

Accepted manuscript: Behavior Therapy, 2021.

[DOI10.1016/j.beth.2021.02.010](https://doi.org/10.1016/j.beth.2021.02.010)

**Nonsuicidal Self-injury is associated with Attenuated Interoceptive
Responses to Self-critical Rumination**

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Acknowledgements: We would like to thank Swansea University for supporting this research.

Competing interests: The authors declare no competing financial interests.

Funding: We received no external funding for this study.

Abstract

Nonsuicidal self-injury (NSSI) is a prevalent and dangerous behavior. Those with a history of NSSI often report high levels of self-critical rumination (SCR), a form of negatively-valenced introspective self-referential processing. It is plausible that this overly analytical style of relating to the self might hinder the ability to process interoceptive signals, thereby increasing the capacity to engage in behaviors that cause bodily harm. Two studies investigated whether trait or state SCR influenced aspects of interoception in those with and without a history of NSSI. In Study 1 ($N = 180$), irrespective of NSSI history, trait SCR was associated with finding attending to the heartbeat unpleasant. However, no associations were observed for interoceptive confidence, or metacognitive insight into their interoceptive abilities (confidence-accuracy correspondence). Trait SCR was associated with having higher interoceptive accuracy, but only in those without a history of NSSI. In Study 2 ($N = 98$), irrespective of NSSI history, state self-criticism led to a more negative interoceptive valence, and reduced participant's metacognitive insight. In those without a history of NSSI, state self-criticism also increased interoceptive accuracy; an effect attenuated in those with NSSI. These findings suggest that those with NSSI are characterised by a blunted interoceptive response to negatively-valenced self-focused attention.

Keywords: Interoception, Rumination, Self-criticism, Self-focused attention, NSSI.

Nonsuicidal Self-injury is associated with Attenuated Interoceptive Responses to Self-critical Rumination

Nonsuicidal self-injury (NSSI) is the deliberate and direct destruction of one's own body tissue (Claes & Vandereycken, 2007) with recent reviews concluding that NSSI may increase the risk of suicide (Franklin et al., 2017; Hamza et al., 2012). Therefore, understanding the etiology of self-injurious behavior is a priority.

In recent years, interoception (i.e., the detection and perception of signals originating from inside the body (DeVile et al., 2020) has emerged as an important correlate of a range of mental health problems. Indeed, those who engage in NSSI consistently report difficulties understanding their internal states (Dodd et al., 2017; Hagan et al., 2019). It has been suggested that reduced interoceptive sensitivity might lead one to feel disconnected from bodily experiences - thereby increasing the capacity to engage in behaviors that cause physical harm (Forrest et al., 2015). Consistent with this hypothesis, those who had attempted suicide were better able to tolerate a breath-hold and cold-pressor challenge, and had lower heartbeat perception accuracy (DeVile et al., 2020). These findings highlight the importance of further understanding interoceptive abnormalities in those who engage in self-injurious behaviors.

Interoception is considered a form of self-referential processing that involves the neural representation of internal signals such as the heartbeat (Qin et al., 2020). Several authors have suggested that there might be an association between interoception and the processing of other self-related stimuli, including higher-level processing such as self-related traits. In this context, it is relevant that self-criticism (i.e., judgmental, condemning, and attacking thoughts directed to the self) has been identified as an important factor predicting NSSI. Although most research is cross-sectional (for a review see Zelkowitz & Cole, 2019), some longitudinal studies have supported that self-criticism is a potential risk-factor for NSSI (Fox

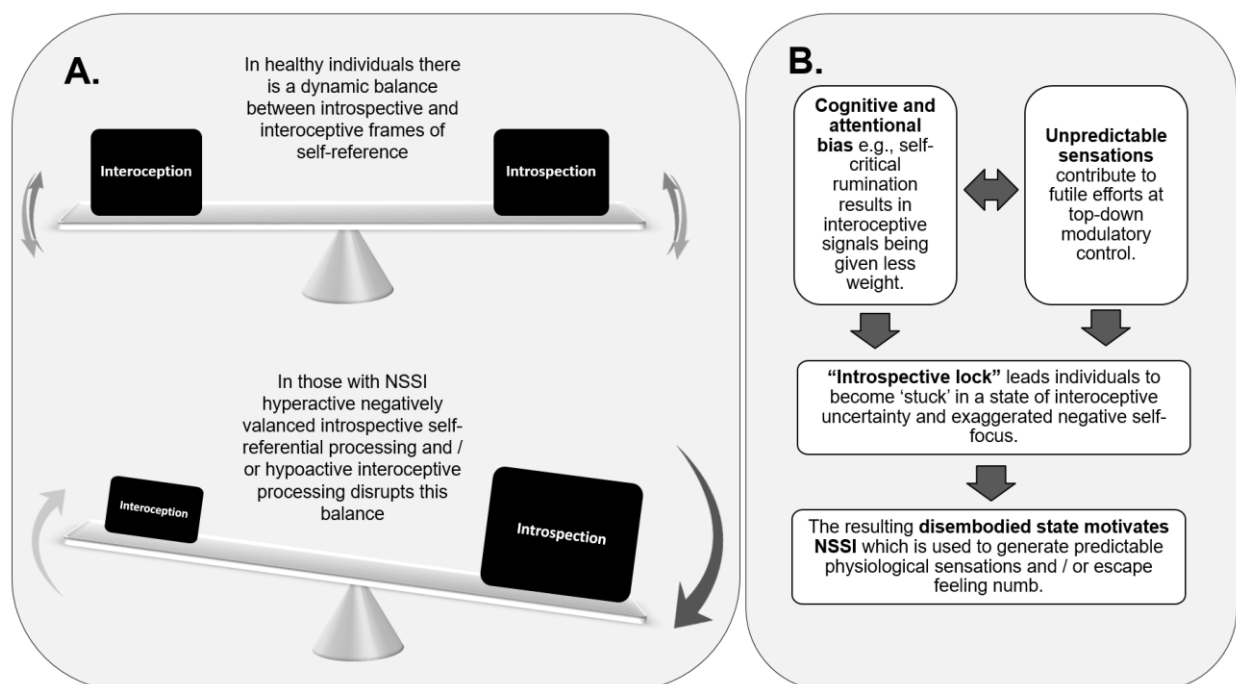
et al., 2018; Perkins et al., 2020). Theoretical models have been produced to account for this association. For example, The Benefits and Barriers Model of Nonsuicidal Self-Injury (Hooley & Franklin, 2018) stipulates that the desire to avoid pain is one of five barriers that prevents most people using NSSI. Further, self-criticism helps individuals to overcome this barrier because it generates the belief that one deserves pain and punishment (Fox et al., 2019; Hooley & Franklin, 2018). Indeed, compared to controls, those who used NSSI had higher pain thresholds, were willing to endure pain for longer, and found pain less unpleasant (for a review see Kirtley et al., 2016). In addition, low self-worth correlated with pain endurance (Fox et al., 2017; Hooley et al., 2010), and was associated with having a less aversive response to pain (Fox et al., 2019).

However, the sensory deficits in those with NSSI and self-criticism, might also reflect a dissociation from bodily signals. Following a review of the self-referential processing literature, Frewen et al (2020) developed a framework to explain how individuals can, via an attention like mechanism, switch between different views of the self. Briefly, two important aspects of self-referential processing are introspective (i.e., cognitive / evaluative) and interoceptive (Frewen et al., 2020). Trait differences in the balance between these frames of reference may explain dispositions towards particular psychological disorders (Frewen et al., 2020). For example, hyperactive introspective self-referential processing may underlie persistent negative thoughts about the self, such as shame, guilt, or worthlessness (Frewen et al., 2020). From this perspective, individuals may become 'locked' into a disembodied analytical view of the self, thereby making switching to an interoceptive focus more difficult. Previously, Paulus and Stein (2010) proposed that an inability to differentiate interoceptive signals may itself contribute to an 'over activity' of self-relevant processing, and attempts at 'top-down' control. In this view, 'angst driven' thoughts about the self are a by-product of a dysfunctional interoceptive system. Together these perspectives imply that there might be a

‘circular causality’ between higher-level self-referent processing and interoception (Figure 1A and B). However, there are limited empirical data to support these views, and a deeper understanding of these processes is required.

Figure 1.

The Introspective Lock Hypothesis: A Conceptual Model of the Association between Interoception, Self-critical Rumination and NSSI



Note. Self-critical rumination is conceptualised as a form of negatively-valenced introspective self-referential processing. **A.** Healthy individuals can switch between an interoceptive and introspective view of the self; this balance is disrupted in NSSI. **B.** An overly analytical style of relating to the self may interfere with the ability to process interoceptive signals. In turn, unpredictable internal sensations could contribute to an increased self-focus in an attempt to clarify what is being felt. This self-perpetuating cycle essentially ‘locks’ individuals into a disembodied state whereby individuals feel detached

from their bodily experiences. This motivates the use of NSSI to generate predictable physiological sensation and / or escape feeling numb.

It is therefore proposed that the introspective frame of reference associated with self-criticism may produce a disembodied state, which interferes with the ability to process afferent bodily sensations. It is possible that some individuals may be unable to disengage from this state hindering the ability to detect interoceptive signals, and use them to inform what is being felt. If correct, this might explain why some individuals report using NSSI to feel ‘something physical’, or to stop feeling ‘numb’ (Edmondson et al., 2016). To test these ideas, two studies examined the effects of *trait* (Study 1), and *state* (Study 2) self-criticism on aspects of interoception, in those with and without a history of NSSI. Based on the reviewed literature, it was hypothesized that those with a history of NSSI would be characterised by self-criticism and deficits in interoception. Additionally, in those with NSSI self-criticism would be associated with having poorer interoceptive abilities.

Study 1: Method

Participants

Participants from the local area were recruited through posters on university notice boards and online adverts on popular social media websites (e.g., Facebook) and online forums (e.g., Reddit). To ensure adequate numbers per group, two adverts were produced – one general advert which did not ask for a history of NSSI, and another seeking volunteers only with a history of NSSI, although in practise all data were collected simultaneously. Those recruited through the general advert that reported a NSSI history were subsequently moved into the NSSI group. No reward was offered for participation. Respondents were excluded if they had a cardiovascular or metabolic disorder, or were pregnant as these factors may influence the interoception task (Young et al., 2019). Given the novelty of the present research question, no prior information about the expected effect size was available.

Therefore, the present sample size (we had aimed to recruit approximately 90 participants per group) was based on previous research examining NSSI and body related constructs (Muehlenkamp & Brausch, 2012), self-criticism and NSSI in relation to other physical sensations (e.g., pain) (Fox et al., 2019), and studies assessing heartbeat perception and other behaviors (Young et al., 2017). Shortly after data collection was completed an effect size became available for the link between rumination and interoceptive accuracy (Schlinkert et al., 2020: Study 2). In the event this suggested that our study was adequately powered. In total the sample comprised 99 females and 92 males with a mean age of 26.72 (11.22). Where random data points were missing for individual items on a scale this was managed via mean substitution – this affected < 2% of the participants. There were 88 participants who self-reported a current or lifetime history of five or more episodes of NSSI. A further 103 participants reported no history of NSSI and served as a comparison sample. Within the NSSI group, 16 reported a history of suicide attempt; 41 reported a psychiatric diagnosis of depression, 19 reported an anxiety disorder, 14 reported eating disorders, and seven reported a personality disorder. Within the no NSSI group, two reported a history of suicide attempt, 16 reported depressions, 12 reported an anxiety disorder, 10 reported eating disorders, and two reported a personality disorder.

The level of endorsement of each NSSI behavior was: 60.5% cutting, 37.2% biting, 26.5% burning, 19.0% carving, 48.3% pinching, 34.9% pulling hair, 57.5% severe scratching, 52.7% banging or hitting self, 47.9% interfering with wound healing, 81.1% grazing skin, 8.2% sticking self with needles, and 21.8% swallowing dangerous substances. Almost all (96.2%) reported more than one type of NSSI behavior. Four individuals who reported a single episode of NSSI were excluded as this may indicate an uncharacteristic act. Seven individuals reported only less harmful forms of NSSI (e.g., pinching, hair pulling, grazing skin, scratching) and were also excluded. Therefore, the analysis proceeded with a sample of

180 participants of which 77 participants endorsed a current or lifetime history of NSSI. This sample of 77 individuals had a median frequency of 10 NSSI episodes during the last year, and 33 lifetime episodes. There were 75 individuals who met the DSM-5 proposed NSSI criterion A, which are five or more instances of NSSI within the last year. All analyses were repeated with only those meeting the criterion A. As this did not influence the results the analysis with all 77 NSSI participants is reported.

Procedure

Participants first provided their written informed consent, then they had conventional Ag/AgCl electrodes and transducers applied, and connected to a BIOPAC MP150 and ECG100C amplifier module (BIOPAC, USA). The interoception test detailed below was then completed. Subsequently, participants completed questionnaires on a computer using a link to the secure online survey platform (Qualtrics). Questionnaires were presented to the participants in random order, with the exception of the demographics questionnaire, which all participants completed last. The procedure took approximately forty minutes to complete. Ethical approval was gained from the Swansea Psychology Department ethics committee and the study was carried out in accordance with the Declaration of Helsinki - Ethical Principles for Medical Research Involving Human Subjects.

Questionnaire Measures

Positive and Negative Affect Scale (PANAS). Previously it was observed that negative affect was associated with interoception (Dunn et al., 2007). Additionally, those with NSSI often report high levels of negative affect (Hooley & Franklin, 2018). Therefore, in this study, the negative affect scale was used as a covariant. The PANAS (Watson & Clark, 1984) comprises two 10 item scales which measure the degree of positive and negative

affect on 5-point Likert-type scales. In the present sample the Cronbach's alpha for the negative scale was .89.

Self-Critical Rumination Scale (SCRS). Both the *style* (i.e., perseverative and self-directed), and the *content* (i.e., self-degrading), of rumination are important in the etiology of NSSI, and have the potential to influence interoception. Therefore, the 10 item SCRS (Smart et al., 2016) was used. This scale specifically assesses repetitive thinking about negative self-evaluations. For example, “*My attention is often focused on aspects of myself that I’m ashamed of*”. Instructions for the scale were: “Please rate how well each item describes you.” The Likert-type scale ranged from 1 to 4 (1 = not at all, 2 = a little, 3 = moderately, 4 = very much). The scale has good psychometric properties including high internal consistency and construct validity (Smart et al., 2016). Cronbach's alpha in the present study was 0.96.

Inventory of Statements about Self-Injury (ISAS). The frequency and functions of NSSI were measured using the ISAS (Klonsky & Glenn, 2009). The first section of the ISAS was used which measures the lifetime frequency of 12 NSSI (e.g. cutting, burning, biting) behaviors performed “intentionally (i.e., on purpose) and without suicidal intent”.

Interoception

To assess interoception we adopted the multidimensional model suggested by Garfinkel et al. (2015), which distinguishes between the interoceptive dimensions *interoceptive accuracy* (performance on objective interoception tasks e.g., heartbeat tracking) (IAc), and *interoceptive awareness* (meta-cognitive awareness of IAc i.e., confidence-accuracy correspondence) (IAw). In addition, recent findings suggest that some populations may not differ in their ability to detect internal signals but instead affectively experience them as more aversive (Strigo et al., 2013). Therefore, we also considered participant's affective response while attending to their heartbeat.

Interoceptive Accuracy. Participants performed a computerised heartbeat counting task (Schandry, 1981) with intervals of 20, 30 and 40s that were separated by 30s rest periods. Prior to each trial, a timer counted backwards from three, and the word ‘start’ appeared. Then the screen went blank and participants silently counted their felt heartbeat until ‘stop’ appeared on the screen. During each trial R-R heartbeat intervals were recorded via the BIOPAC. Participants were clearly instructed to only report perceptually felt heartbeats and not to guess or use of an exteroceptive aid (such as taking one's pulse) (Desmedt et al., 2020). At the end of each period participants reported the number of felt heartbeats using the computer keyboard. The participants were not informed about the length of the counting phases, nor about the quality of their performance. After the heartbeat counting task, participants completed a parallel task where they estimated the number of seconds that had passed. To control for any potential effects of time estimation, the transformation $1 - \frac{\sum ((\text{abs}(\text{actual HR} - \text{time estimation}) / (\text{actual HR} + \text{time estimation})) + ((\text{abs}(\text{actual HR} - \text{reported HR}) / (\text{actual HR} + \text{reported HR})) / (\text{actual HR} + \text{reported HR} + \text{time estimation}))}{2}$ was used to calculate heartbeat tracking scores (Desmedt et al., 2020). These scores were then averaged to form a mean heartbeat tracking score (Interoceptive accuracy). The interoception score varied between 0 and 1 with a higher score indicating better accuracy. This measure assesses the correspondence between an individual's beliefs about cardiac sensations and actual heartbeats. The internal consistency of this measure was good: Cronbach's $\alpha = 0.84$.

Interoceptive Awareness. At the end of each trial, participants were asked to indicate, on a computerised visual analogue scale (VAS), how confident they were in their own accuracy where 0 indicated “*Not at all confident*” and 100 “*Completely confident*”. The within-participant Pearson correlation, r , between confidence and accuracy provided an index of IAw (Garfinkel et al., 2015). This index is a measure of participant's meta-cognitive

insight into their interoceptive abilities. To establish effects on, and to control for, metacognitive bias i.e., trait over / under confidence, a mean confidence score was also calculated.

Interoceptive Affective Response. At the end of each heartbeat counting trial participants rated how pleasant they found focusing on their heartbeat using a computerised VAS with 0 indicating “*Extremely unpleasant*” and 100 “*Extremely pleasant*”. The mean pleasantness rating was used to indicate the participant’s affective response to attending to their interoceptive signals.

Statistical Analysis

Sample characteristics were described using means, standard deviations and frequencies and reported above. Initially, the univariate association between self-critical rumination and NSSI was established, as well as the multivariate associations between the interoceptive indices and NSSI. These analyses were necessary to support our model as hitherto it has not been established whether the present interoceptive indices differ in NSSI. This analysis is available as [supplementary information](#). To summarise, it was confirmed that those with a history of NSSI had higher levels of *trait* self-criticism. Those with NSSI had less confidence in their ability to report how many heartbeats were felt, and they had a negative affective response to attending to their heartbeat (Supplementary Table 1). Additionally, those with the most frequent NSSI were less accurate in detecting their heartbeat which is consistent with the suggestion that a decreased connection to the body might facilitate self-injurious behaviors (DeVille et al., 2020) (Supplementary Table 2). To examine our hypothesis that in those with NSSI *trait* self-critical rumination would be associated with interoception, partial correlations were used. To examine whether the pattern of associations varied according to NSSI history, two separate matrices were examined in

those with and without NSSI. To control for negative affect, this factor was entered as a covariant in both analyses. Shapiro Wilks test determined that the dependant variable (self-critical rumination) was normally distributed in both samples: NSSI ($p < 0.08$) and No NSSI ($p < 0.07$). Additionally, inspection of the normal Q-Q plot showed that residuals followed a normal distribution, with the exception of interoceptive awareness which was slightly over-dispersed. Cook's distance was used to detect possible outliers (Cook, 1977). To avoid removing excess variability we set a liberal threshold of 0.1. Cases with a Cook's Distance exceeding this threshold were excluded and the data re-analysed. Given the large number of associations tested in the present study Benjamini and Hochberg's false discovery rate (FDR) was employed. The FDR was controlled at $\delta = 0.05$ (Benjamini & Hochberg, 1995).

Study 1: Results

Associations between Self-critical Rumination and Interoception

Within the no-NSSI group, one case was identified as an outlier: Cook's distance > 0.1 . As removing this case did not alter the results, the case was retained. After accounting for negative affect, interoceptive accuracy was positively associated with self-critical rumination ($r = 0.232, p < 0.018$). In addition, higher self-critical rumination was associated with perceiving internal sensations as more unpleasant ($r = -0.477, p < 0.0001$). However, there was no associations between self-critical rumination and interoceptive awareness ($r = -0.111, p = 0.263$), or self-critical rumination and confidence ($r = 0.021, p = 0.832$).

When those who had used NSSI were considered, those high in self-critical rumination reported experiencing their internal sensations as more unpleasant ($r = -0.385, p < 0.001$). However, self-critical rumination was not associated with any of the other interoceptive indices: interoceptive accuracy ($r = -0.052, p = 0.658$), interoceptive awareness ($r = -0.131, p = 0.259$), and confidence ($r = 0.195, p = 0.091$).

Study 1: Summary

In those with and without a history of NSSI, *trait* self-critical rumination was associated with finding focusing on the heartbeat to be more unpleasant. Although more research is needed, this finding suggests that negative biases associated with self-criticism may extend to the way ambiguous (internal) information is interpreted. A key finding was that in those with NSSI, self-critical rumination was not associated with a lower heartbeat counting accuracy. Thus our hypothesis that in those with NSSI, self-criticism would be associated with a poorer ability to attend to internal signals was not supported (discussed further in the main discussion). However, in the non-NSSI group, self-critical rumination was associated with having *better* heartbeat counting performance. Tentatively, these findings suggest a blunted modulation of interoceptive processing in response to negatively-valenced self-focused attention in those with NSSI. To further explore this effect, a second study was conducted to assess the interoceptive response to *state* self-criticism in those with and without NSSI. To determine whether the valence of self-focused attention was important, Study 2 also included a self-compassion manipulation.

Study 2: Method

Participants

Participants were recruited through Swansea University participant pool. As in Study 1, two adverts were produced – one general advert did not ask for a history of NSSI, and another sought only volunteers with a history of NSSI. To maximise sample homogeneity only adult females were recruited for this study (mean age 23.20 (9.65)). The sample size was based on the expected power for a between-subject interaction calculated using G*Power based on the following parameters: six between-subject groups (three self-attention conditions, two NSSI groups), $\alpha = 0.05$, a two-tailed test, and 80% power to detect a

medium-large sized effect (Cohen's $f = 0.3$). This gave an estimated total sample size requirement of $N = 90$. In total, 98 participants took part of whom 49 endorsed a past year history of using NSSI five or more times. Only participants endorsing no-NSSI or more serious forms of NSSI were invited to take part. Other exclusion criteria were the same as Study 1. The level of endorsement of each NSSI behavior was: 72.2% cutting 43.7% biting, 39.3% burning, 21.9% carving, 56.5% severe scratching, and 18.8% swallowing dangerous substances. Almost all (97.4%) the NSSI participants reported more than one type of NSSI behavior. For the purposes of the present study participants were classified as either having, or having not used NSSI.

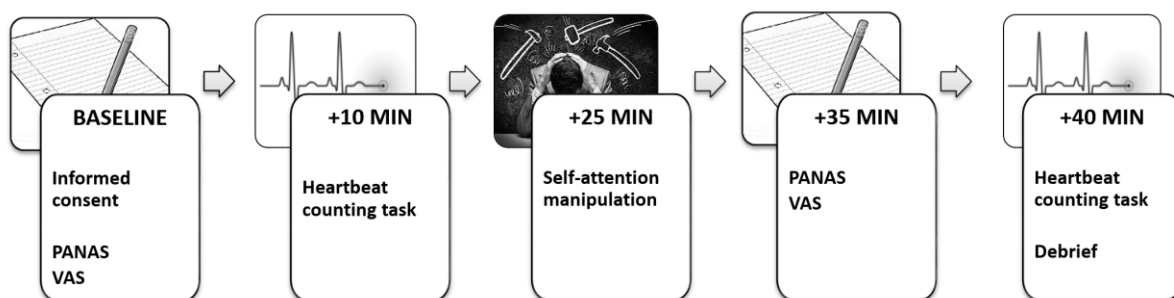
Procedure

Before arriving at the laboratory participants completed the ISAS online via Quatrics to assess NSSI history and frequency. Participants who reported using NSSI five or more times in the previous year were invited to take part in the laboratory based experiment. Those who reported never having used NSSI served as a comparator group. The procedure is outlined in Figure 2. Participants provided their written informed consent, then rated their current level of negative affect, self-criticism, and self-compassion. Next they completed the heartbeat counting task as described in Study 1. Participants were then allocated to one of the three self-attention conditions: self-criticism, self-compassion, or neutral. Based on the findings from Study 1, baseline differences were anticipated in self-criticism and interoception between NSSI groups. Therefore, to avoid difficulties with regression to the mean, NSSI and control participants were matched on their baseline interoception and affect scores, and an even distribution across conditions was ensured (Table 1). This was achieved by enrolling a large number of non-NSSI participants and selecting those who had a 'match' in the NSSI group. The remaining participants who did not have a match subsequently took part in a

different study (data not reported here). Immediately, after the self-attention manipulation, participants again rated their current level of negative affect, self-criticism, and self-compassion, and completed the heartbeat counting task for a second time. Overall, the procedure lasted approximately 55 minutes and to avoid effects of circadian rhythms e.g., cortisol and heartrate, all participants were tested in the afternoon. The procedure was approved by Swansea University ethics committee and carried out in accordance with the Declaration of Helsinki - Ethical Principles for Medical Research Involving Human Subjects.

Figure 2.

The Experimental Procedure used in Study 2



Interoception, Affect and NSSI measures

NSSI and affect data were collected using the methods described in Study 1. The items that comprise the negative affect scale of the PANAS were used to assess negative affect before and after the manipulation – for the ‘after’ rating participants reported how they felt at that moment. The heartbeat counting task was performed, and interoceptive indices were calculated, as described in Study 1.

Self-attention Manipulation

Self-criticism. Participants were given three minutes to write about a negative event that they experienced that made them feel bad about themselves—something that they did

wrong or had failed at. They were told to describe the event in as much detail as possible, including how they felt about themselves during the event. For the second three minutes they were explicitly asked to critically evaluate some ways in which the event that occurred was their fault expressing disapproval of what happened and how they acted during the event.

Self-compassion. Arguably, self-compassion is most relevant in the context of self-criticism (Neff, 2003). Therefore, to maintain consistency with previous research that has manipulated self-compassion (e.g., Breines & Chen, 2012; Petrocchi et al., 2017), the first three minutes were identical to the self-criticism condition. However, during the second three minutes, participants were asked to describe some ways in which other people also experience similar events. They were told to write expressing understanding and kindness to themselves in the same way that they might talk to a friend who had undergone the same experience. They were told to try not to judge themselves or how they acted during the event.

Neutral. Participants wrote for six minutes about a non-emotional story they had recently seen on TV or read. The aim here was to limit participant's self-focused attention.

To ensure adequacy of the manipulation, all scripts were rated by two independent researchers on their self-criticism / compassion content. This information is available as supplementary information. Although the self-attention manipulation was short it was similar to previous research that examined rumination in NSSI (Selby et al., 2009), self-focused attention on interoception (Ainley et al., 2012), rumination on other cardiovascular and hormonal responses (Ottaviani et al., 2016), and self-compassion on aspects of psychology (Breines & Chen, 2012).

Self-criticism / Self-compassion Measurement

Before and after the self-attention manipulation, participants were asked to answer the following questions using computerised 100mm visual analogue scales (VAS) anchored by

'Extremely' and 'Not at all': 'How self-critical do you feel right now?' and 'How self-compassionate do you feel right now?' A number of distractor VAS were also used e.g., 'How tired do you feel right now'. These are not reported.

Table 1

Baseline scores for those who with and without a history of NSSI and who took part in the self-attention manipulations

| | Self-criticism | | Self-compassion | | Neutral | | <i>F</i> value for Group x NSSI interaction |
|------------------------|-----------------------|--------------------------|-----------------------|--------------------------|-----------------------|--------------------------|---|
| | NSSI <i>n</i> = 18 | No NSSI <i>n</i> = 18 | NSSI <i>n</i> = 18 | No NSSI <i>n</i> = 18 | NSSI <i>n</i> = 13 | No NSSI <i>n</i> = 13 | |
| Self-compassion | 52.4(15.9) | 47.1(23.2) | 60.2(28.2) | 43.0(22.5) | 51.6(24.3) | 42.6(29.3) | 0.169 |
| Self-criticism | 42.5(21.2) | 48.5(26.9) | 48.7(24.7) | 43.2(15.1) | 54.0(19.5) | 54.0(24.2) | 1.886 |
| Negative affect | 14.4(3.2) | 15.1(4.1) | 16.6(5.2) | 16.6(4.2) | 16.2(3.7) | 18.9(9.6) | 0.821 |
| IAc | 0.78(0.11) | 0.77(0.15) | 0.77(0.11) | 0.75(0.16) | 0.77(0.15) | 0.82(0.12) | 0.513 |
| IAw | 0.35(0.33) | 0.36(0.51) | 0.21(0.38) | 0.19(0.47) | 0.27(0.44) | 0.16(0.48) | 0.072 |
| Confidence | 40.5(20.3) | 44.5(21.1) | 47.5(15.2) | 41.6(18.5) | 45.5(18.0) | 44.9(20.4) | 0.939 |
| Pleasantness | 49.5(17.7) | 48.8(16.6) | 47.1(21.4) | 47.1(21.5) | 47.8(17.2) | 49.9(19.7) | 0.089 |

Note. Participants were successfully matched such that there were no statistically significant baseline differences. IAc – interoceptive accuracy, IAw – interoceptive awareness, NSSI – nonsuicidal self-injury.

Statistical Analysis

Sample characteristics were reported above and a multivariate ANOVA confirmed that groups were well matched at baseline (Table 1). To establish whether the self-attention manipulation had been successful a 3 (Self-criticism / Self-compassion / Neutral) x 2 (NSSI / No NSSI) univariate ANOVA was conducted on the change in negative affect (PANAS) and self-criticism (VAS) and self-compassion (VAS). Similarly, to determine whether self-

criticism / compassion influenced interoception in those with / without NSSI data were analysed using a series of 3 (Self-criticism / Self-compassion / Neutral) x 2 (NSSI / No NSSI) univariate ANOVAs. Benjamini and Hochberg's false discovery rate (FDR) was applied to the omnibus test. The FDR was controlled at $\delta = 0.05$ (Benjamini & Hochberg, 1995). Bonferroni t tests were used to probe significant interactions. Inspection of the normal Q-Q plot showed that residuals followed a roughly normal distribution. As in Study 1, Cook's distance with a threshold of 0.1 was used to detect possible outliers (Cook, 1977).

Study 2: Results

Manipulation Check

Our manipulation checks confirmed that the paradigm was successful. Those in the self-criticism group had an increase in self-criticism and negative affect, whereas those in the self-compassion and neutral did not. In addition, those in the self-compassion group had an increase in self compassion compared to the other groups. This analysis is available as supplementary information.

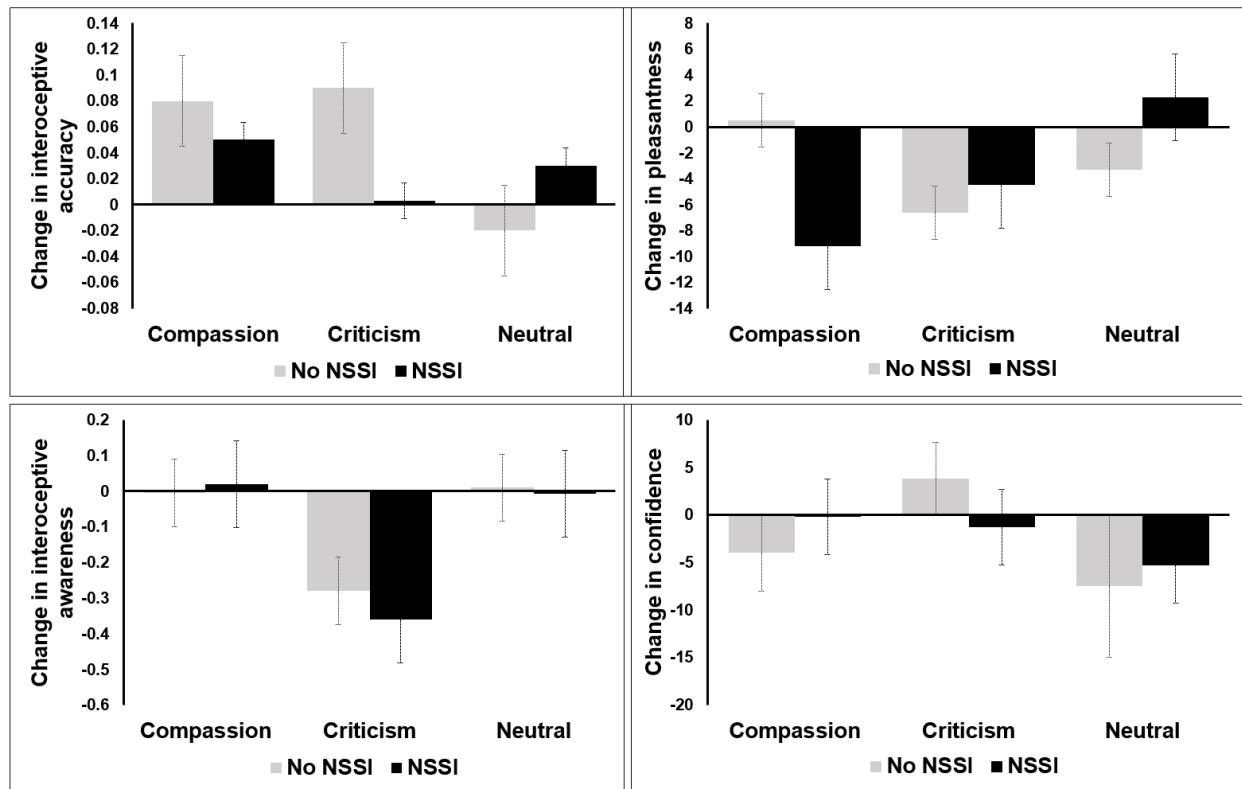
Interoceptive Accuracy (IAc)

The main effect of NSSI was not significant ($F = (1, 92) = 0.865, p = 0.355, \eta^2 = 0.009$), however, there was a significant main effect of group ($F = (2, 92) = 3.227, p = 0.044, \eta^2 = 0.066$). Interoceptive accuracy increased in the self-compassion condition compared to the neutral condition ($p < 0.014$). The self-compassion and the self-criticism groups did not differ ($p = 0.394$). There was a tendency for those in the self-criticism condition to have an increase in interoceptive accuracy compared to the neutral condition, although this did not reach significance ($p = 0.086$). In addition, the Group X NSSI interaction was significant ($F = (2, 92) = 3.711, p = 0.028, \eta^2 = 0.075$), however, as the FDR q value for this interaction

was 0.025 this effect should be interpreted with cautiously. Nonetheless, follow-up tests revealed that in the self-criticism group there was a significant difference in the degree of interoceptive accuracy change between those with a history of NSSI and those without ($p < 0.012$) (Figure 3). The same differences in the self-compassion ($p = 0.433$) and neutral ($p = 0.166$) conditions were not significant. In addition, in those without a history of NSSI there was a significant difference between the neutral and the self-criticism ($p < 0.002$), and the neutral and self-compassion ($p < 0.005$) conditions, although no difference was observed between self-criticism and self-compassion conditions ($p = 0.777$). In those with a history of NSSI, there were no differences between conditions (all $p > 0.1$). This pattern of findings suggested that self-focused attention in the form of either self-criticism or self-compassion increased interoceptive accuracy in non-NSSI individuals. However, this increase in interoceptive accuracy was attenuated in those with NSSI, particularly in response to self-criticism (Figure 3).

Interoceptive Awareness (IAw)

One outlier (Cook's distances > 0.1) was identified and removed from the self-criticism condition. The interaction Group X NSSI was not significant ($F = (2, 91) = 0.069, p = 0.934, \eta^2 = 0.002$), as was the main effect of NSSI ($F = (1, 91) = 0.049, p = 0.825, \eta^2 = 0.001$). However, there was a main effect of group ($F = (1, 91) = 3.403, p = 0.038, \eta^2 = 0.070$). Follow-up tests revealed a significant decrease in interoceptive awareness in all participants in the self-criticism compared to both the self-compassion ($p < 0.022$) and the neutral ($p < 0.036$) conditions. The neutral and the self-compassion conditions did not differ ($p = 0.990$). This finding suggested that a negative self-focus reduces the capacity to accurately judge one's ability to track internal sensations.

Figure 3.***The effect of Self-criticism and Self-compassion on Interoceptive Accuracy, Awareness and Valence***

Note. $N = 98$. Top left: In those without a history of NSSI self-criticism ($p < 0.002$) and self-compassion ($p < 0.005$) increased interoceptive compared to the neutral condition. These effects were attenuated in those who have used NSSI. Top right: Those without a history of NSSI found focusing on their heartbeat more aversive if they engaged in self-criticism, rather than self-compassion ($p < 0.049$), whereas those with a history of NSSI found focusing on their heartbeat more unpleasant after self-compassion ($p < 0.008$). Bottom left: All participants had a decrease in interoceptive awareness in the self-criticism compared to both self-compassion ($p < 0.022$) and the neutral ($p < 0.036$) conditions. Bottom right: Interoceptive confidence did not change in any of the conditions.

Interoceptive Valence (pleasantness)

Both main effects were not significant: Group ($F = (2, 92) = 1.782, p = 0.174, \eta^2 = 0.037$), and NSSI ($F = (1, 92) = 0.089, p = 0.766, \eta^2 = 0.001$). However, the Group X NSSI interaction was significant ($F = (1, 92) = 4.578, p = 0.013, \eta^2 = 0.091$). Those without a history of NSSI found focusing on their heartbeat more aversive when they engaged in self-criticism, rather than self-compassion ($p < 0.049$). However, the compassion and neutral ($p = 0.330$), and the criticism and neutral conditions ($p < 0.389$) did not differ. In those with a history of NSSI the neutral and self-criticism conditions did not differ ($p < 0.082$), and neither did the compassion and criticism conditions ($p = 0.196$). However, those with a history of NSSI found focusing on their heartbeat significantly more unpleasant if they engaged in self-compassion, compared to the neutral condition ($p < 0.004$). These findings suggest that state self-criticism may negatively bias the way internal signals are evaluated. More intriguingly, they suggested that those with a history of NSSI are likely to evaluate interoceptive signals more negatively after engaging in self-compassion.

Interoceptive Confidence

The main effect of group was not significant ($F = (1, 92) = 1.803, p = 0.171, \eta^2 = 0.038$). Similarly, the main effect of NSSI did not reach significance ($F = (1, 92) = 0.006, p = 0.939, \eta^2 = 0.000$), and neither did the Group X NSSI interaction ($F = (2, 92) = 0.790, p = 0.457, \eta^2 = 0.017$).

It was also considered whether there were significant correlations between the change in self-criticism / self-compassion, and change in the interoceptive indices, depending on the conditions: in the self-criticism condition there was a positive association between self-criticism and interoceptive accuracy (Supplementary Figure 1).

Study 2: Summary

State self-criticism negatively biased the affective response to focusing on the heartbeat, although the effect only reached significance in those with no history of NSSI. Irrespective of NSSI history, *state* self-criticism reduced participant's insight into their interoceptive abilities (Figure 3). Those with a history of NSSI found focusing on their heartbeat more aversive after engaging in self-compassion. In addition, whilst self-criticism and self-compassion increased interoceptive accuracy in healthy participants, these effects were attenuated in those with a history of NSSI, particularly in response to self-criticism.

Discussion

Table 4 summarises the findings across both studies. In those with and without a history of NSSI, *trait* (Study 1) self-criticism was associated with finding attending to the heartbeat more unpleasant. Similarly, in those with no history of NSSI *state* (Study 2) self-criticism induced a negative interoceptive valence. State self-criticism also reduced interoceptive meta-cognitive insight. Both trait and state self-criticism were associated with having higher heartbeat counting accuracy in non-NSSI participants, but not in those with a history of NSSI (Figure 3).

Table 4.

Results from Study 1 and Study 2 which examined the effects of trait and state self-criticism on interoception in those with and without a history of NSSI.

| | Study 1 | | Study 2 | |
|---------------------|----------------------|---------|----------------------|---------|
| | Trait self-criticism | | State self-criticism | |
| | NSSI | No NSSI | NSSI | No NSSI |
| IAc | – | ↑ | – | ↑ |
| IAw | – | – | ↓ | ↓ |
| Confidence | – | – | – | – |
| Pleasantness | ↓ | ↓ | – | ↓ |

Note. NA – Negative affect. IAc – Interoceptive accuracy. IAw – Interoceptive awareness. – No change. ↑ Increased. ↓ Decreased.

Theoretical models of self-injurious behavior have suggested that certain factors might increase the capacity to physically harm the body (Hooley & Franklin, 2018; Joiner Jr et al., 2005; Klonsky & May, 2015). It is possible that interoceptive deficits may be one such trait (Dodd et al., 2017; Hagan et al., 2019). Findings from the present report are consistent with these views. In Study 1, those with the most frequent NSSI less accurately detected their heartbeat (Supplementary Table 2). In addition, those who engaged in NSSI were less confident in their ability to track their heartbeat, and reported that doing so was unpleasant (Supplementary Table 1 and 2). Although causation cannot be determined, these data highlight that interoceptive uncertainty, interpretational biases, and low interoceptive accuracy could potentially play a role in self-injurious behaviors (also see DeVille et al., 2020). It is notable that those who have used NSSI also had higher pain thresholds, and endured pain for longer (For a review see Kirtley et al., 2016). Combined with the present data, this raises the possibility that those with NSSI may be characterised by interoceptive deficits across multiple domains. Nonetheless, further research assessing interoception across a number of modalities (e.g., somatosensory, proprioceptive, respiratory) and levels (e.g., subjective / objective, conscious / unconscious, affective / neutral) will be required to determine whether this is the case.

Here we investigated whether deficiencies in interoception could be partially attributed to a negatively-valenced introspective self-focused attention, specifically self-critical rumination. It had been hypothesised that in those with NSSI, self-criticism would be associated with having poorer interoceptive abilities (Figure 1). However, rather than self-criticism being *negatively* associated with interoceptive accuracy in those who have used NSSI, self-criticism was instead *positively* associated with interoceptive accuracy in non-NSSI participants. Specifically, in Study 1, *trait* self-critical rumination was associated with

performing better in a heartbeat counting task; an effect limited to individuals without a history of NSSI. Similarly, in Study 2, in those without a history of NSSI, *state* self-criticism led to an increase in heartbeat perception accuracy. These findings suggested that the NSSI group failed to demonstrate an increase in interoceptive processing in response to self-criticism, in contrast to the increased response in the non-NSSI participants (Table 4).

It is possible that in those who have never used NSSI, self-critical rumination (Study 1), and *state* self-criticism (Study 2) were associated with better heartbeat counting accuracy due to their self-referential nature. For instance, a key neural structure activated during attention to the heartbeat is the insula (Schulz, 2016). Consistently, meta-analytic reviews of neuroimaging studies have reported insula involvement in the processing of other self-referential stimuli, such as self-related traits, autobiographical memories, and affective states such as guilt (Qin et al., 2020). Interestingly, increasing self-focused attention through mirror exposure also accentuated heartbeat counting accuracy (Ainley et al., 2012). These authors suggested that increased attention on the self may influence ‘top-down’ gating of attention to internal signals, thereby increasing interoceptive sensitivity (Ainley et al., 2012). Thus, it is possible that the self-referential nature of self-criticism may have made it easier for healthy participants to attend to their heartbeat.

However, an important consideration is that with the heartbeat counting task it is difficult to differentiate between a change in sensory sensitivity and a lowering of the detection threshold (which could lead to false positives). The vast majority of individuals who perform this task underestimate the number of heartbeats during a given epoch. This raises the possibility that an increase in interoceptive ‘accuracy’ could in fact reflect an increased propensity to erroneously report feeling a heartbeat (Zamariola et al., 2018). This is relevant as it is possible that self-focused attention may have made participants ‘feel’ as though they were experiencing heartbeats when in fact they were not. This would have

increased the number of heartbeats they reported per epoch bringing them more in line with their actual heartrate. In this sense it remains possible that self-criticism may have induced, in non-NSSI participants, ‘illusory’ interoceptive signals. This possibility could be explored by using a heartbeat discrimination task based on the method of constant stimuli by calculating signal detection theory indices (Young et al., 2017).

Nonetheless, it is interesting that in those with a history of NSSI, interoceptive accuracy was not correlated with self-critical rumination (Study 1), and was not affected by *state* self-criticism (Study 2) (Table 4; Figure 3). To date, only one other study has explored self-focussed attention in a clinical population. Consistent with the present finding, self-observation using a webcam did not increase heartbeat perception accuracy in those with anorexia nervosa (Pollatos et al., 2016). Together with the present findings, this suggests that interoceptive responsivity to self-focused attention may be diminished in clinical populations, including those with NSSI.

One explanation may be that non-NSSI participants more easily switched from an introspective to an interoceptive frame of self-reference. In contrast the NSSI group may have been less able to disengage from the self-critical introspective frame of self-reference, making subsequently attending to their heartbeat challenging (Figure 1). In support of this possibility, those who has used NSSI reported poorer attentional switching abilities (Drabble et al., 2014). In addition, attention is thought to play a central role in interoception (Petzschner et al., 2019). Thus speculatively, better attentional switching abilities may provide a protective buffer against self-injurious behavior by facilitating the disengagement from negatively-valenced introspective self-referential thought patterns. Future research examining the link between attention and interoception in NSSI may be profitable.

It is also possible that in NSSI, hyperactive self-referent processing, such as self-critical rumination, may in fact be driven by a dysfunctional interoceptive system (rather than

vice versa) (Figure 1). That is, hypoactive interoceptive processing may contribute to hyperactive yet futile efforts at top-down modulatory control, which could be subjectively experienced as perseverative self-referent thoughts. Indeed, several authors have proposed that interoception grounds the processing of other self-relevant information (Qin et al., 2020), and that perseverative thoughts about the self are a consequence of a poor interoceptive functioning (Paulus & Stein, 2010). In the future, studies should explore these hypotheses using paradigms that involve the physiological perturbation of interoceptive signals (Villani et al., 2019). This would help decipher whether interoceptive responsivity is impaired in NSSI more generally, or specifically in response to self-criticism.

It was also observed that both trait and state self-criticism were associated with participants reporting more unpleasantness when focusing on the heartbeat. These findings suggested that a negatively biased view of the self might extend to the interpretation of internal information. These effects are not surprising given that interoceptive signals are likely to be ambiguous, and that negative interpretational biases, especially for ambiguous self-related stimuli, are common (Everaert et al., 2017). In contrast to non-NSSI participants, in whom the increased unpleasantness paralleled an increase in interoceptive accuracy, in those with NSSI this aversive affective response to the heartbeat occurred in the context of relatively lower interoceptive accuracy. These findings suggested that in NSSI cardioceptive accuracy and the associated affective response may be disconnected, such that the affective response is proportionally exaggerated. This suggests that interventions, for example some exposure therapies that lead to an increased tolerance of body states, may be beneficial for use in NSSI. It is worth noting that in Study 2, the self-compassion manipulation induced a negative response to focusing on the heartbeat: an effect specific to those with NSSI (Figure 3). This effect might be explained by a process resembling ‘backdraft’ (i.e., self-compassion can initially make some people feel worse as they begin to identify with parts of themselves

that they previously disliked / were ashamed off (Neff, 2003)), and suggests that self-compassion based therapies may need to be applied with caution. Future research should examine the effects of compassion focused therapy over a longer period of time to determine whether these negative effects dissipate. Experiencing heightened interoceptive accuracy in the context of self-compassion might over-time lead to a re-evaluation of the associated affective qualities.

Finally, we observed that in all participants, state self-criticism reduced participant's interoceptive meta-cognitive insight (Study 2). Although 'insight' is emerging as a potentially important interoceptive component (Young et al., 2017), it remains sparsely investigated. Therefore, any interpretation of this finding is at present speculative. Nonetheless, we posit that the present finding might indicate that state self-criticism leads to a disconnect between interoceptive processing and higher order cognitive processing, such as error monitoring, that may be important for the accuracy of retrospective judgements of performance. These data suggest that further investigation in this area might be profitable.

Inevitably, this study has some limitations. In Study 1 we chose to focus on self-critical rumination, as this capture's both the perseverative *style* and the self-degrading *content*, that might be important in NSSI. However, it might be valuable to examine other types of rumination, such as depressive rumination and to compare negatively-valenced self-focus with neutral self-focus.

The second study considered only females to reduce sample heterogeneity. nonetheless, this inevitably reduces generalisability and requires replication in a male sample. Finally, our model proposed that a disembodied state might motivate NSSI to generate predictable physiological sensations and / or escape feeling numb (Figure 1). However, we did not assess the associations between interoception and NSSI functions, and emotional numbness is one of the less

commonly cited motivations for NSSI (Taylor et al., 2017). As such there are aspects of the model that require further testing.

In summary, in two studies those with a history of NSSI were characterised by a range of interoceptive deficits. Specifically, those with a history of NSSI had lower confidence in their interoceptive abilities, and found attending to their heartbeat more unpleasant (Study 1: supplementary information). In addition, those with the most frequent NSSI less accurately counted their heartbeat (Study 1: supplementary information). Importantly, those with NSSI also had a blunted modulation of interoceptive processing in response to negatively-valenced self-focused attention. Specifically, whereas in non-NSSI participants interoceptive accuracy was positively associated with trait self-critical rumination (Study 1), and increased in response to state self-criticism (Study 2), these effects were absent in those with NSSI. In addition, both trait and state self-criticism were associated with finding attending to the heartbeat more unpleasant, and having lower interoceptive meta-cognitive insight. These findings highlight a possible imbalance between introspective and interoceptive processes in NSSI (Figure 1A), which could be driven by an inability to modulate interoceptive processes. If confirmed, these findings could point towards the use of innovative therapies that can directly alter interoceptive states, and aid in their re-evaluation, for example, manual therapies (Edwards et al., 2018), or non-invasive transcutaneous vagal nerve stimulation (Villani et al., 2019).

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