in interoceptive sensitivity on the basis of the Schandry counting task
7 are actually due to one or more of the many covariates of interoceptive sensitivity that have
8 been reported. For example, individual differences in attentional focus (Babo-Rebelo, *et al.*,
9 2016; Garcia-Cordero, *et al.*, 2016; Montoya, *et al.*, 1993), emotion/stress/arousal (Couto, *et*
10 *al.*, 2015; Gray, *et al.*, 2007; Luft & Bhattacharya, 2015; MacKinnon, *et al.*, 2013) and
11 motivation (Schulz, *et al.*, 2015; Weitkunat & Schandry, 1990) have all been reported to be
12 associated with HEP amplitude. It seems plausible that any or all of these processes may
13 predispose individuals to acquire more or less accurate, albeit indirect, knowledge of their
14 heart rates and thereby to achieve higher or lower scores on the Schandry HBC test. In
15 other words, a third variable (e.g., attention, effort) may be responsible for the relationship
16 reported between HBC performance and HEP amplitudes.

17 **Heartbeat Detection**

18 Unlike heartbeat counting tasks, in which high performance scores may be achieved
19 through indirectly-acquired knowledge of cardiac performance, good performance on Heart
20 Beat Detection (HBD) tasks appears unequivocally to depend on the detection of heartbeat
21 sensations (for review see Brener & Ring, 2016). These tasks require participants to judge
22 whether heartbeat sensations are or are not simultaneous with exteroceptive stimuli

HEARTBEAT COUNTING VERSUS DETECTION

1 presented at different delays (at least two) following the onset of the electromechanical
2 systole. In most two-interval HBD procedures, both the positive (HB-coincident) and
3 negative (HB-noncoincident) delays have been chosen on the basis of estimates of when,
4 following the R-wave of the ECG, the pressure pulse wave generated by ventricular
5 contraction will stimulate mechanoreceptors in or adjacent to the heart or major vessels of
6 the circulatory system, see (Whitehead, *et al.*, 1977).

7 However, recognizing that individuals show wide variation in the timing of their
8 heartbeat sensations, some heartbeat discrimination methods (Brener & Kluitse, 1988;
9 Brener, *et al.*, 1993; Yates, *et al.*, 1985) require individuals to judge the simultaneity of
10 heartbeat sensations and exteroceptive stimuli presented at six delays following the R-wave
11 (R+0, R+100, R+200, R+300, R+400, R+500 ms). These six-interval tasks span the cardiac
12 cycle more completely thereby permitting participants to identify the temporal location of
13 their heartbeat sensations with fewer restrictions than two interval tasks. Two-interval tasks
14 assume that heartbeat sensations occur at the same temporal location in the cardiac cycle in
15 all individuals and seek to answer the question of whether or not individuals can detect such
16 sensations. In contrast, six-interval HBD tasks are able to answer the question of when
17 during the cardiac cycle each participant senses heartbeat sensations.

18 On each trial of the six-interval task, a series of brief exteroceptive stimuli (say,
19 tones) is presented at one of the six intervals following each R-wave of the ECG. At the end
20 of the trial the participant renders a judgment of whether or not those tones were
21 simultaneous with heartbeat sensations. Over a large number of trials, a distribution of
22 simultaneous judgments across the six intervals is generated. If this observed distribution of

HEARTBEAT COUNTING VERSUS DETECTION

1 simultaneous judgments differs significantly by chi-square from a rectangular distribution, in
2 which judgments are expected to be equiprobable across the six intervals, then that
3 participant is classified as a heartbeat detector. The dispersion of the distribution of
4 simultaneous judgments across the six intervals, as measured by the interquartile range,
5 provides a continuous measure of the precision or accuracy of heartbeat detection; this is
6 what is referred to as the interval of uncertainty in the method of constant stimuli
7 (Gescheider, 2013). The logic of these multi-interval HBD tasks, as well as the standard
8 statistical methods that are employed to assess performance, provide such tasks with high
9 face validity. Furthermore, the reliability (split-half and test-retest) as well as the convergent²
10 and discriminant validity of the tasks have been thoroughly tested (Brener, et al., 1993;
11 Brener, et al., 1994; Jones, et al., 1990; Schneider, et al., 1998), thereby providing a defensible
12 standard for assessing heartbeat detection accuracy using non-invasive methods.

13 Nevertheless, the method has been criticized by Wiens and Palmer (2001) on the
14 grounds that the chi-square test is “needlessly insensitive” to their preferred criterion of
15 heartbeat discrimination which is that the distribution of simultaneous judgments across the
16 six R-Wave-to-Stimulus intervals is best described by a quadratic or inverted-U shaped
17 function. In such a function, stimuli presented at R+0 and R+500 ms are judged to be least
18 simultaneous with heartbeat sensation, stimuli at R+200 and R+300 ms most simultaneous,
19 and stimuli at R+100 and R+400 ms between these two extremes. While this \cap -shaped
20 function does accurately describe the group averages for heartbeat detectors in published
21 reports of performance on the MCS (See Figure 2 in Brener & Ring, 1995), it does not best
22 describe the choice distributions of a substantial proportion of the individual members of

HEARTBEAT COUNTING VERSUS DETECTION

1 these groups who meet standard statistical criteria for classification as heartbeat detectors
2 (Yates et al, 1985; Brener & Ring, 2016). Furthermore, not all datasets that exhibit significant
3 quadratic (\cap) trends have distributions of simultaneous judgments that differ significantly
4 from chance (Yates et al, 1985; Wiens & Palmer, 2001).

5 Wiens and Palmer (2001) also argue that certain two-interval HBD tasks are
6 preferable to six-interval tasks because they “tended to be more sensitive than chi-square
7 analysis in detecting relationships with “criterion” variables (better detectors have less affect,
8 a lower age, and tend to be male) that have been shown to correlate with heartbeat
9 detection. This inference is questionable on the grounds that the criterion variables
10 employed by Wiens and Palmer to judge the validity of their favored indices were identified
11 on the basis of their correlations with yet other tests of cardiac detection that are
12 themselves of dubious validity (for review see Brener & Ring, 2016).

13 Another criticism of heartbeat detection tasks is that the simultaneity paradigm is
14 impaired because it requires participants to attend “simultaneously to cardiac sensation and
15 external stimuli” (Couto, et al., 2015). However, since the nervous system is continuously
16 engaged in parallel processing of sensory inputs from internal and external receptors, e.g.
17 (Molholm, et al., 2002) and our ability to judge simultaneity is very precise indeed – we can
18 tell whether two stimuli presented to different modalities are simultaneous or not with a
19 resolution of less than 20 milliseconds (Zampini, et al., 2005) – performance on HBD tasks is
20 not limited by this general perceptual ability.

21 Thus, cases for the validity of both the HBC and 6-interval HBD measures have been
22 presented by proponents of these methods while questions of their validity have been raised

HEARTBEAT COUNTING VERSUS DETECTION

1 by critics of each of the methods. Some investigators have reported that performance on the
2 HBC task is related to HBD performance on two-alternative forced-choice tasks (Hart, *et al.*,
3 2013; Knoll & Hodapp, 1992), but others have found performance on the two tasks to be
4 uncorrelated (Forkmann, *et al.*, 2016; Kandasamy, *et al.*, 2016; Phillips, *et al.*, 1999; Schulz, *et*
5 *al.*, 2013; Weisz, *et al.*, 1988), also see Knoll & Hodapp (1992)³. In this context, the current
6 experiment was undertaken in order to clarify the extent to which the HBC task (Schandry;
7 1981) and the six-interval HBD task (Brener *et al.*; 1993) measure the same or different
8 abilities. Further information about the current implementation of the HBC task can be
9 found in a previous report by Ring and Brener (1996).

10 **Method**

11 *Participants*

12 Forty-eight undergraduates (18 males, 30 females) aged 18-20 ($M = 18.69$, $SD = 0.78$)
13 years participated for course credit. Their mean height was 1.67 ($SD = 0.08$) m, mean weight
14 was 61.45 ($SD = 9.94$) kg, and mean body mass index was 21.93 ($SD = 2.63$) kg/m². In terms
15 of fitness, on average, they exercised for 5.39 ($SD = 4.36$) hours per week, completed 2.26
16 ($SD = 1.38$) athletic activities per week, and had a resting heart rate (beats per minute) of
17 70.00 ($SD = 10.62$) when supine, 75.50 ($SD = 11.50$) when sitting, and 86.87 ($SD = 12.69$)
18 when standing.

19 *Apparatus*

20 A computer presented experimental stimuli and collected responses. It also detected
21 and processed heartbeats (R-waves) from an electrocardiogram recorded using a lead II
22 electrode configuration. During a familiarization task, supra-threshold vibrotactile stimuli

HEARTBEAT COUNTING VERSUS DETECTION

1 (250 Hz, 10 ms) were delivered to the finger using a piezo-oscillator and during the heartbeat
2 and familiarization tasks, auditory stimuli (1000 Hz, 10 ms, 75 dB) were delivered through
3 speakers.

4 *Procedure*

5 Participants completed one task per session in counterbalanced order. Each
6 laboratory session, which lasted less than one hour, was scheduled on a separate day. The
7 amount of time separating the heartbeat counting task session and the heartbeat detection
8 task session ranged from 1 to 8 days. During the session, participants sat upright in a
9 sound-and-light-attenuated room and were told that direct palpation of their pulse was not
10 allowed.

11 *Heartbeat counting task (Schandry, 1981).* Participants were instructed to count
12 heartbeats silently during three periods (25, 35, 45 s). A single tone signaled the start and
13 two tones signaled the end of each period. Specifically, they were instructed to “*count your*
14 *heartbeats silently without taking your pulse, beginning with the single tone and ending with the*
15 *double tone*”. Participants then reported the number of counted heartbeats. A 45 s interval
16 separated each period. Participants were told that the periods varied in length but were not
17 told the duration of each period. This sequence of three counting periods was later repeated
18 to compute test-retest reliability across the two parts of the heartbeat counting task ⁴.

19 *Heartbeat detection task (Brener, et al., 1993).* On each trial participants were
20 presented with 10 tones at one of six R-wave to tone intervals (0, 100, 200, 300, 400, 500
21 ms). Following the tenth tone they were instructed to press the appropriate button to
22 indicate whether the tones had or had not been simultaneous with heartbeat sensations. The

HEARTBEAT COUNTING VERSUS DETECTION

1 next trial started five seconds after each simultaneous/non-simultaneous button press. A
2 quasi-random sequence of intervals was used, with the constraints that each interval
3 occurred 10 times in each block of 60 trials, 10 times on odd-numbered trials, and 10 times
4 on even-numbered trials. Each interval occurred 20 times. Prior to the heartbeat detection
5 task, participants judged the simultaneity of vibrations and tones during a 30-trial
6 familiarization task that acquainted them with the general demands of intermodal simultaneity
7 judgments (Brener, et al., 1993).

8 *Measures*

9 The accuracy of heartbeat detection was indexed by the interquartile range of the
10 distribution of simultaneous judgments across the six intervals of the HBD task (Brener, et
11 al., 1993). Figure 1 shows how this measure was computed. The accuracy of heartbeat
12 counting was indexed by the perception score, calculated from differences in the numbers of
13 actual and counted heartbeats across the three counting periods in the HBC task (Schandry,
14 1981). A perfect perception score equals one; the score declines as more heartbeats are
15 reported or unreported than actually occurred.

16 *Data Analysis*

17 The dataset was examined for missing values, outliers and normality (Tabachnick &
18 Fidell (2007). No missing values were found. No extreme outliers, defined as three standard
19 deviations from the mean, were detected. The kurtosis and skewness values for each variable
20 indicated normal distributions (-0.71 to 1.23 and -1.18 to -0.68, respectively) based on
21 cutoff values of 10 for kurtosis and 3 for skewness. As illustrated in Figure 2, MCS
22 performance was in line with previous reports. By χ^2 analysis ($p < .05$), the percentage of

HEARTBEAT COUNTING VERSUS DETECTION

1 detectors in this study (27%) fell within the range reported in independent studies using the
2 MCS method: 19% (Wiens & Palmer, 2001), 29% (Schneider et al, 1998) and 32% (Young et
3 al, (2017).

4 **Results**

5 *Validity and Reliability*

6 The convergent validity of the two tasks was assessed by examining the correlation
7 between the two accuracy measures (see Figure 3). The interquartile range ($M = 265$, $SD =$
8 48 ms) was not significantly correlated with the perception score ($M = 0.61$, $SD = 0.29$), $r(46)$
9 $= -.04$, $p = .77$. This null finding was confirmed by a corresponding Spearman rank order
10 correlation: $r = .02$, $p = .90$.

11 The performances of participants who satisfied the X2 criterion ($p < .05$) for
12 classification as “detectors” on the MCS procedure are identified in Figure 3 by filled-in black
13 squares. Since heartbeat detection is a prerequisite to heartbeat counting, it is to be
14 expected that detectors would be well represented among participants who had high
15 Perception Scores on the HBC procedure. However, it will be seen that of the 17
16 participants who have Perception Scores equal to or greater than 0.80, nine (53%) were
17 detectors. It is inferred that the remaining eight participants (47%) achieved their high
18 Perception Scores on the basis of beliefs. *This suggests that while participants with good
19 heartbeat detection scores should be good at counting heartbeats whereas participants with
20 good heartbeat counting scores may not necessarily be good at detecting heartbeats.*

21 Split-half reliability was assessed by correlating the interquartile range computed on
22 the first half of the trials (i.e., 1-60) with the interquartile range computed on the second half

HEARTBEAT COUNTING VERSUS DETECTION

1 of the trials (i.e. 61-120), $r(46) = .60, p < .001$. Odd-even reliability was assessed by
2 correlating the interquartile ranges computed on odd-numbered trials (i.e., 1, 3, 5, ..., 119)
3 and with the interquartile ranges computed on even-numbered trials (i.e., 2, 4, 6, ..., 120),
4 $r(46) = .50, p < .001$. Test-retest reliability was assessed by correlating the perception scores
5 associated with the three counting periods in Part 1 with perception scores in Part 3, $r(46) =$
6 $.67, p < .001$. These significant positive intra-task correlation coefficients indicate that the
7 heartbeat detection and heartbeat counting tasks yielded reliable measures of detection and
8 counting, respectively.

9 *Supplementary Analyses*

10 Correlational analyses indicated that the perception score and IQR were not
11 significantly related to gender ($r = .27$ & $-.25$), age ($r = -.14$ & $-.16$), body mass index ($r = -.01$
12 & $-.18$), exercise hours ($r = -.08$ & $.19$), exercise frequency ($r = -.07$ & $-.05$), and resting heart
13 rate ($r = .22$ & $-.10$), respectively.

14 **Discussion**

15 Our purposes were to evaluate the reliability of two tasks designed to assess the
16 ability to detect heartbeat sensations and to examine the relationship between performance
17 on them. It was found that, although both tasks yielded reliable accuracy measures, heartbeat
18 counting scores were unrelated to heartbeat detection scores in this sample of university
19 students. This evidence adds to previous findings that heartbeat counting scores are
20 uncorrelated with heartbeat detection scores on two-alternative forced-choice tasks
21 (Forkmann, et al., 2016; Kandasamy, et al., 2016; Knoll & Hodapp, 1992; Phillips, et al., 1999;
22 Schulz, et al., 2013; Weisz, et al., 1988).

HEARTBEAT COUNTING VERSUS DETECTION

1 Unlike heartbeat detection tasks, the heartbeat counting task can yield high, and, by
2 implication, accurate, perception scores without participants detecting heartbeat sensations.
3 That individuals' verbal reports about their cardiac activity may be based on prior knowledge
4 of heart rate as well as on heartbeat sensations has been demonstrated in several
5 experiments (e.g., Pennebaker & Epstein, 1983; Phillips, et al., 1999; Ring & Brener, 1996;
6 Ring et al., 2015; Windmann, et al., 1999). Therefore, counting performance may be stable
7 over time without necessarily reflecting sensitivity to cardiac sensations. Indeed, the current
8 findings indicated that the ability to count heartbeats is not a valid indicator of the ability to
9 detect heartbeat sensations as measured by the six-interval task used in this study. In this
10 connection it may be noted that despite substantial differences in the MCS X^2 s of the Good
11 and Poor subjects ($X^2_{\text{Good}} = 68.24$; $X^2_{\text{Poor}} = 2.27$) displayed in Figure 1, their heartbeat
12 Counting Perception Scores (PS) were very similar ($PS_{\text{Good}} = 0.83$; $PS_{\text{Poor}} = 0.88$).

13 This six-interval heartbeat detection task, which is based on the Method of Constant
14 Stimuli, yields a distribution of simultaneous judgments across the intervals on each session
15 from which an index of precision – the interquartile range - may be computed. The
16 interquartile range has been found to be reliable over sessions (Ring, et al., 1994; Schneider,
17 et al., 1998) and within a session (Brener, et al., 1993; current study). Furthermore, the
18 distribution of simultaneous judgments for each participant may be submitted to statistical
19 analysis to determine whether or not that participant's performance deviates from chance
20 and therefore qualifies the participant as a heartbeat detector. It is worth noting that no such
21 criterion is available to distinguish between high Perception Scores in the HBC task that are
22 based on detecting the pulsatile action of the heart and high Perception Scores that are based

HEARTBEAT COUNTING VERSUS DETECTION

1 on some other process that does not involve cardiac interoception. Therefore, the influence
2 of guessing on counting performance cannot be determined using the standard instructions
3 and assessments of task performance (cf. Brener & Ring, 2016).

4 Performance on the heartbeat detection task also meets the criteria for internal
5 (Schneider, et al., 1998), construct (Brener, et al., 1993; Jones, et al., 1990), and face validity.
6 No other procedures for measuring the accuracy of heartbeat detection have shown
7 comparable psychometric properties.

8 In contrast, accumulating evidence questions the validity of the heartbeat counting
9 task as a method for assessing the ability to detect heartbeat sensations. Its continued
10 popularity among researchers may be due to its simplicity and brevity. However, since
11 performance on the task may reflect estimating, guessing or inferring the number of
12 heartbeats rather than counting them, it would seem ill-advised to use the HBC method to
13 index sensitivity to heartbeat sensations and, even less, interoceptive sensitivity (Knoll &
14 Hodapp, 1992).

15 Nevertheless performance on the HBC task has been reported to predict a broad
16 range of emotional, perceptual, cognitive, psychosocial and clinical processes as well neural
17 activity recorded by heart evoked potentials and MRIs. (see Tsakiris & Critchley, 2016 for an
18 overview of current work). If these predictions, mostly made on the basis of HBC
19 performance, are really due to variations in interoceptive sensitivity, then it is to be expected
20 that they will be confirmed by predictions based on other established tests of interoceptive
21 accuracy. In the absence of such confirmation, further work will be needed to reveal what
22 the predictive characteristic is that is being tapped by the HBC test.

HEARTBEAT COUNTING VERSUS DETECTION

1 A factor that could limit the generalizability of the results of this study is that while
2 the participant sample was of a reasonable size (48 participants), it comprised only young
3 college students. Whether the same results would be obtained in other populations remains
4 to be determined. Another consideration related to the generalizability of the results is that
5 the MCS task, by requiring judgments of the simultaneity of exteroceptive and interoceptive
6 stimuli, is thought by some (e.g. Couto et al., 2015) to be too difficult. If this view is accurate,
7 then the zero correlation between the MCS IQR and the Schandry et al (1981) Perception
8 Score reported here may be an underestimate. However, the conjecture that the MCS is too
9 difficult has yet to be fully articulated or tested. According to Couto et al (1981) the
10 difficulty of heartbeat detection tasks that rely on judging the simultaneity of external stimuli
11 and heartbeat sensations is that “.. interference (is) generated by attending simultaneously to
12 cardiac sensation and external stimuli ...”.

13 However, this hypothesis is inconsistent with the substantial experimental literature
14 on judging intersensory (intermodal) simultaneity and order. The work indicates that such
15 judgments are involved in a broad range of everyday behaviors (Vroomen & Keetels, 2010)
16 and confer numerous behavioral and perceptual benefits (Noel et al, 2016). While
17 interoception has not commonly been examined in the intersensory context, phenomena
18 such as bait shyness (Garcia & Koelling, 1966), food preferences and aversions (Booth, 1985)
19 and interoceptive conditioning (Razran, 1961) make clear the functional importance and
20 ubiquity of processing interoceptive-exteroceptive contingencies.

21 In conclusion, the current study adds to the accumulating body of evidence that
22 questions the validity of the HBC counting task as measure of cardioception. Unlike

HEARTBEAT COUNTING VERSUS DETECTION

1 two-interval HBD tests of sensitivity to heartbeat sensations, the MCS test used here does
2 not make unjustifiable assumptions about when during the cardiac cycle, the heartbeat
3 sensation occurs. As suggested earlier, research employing a multi-interval heartbeat
4 detection task such as the MCS could help to resolve whether the numerous cognitive,
5 psychosocial, clinical and emotional correlates of heartbeat counting performance are due to
6 cardioceptive sensitivity or some other, yet-to-be-identified, characteristic.

7

8

9

HEARTBEAT COUNTING VERSUS DETECTION

1

References

- 2 Ainley, V., Apps, M. A., Fotopoulou, A., & Tsakiris, M. (2016). 'Bodily
3 precision': a predictive coding account of individual differences in
4 interoceptive accuracy. *Philos Trans R Soc Lond B Biol Sci*, *371*(1708).
5 doi:10.1098/rstb.2016.0003
- 6 Antony, M. M., Meadows, E. A., Brown, T. A., & Barlow, D. H. (1994). Cardiac
7 awareness before and after cognitive-behavioral treatment for panic
8 disorder. *Journal of Anxiety Disorders*, *8*(4), 341–350.
- 9 Babo-Rebelo, M., Wolpert, N., Adam, C., Hasboun, D., & Tallon-Baudry, C. (2016).
10 Is the cardiac monitoring function related to the self in both the default
11 network and right anterior insula? *Philos Trans R Soc Lond B Biol Sci*,
12 *371*(1708). doi:10.1098/rstb.2016.0004
- 13 Barrett, L. F., Quigley, K. S., & Hamilton, P. (2016). An active inference theory
14 of allostasis and interoception in depression. *Philos Trans R Soc Lond*
15 *B Biol Sci*, *371*(1708). doi:10.1098/rstb.2016.0011
- 16 Brener, J., & Kluitse, C. (1988). Heartbeat Detection: Judgments of the
17 Simultaneity of External Stimuli and Heartbeats. *Psychophysiology*,
18 *25*(5), 554–561.
- 19 Brener, J., Liu, X., & Ring, C. (1993). A method of constant stimuli for examining
20 heartbeat detection: Comparison of the Brener-Kluitse and Whitehead
21 methods. *Psychophysiology*, *30*, 657–665.
- 22 Brener, J., & Ring, C. (2016). Towards a psychophysics of interoceptive
23 processes: the measurement of heartbeat detection. *Philos Trans R Soc Lond*
24 *B Biol Sci*, *371*(1708). doi:10.1098/rstb.2016.0015
- 25 Brener, J., Ring, C., & Liu, X. (1994). Effects of data limitations on heartbeat
26 detection in the method of constant stimuli. *Psychophysiology*, *31*,
27 309–312.
- 28 Canales-Johnson, A., Silva, C., Huepe, D., Rivera-Rei, A., Noreika, V., Garcia
29 Mdel, C., . . . Bekinschtein, T. A. (2015). Auditory Feedback
30 Differentially Modulates Behavioral and Neural Markers of Objective and
31 Subjective Performance When Tapping to Your Heartbeat. *Cereb Cortex*,
32 *25*(11), 4490–4503. doi:10.1093/cercor/bhv076
- 33 Couto, B., Adolphi, F., Seden, L., Salles, A., Canales-Johnson, A.,
34 Alvarez-Abut, P., . . . Ibanez, A. (2015). Disentangling interoception:
35 insights from focal strokes affecting the perception of external and
36 internal milieus. *Front Psychol*, *6*, 503. doi:10.3389/fpsyg.2015.00503

HEARTBEAT COUNTING VERSUS DETECTION

- 1 Dale, A., & Anderson, D. (1978). INFORMATION VARIABLES IN VOLUNTARY CONTROL AND
2 CLASSICAL CONDITIONING OF HEART RATE- FIELD DEPENDENCE AND HEART-RATE
3 PERCEPTION. *Perceptual and Motor Skills*, 47, 79–85.
- 4 Flynn, D. M., & Clemens, W. J. (1988). On the Validity of Heartbeat Tracking
5 Tasks. *Psychophysiology*, 25(1), 92–96.
- 6 Forkmann, T., Scherer, A., Meessen, J., Michal, M., Schachinger, H., Vogeled,
7 C., & Schulz, A. (2016). Making sense of what you sense: Disentangling
8 interoceptive awareness, sensibility and accuracy. *Int J Psychophysiol*,
9 109, 71–80. doi:10.1016/j.ijpsycho.2016.09.019
- 10 Garcia-Cordero, I., Sedeno, L., de la Fuente, L., Slachevsky, A., Forno, G.,
11 Klein, F., . . . Ibanez, A. (2016). Feeling, learning from and being aware
12 of inner states: interoceptive dimensions in neurodegeneration and
13 stroke. *Philos Trans R Soc Lond B Biol Sci*, 371(1708).
14 doi:10.1098/rstb.2016.0006
- 15 Garfinkel, S. N., Seth, A. K., Barrett, A. B., Suzuki, K., & Critchley, H. D.
16 (2015). Knowing your own heart: distinguishing interoceptive accuracy
17 from interoceptive awareness. *Biol Psychol*, 104, 65–74.
18 doi:10.1016/j.biopsycho.2014.11.004
- 19 Gray, M. A., Taggart, P., Sutton, P. M., Groves, D., Holdright, D. R., Bradbury,
20 D., . . . Critchley, H. D. (2007). A cortical potential reflecting cardiac
21 function. *Proc Natl Acad Sci U S A*, 104(16), 6818–6823.
22 doi:10.1073/pnas.0609509104
- 23 Hart, N., McGowan, J., Minati, L., & Critchley, H. (2013). Emotional regulation
24 and bodily sensation: interoceptive awareness is intact in borderline
25 personality disorder. *Journal of Personality Disorders*, 27(4), 506–518.
- 26 Jones, G. E. (1994). Perception of visceral sensations: A review of recent
27 findings, methodologies, and future directions. In J. R. Jennings, P. K.
28 Ackles, & M. G. H. Coles (Eds.), *Advances in Psychophysiology* (Vol. 5).
29 London: London: Jessica Kingsley Publishers.
- 30 Jones, G. E., Higgins, L. J., Hawks, J. M., & Wootton, E. (1990).
31 Intercorrelations between discrimination indices derived from the
32 Whitehead and Brener Kluvitse heartbeat perception paradigms.
33 *Psychophysiology*, 27(Suppl. 4A), S42 (Abstract).
- 34 Kandasamy, N., Garfinkel, S. N., Page, L., Hardy, B., Critchley, H. D., Gurnell,
35 M., & Coates, J. M. (2016). Interoceptive Ability Predicts Survival on
36 a London Trading Floor. *Scientific Reports*, 6. doi:10.1038/srep32986
- 37 Katkin, E. S., Cestaro, V. L., & Weitkunat, R. (1991). Individual differences
38 in cortical evoked potentials as a function of heartbeat detection
39 ability. . *International Journal of Neuroscience*, 61, 269–276.

HEARTBEAT COUNTING VERSUS DETECTION

- 1 Katkin, E. S., & Reed, S. D. (1988). Cardiovascular asymmetries and cardiac
2 perception. *International Journal of Neuroscience*, *39*, 45–52.
- 3 Kleckner, I. R., Wormwood, J. B., Simmons, W. K., Barrett, L. F., & Quigley,
4 K. S. (2015). Methodological recommendations for a heartbeat
5 detection-based measure of interoceptive sensitivity. *Psychophysiology*,
6 *52*(11), 1432–1440. doi:10.1111/psyp.12503
- 7 Knoll, J. F., & Hodapp, V. (1992). A Comparison between Two Methods for Assessing
8 Heartbeat Perception. *Psychophysiology*, *29*(1), 218–222.
- 9 Luft, C. D., & Bhattacharya, J. (2015). Aroused with heart: Modulation of
10 heartbeat evoked potential by arousal induction and its oscillatory
11 correlates. *Sci Rep*, *5*, 15717. doi:10.1038/srep15717
- 12 MacKinnon, S., Gevirtz, R., McGraty, R., & Brown, M. (2013). Utilizing heartbeat
13 evoked potentials to identify cardiac regulation of vagal afferents
14 during emotion and resonant breathing. *Appl Psychophysiol Biofeedback*,
15 *38*(4), 241–255. doi:10.1007/s10484-013-9226-5
- 16 Molholm, S., Ritter, W., Murray, M. M., Javitt, D. C., Schroeder, C. E., & Foxe,
17 J. J. (2002). Multisensory auditory , visual interactions during early
18 sensory processing in humans: a high-density electrical mapping study.
19 *Cognitive Brain Research*, *14*(1), 115–128.
20 doi:10.1016/s0926-6410(02)00066-6
- 21 Montoya, P., Schandry, R., & Muller, A. (1993). Heartbeat evoked potentials
22 (HEP): topography and influence of cardiac awareness and focus of
23 attention. *Electroencephalography and clinical Neurophysiology*, *88*,
24 163–172.
- 25 Pennebaker, J. W. (1981). Stimulus Characteristics Influencing Estimation of
26 Heart Rate. *Psychophysiology*, *18*(5), 540–548.
- 27 Pennebaker, J. W., & Hoover, C. W. (1984). Visceral perception versus visceral
28 detection: Disentangling methods and assumptions. *Biofeedback and Seld*
29 *Regulation*, *9*, 339–352.
- 30 Pfleiderer, B., Berse, T., Stroux, D., Ewert, A., Konrad, C., & Gerlach, A. L.
31 (2014). Internal focus of attention in anxiety-sensitive females
32 up-regulates amygdala activity: an fMRI study. *Journal of Neural*
33 *ransmission*, *121*, 1417–1428. doi:10.1007/s00702-014-1248-5)
- 34 Phillips, G. C., Jones, G. E., Rieger, E. J., & Snell, J. B. (1999). Effects
35 of the presentation of false heart-rate feedback on the performance of
36 two common heartbeat-detection tasks. *Psychophysiology*, *36*, 594–510.
- 37 Pollatos, O., Kirsch, W., & Schandry, R. (2005). On the relationship between
38 interoceptive awareness, emotional experience, and brain processes. .
39 *Cogn. Brain Res.*, *25*, 948–962.

HEARTBEAT COUNTING VERSUS DETECTION

- 1 Pollatos, O., & Schandry, R. (2004). Accuracy of heartbeat perception is
2 reflected in the amplitude of the heartbeat-evoked brain potential.
3 *Psychophysiology*, *41*(3), 476–482. doi:10.1111/1469–8986.2004.00170.x
- 4 Pollatos, O., Schandry, R., Auer, D. P., & Kaufmann, C. (2007). Brain structures
5 mediating cardiovascular arousal and interoceptive awareness. *Brain Res*,
6 *1141*, 178–187. doi:10.1016/j.brainres.2007.01.026
- 7 Ring, C., & Brener, J. (1996). Influence of beliefs about heart rate and actual
8 heart rate on heartbeat counting. *Psychophysiology*, *33*, 541–546.
- 9 Ring, C., Brener, J., Knapp, K., & Mailloux, J. (2015). Effects of heartbeat
10 feedback on beliefs about heart rate and heartbeat counting: a cautionary
11 tale about interoceptive awareness. *Biol Psychol*, *104*, 193–198.
12 doi:10.1016/j.biopsycho.2014.12.010
- 13 Schandry, R. (1981). Heart Beat Perception and Emotional Experience.
14 *Psychophysiology*, *18*(4), 483–488.
- 15 Schandry, R., Sparrer, B., & Weitkunat, R. (1986). From the heart to the brain:
16 A study of heart beat contingent scalp potentials. *International Journal*
17 *of Neuroscience*, *30*, 261–275.
- 18 Schneider, T. R., Ring, C., & Katkin, E. S. (1998). A test of the validity of
19 the method of constant stimuli as an index of heartbeat detection.
20 *Psychophysiology*, *35*, 86–89.
- 21 Schulz, A., Ferreira de Sa, D. S., Dierolf, A. M., Lutz, A., van Dyck, Z., Vogele,
22 C., & Schachinger, H. (2015). Short-term food deprivation increases
23 amplitudes of heartbeat-evoked potentials. *Psychophysiology*, *52*(5),
24 695–703. doi:10.1111/psyp.12388
- 25 Schulz, A., Lass-Hennemann, J., Sutterlin, S., Schachinger, H., & Vogele, C.
26 (2013). Cold pressor stress induces opposite effects on cardioceptive
27 accuracy dependent on assessment paradigm. *Biol Psychol*, *93*(1), 167–174.
28 doi:10.1016/j.biopsycho.2013.01.007
- 29 Seth, A. K., & Friston, K. J. (2016). Active interoceptive inference and the
30 emotional brain. *Philos Trans R Soc Lond B Biol Sci*, *371*(1708).
31 doi:10.1098/rstb.2016.0007
- 32 Shivkumar, K., Ajijola, O. A., Anand, I., Armour, J. A., Chen, P. S., Esler,
33 M., . . . Zipes, D. P. (2016). Clinical neurocardiology—defining the value
34 of neuroscience-based cardiovascular therapeutics. *J Physiol*.
35 doi:10.1113/JP271870
- 36 Simmons, W. K., Avery, J. A., Barcalow, J. C., Bodurka, J., Drevets, W. C., &
37 Bellgowan, P. (2013). Keeping the body in mind: Insula functional
38 organization and functional connectivity integrate interoceptive,

HEARTBEAT COUNTING VERSUS DETECTION

- 1 exteroceptive, and emotional awareness. *Human Brain Mapping*, 34,
2 2944–2958.
- 3 Tsakiris, M., & Critchley, H. (2016). Interoception beyond homeostasis:
4 affect, cognition and mental health. *Phil. Trans. R. Soc. B*, 371(0002).
- 5 Weisz, J., Balázs, L., & Ádám, G. (1988). The Influence of Self-Focused Attention
6 on Heartbeat Perception. *Psychophysiology*, 23(2), 193–199.
- 7 Weitkunat, R., & Schandry, R. (1990). Motivation and heartbeat evoked
8 potentials. *Journal of Psychophysiology*, 4(1), 33–40.
- 9 Whitehead, W., Drescher, V. M., Heiman, P., & Blackwell, B. (1977). Relation
10 of heart rate control to heartbeat perception. *Biofeedback and Seld*
11 *Regulation*, 2, 371–392.
- 12 Windmann, S., Schonecke, O. W., Frohlig, G., & Maldener, G. (1999). Dissociating
13 beliefs about heart rates and actual heart rates in patients with
14 pacemakers. *Psychophysiology*, 36, 339–342.
- 15 Yates, A. J., Jones, K. E., Marie, G. V., & Hogben, J. H. (1985). Detection of
16 the Heartbeat and Events in the Cardiac Cycle. *Psychophysiology*, 22(5),
17 561–567.
- 18 Yuan, H., Yan, H.-M., Xu, X.-G., Han, F., & Yan, Q. (2007). Effect of heartbeat
19 perception on heartbeat evoked potential waves. *Neuroscience Bulletin*,
20 23(6), 357–362.
- 21 Zampini, M., Guest, S., Shore, D. I., & Spence, C. (2005). Audio ,visual
22 simultaneity judgments. *Perception and Psychphysics*, 67(3), 531–544.
- 23
- 24

HEARTBEAT COUNTING VERSUS DETECTION

1 **Notes**

- 2 1. We do not deal here with evidence for a general interoceptive sensitivity or, if it exists,
3 whether cardioceptive sensitivity is a valid index of this general sensory characteristic.
4 However, several researchers have presented evidence on this issue, (e.g., Garfinkel, et
5 al., 2016; Herbert, et al., 2012; Kollenbaum, et al., 1996; Steptoe & Noll, 1997; Whitehead
6 & Drescher, 1980).
- 7
- 8 2. Brener, Liu and Ring (1993) found that performance accuracy on the MCS task, measured
9 by the IQR, was significantly correlated ($\rho = -.59$) with performance accuracy on the
10 Whitehead task, measured using A' , a non-parametric index which is preferred over d'
11 when there is only one pair of hit and false alarm rates. The full dataset, including d' and
12 several other statistics that have been reported in the experimental literature, are
13 presented in their appendix.
- 14
- 15 3. The study by Knoll and Hodapp (1992) is often cited as evidence that HBC and HBD
16 methods yield similar results. However, while these investigators did find that good and
17 poor heartbeat detectors on the two methods were classified similarly, the performance
18 of those in the middle range was uncorrelated. Furthermore these authors also advised
19 using HBD methods when the interest is in assessing heartbeat detection and only using
20 the HBC methods “when it makes no difference whether heartbeat perception ability or
21 the ability to estimate heart rate is being assessed.”

22

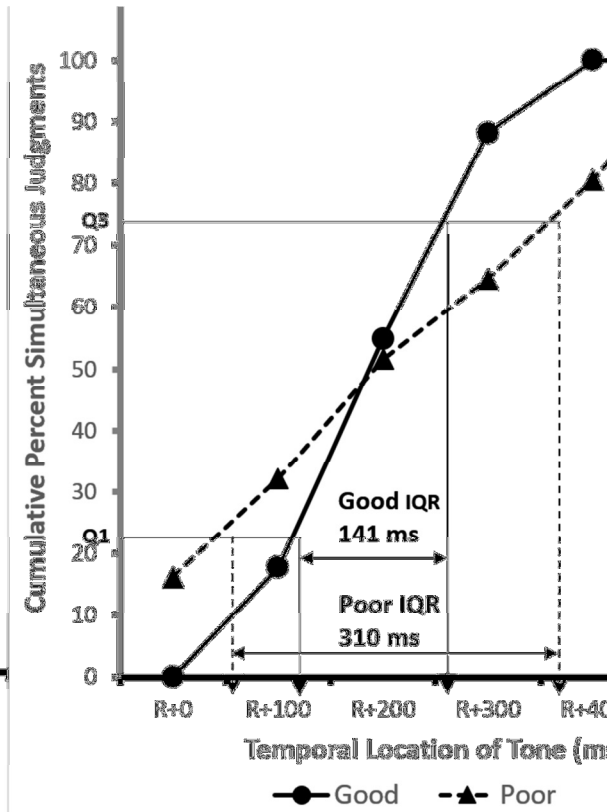
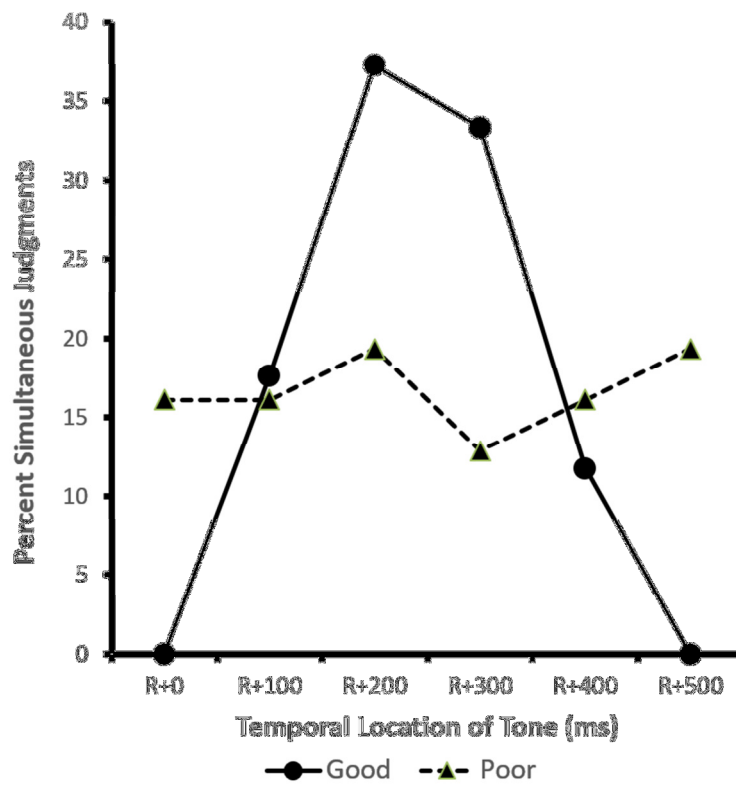
HEARTBEAT COUNTING VERSUS DETECTION

1 4. The session comprised three parts. In Part 1, participants counted heartbeats for three
2 counting periods while sitting, standing, supine, and post-exercise. In Part 2, they counted
3 vibrations for three periods. In Part 3, they repeated Part 1. The data from periods 1-3
4 (Part 1), during which participants performed the task while sitting, were used to
5 compute a perception score. This perception score from Part 1 was correlated with the
6 IQR measure from the HBD task to assess validity and correlated with the perception
7 score from periods 25-27 (Part 3) to assess reliability. The full dataset was analyzed in a
8 previous report (Ring & Brener, 1996).

9

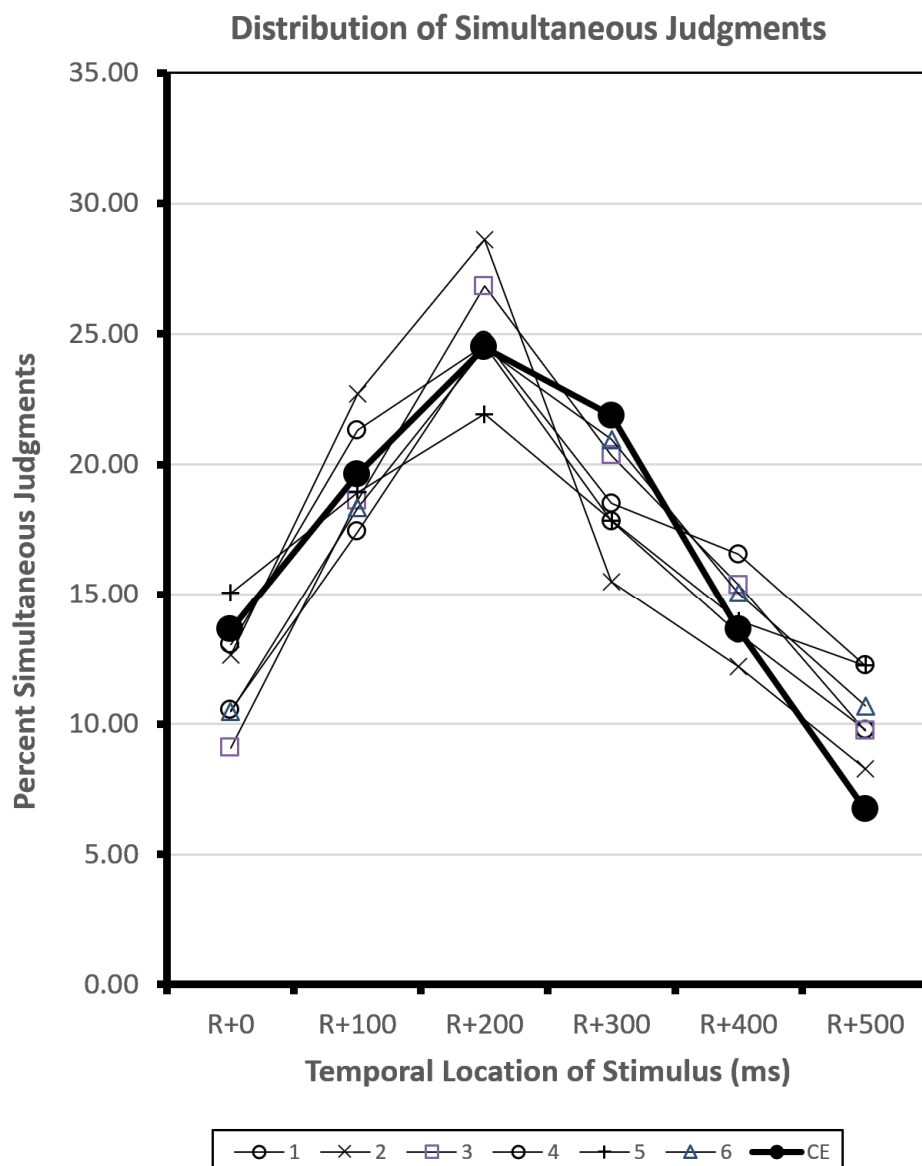
Figure 1. The left diagram shows the percentages of all simultaneous judgments for tones presented at each of the six R wave to Tone intervals for a Good heartbeat detector and a Poor heartbeat detector from the current experiment. The Good participant most frequently judged tones presented at R+200 ms to be simultaneous with heartbeat sensations and never judge tones presented at R+0 and R+500 ms to be simultaneous with heartbeats. The Poor participant, however, judged tones at each of the six intervals to be simultaneous with heartbeats with approximately the same probability. The right diagram illustrates cumulative percentage frequency distributions corresponding to the distributions for the Good and Poor participants shown on the left. The calculation of IQRs for those two participants is also illustrated here. This entailed calculating the R-wave to Tone intervals corresponding to the first quartile (Q1 or 25th percentile) and third quartile (Q3 or 75th percentile) of the Cumulative Percentage Frequency distributions of simultaneous judgments for each participant. The IQR for each participant was then calculated by subtracting their Q1 interval from their Q3 interval. This procedure yielded an IQR of 310 ms for the Poor participant and IQR of 141 ms for the Good participant.

HEARTBEAT COUNTING VERSUS DETECTION



HEARTBEAT COUNTING VERSUS DETECTION

Figure 2. The combined distribution of simultaneity judgments of detectors (Chi-square $p < .01$) in the Current Experiment (CE) displayed as a heavy line over the distributions reported in six previous replications (1-6) of the MCS procedure. (1) Ring & Brener 1989, 1992; (2) Brener & Ring, 1989; (3) Ring & Brener, 1990; (4) Brener, Ring & Wilmers, 1990; (5) Ring & Brener, 1991; (6) Jones, personal Communication). Note that in all datasets most simultaneous judgments are for stimuli at R+200 ms and fewest at R+0 ms and R+400 ms.



HEARTBEAT COUNTING VERSUS DETECTION

Figure 3. Heartbeat detection performance in relation to heartbeat counting performance. The interquartile range was unrelated to the perception score: $r(46) = -.04$, $p = .77$; $\rho(46) = .02$, $p = .90$. The data points of participants classified as “detectors” by Chi-square ($p < .05$) are filled in black. Since heartbeat detection is prerequisite to counting heartbeats accurately, it is to be expected that a relatively high proportion of participants (9/17) who have HBC Perception Scores ≥ 0.80 will be heartbeat detectors. However, the observation that approximately half the participants (8/17) whose Perception Scores were ≥ 0.80 failed to meet the statistical criteria for classification as heartbeat detectors suggests that their Perception Scores were based on processes other than heartbeat counting.

