



Short communication

Knowledge of resting heart rate mediates the relationship between intelligence and the heartbeat counting task

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ABSTRACT

Evidence suggests that intelligence is positively associated with performance on the heartbeat counting task (HCT). The HCT is often employed as measure of interoception – the ability to perceive the internal state of one's body – however its use remains controversial as performance on the HCT is strongly influenced by knowledge of resting heart rate. This raises the possibility that heart rate knowledge may mediate the previously-observed association between intelligence and HCT performance. Study One demonstrates an association between intelligence and HCT performance ($N = 94$), and Study Two demonstrates that this relationship is mediated by knowledge of the average resting heart rate ($N = 134$). These data underscore the need to account for the influence of prior knowledge and beliefs when examining individual differences in cardiac interoceptive accuracy using the HCT.

1. Introduction

There is increasing appreciation of the importance of interoception, the perception of the internal state of one's body, for higher-order cognition. Interoception is thought to be involved in emotional processing, and contributes towards aspects of learning and decision-making (e.g., Dunn et al., 2010; Herbert, Herbert, & Pollatos, 2011; Terasawa, Moriguchi, Tochizawa, & Umeda, 2014), making research into individual differences in interoception crucial. Various factors have been associated with interoceptive ability, at least in the cardiac domain, including physiological factors such as body mass index and blood pressure (Khalsa, Rudrauf, Sandesara, Olshansky, & Tranel, 2009; Murphy, Brewer, Catmur, & Bird, 2017; Murphy, Geary, Millgate, Catmur, & Bird, 2017; O'Brien, Reid, & Jones, 1998), and psychological factors including psychopathology and alexithymia (Khalsa & Lapidus, 2016; Murphy, Brewer et al., 2017). However, the measures used to quantify interoceptive ability within the cardiac domain remain controversial, with many questioning whether the most commonly used measure of interoception, the heartbeat counting task (HCT), should be considered a measure of interoception at all (see Brener & Ring, 2016).

Recent research suggests that higher intelligence is associated with better performance on the HCT, which requires participants to count their heartbeats over a series of intervals, with accuracy determined through comparison with an objective record (Dale & Anderson, 1978; Schandry, 1981). Using the HCT in both neurotypical and autistic samples, Mash, Schauder, Cochran, Park, and Cascio (2017) showed first that higher IQ is associated with better HCT performance, and second that deterioration in performance with advancing age (previously reported by Khalsa, Rudrauf, & Tranel, 2009; Murphy, Geary et al., 2017) varies as a function of IQ. Research into the possible mechanism by which intelligence influences performance on the HCT is lacking, but as HCT performance is strongly influenced by participants' beliefs about, and knowledge of, resting heart rate (Phillips, Jones, Rieger, & Snell, 1999; Ring & Brener, 1996; Ring, Brener, Knapp, & Mailloux, 2015; Windmann, Schonecke, Fröhlig, & Maldener, 1999), it is possible that higher intelligence results in more accurate knowledge of average resting heart rate, which in turn results in better HCT performance. It is this model that we tested here: in Study One ('replication') we replicated the relationship between HCT performance and IQ, whereas in Study Two ('extension') we replicated this association,

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determined its specificity, and tested whether the association between IQ and HCT performance is mediated by knowledge of the average resting heart rate.

2. General method

For both studies, ethical approval was granted by the local committee. All participants gave informed consent, and were debriefed upon task completion.

The HCT was utilised across both studies. Objective heart rate was measured using a pulse oximeter (Contec Systems, CMS-50D β ; Qinhuangdao, China). 4 counting periods were utilised (25, 35, 45, 100 or 28, 38, 48, 103 s). IQ was measured using the matrix and vocabulary subtests of the Wechsler Abbreviated Scale of Intelligence, Second Edition (Wechsler, 2011), a measure designed for use in the age range (s) employed.

Accuracy on the HCT was measured on a scale from 0 to 100: $((1 - (\text{Absolute} ((\text{Actual number of heartbeats} - \text{participant's estimate})/(\text{Actual number of heartbeats})) * 100)/\text{Number of counting periods}))$. Higher scores indicate better performance (Shah, Hall, Catmur, & Bird, 2016). For Study Two, time perception accuracy (see Study Two: Extension) was calculated using the same equation but with the number of seconds replacing the number of heartbeats.

3. Study One: replication

The aim of Study One was to replicate the association between IQ and HCT performance.

3.1. Method: Study One

3.1.1. Participants

We tested 94 participants with no known psychiatric or neurological conditions ($M_{age} = 24.90$, $SD_{age} = 9.92$, age range 18–46 years, 60 identifying as female, 33 as male, and one as non-binary).

3.2. Results: Study One

As predicted, a small but significant relationship between IQ and HCT performance was observed ($r(92) = 0.261$, $p = .011$).

4. Study Two: extension

Study Two had three aims: 1) to replicate the relationship between IQ and HCT performance, 2) to determine the specificity of this relationship, and 3) given evidence that the HCT is strongly influenced by the accuracy of participants' knowledge of resting heart rate (Murphy, Geary et al., 2017; Phillips et al., 1999; Ring & Brener, 1996; Ring et al., 2015; Windmann et al., 1999), to determine whether higher IQ results in more accurate knowledge of average resting heart rate, improving HCT performance.

4.1. Participants

In Study Two, we tested 140 additional participants, with no known psychiatric or neurological conditions. As older adults were included, participants completed the Mini Mental State Examination test (MMSE; Folstein, Folstein, & McHugh, 1975). 6 participants were excluded (one scored below threshold on the MMSE, two disclosed psychiatric/neurological conditions post-testing; one was excluded due to equipment failure, two failed to provide average resting heart rate estimates) resulting in 134 valid cases ($M_{age} = 55.02$, $SD_{age} = 19.58$, Age range 20–90 years, 49 Males). To minimise effects of elevated heart rate on accuracy (Knapp-Kline & Kline, 2005), participants were asked to refrain from caffeine for six hours prior to testing.

4.2. Method: Study Two

HCT performance was quantified as per Study One (replication). As a control, participants also completed a timing accuracy task (TAT) where they were required to count seconds instead of heartbeats (Ainley, Brass, & Tsakiris, 2014; Shah et al., 2016). For both the HCT and the TAT four counting periods were utilised (25, 35, 45, 100 s or 28, 38, 48, 103 s). Counting periods (e.g., 25 vs 28), task order (TAT vs HCT) and the order of individual counting periods were counter-balanced across participants (see Murphy, Geary et al., 2017). Task order did not affect HCT, $t(132) = 1.855$, $p > .05$, or TAT, $t(132) = 1.252$, $p > .05$. After both tasks, participants estimated the average person's resting heart rate ('How many times do you think the average person's heart beats in one minute when they are at rest?'). Correlations between participants' raw estimates of average resting heartbeat and their own resting heart rate during the HCT (averaged across the last 60 s of the longest counting period examined; 100 or 103 s), revealed a positive trend ($r(132) = 0.169$, $p = .051$).

Participants' knowledge of average resting heart rate was calculated as the absolute difference between participant estimates and the grand mean of true resting heart rate reported in studies with large sample sizes (Agelink et al., 2001; Ramaekers, Ector, Aubert, Rubens, & Van de Werf, 1998; Grand mean = 72.26 beats per minute). Higher scores indicate less accurate knowledge about the average person's heart rate (Murphy, Geary et al., 2017).

4.3. Results: Study Two

As predicted, HCT performance was associated with IQ ($r(132) = 0.192$, $p = .026$), and negatively correlated with inaccuracy of average resting heart rate estimates ($r(132) = -0.211$, $p = .010$). IQ was also inversely associated with inaccuracy of average resting heart rate estimates ($r(132) = -0.363$, $p < .001$). Timing accuracy was not associated with inaccuracy of average heart rate estimates, IQ or HCT accuracy (all $p > .10$).

Mediation modelling was conducted using an SPSS macro (Process) (Hayes, 2013; Preacher and Hayes, 2008). For indirect effects, 95% (two-tailed) bias-corrected bootstrapped confidence intervals (CI's) were calculated using 10,000 repetitions. For indirect effects, CI's that do not cross zero are significant. Standardised values are reported. Knowledge of average resting heart rate fully mediated the relationship between IQ and HCT performance (*Indirect effect* = 0.063, $SE = 0.33$, $CI [0.01, 1.4]$), with no remaining direct effect observed (*Direct effect* = 0.13, $SE = 0.09$, $t = 1.42$, $p > .15$).

5. Discussion

The present studies sought to examine the relationship between IQ and performance on the HCT, and the mediating role of knowledge of average resting heart rate. In Study One (replication), IQ predicted HCT performance. Study Two (extension) replicated this finding, and found that 1) the relationship between intelligence and HCT performance was specific (no relationship between intelligence and timing accuracy was observed), and 2) knowledge of average resting heart rate mediated the relationship between IQ and HCT performance.

These findings replicate previous demonstrations of a relationship between intelligence and HCT performance (Mash et al., 2017), and extend these by suggesting that this relationship is mediated by the accuracy of participants' knowledge of the average resting heart rate. As such, these data are consistent with a body of research demonstrating the influence of beliefs and prior knowledge concerning heart rate on the HCT (Murphy, Geary et al., 2017; Phillips et al., 1999; Ring & Brener, 1996; Ring et al., 2015; Windmann et al., 1999).

If the HCT can be considered to be a measure of interoception, it is possible to speculate that these results demonstrate a true effect of intelligence on interoception; knowledge of the frequency of the signal to

be perceived (heart rate) may allow it to be detected and discriminated from other internal signals with greater accuracy. Alternatively, knowledge of the average heart rate may allow for better performance on the HCT without impacting interoception; knowledge of the average heart rate may allow those who cannot perceive their heart rate to perform well if they can either judge the length of time during which they are required to count their heartbeats, or count at a pace or rhythm that approximates their true heartbeat. The fact that other measures thought to quantify cardiac interoceptive accuracy, such as the heartbeat discrimination task (Whitehead, Drescher, Heiman, & Blackwell, 1977), are less susceptible to belief manipulations than the HCT (Phillips et al., 1999), points to the latter interpretation and are consistent with the proposal that even if the HCT does provide a measure of cardiac interoceptive accuracy, it is strongly influenced by beliefs and prior knowledge. Regardless of whether the effect is truly on interoception, these data show that when examining the relationship between the HCT and psychological factors, the contribution of beliefs and prior knowledge cannot be neglected.

Finally, it is important to acknowledge that whilst it is possible to speculate as to the direction of the effects obtained, the use of cross sectional data prevents such causal claims. Future research which manipulates participants' beliefs about their heartrate may allow us to examine whether prior knowledge is the mechanism by which intelligence confers better performance on the HCT.

Data declaration

The data presented in Study Two is part of a wider investigation reported in part in Murphy, Geary et al. (2017).

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