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## **How Might Interoceptive Accuracy Training Work?**

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## **Abstract**

With growing interest in interoceptive training to enhance the perception of internal bodily signals, there is a need to consider the mechanisms by which training may improve performance on tests of interoceptive accuracy (i.e., tests designed to measure how well signals from the body can be perceived). In this brief paper we use the example of cardiac interoceptive accuracy training to outline several possible mechanisms by which such training may result in improvement on tests of cardiac interoceptive accuracy. We show that under many of these mechanisms, evidence of improvement on tasks that claim to measure cardiac interoceptive accuracy does not reflect improvement in the perception of cardiac signals. We provide several recommendations to mitigate the potential influence of factors unrelated to interoceptive accuracy, enabling it to be determined that an improvement in interoceptive accuracy has occurred following training.

**Keywords:** Interoception; Cardiac Interoception; Cardiac Interoceptive Accuracy; Interoceptive Training; Biofeedback.

## **Highlights**

- There is growing interest in interoceptive accuracy training
- Here we assess how training may improve cardiac interoceptive accuracy test scores
- Improvement on tests may not always reflect increased interoceptive accuracy
- We conclude improvements may be driven by non-interoceptive factors
- Suggestions for isolating interoceptive and non-interoceptive effects are made

There is growing interest in the clinical potential of interoceptive accuracy training (Quadt et al., 2021; for a review see Ritz, Meuret & Corner, 2024) – training designed to increase the degree to which individuals can perceive their bodily signals. Such training may include simple biofeedback in which internal bodily signals are made perceivable through exteroceptive perceptual systems such as vision or audition, or the completion of tests of interoceptive accuracy with trial-by-trial feedback (e.g., Quadt et al., 2021; Schaefer et al., 2014; Sugawara et al., 2020; Meyerholz et al., 2018; Rominger, Graßmann, Weber, & Schwerdtfeger, 2021; Schenk et al., 2020; Schandry, & Weitkunat, 1990; Katkin, Blascovich, & Goldband, 1981; Schillings, et al., 2022; for a review see Köteles, 2024). While the effectiveness of such interoceptive accuracy training on clinical outcomes has yet to be established with any degree of certainty – as to our knowledge only one randomised control trial including interoceptive accuracy training has been published and the results were ambiguous with respect to interoception (Quadt et al., 2021) - we wanted to write this short piece to reflect upon how one might know if interoceptive accuracy training has indeed increased interoceptive accuracy. Indeed, despite a body of evidence dating back to the 1970's that suggests training often result in improvements on tests of cardiac interoceptive accuracy (for a review see Köteles, 2024), we think the jury is still out as to whether interoceptive accuracy can really be improved. We hope the following recommendations allow it to be determined whether interoceptive accuracy training has truly increased interoceptive accuracy, even when performance on tests that are designed to measure interoceptive accuracy improve following such training. As we argue in this piece, evidence of improvement in test scores may not always mean that changes are driven by improvement in the perception of bodily signals (for arguments in the same vein see Köteles, 2024; Schandry, & Weitkunat, 1990; Katkin, et al., 1981). It is well acknowledged that evidence of improvement on a particular test may arise from any one of a number of constituent processes

required for the test, even in the absence of an improvement in the process the test was designed to measure (e.g., improvements on tests of matrix reasoning following repeated testing is not taken as evidence for an improvement in intelligence; e.g., Staff, Hogan & Whalley, 2014), and the same is true in the area of cardiac interoceptive accuracy.

We focus on cardiac interoceptive accuracy given its predominance in the literature, but the points raised below would apply to other forms of interoceptive training that aim to improve the *perception* of internal signals specifically. Note that there are many ways that individuals may differ with respect to interoception other than the accuracy of perception, including attentional and evaluative processes, and there are many other interventions that are designed to, or may impact, these alternative aspects of interoception and improve clinical outcomes (see Köteles, 2024). Whilst the effectiveness of interoceptive interventions that may impact these alternative aspects of interoception also remains unclear – with a review of randomised control trials finding that only 50% were effective (Khoury, Lutz, & Schuman-Olivier, 2018) – none of these interventions involved interoceptive accuracy training designed to impact the accuracy of the perception of bodily signals. This review does not aim to be exhaustive and instead focuses specifically on interoceptive accuracy (specifically cardiac interoceptive accuracy), and training protocols designed to modulate this facet of interoception to improve clinical outcomes. The focus on cardiac interoceptive accuracy is due to the increase in the use of training protocols to increase this aspect of interoception across clinical groups in recent years (e.g., Quadt et al., 2021). We define cardiac interoceptive accuracy as the ability to correctly perceive heartbeat sensations and present the following mechanisms by which cardiac interoceptive accuracy (or at least scores on tasks that are designed to measure cardiac interoceptive accuracy) may improve following cardiac interoceptive accuracy training.

***1. Interoceptive accuracy increases through improved signal detection (i.e., improved perception)***

Possibly the most desirable scenario. Here a participant cannot feel their heartbeats when tested initially – they perform at chance - but comes to be able to do so as a result of training. This participant, whilst initially non-interoceptive (they would perform at chance on a valid test of cardiac interoceptive accuracy), is now interoceptive following training. This may occur if, for example, heartbeats were initially below the perceptual threshold, but biofeedback training allowed the participant to focus their attention on the temporal period in which heart beats occur. Such temporally-focussed attention may result in the signal becoming perceptible due to attentional modulation of the cardiac signal. There is a body of literature that demonstrates attentional effects on perception; for example, in vision, perception is enhanced by spatial cueing both before and after stimulus presentation, as well as temporal cueing (e.g., Sergent et al., 2013; Nobre & Van Ede, 2018). It is conceivable that perceptual improvements following cardiac interoceptive accuracy training could result from similar attentional mechanisms, whereby cueing attention to the temporal window where heartbeats occur enhances cardiac interoceptive accuracy (i.e. perception). Intuitively, however, it seems implausible that this could be sustained for an extended period of time. Perhaps more likely is a tactile equivalent of feature-based attentional selection in vision (e.g., Maunsell & Treue, 2006), where features (such as shape or colour) are selected for attention and, as a result, perception is enhanced (e.g., Rossi, & Paradiso, 1995). Whether perception of heartbeats via their tactile properties ‘counts’ as interoceptive accuracy is matter of debate, however, as some may view this route as non-interoceptive (Desmedt et al., 2023a; 2023b).

***2. Interoceptive accuracy does not improve – scores on a test of interoceptive accuracy improve through signal discrimination and recognition***

Under this scenario a participant could always feel their heartbeats, but were unable to recognise their heartbeats in the presence of other bodily signals (e.g., those related to respiration) and/or did not know it was their heartbeats that they were feeling. For example, biofeedback training in which heartbeats are presented to participants may allow them to learn which signals are their heartbeats and use those signals in subsequent tests of cardiac interoceptive accuracy. Alternatively, the training may act to reduce the noise masking the heartbeat signal (which might also be achieved through floatation therapy via sensory deprivation; Feinstein et al., 2018), or temporarily make the signal more perceptible (for example through instructed exercise or a stress-inducing procedure; Quadt et al., 2021; Schenk et al., 2020), allowing the cardiac signal to be recognised during a test of cardiac interoceptive accuracy (typically performed while at rest) following training. Such effects are somewhat analogous to inattention blindness demonstrated in the areas of visual and auditory perception (e.g., the “Gorilla Effect”; Simons and Chabris, 1999; Dalton & Fraenkel, 2012). Whilst the perception of cardiac signals has not improved (the participant was always able to perceive their heartbeat sensations), the participant is now able to distinguish their heartbeat sensations from other signals (i.e., signal discrimination) and label this sensation as their heartbeat (i.e., signal recognition). Whether such improvements are taken as evidence of an improvement in cardiac interoceptive accuracy depends on one’s definition of interoception. Indeed, many models of interoception separate perception (‘accuracy’ or ‘sensitivity’) from localisation of a sensation to a specific organ channel (‘discrimination’ or ‘localisation’) and one’s ability to consciously report (i.e., label the sensations as their heartbeats; ‘detection’; Khalsa et al., 2018; Desmedt et al., 2023b). Under these definitions, improvements on tests of cardiac interoceptive accuracy following training as a result of

these processes would not reflect a change in cardiac interoceptive accuracy as perception has not improved.

### ***3. Interoceptive accuracy does not improve – but participant learns to make interoceptive signals more perceivable***

Thus far, and previously (Plans et al., 2021), we have argued that how interoceptive accuracy is characterised is of crucial importance. This becomes especially relevant under this scenario as, when it is claimed that a participant is not interoceptive, what is typically meant in terms of cardiac interoceptive accuracy is that the participant cannot feel their heartbeats *at rest*, at a particular point in time (i.e., they perform at chance on a valid test). While a substantial proportion of individuals cannot feel their heartbeats at rest, it is likely that a large majority of individuals can feel their heartbeats in some circumstances - such as after vigorous exercise (see Katkin, 1985). If this is the case, then repeated practice on tests of cardiac interoceptive accuracy may result in the participant learning (consciously or unconsciously) to boost cardiac interoceptive signals such that they become perceptible (as argued also by Katkin et al., 1981). Such strategies may include breath holding or tensing of the muscles. As tasks of cardiac interoceptive accuracy do not separate signal strength from perceptual sensitivity (Desmedt et al., 2023a), under this scenario performance on tests of cardiac interoceptive accuracy are improved not through increased perceptual sensitivity, but by the participant learning strategies that boost signal strength. Whether improvements under this scenario are taken as evidence of improved cardiac interoceptive accuracy depends on one's definition of interoceptive accuracy. If we care only that participants can perceive their heartbeats, then learning strategies to boost heartbeat signals such that they can be perceived even without an increase in perceptual sensitivity may be taken as evidence of improvements in cardiac interoceptive accuracy. However, if the aim of cardiac interoceptive accuracy

training is to improve the *perception* of cardiac signals (i.e., to boost perceptual sensitivity in a similar manner to how spectacles improve distance vision in myopia – ‘nearsightedness’ – where far objects cannot be seen clearly), then learning strategies to boost signal strength would not be evidence of an improvement in cardiac interoceptive accuracy (as it would be akin to an individual with myopia learning to move closer to a visual stimulus in order to see it).

#### ***4. Interoceptive accuracy does not improve but participants learn test parameters***

Under this scenario interoceptive accuracy does not improve but participants learn test parameters which enable them to improve their scores. For example, cardiac interoceptive accuracy is often tested using the Heartbeat Detection Task (Whitehead et al., 1977), in which participants are asked to judge whether a series of tones occurs synchronously with their heartbeats. Participants are judged to be ‘interoceptive’ (able to perceive cardiac sensations) when they chose tones predefined to be synchronous with their heartbeat over tones predefined to be asynchronous with their heartbeat at above chance levels (Brener & Ring, 2016; Hickman et al., 2020). The tones predefined to occur synchronously with perceived heartbeats are typically presented approximately 200ms after the heart’s r-wave and the asynchronous tones presented approximately 500ms after the heart’s r-wave. In the vast majority of studies, a participant is only judged to be correct if they select the tones presented 200ms after the r-wave as synchronous (for reviews see Brener & Ring, 2016; Hickman et al., 2020). Problematically, although most individuals perceive tones with a delay of ~200-300ms as synchronous with their heartbeat, there are considerable individual differences in the delay following the r-wave at which individuals perceive tones to be synchronous with their heartbeats, with some participants showing an ‘inverse’ preference for the increased delay (see Brener & Ring, 2016; Brener et al., 1993; Ring & Brener, 1992; Betka et al., 2021). If a

participant is able to perceive their heartbeat sensations (i.e., they are interoceptive) but feel their heartbeat closer to the ‘asynchronous’ tone than the ‘synchronous’ tone<sup>1</sup>, they will be judged non-interoceptive before cardiac interoceptive accuracy training. If the cardiac interoceptive accuracy training consists of repeated performance of the Heartbeat Detection Task with feedback (Quadt et al., 2021; Sugawara et al., 2020), they will learn that choosing the ‘synchronous’ tone is required of them and suddenly appear interoceptive. Under this scenario, the participant was always able to perceive their heartbeats but appeared non-interoceptive because the delay following the r-wave at which they perceive their heartbeats did not match that predefined by the experimenter. As in other scenarios, in this case training does not improve interoceptive accuracy (i.e., their heartbeat perception is unaffected), instead they have learnt to respond ‘synchronous’ when the tone is presented at a delay of 200ms following the r-wave, rather than respond ‘synchronous’ when the tone aligns with their perceived heartbeats. Concerns regarding whether training has increased interoceptive accuracy (i.e. perception), or has simply increased familiarity with test parameters, have long featured in discussions regarding cardiac interoceptive accuracy training and are not restricted to the example provided above (cf. Schandry, & Weitkunat, 1990).

##### ***5. Interoceptive accuracy does not improve but the participant learns to ‘cheat’ at test***

This is a more extreme example of the scenario above and is made possible if a test susceptible to ‘cheating’ such as the Heartbeat Counting Task is used to assess cardiac interoceptive accuracy. In the Heartbeat Counting Task participants are required to count the number of times their heart beat during a set period, and their count is compared to an objective record (Dale & Anderson, 1978; Schandry, 1981). Despite being widely used,

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<sup>1</sup> Note that even if the task is scored such that a participant who selects tones presented at either delay at above chance levels is considered interoceptive, the same scenario would occur if a participant perceives tones to be synchronous with their heartbeat at a delay that falls between the delays used for the predefined synchronous and asynchronous tone series (see for discussion Ring & Brener, 1996).

completely non-interoceptive participants (participants who cannot perceive heartbeat sensations) can do well on this task if they know their resting heart rate. The issues with this task and other ‘estimation tasks’ have been extensively discussed in the literature and are too numerous to cover in depth (for detailed reviews see Brener & Ring, 2016; Desmedt et al., 2023a; Ferentzi, Wilhelm, & Köteles, 2022) but particularly relevant to cardiac interoceptive accuracy training is a body of evidence demonstrating that false heart rate feedback has a large effect on Heartbeat Counting Task scores. These data indicate that a large amount of the variance in Heartbeat Counting Task scores is attributable to heart rate estimation rather than the ability to perceive heartbeats (e.g., Phillips et al., 1999; Ring et al., 2015; Ring & Brener, 1996; Windmann et al., 1999).

A non-interoceptive participant who cannot feel their heartbeat and does not know their resting heart rate could learn their resting heartrate through biofeedback training or training involving performance of the Heartbeat Detection Task (where stimuli are always presented at the participant’s heartrate<sup>2</sup>; Sugawara et al., 2020). This participant may appear interoceptive after training as they can use knowledge of their heartrate gained through training to improve their performance on the Heartbeat Counting Task, even though they actually remain unable to feel their heartbeats (e.g., Schaefer et al., 2014; Meyerholz et al., 2018). Under this scenario, cardiac interoceptive accuracy has not improved following training (there is no improvement in the participant’s ability to perceive their heartbeats), but as their Heartbeat Counting Task performance has improved one may erroneously conclude that they have become interoceptive (i.e., able to feel their heartbeats) following training. The possibility that heart rate knowledge acquired during interoceptive training may enhance Heartbeat Counting scores in the absence of perceptual improvements may explain why

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<sup>2</sup> Note that even if the heartbeat counting task is completed before the heartbeat detection task during testing and training sessions as per Quadt et al., (2021), it is likely that participants would still learn their typical resting heart rate over the course of repeated training sessions.

training individuals to tap in response to their heartbeats in a given time window improves performance on the Heartbeat Counting Task (e.g., Meyerholz et al., 2018), but not the Heartbeat Detection Task (Rominger et al., 2021), as Detection Tasks are typically unaffected by heart rate knowledge (for a review see Brener & Ring, 2016).

### ***6. Interoceptive accuracy does not improve but other cognitive abilities essential for test performance improve***

Under this scenario, an interoceptive participant (a participant who can perceive their heartbeat) either fails, or scores poorly on, a test of interoceptive accuracy because they are not good at an aspect of the task unrelated to interoceptive accuracy (Knapp et al., 1997; cf. Schandry, & Weitkunat, 1990). For example, many tests of cardiac interoceptive accuracy require participants to switch between internally- and externally- focussed attention (attention switching), integrate signals in different modalities (multisensory integration), or sustain their attention towards cardiac sensations for a long duration (sustained attention; for a review see Desmedt et al., 2023a). If the interoceptive accuracy training improves these non-interoceptive aspects in a participant (e.g., domain-general attention switching capabilities), they may then pass (or improve their score) on interoceptive accuracy tests even though interoceptive accuracy itself may not have improved at all. For example, evidence suggests that general multi-sensory integration processes contribute towards performance on the Heartbeat Detection Task, with almost 25% of the variance in heartbeat detection ability explained by the ability to judge the simultaneity of exteroceptive (rather than interoceptive) stimuli such as lights and tones (Knapp et al., 1997). Importantly, evidence suggests that multi-sensory integration can be improved following training (O'Brien et al., 2023). In this scenario, if interoceptive accuracy training improves an interoceptive participants' ability to integrate stimuli where this was previously a problem, it would appear that training

had improved the participant's heartbeat perception when assessed with the Heartbeat Detection Task, even though the participant's ability to perceive heartbeats would in fact be unchanged. Thus, rather than a change in interoceptive accuracy, a change in participants' ability to perform non-interoceptive aspects of the task is the mechanism underlying improvements on tasks of cardiac interoceptive accuracy following training.

***7. Interoceptive accuracy does not improve, but perception of heartbeats becomes less stressful through exposure or provision of therapeutic materials***

Under this scenario, a participant is interoceptive (they are able to perceive heartbeats) but attending to their heart beats is stressful and/or anxiety inducing and this stress or anxiety impairs their performance on interoceptive accuracy tasks such that they appear non-interoceptive. Exposure to heart beats induced by interoceptive accuracy training may reduce the stress or anxiety associated with heartbeat perception (especially if accompanied by therapeutic materials designed to reduce this e.g., Quadt et al., 2021), meaning that the participant can demonstrate their interoceptive ability when tested post-training. Under this scenario, cardiac interoceptive accuracy training may be a useful therapeutic (as the stress/anxiety that is induced by attention to heartbeat sensations has been reduced), but improvements in performance following such training are due to reductions in stress and anxiety and not due to improvements in cardiac interoceptive accuracy. For this participant, one would predict similar improvements in performance on tasks of cardiac interoceptive accuracy simply through repeated attention or exposure to their heartbeats, without feedback aimed at improving cardiac *perception*.

If cardiac interoceptive accuracy training reduces the stress/anxiety induced by attending to heartbeat sensations, changes in the cardiac response over the course of training may also contribute towards improvements in test scores. To take an extreme example, consider an

interoceptive participant for whom attending to heartbeat sensations is extremely anxiety inducing. If in the initial testing session this individual had a heartrate of 200 beats per minute, resulting in an IBI of 300ms, then stimuli predefined to be synchronous and those predefined to be asynchronous in the Heartbeat Detection Task would occur at the same point in the cardiac cycle. Thus, the participant would have no basis to differentiate between the two and likely be labelled non-interoceptive. Even if heartrate was slightly lower, so that the point in the cardiac cycle is not *exactly* the same, the difference between the two may not be perceivable to the participant. If over the course of training the stress/anxiety induced by attending to heartbeat sensations is reduced, resulting in very little elevation in heart rate when attending to heartbeat sensations post-training, the participant may improve their test scores following training because the difference between the synchronous and asynchronous delays is now more discernible, and not because perception of heartbeats themselves has improved. Similarly, as performance in the Heartbeat Counting Task is often characterised by underestimation (see Ring & Brener 2016), a reduction in heart rate following training would also likely result in improved performance on the Heartbeat Counting Task as there would be less of a discrepancy between estimated and objectively recorded heartbeats even for a non-interoceptive participant. Again, such a performance improvement would occur via non-perceptual mechanisms and thus not indicate improved interoceptive accuracy.

### ***Recommendations***

The above presents 7 different mechanisms, all of which present as if interoceptive accuracy training has resulted in improved cardiac interoceptive accuracy, when in fact only one scenario involves a genuine increase in cardiac interoceptive accuracy. Some of these scenarios can be guarded against by using tests which cannot be passed using knowledge of heart rate even while not being interoceptive, or which do not make invalid assumptions

about the timing of heartbeat perception. For these reasons we favour using the Phase Adjustment Task as a measure of cardiac interoceptive accuracy (Plans et al., 2021; for a discussion of cardiac interoceptive accuracy measures see Brener & Ring, 2016; Desmedt et al., 2023a; Murphy & Bird, 2024). This task, or any other valid cardiac interoceptive accuracy task used to evaluate the effectiveness of cardiac interoceptive accuracy training, should be accompanied by a control (or at least screener) task to enable it to be seen whether non-interoceptive factors are responsible for, or relate to, improved task performance (addressing scenarios 4, 5 and 6). As discussed below, ideally training on a structurally identical exteroceptive control task should also be used to rule out the possibility that non-interoceptive factors contribute towards improvements in scores.

Other scenarios are addressed by avoiding the confound of cardiac interoceptive accuracy training with psychoeducational materials (scenario 7; Quadt et al., 2021), by measuring cardiac parameters (e.g., blood pressure, heart rate variability) across pre- and post- training testing sessions, and during training itself (scenarios 3 and 7), or by comparing the effectiveness of cardiac interoceptive accuracy training to cardiac interoceptive exposure without feedback aimed at improving perception (scenario 7). Further ways to address non-interoceptive effects (e.g., scenario 4) include demonstrating transfer effects of cardiac interoceptive accuracy training on valid tests of cardiac interoceptive accuracy not used during training, and ensuring that training effects are not confounded with general task practice effects (e.g., by including a control group completing cardiac interoceptive accuracy tasks without feedback; relevant also for scenario 7). Most challenging is distinguishing between scenarios 1 and 2, characterised by an improvement in the *perception* of cardiac signals vs. the *recognition/discrimination* of these signals, respectively. Whether we need to distinguish between these possibilities depends on the overall aim of training. In principle however, if participants can perceive but not recognise cardiac signals then psychoeducation

alone (e.g., information about the frequency and duration of heartbeats) should lead to successful performance on tests of cardiac interoceptive accuracy due to improved signal recognition. If cardiac signals cannot be perceived, then psychoeducation alone is unlikely to be effective. Through the same mechanism one may observe retrospective effects of biofeedback or psychoeducation – if the Heartbeat Detection Task is modified such that high tones accompany one delay and low tones the other, but the participant performs at chance due to a failure to recognise or discriminate their heartbeats, biofeedback or psychoeducation allowing them to recognise or discriminate their heartbeat may allow them retrospectively to recognise that one type of tone accompanied heartbeats on the test<sup>3</sup>.

We suggest that the following experimental design may help to isolate these different mechanisms and allow it to be determined whether perceptual improvements underlie changes in (clinical) variables of interest. Ideally, two valid tests of cardiac interoceptive accuracy would be administered at baseline alongside two structurally identical non-interoceptive control tasks. These tasks should be administered on several occasions at baseline, to control for any state effects on interoception, with cardiac parameters (e.g., blood pressure) also assessed. Several training regimes would ideally be compared across five groups: 1) interoceptive feedback training on one of the interoceptive tasks (with the training task counterbalanced across groups); 2) practice of the same interoceptive task (without feedback); 3) non-interoceptive training (e.g., training on the control task matched to the interoceptive task used in training); 4) interoceptive exposure (exposure to heartbeat sensations in the absence of a task or feedback); 5) and psychoeducation (regarding the frequency/temporal duration etc. of heartbeats). Throughout training, cardiac parameters should be assessed. Post-training, the same tests (interoceptive and control tasks) should be

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<sup>3</sup> It should be recognised that the use of the two-alternative forced choice version of the Heartbeat Detection Task is liable to incorrectly classify a proportion of individuals who can perceive their heart beats as non-perceivers (Ring & Brener, 2016).

repeated under the same conditions (on several occasions, whilst recording cardiac parameters), as well as the second valid test of cardiac interoceptive accuracy that did not feature in training. Only where interoceptive feedback training shows significantly greater improvements in performance compared to the other conditions on both the trained, and untrained, test of cardiac interoceptive accuracy (that cannot be attributed to changes in cardiac parameters) could we conclude that perceptual changes in cardiac interoceptive accuracy likely underlie improvements in scores.

For outcome variables (e.g., anxiety), the same principle applies. If interoceptive accuracy improvements contribute to improved outcomes, one would expect a significantly greater effect in the interoceptive training group when compared to the other groups, and that changes in interoceptive accuracy (difference scores comparing pre- and post-training) should be significantly better correlated with changes in the outcome variables of interest (e.g., anxiety) than the control task, and that this would be specific to the group who received interoceptive feedback training and not attributable to changes in cardiac parameters. To demonstrate that training targeting interoceptive accuracy is effective, we would expect to see a significantly greater differential correlation in this group compared to the other groups.

Where this is not the case (e.g., if the effect of interoceptive exposure on outcome variables such as anxiety is equivalent to that of interoceptive accuracy training), one would be unable to conclude that changes in cardiac interoceptive accuracy (i.e. perception of cardiac signals) underlie improved outcomes. In line with best practice, all planned analyses (including scoring of tasks) should be pre-registered and deviations from protocols should only be accepted as evidence of efficacy when replicated.

An improved focus on methods to show that interoceptive accuracy training truly improves interoceptive accuracy will enable any clinical effects of improved interoceptive accuracy to be established. If the overall aim of training is therapeutic benefits, then improvements under

scenarios 2 and 7, and potentially 3, may still be beneficial for some groups, but changes in cardiac interoceptive accuracy would not be the mechanism underlying clinical improvements. Indeed, a recent pre-print using conventional scoring methods for common measures of cardiac interoceptive accuracy, showed that changes in cardiac interoceptive accuracy following training were uncorrelated with changes in state and trait anxiety (Suksasilp et al., 2024), suggesting that changes in accuracy may not be the mechanism underlying clinical improvements.

Finally, it should be noted that interoceptive exposure alongside cognitive behavioural therapy is already a well-established treatment, and it remains to be established whether training targeting cardiac interoceptive accuracy yields additional therapeutic benefits, or indeed whether it has negative effects (Ritz et al., 2024; Köteles, 2024). Indeed, the existing evidence on training perception of airway obstruction (Feldman et al., 2012; Janssens & Harver, 2015), plus models of panic and anxiety (Clark, 1999), suggest that training interoceptive accuracy alone may produce negative outcomes (for a discussion see Ritz et al., 2024). This work highlights the importance of determining the exact mechanisms underlying any improvements in interoceptive accuracy following interoceptive accuracy training.

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**Conflict of interest**

JM and GB have completed paid consultancy work for Healios for work on interoception.

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