

Multidimensional Cardioception & Trait Anxiety: Potential Clues from Baroreflex Sensitivity

Shara Soyini Grant

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Bruce H. Friedman, Chair  
Martha Ann Bell  
Rachel A. Diana  
Russell T. Jones

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Shara Soyini Grant

## **Abstract (Academic)**

Interoception, the perception of the body's physiological state, is often studied in relation to emotion processing. Particularly, cardioception has been largely implicated in anxiety. Three related but distinct dimensions of interoception have recently emerged in the literature: sensibility (IS), accuracy (IAC), and awareness (IAW). Divergent findings regarding interoception and anxiety may result from lacking appreciation for interoceptive dimensions. Additionally, the role of cardiovascular afferent feedback in anxiety and interoception is largely unknown. Baroreflex sensitivity (BRS) has been implicated in interoceptive processes yet no known research directly measures this in relation to multidimensional cardioception. The present study aimed to assess the degree to which IS, IAC, IAW, and BRS predict trait anxiety at rest and during anticipatory anxiety. Results partially suggest increased IAC and BRS, but more variable IS and IAW in relation to trait anxiety. Overall, results show complex associations among factors, suggesting increased specificity among the constructs. Results highlight the importance of attention to construct validity and method variance in the study of interoceptive subdomains. Finally, the present study helps to pave the way for continued investigations concerning cardioception in enduring anxiety and the related role of the baroreflex in cardiac afferent processes.

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## **Abstract (General)**

Interoception, the perception of the body's physiological state, is often studied in relation to emotion processing. Particularly, cardioception (the sense of cardiac activity, such as the perception of a racing heart) has been largely implicated in anxiety. Three related but distinct dimensions of interoception have recently emerged in the literature: sensibility (IS), accuracy (IAC), and awareness (IAW). Divergent findings regarding interoception and anxiety may result from lacking appreciation for interoceptive dimensions. Additionally, the role of cardiovascular feedback to the brain in anxiety and interoception is largely unknown. The baroreflex system rapidly modulates activity of the heart in accordance with short-term blood pressure changes. The sensitivity of this homeostatic baroreflex system (BRS) also plays a role in interoceptive processes, yet no known research directly measures this in relation to multidimensional cardioception. The present study aimed to assess the degree to which IS, IAC, IAW, and BRS predict dispositional anxiety at rest and during anticipatory anxiety. Results partially suggest increased IAC and BRS, but more variable IS and IAW in relation to dispositional anxiety. Overall, results show complex associations among factors, suggesting increased specificity among the variables. Results highlight the importance of attention to measurement precision and various ways to assess the dimensions of interoception. Finally, the present study helps to pave the way for continued research concerning perception of the heart's activity in enduring anxiety and the related role of cardiovascular activity at various levels of conscious awareness. Ultimately, research on this topic is highly important for the eventual improvement of existing therapeutics for individuals regularly experiencing severe anxiety.

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### List of Abbreviations

<i>Abbreviation</i>	
<b>AS</b>	Anxiety Sensitivity
<b>ASI-R</b>	Anxiety Sensitivity Index- Revised
<b>FNE-II</b>	Brief Fear of Negative Evaluation Scale-Revised
<b>BRS</b>	Baroreflex Sensitivity
<b>HF-HRV</b>	High-Frequency Heart Rate Variability
<b>HHQ</b>	Health History Questionnaire
<b>IAC</b>	Interoceptive Accuracy
<b>IAW</b>	Interoceptive Awareness
<b>IS</b>	Interoceptive Sensibility
<b>MAIA</b>	Multidimensional Assessment of Interoceptive Awareness
<b>MCS</b>	Interval Method of Constant Stimuli
<b>PHQ-9</b>	Patient Health Questionnaire
<b>STAI</b>	State-Trait Anxiety Inventory
<b>TA</b>	Trait Anxiety

## Multidimensional Cardioception & Trait Anxiety: Potential Clues from Baroreflex Sensitivity

### 1. Introduction

The existence of interactions among visceral physiology, affect, and perception are well-established. Interoception is broadly defined as the sense of the physiological condition of the body; a sense which is crucial to self-awareness, self-regulation, and emotion processing (Craig, 2003). Foundational emotion theories (e.g. James, 1885; 1894), have reflected a substantial appreciation for the role of interoception in emotion processing. James argued that emotions arise from bodily changes. More recent theories continue to highlight the significance of bodily sensations in terms of both emotional responding, decision-making, and action (e.g. *somatic marker hypothesis*; Damasio, 1991). Based on homeostatic afferent activity, interoception involves both multilevel processing and assessment of one's internal physiological state. In contrast to earlier notions of interoception as reflecting merely feedback processes, more recent emotion theories reconceptualize interoception to be an iterative process. This is exemplified in Bayesian and predictive coding models, in which emotions arise from active inferences of predictions of the sources of interoceptive afferents, and highlight the continued updating of comparisons between predicted and actual bodily sensations (e.g. Seth, 2013; Barrett, 2017). In other words, emotions involve cognitive evaluations (i.e. appraisals) of the causes of physiological changes, which then affect autonomic regulation and emotion processing.

Awareness of one's own emotional state involves integration of interoceptive information along with interpretation of the present situation (Terasawa, Fukushima, & Umeda, 2013). In concert with emotion processing, interoception also plays a considerable role in stress

responding and in behavioral processes related to afferent physiology, more broadly (Craig, 2003).

A fundamental factor in anxiety is a negative evaluative bias of self-referential information, typically involving fear and/or worry about the future. Much literature reveals that state, trait, and pathological anxiety reveal concomitant interoceptive factors that help to shape the experience of anxiety (Schulz & Vogele, 2015; Paulus & Stein, 2010; Domschke, Stevens, Pfleiderer, & Gerlach, 2010). As hyperarousal theories of anxiety suggest, high levels of trait anxiety (TA) may indeed serve as a foundation for persistent autonomic stress reactivity (Reiss, 1997). A recent model holds that interoception serves as a crucial mediator in the relationship between dysregulated stress responses and physical symptoms of pathological anxiety (Schulz & Vogele, 2015; See Appendix A).

Interoceptive abilities are generally conceived as a somewhat invariable sense that remains relatively stable across time, similar to temperament (Mallorqui-Bague et al., 2016). Therefore, examination of individual differences in interoceptive processes is potentially informative in the study of anxiety and interoception. The relation of interoception to cardiac performance under physical stress is well-established (O'Brien, Reid, & Jones, 1998; Schandry & Bestler, 1995). Based on a substantial and burgeoning body of literature, dysregulated interoceptive processes are believed to underlie heterogeneous forms of anxious tendencies and pathological anxiety (Schulz & Vogele, 2015; Paulus & Stein, 2010; Yoris et al., 2015). Nevertheless, the precise contributions of cardiac interoception to the experience of trait or pathological anxiety still remain somewhat poorly understood.

Below is a review of extant literature concerning interoception, the relationship of cardioception to state and TA, a description of interoceptive dimensions, and a discussion of

theoretical associations of baroreflex sensitivity (BRS) (a physiological indicator of afferent cardiovascular processes and cardiac control) to these constructs. Subsequent to this review, this paper will describe the current empirical study, which was conducted primarily to illuminate previously uninvestigated contributions of BRS to cardioception in relation to TA.

## **2. Literature Review**

### **2.1. Interoception: Defining the Construct**

Though the construct of interoception has multiple definitions, as does any psychological construct, it generally refers to the sense/perception of the internal state or condition of the body (Craig, 2003) or the phenomenological experience of the body state and bodily responses (Ceunen, Vlaeyen, & Van Diest, 2016). Although interoception may be conceived of as a niche area of study, in actuality, this phenomenon is highly relevant to a wide array of empirical studies in psychology. Research specifically examining interoception has garnered growing interest within the last few decades, as scientific appreciation for its role in cognitive, affective, behavioral, physiological, and clinical phenomena has increased. A wealth of literature clearly supports the notion that interoceptive processes are integral to pain processing, emotion processing, body ownership and sense of self, physiological regulation of internal states, as well as numerous other psychological and physiological processes and constructs (Craig, 2003).

Interoception, according to its broad definition, includes senses from various bodily sources. As such, interoceptive processes are associated with numerous bodily functions and sensations, such as pain, temperature, muscular and visceral sensations, sensual touch, itch, vasomotor, and cardiac activity (Craig, 2003). Due to the widely inclusive definitions of interoception, it is appropriate to be specific in scientific investigations and discussions

surrounding the phenomenon. Furthermore, there is not sufficient evidence to corroborate the notion that interoceptive aspects pertaining to the multiple sources of bodily sensations operate identically across these senses.

Research on interoception often focuses on examinations of perception of cardiac activity, yet terminology used to describe this cardiac interoception is nonspecific. For example, in such research, the term “interoception” is often used in both methodological contexts and theoretical discussions surrounding cardiac perceptions. Instead, for increased precision, the terms “cardiac interoception” or “cardioception” should be used in reference to interoception as it pertains to cardiac activity.

## **2.2. Cardiac Interoception**

Cardiovascular mechanisms closely relate to affective processing, and cardiac cues are highly salient. For example, the experience of intense state anxiety is accompanied by cardiac reactivity (e.g. myocardial contractility; Dalton, Kalin, Grist, & Davidson, 2005). Cardiac interoception (or cardioception) is a particularly dominant factor in emotional experience. It has been demonstrated that neural regions strongly involved in emotion processing (including the insula, prefrontal cortex, somatosensory and anterior cingulate cortices) are also activated during focused attention on heartbeats as well as processing and regulation of cardiovascular signals (Pollatos, Kirsch, & Schandry, 2005; Nguyen, Breakspear, Hu, & Guo, 2016). Empirical literature investigating interoception often examines cardioception because cardiac activity closely aligns with emotion processing, and because heartbeats are distinct and easily measured autonomic events (Lackner & Fresco, 2016). These concepts will be revisited and further discussed.

Most cardioceptive research directly investigates chronotropic aspects of cardiac activity (e.g. heart rate). Of note, cardioception also includes the perception of the strength with which the heart beats, although this will not be further elaborated in this paper.

### **2.3. Dimensions of Cardioception**

Seeming inconclusiveness surrounding the relation of cardioception to anxiety may be partially due to under-appreciation of the highly complex and multifaceted nature of interoception. Previous research concerning interoception has often been based on vague and imprecise conceptualizations and operational definitions. However, recent empirical efforts have been initiated to specify aspects of body sense and awareness (Mehling et al., 2012; Garfinkel et al., 2013). Mounting empirical support reveals physiological and functional distinctions among interoceptive subdomains, largely based on the fact that not all interoceptive sensory information enters consciousness. For example, a study using electroencephalography (EEG) revealed a behavioral and neural dissociation between learning to follow one's heartbeat and metacognitive awareness (Canales-Johnson et al., 2015). The former was associated with enhanced interoceptive performance on heartbeat detection tasks, but not necessarily its awareness. Indeed, an individual may conceivably be highly vigilant to cardiac cues, yet subjective interpretation of these cues may not be entirely accurate.

Current literature suggests that interoception may be conceptually partitioned into three related but distinct dimensions, with differing associated mechanisms (Garfinkel et al., 2013; Garfinkel et al., 2015): Interoceptive sensibility (IS), interoceptive accuracy (IAC), and interoceptive awareness (IAW) (See Appendix B). IS refers to the dispositional tendency to focus attention internally on autonomic cues. This is a subjective construct reflecting level of

engagement with interoceptive signals. By contrast, IAC assesses interoceptive precision and is based on objective behavioral tests. In comparison, IAW, which by its very nature is related to both IS and IAC, is the degree of correspondence between the two dimensions. In essence, it is the metacognitive awareness of interoceptive accuracy. Anxiety research examining interoception may benefit from increased specification of particular dimensions within this tripartite model.

**2.3.1. Interoceptive accuracy.** Compared to visceral sensations such as thirst or hunger, there is a considerable individual variability in cardioceptive acuity (Canalae-Johnson et al. 2015). Among the many potential correlates of interoceptive accuracy, literature suggests that TA may be associated with such abilities, although findings are varied.

**2.3.1.1. Methods to index interoceptive accuracy.** IAC is typically assessed via heartbeat detection tasks in order to quantify individual differences in cardioceptive aptitude. The literature highlights two commonly used experimental paradigms of heartbeat detection: signal detection tasks and mental tracking tasks. The strengths and weaknesses of both tasks are described below. It is also important to note that cardioception extends beyond perception of heartbeat timing (e.g., other cardiodynamic parameters such as those related to cardiac inotropy), and that some implicit methods have been developed to examine these in terms of IAC (e.g. Azevedo, Aglioti, & Lenggenhager, 2016). However, these are external to the focus of this paper and will not be discussed further.

Signal detection tasks for heartbeat timing involve comparison of externally generated stimuli (typically those that are auditory in nature, e.g. beeps) to the rhythm of one's own heartbeat (Whitehead, Drescher, Heiman, & Blackwell, 1977; Ehlers, Margraf, Roth, Taylor &

Birbaumer, 1988). For example, subjects may be asked to choose their own heart rhythm from a series of auditory tones, without feeling a pulse (e.g. Brener & Kluitse, 1988).

While this paradigm allows for cross-modality comparison of detection abilities, perceptual sensitivity and circumvention of response bias, externally generated signals may potentially create distraction from internal focus, as per the competition of cues hypothesis (Harver et al., 1993; Pennebaker & Brittingham, 1982). Task performance requires attentive processes across two sensory modalities. Secondly, signal detection tasks, which are commonly two-interval discrimination tasks, are based on the faulty assumption that heartbeat sensations occur at the same temporal location on the ECG waveform across individuals and situations (e.g. during stress inductions). Finally, signal detection tasks prove to be highly difficult to complete. Only about 25%-33% of people reliably judge heartbeat sensations as being simultaneous or non-simultaneous with the auditory stimuli in this paradigm, which yields low sensitivity in identifying heartbeat detection abilities (Ring, 1993).

The interval method of constant stimuli (MCS) is a signal detection task based on classical psychophysics, and appears to elude many issues arising from the aforementioned paradigms, as it allows subjects to identify the temporal location of heartbeat sensations during cardiac cycles (Brener & Ring, 2016). In this task, subjects are presented with multiple series of auditory signals presented at various intervals following the R-wave (ventricular depolarization). Instructions are to indicate whether or not tones are simultaneous with heartbeat sensations. Aside from idiosyncrasies in cardioception specifically, heartbeat signal detection task performance is also related to other factors including general sensitivity to both internal and external signals as well as decision-making processes (as in signal detection theory (MacMillan et al., 2002)).

Another methodology to assess cardioception is mental tracking tasks. In this paradigm, subjects are instructed to silently count their heartbeats using intervals of varying lengths, in the absence of feeling a pulse (Schandry, 1981). Subjects then report the number of counted heartbeats within the given intervals, which are then compared to actual heartbeats as provided by electrocardiography (ECG) output. Outcome measures for accuracy are either a dichotomous score (i.e. high or low accuracy) or percentage of error.

This method has received critiques including the notion that responses are prone to bias. In essence, subjects may use prior knowledge of average heart rates to estimate their reported number of heartbeats (Brener & Ring, 2016). One way to control for this potential limitation is to combine more than one interoceptive task and/or to randomly present various interval durations, thereby reducing the likelihood of possibly biased estimations (e.g. Ainley, Brass, Tsakiris, 2014). Experimental protocols have also measured subjects' time estimation accuracy and resting heart rate belief accuracy in order to statistically control for this possible confound (Dunn, Stefanovich, Evans, Oliver, Hawkins, & Dalgleish, 2010). The Schandry task remains a commonly used methodology in interoceptive research due to its practical ease of use, and its ability to reliably detect inter-individual differences, particularly among clinical samples versus healthy controls (Van der Does, Antony, Ehlers, & Barsky, 2000).

**2.3.2. Interoceptive Sensibility.** A facet that is distinct from interoceptive accuracy is the subjective interpretation of interoceptive abilities and/or self-perceived tendency to be inwardly attuned to the body's state. This perception, termed interoceptive sensibility (IS), is the self-evaluated assessment of subjective interoception (Garfinkel et al., 2015).

**2.3.2.1. Methods to index interoceptive sensibility.** This domain is commonly indexed using a variety of self-report instruments such as the Body Vigilance Scale (BVS, Schmidt,

Lerew & Trakowski, 1997), Body Sensations Interpretation Questionnaire (BSIQ; Clark et al., 1997), or Body Sensations Questionnaire (BSQ; Chambless et al., 1984). In light of increasing appreciation for complexities of interoception, a more recent questionnaire, the Multidimensional Assessment of Interoceptive Awareness, assesses a broader range of interoceptive facets such as attention regulation and emotional awareness (MAIA; Mehling et al., 2012).

Another method of assessing IS involves self-reported confidence about accuracy for each trial of a cardioceptive task. This approach provides a more specific state measure of IS compared to questionnaire responses which reflect overall tendencies to notice interoceptive signals. Also, an advantage is that the scores are specific to cardioceptive sensibility, versus more global instruments, which tend to include only few items pertaining to cardiac perception.

Cardioceptive sensibility plays a pivotal role in the pathogenesis of anxiety. As mentioned, robust findings reveal that anxiety is often associated with interoceptive hypervigilance, or increased self-reported attention to subjectively threatening bodily signals and threat-related interpretations of bodily cues (Paulus & Stein, 2010; See Appendix C). Anxiety sensitivity (AS), the fear of anxiety-related sensations, is crucial in the experience of many forms of pathological anxiety (e.g. in panic disorder and posttraumatic stress disorder). These affective occurrences underlie overall increased IS in those with trait or clinical anxiety.

**2.3.3. Interoceptive Awareness.** IAW is the metacognitive awareness of interoceptive accuracy (Garfinkel et al., 2015). Fundamentally, this refers to the correspondence between interoceptive accuracy and confidence or tendency to be interoceptively attuned. For example, high cardiac IAW reflects an individual's ability to know whether or not they are accurately assessing heart-timing.

**2.3.3.1. Methods to index interoceptive awareness.** IAW is typically assessed via either Pearson correlation,  $r$ , between confidence and accuracy or receiver operating characteristic (ROC) curve analysis of the degree to which confidence predicts accuracy (Green & Swets, 1966; Garfinkel et al., 2015). When assessed via correlation analyses, these scores are generally calculated using mean values of within-person, within-trial correspondence between IS (trial confidence) and trial IAC.

**2.3.4. Empirical research concerning interoceptive facets.** Despite increasing indications suggesting the presence of distinctive interoceptive facets, only three known studies have empirically investigated the specific aforesaid domains (IS, AIC, and IAW) in a single study. Garfinkel et al. (2015) found partial independence of the facets, supporting the theoretical distinction among the dimensions. Specifically, IS and IAW significantly predicted IAC. Meessen et al. (2016) further demonstrated that the dimensions were uncorrelated. An additional recent study found partial support for divergence among the facets, suggesting the utility in parsing these subdomains apart (Forkmann et al., 2016). While this appears convincing, further research assessing this model is necessary.

Forkmann et al. (2016) suggest the addition of a fourth facet to the extant three-dimensional model: objective physiological states. This study examined whether cardiovascular activation assessed via heart rate reactivity is differentially associated with the interoceptive facets IS, IAC, and IAW. Following results from heartbeat tracking tasks (i.e. mental tracking tasks; Schandry, 1981), findings revealed that IS and IAW significantly predicted mean heart rate. Mean heart rate also significantly predicted IAW (Forkmann et al., 2016). This study highlights the obvious but understudied relevance of resting and reactivity cardiovascular measures in cardioceptive processes.

## 2.4. Cardioception and Emotions

Efferent cardiovascular signals are significantly modulated by state emotions in the short-term (e.g. state anxiety). Also, enduring psychological stress and strong negative emotions (e.g. chronic worry) are associated with an array of cardiovascular diseases, as a wealth of literature has long supported (Watkins et al., 1999; Cohen, Edmonson, & Kronish, 2015). The complex interplay between emotional responses to situations or events and cardiovascular activity includes descending signals impacting autonomic (e.g. cardiovascular) responses, as well as ascending signals from interoceptive brain centers. Perception of the body's physiological state, particularly in the case of perceiving one's own cardiac activity, is a key component of emotional experience.

**2.4.1. Predictive Coding.** Emergent models in cognitive neuroscience that continue to gain traction purport the existence of generative models of cognition that rely upon hierarchical predictive cross-talk among top-down and bottom-up networks. Such predictive coding models have been applied to a wide variety of cognitive functions, including interoception. Within interoceptive predictive coding (also termed 'active interoceptive inference') frameworks, this communication is based upon top-down predictions and expectations as well as bottom-up prediction error signals pertaining to visceral signals (Seth & Critchley, 2013). More specifically, predictions about the causes of internal physiological state are compared with perception of actual internal sensory feedback (Seth, 2013). Resultant prediction error (the difference between these two components) is perceived, and updates perception which subsequently informs perception and/or behavior.

**2.4.2. Cardioception and state anxiety.** Cardioceptive research concerning anxiety often focuses on dispositional or pathological anxiety (i.e. enduring anxiety as an individual differences variable). By contrast, less research has been devoted specifically to exploring cardioceptive accuracy during state anxiety. This may be partially due to two assumptions: (1) that IAC is highly inflexible across contexts. (2) that ability to *accurately* perceive heartbeats is always increased in an anxious state. Despite the intuitive assumption that state anxiety correlates positively with cardioceptive accuracy, empirical evidence reveals that this relationship is complex and also somewhat unclear. The degree to which this notion is supported in the literature depends upon potentially important moderators. These modulating factors include the specific experimental paradigm used to index cardioceptive accuracy, the nature of the acute stressor, and concomitant cardiovascular responses.

For instance, IAC as assessed by the visual Whitehead heartbeat discrimination task has been shown to decrease during a socially evaluated cold pressor task, whereas performance on the Schandry heartbeat tracking task was greater during the cold pressor task (Schulz, Lass-Hennemann, Sütterlin, Schächinger, & Vögele, 2013). These paradigm-specific opposing patterns in IAC during the acute stressor are likely due to differences in attentional allocation. Acute stress may narrow attentional resources via focused attention on task-relevant stimuli and/or cognitions (Chajut & Algom, 2003). In essence, the heartbeat tracking task involves both internally- and externally-directed attention, hence demanding multimodal attention and recruiting greater attentional resources than the unimodal and more viscerally-focused Schandry task (Schulz et al., 2013).

Of note, the effects of acute stress on IAC may ultimately depend heavily upon degree of subjective psychophysiological stress. In other words, as in the basic premise of the Yerkes-

Dodson Law, acute stress may either assist or degrade performance depending on relative level of physiological arousal (Yerkes & Dodson, 1908). Specifically, this principle is characterized by an inverted-U function, which is a degree that is largely task-variable. For example, at increased task difficulty, the optimal level of physiological arousal is less than that of a moderately difficult task, and even less than for an easier task.

During acute stress, IAC, as assessed via performance on heartbeat perception tasks, partly depends upon degree and type of specific cardiovascular reactivity to the stressor. Empirical work suggests that increased perception of heartbeats is more closely associated with increased stroke volume versus heart rate increases (e.g. Forkmann et al., 2016). For instance, cardiovascular stress responses dominated by increased stroke volume are due to sympathetic influences, whereas heart rate responses are influenced by both sympathetic and parasympathetic activity due to the dual-innervation of these ANS circuits at the sino-atrial node. Therefore, it is worth examining the potentially varying effects of both cardiac inotropic and chronotropic responses to acute stress on cardioception, and hence tests of performance on cardioceptive accuracy. Finally, the aforementioned studies did not directly assess individual differences in TA. It is not entirely clear how trait or pathological anxiety may moderate these findings. More work is required to elucidate this topic.

**2.4.3. Cardioception and attention.** A considerable body of literature highlights the importance of attention to threat in relation to anxiety. This literature concerns allocation of attention during state anxiety as well as attention biases associated with trait and pathological anxiety. Frequently, this research examines attention to external/environmental threat; however, concomitant autonomic cues are a key part of the experience of anxiety (e.g. heightened cardiac

activity). They may in and of themselves serve as subjective threat cues. Therefore, in addition to external threat cues, subjectively perceived internal threat cues may signal specific alerting responses.

The role of attention in cardioception is complex. High TA individuals tend to report high IS, likely due to frequently engaged attention to peripheral physiological cues, at least at early stages of attentional processing. However, the potential role of disengagement from perceived internal threat (e.g. in the context of cardioception) at longer durations or less automatic stages of processing remains somewhat unclear (e.g. Koster, Crombez, Verschuere, Van Damme, & Wiersema, 2006). Interestingly, in a sample of high symptom reporters with medically unexplained symptoms (MUS), high MUS persons show decreased IAC, despite frequently engaged attention to physiological activity (Bogaerts et al., 2008). Despite hypervigilance, if these individuals tend to disengage from threat-related physiological activity during later stages of attention processing, this disengagement would inhibit the thorough processing of physiological activity required for accurate perception. This serves as yet another example of the potential dissociation between IS and IAC.

Of note, subjectively reported tendency to focus attention on internal physiological cues (i.e. IS) in and of itself may or may not generate perception of threat (e.g. in non-MUS populations). In other words, attention is necessary, but not sufficient. Rather, the appraisal of interoceptive experience reflects the subjective meaning assigned to this perception. Importantly, a hallmark of heightened levels of TA is both increased IS as well as tendency to interpret interoceptive cues as threat-relevant. Nevertheless, there is great importance in differentiating anxiety-driven from mindful cardioceptive attention (Mehling, 2016). The MAIA provides

greater specificity than most existing self-report measures that indirectly assess interoceptive attentional tendencies (Mehling et al., 2012).

Increased complexity stems from consideration of effortful versus automatic attention to interoceptive cues. Interoceptive laboratory tasks typically require effortful, focused, and sustained attention. Subjects are explicitly instructed to attend to their physiological stimuli. Conversely, automatic attentive processes occur without conscious effort or control, and may even occur in the absence of conscious awareness. Relatively automatic interoceptive processes are far more commonly experienced in daily life. Accounting for distinctions and dynamic interactions between effortful and automatic interoceptive attention may be especially informative. Interoceptive attention control may serve as a coping strategy for anxious individuals (Derryberry & Reed, 2002).

**2.4.3.1. Subjective unsafety.** In contrast to most cognitive theories explaining the etiology of anxious pathologies, some more recent models of chronic anxiety focus on the role of intolerance of uncertainty, as opposed to attention to threat, per se (e.g. Carleton 2016). The generalized unsafety theory of stress (GUTS) model is a parsimonious perspective concerning the development of chronic stress and anxiety. It highlights the importance of an absent subjective sense of safety, rather than preferential attention to objective threat (Brosschot, Verkuil, & Thayer, 2016). The model proposes that default physiological stress responses are typically under tonic inhibition in everyday/safe contexts. However, when chronically uninhibited by prefrontal top-down cognitive control, these responses dominate and may lead to chronic stress and anxiety.

The GUTS model also explains that interpretive biases (tendency to interpret ambiguity as threat), often characteristic of anxious pathologies, are substantially founded in chronic

generalized unsafety (Brosschot et al., 2016). This protracted and largely unconscious perception of unsafety in the absence of an actual threat is proposed to drive dysregulated psychophysiological responses associated with chronic anxiety.

**2.4.5. Cardioception and trait or pathological anxiety.** Ostensibly, these principles about unsafety may also be applied to interoceptive processes. For example, in the context of cardioception among some highly anxious individuals, interpretation of neutral information (e.g. one's resting heartbeat) may be misinterpreted or interpreted as unsafe. Additionally, highly anxious individuals tend to have persistently increased autonomic stress responses (e.g. increased heart rate and decreased resting HF-HRV- an index of cardiac vagal control). This hyperactive physiological activity (whether or not perceived consciously) may create an inability to recognize safety even external to contexts with apparent threats (Brosschot et al., 2016). The tendency of anxious individuals to experience high IS may be associated with this aforementioned relationship.

Although decades of research have been dedicated to understanding interoceptive processes in anxiety, taken together, existing studies remain somewhat inconclusive and reveal conflicting results. The majority of studies report greater interoceptive abilities among anxious individuals versus control subjects, which is supported by the occurrence of a positive correlation between IAC and subjective emotional intensity (e.g. Dunn et al., 2010<sup>a</sup>; Wiens, Mezzacappa, & Katkin, 2000). A review concerning interoceptive abilities in anxiety and anxiety disorders reports overall superior performance on tests of IAC (Domschke et al., 2010).

The most consistent findings linking anxiety with superior IAC tend to be found in patients with panic disorder (e.g. Van der Does et al., 2000). Some studies indicate either no associations between anxiety and IAC, or decreased IAC in relation to anxiety. For example,

Yoris et al. (2015) found lower heartbeat accuracy or no significant difference between panic disorder patients and control subjects. Patients did not differ from controls in IAC, but did present increased negative reflexive thoughts about bodily sensations (i.e. IAW).

Some studies of interoceptive accuracy in anxiety have involved investigation of other forms of anxiety aside from panic symptomatology. Pathological health anxiety (PHA) (now described as somatic symptom disorder or illness anxiety disorder) and characterized by persistent fear due to misinterpretation of benign bodily signals as signs of serious illness (American Psychiatric Association, 2013). PHA is closely associated with increased anxiety sensitivity. A recent study found no clear superior ability of PHA patients versus controls to detect heartbeats (Krautwurst, Gerlach, & Witthoft, 2016). However, PHA subjects showed a significantly higher tendency to overreport bodily symptoms of physiological stress reactivity.

Difficulty in integrating findings concerning interoception and anxiety is likely due to a number of factors, including: differences in empirical methodology, lack of consensus on terminology used to describe interoceptive domains, or simple lack of appreciation of the multifaceted nature of interoception. Studies of cardioception in anxiety rarely investigate IAW, which could partially explain seemingly conflicting findings concerning potential interoceptive abnormalities in anxiety. For example, individuals high in social anxiety, which is characterized by a marked fear of social situations and negative social evaluation, may be higher in IAC than those who are lower in social anxiety (Stevens et al., 2011).

It is certainly conceivable that a weak relationship between IS and IAC (i.e. IAW) could commonly occur highly anxious individuals, and may be a superior predictor of anxiety symptoms than either IS or IAC alone, which some research has supported. Therefore this possibility demands further attention. For example, in a study examining interoceptive facets

among a sample with Autism Spectrum Disorders, (ASD; a disorder often comorbid with pathological anxiety), the discrepancy between IS and IAC predicted anxiety symptomatology beyond the effect of ASD severity (Garfinkel et al., 2016). This example highlights the potential importance of investigating relations among the interoceptive facets in examination of various psychopathologies, rather than simply examining these facets in isolation.

Overall, findings concerning cardioceptive accuracy in relation to dispositional anxiety generally suggest heightened IAC, but diverge in some instances. As such, the roles of interoceptive factors in anxiety generation and maintenance remain to be seen. Predictive coding hypotheses align with the view that in pathological anxiety, there is a divergence between expected and actual processing of internal physiological cues (Paulus & Stein, 2010). According to this hypothesis, anxiety is the product of increased anticipation of aversive interoceptive afferents including those not predictive of aversive consequences. Interoceptive abnormalities in anxiety may be due to misattributions of the source of heightened cardiac stress reactivity (e.g. increased heart rate) (Paulus & Stein, 2010). Therefore, in this scenario, it may be inferred that anxiety is associated with inaccurate *appraisals* of the meaning of interoceptive signals, despite probable heightened interoceptive attention and accuracy.

## **2.5. Physiological Processes Underlying Cardioception**

In addition to increased investigation of the previously described interoceptive facets, the study of cardioception in relation to anxiety also calls for greater focus on contributions of autonomic factors. Processing of homeostatic afferent activity largely comprises the physiological substrates of interoceptive signal processing (Critchley & Garfinkel, 2015). These

substrates involve integration between both central and peripheral nervous system mechanisms. Interoceptive signals are propagated to the brain via multiple afferent pathways.

While recent theoretical models of interoception in anxiety reflect an appreciation for the complexity of interactive processes (e.g. including the important symbiotic contributions of both top-down and bottom-up processes), empirical work has typically relied on brain-based measures (i.e. fMRI, EEG, PET) to study physiological correlates of interoception.

**2.5.1. Central Nervous System.** Functional neuroimaging literature concerning cognitive processing of internal bodily signals describes an afferent neural system supporting interoception. This system includes the centrally important insular, somatomotor, and anterior cingulate (ACC) cortices (Critchley, Wiens, Rotshtein, Ohman, Dolan, 2004). Particularly, activity of the dorsal and anterior insular (AIC) cortices have been found to be a primary neural correlate of interoceptive processes related to various sensory modalities (Craig, 2002; Seth, 2013). The insular cortex plays a critical role in emotional awareness (Gu et al., 2013). The AIC is often considered a ‘limbic sensory area’ and is highly involved in the conscious awareness of interoceptive information (Seth, 2013). The bilateral insular cortices are located below the frontal and temporal lobes, and share widespread reciprocal connections with these regions as well as limbic and parietal areas (Flynn, Benson, & Ardila, 1999). These networks underlie the integration of limbic, visceromotor, viscerosensory, and autonomic functions in the insula (Gu, Hof, Friston, & Fan, 2013).

The AIC shares structural and function connections with the ACC, and the two regions are commonly coactivated (Gu et al., 2013). The ACC, a ‘limbic motor area’, is an output control region, involved in (among several other roles) executive control of affective processes (Vogt, Finch, & Olson, 1992). Visceromotor regions send projections to the spinal cord through

connections that travel through the amygdala, ventral striatum, hypothalamus, and periaqueductal grey (Barrett & Simmons; 2015).

Processing of cardiac sensations specifically involves the insula, dorsal cingulate gyrus, and dorsomedial prefrontal cortex. A study using conjunction analysis with BOLD responses during a heartbeat perception task and enhanced cardiac load elicited via physical stress showed activation of the insular cortex, dorsal cingulate gyrus, somatosensory cortex, supplementary motor area, and thalamus (Pollatos, Schandry, Auer, & Kaufmann, 2007).

Structural and functional aberrances in brain regions associated with interoception are associated with interoceptive abnormalities concerning anxious pathologies. For example, studies of clinically anxious subjects have highlighted dysregulation in brain regions central to interoceptive processing, such as the anterior and posterior insula, anterior cingulate cortex, and dorsolateral prefrontal cortex (Paulus & Stein, 2010). In Pollatos et al. (2007), trait negative emotionality (i.e. TA and neuroticism) was positively associated with the BOLD response during the heartbeat perception task in the dorsal cingulate gyrus and dorsomedial prefrontal cortex.

**2.5.2. Autonomic Nervous System.** While neuroimaging studies examining cognitive processing of interoceptive information provide valuable insight into the understanding of interoception in anxiety, peripheral nervous system measures are less common in interoception-focused research. However, it is difficult to fully apprehend the dynamic processes and mechanisms of interoception in anxiety without adequate consideration of visceral-afferent neural signals.

Interoceptive processing involves multiple interacting systems including the autonomic and somatic nervous systems. Changes in the viscera, muscles, and skin initiate ascending interoceptive signal transmission to the nucleus of the solitary tract, parabrachial nucleus, and

thalamus prior to signal relay to the interoceptive cortex (Craig, 2003). The parabrachial nucleus is the primary integration area for homeostatic afferent activity including cardiovascular and respiratory balances (Craig, 2003; Saper, 2002). The vagus nerve is importantly involved in this process, as signals are transmitted from vagal afferents to the nucleus of the solitary tract.

In addition to central nervous system contributions, individual differences in cardiac interoceptive processes also take form via differences in autonomic regulation (e.g. afferent visceral feedback). Cardiovascular autonomic dysregulation is robustly associated with both pathological anxiety and aberrant interoceptive functioning (Friedman, 2007; Yeragani, Tancer, Seema, Josyulab, & Desai, 2006; Alvares, Quintana, Hickie, & Guastella, 2016; Paulus & Stein, 2010).

Functional aberrances in dysautonomia offer insight into the importance of autonomic processes in cardioceptive and emotional processes. For example, postural tachycardia syndrome (PoTS) and vasovagal syncope (VVS) are associated with a failure to engage autonomic reflexes (Owens, Friston, Low, Mathias, & Critchley, 2018). These disorders are characterized by orthostatic intolerance which causes symptoms including lightheadedness or fainting. The pathology involves homeostatic afferent abnormalities leading to reduced IAC compared to healthy controls. Additionally, IAC in patients with PoTS and VVS, is negatively associated with somatic and cardiac-focused anxiety sensitivity (Owens, Low, Iodice, Critchley, & Mathias, 2017).

**2.5.2.1. The baroreflex system.** The baroreflex system is the most important system of cardiovascular autonomic control and the role of baroreceptors in cardioception involves a multistep process of signal transmission (Duschek, Werner, & Reyes del Paso, 2013). Arterial mechanoreceptors (baroreceptors) located in the aortic arch and innervating the carotid sinus are

activated upon sensing stretch in vascular walls immediately following each heartbeat. The baroreflex is a negative feedback loop adjusting cardiac activity (e.g. heart period) in response to blood pressure fluctuations. This reflex also elicits autonomic responses adjusting sympathetic outflow to the entire body. The arterial baroreflex adjusts systemic vascular resistance, thereby buffering blood pressure. With acute increases in blood pressure, e.g. during stressful tasks and manipulations, the baroreflex down-regulates sympathetic activity and enhances parasympathetic tone (Swenne, 2013). Additionally, the central nervous branch of the baroreflex system relays signals to the brainstem as well as higher-order cerebral areas, allowing cardiovascular information to impact cortical activity, providing further modulation of baroreflex activity (Duschek et al., 2013). Unlike high-frequency heart rate variability (HF-HRV) (an index of cardiac vagal control), baroreflexes modulate both sympathetic and parasympathetic activity (Swenne, 2013). Still, BRS can be conceived of as an index of cardiac regulation, as the functional properties of the baroreflex system are significantly impacted by vagal activity. Specifically, baroreflex function is positively correlated with tonic parasympathetic cardiac control (Reyes del Paso, Langewitz, Robles, & Perez, 1996).

Given the important role of autonomic regulation in cardioceptive processes, it is likely that baroreflex activity may serve not only as a mediator but as a moderating factor in the experience of cardiac sensations contributing to enduring anxiety. The system is intricately involved in the interaction of cardiovascular afferent signals and descending information from the brain (e.g. anterior insular cortex (AIC) to the periphery (Gianaros, Onyewuenyi, Sheu, Christie, & Critchley, 2012). In this regard, signals from baroreceptors also influence perception, cognition and affect (Gray et al., 2012; Garfinkel et al., 2014; Owens et al., 2018).

Even outside of conscious perception of cardiac afferent information, a significant body of literature has highlighted the preconscious influence of cardiac cycle timing on emotion processing and affective judgment. Presentation of affective visual information during cardiac systole (during phasic baroreceptor activation) modulates perception of emotionality. For example, facial expressions of both fear and disgust presented briefly (e.g. 100 ms) during systole (ECG R-wave) versus at the ECG T-wave are perceived as more intense (Garfinkel et al., 2014; Gray et al., 2012). Imaging research suggests that cardiac timing influences on emotion appraisal are mediated by the periaqueductal grey (Gray et al., 2012).

The degree to which cardiac cycle timing effects influence emotional processing in the aforementioned way is partially moderated by anxiety. It has been demonstrated that both dispositional as well as state anxiety are associated with less relative inhibition of fear processing at diastole versus systole (Garfinkel et al., 2014). Such research highlights the relevance of cycle- to-cycle afferent signaling and cardiac control in anxious experience, although mechanistic anxiety effects on cardiac modulation are not yet specified. The precise role of baroreflex dysfunction in contributing to this phenomenon has yet to be explored, yet together, research supports the likelihood that baroreflex functioning is a key contributor, due to its role in cardiac cycle timing effects.

## **2.6. Baroreflex Sensitivity as a Cardioceptive Correlate**

As previously discussed, the primary functions of the baroreflex system include but extend beyond cardiovascular control. Cardioception is highly supported by activity of this system. This fact highlights a need to explore understudied basic physiological processes

underlying the perceptual and preconscious processing of internal signals, especially within the context of anxiety.

There are few known methods assessing baro-afferent signal transmission in the study of psychological processes. Cardiac Modulation of Startle (CMS) is one such pre-attentive approach in which EMG responses in a startle paradigm vary depending on timing effects of the acoustic startle probe during various times in the cardiac cycle (Schulz et al., 2009). Baroreflex sensitivity (BRS) is another among few known psychophysiological indicators used to assess transmission of interoceptive signals below the level of conscious awareness. BRS, which reflects a quantification of baroreflex responsivity and requires baro-afferent signal transmission, is an indicator of the integrity of the baro-afferent neural system. BRS has therefore also been implicated in interoceptive abilities and experiences (Frattola et al., 1997; Schulz & Voegelé, 2015; Garfinkel et al., 2013). Although actions of interoceptors such as baro-afferent neural signal function cannot be consciously perceived, these signals comprise a key neural component of conscious cardioception (Dworkin, 2007).

With significant roles in affective processing, it is likely that cardioception is related to numerous autonomic measures such as heart rate. For example, heart rate is inversely related to stroke volume, and higher heart rate (coupled with lower stroke volume) is associated with decreased perception of afferent neural signals per single heartbeat (Forkmann, et al., 2016; Schandry, Bestler, & Montoya, 1993). Although heart rate is related to cardioception, as in Forkmann et al. (2016) study, BRS is likely a superior indicator of interoceptive functioning due to the fact that it more directly reflects the integrity and functioning of afferent autonomic nerves. Additionally, the baroreflex system is intrinsically involved in the relay of information to the brain about the rate of and strength with which the heart is beating via signals from arterial

baroreceptors. This afferent information is presumed to be the basis of affective states of physiological responses and of interoceptive representation of cardiovascular reactivity (Garfinkel & Critchley, 2016; Critchley & Garfinkel, 2015). Therefore, BRS is theoretically a prime variable for examination in interoceptive research.

## **2.7. Relevance of Baroreflex Sensitivity (BRS) to Anxiety**

Further support for the use of BRS in the study of interoception in anxiety in particular, is reflected by the existence of acute changes in BRS with acute stress, and dysregulated BRS functioning in anxiety. State anxiety is significantly related to reductions in baroreflex cardiac control (Watkins, Grossman, Krishnan, & Blumenthal, 1999). Acute psychological stressors reduce BRS, likely due in large part to vagal withdrawal, and anxiety is generally associated with dysregulated BRS processes (Duschek & Reyes del Paso, 2007; Virtanen et al., 2003). The functional neural mechanisms by which acute psychological stress-induced BRS reduction occurs are suggested to be lesser relative deactivation and greater relative activation within specific areas of the insula, amygdala, and cingulate cortex relevant for stress-elicited BP increases (Gianaros et al., 2012). These neural regions are also highly implicated for interoceptive processing.

Evidence also suggests that BRS is associated with worry, an emotion closely related to anticipatory anxiety, involving uncontrollable ruminative anticipation of potential threats. Specifically, proneness to worry is negatively correlated with BRS and blood pressure (Delgado, Vila, & Reyes del Paso, 2014). Anxiety severity is associated with reduced resting supine BRS and increased blood pressure variability independent of age and gender (Virtanen et al., 2003).

Blood pressure variability is inversely related to the ability of baroreceptors to modulate heart rate and blood pressure (Mancia et al., 1986).

Much evidence suggests that baroreflex control not only plays an important role in parasympathetic activity but sympathetic nerve activity as well (Huggett et al., 2004; Jackson, 2005). In fact, anxiety is often found to significantly relate to autonomic dysfunction (e.g. in patients with metabolic nerve syndrome; Toschi-Dias et al., 2013). Emergent models have increasingly identified autonomic abnormalities or dysregulation as part of a holistic conceptualization of pathological anxiety.

## **2.8. Measurement of BRS**

Multiple methods of indexing BRS have been used in clinical and laboratory settings. Invasive methods most commonly involve intravenous administration of vasoactive (primarily vasoconstrictive) pharmacological substances in order to examine the vagal component of the baroreflex system. For example, phenylephrine, a pure  $\alpha$ -adrenoreceptor agonist without direct effects on cardiac contractility and the central nervous system is often used for this purpose (La Rovere, Pinna, & Raczak, 2008). Due to inherent limitations in using pharmacological methods such as confounding psychological and physiological effects of vasoactive injections (e.g. pain, emotional responses, reflexogenic cardiopulmonary responses), other options for measuring BRS are also used (La Rovere et al., 2008). In psychophysiological as well as increasingly in clinical investigations, researchers have opted for non-invasive techniques such as postural or mechanical manipulations.

Psychophysiological research measuring BRS tends to examine spontaneous oscillations in BP and interbeat intervals using noninvasive analytic approaches (Parati, et al., 1995). Similar

to other methods, analysis of spontaneous BRS requires simultaneous acquisition of beat-to-beat BP and ECG signals. The sequence method is a time-domain analysis. Essentially, this method is based on identification of a given number of (typically three or more) consecutive beats in which progressive increases or decreases in SBP and accompanied by progressive increases or decreases in interbeat intervals. The outcome unit of measurement is ms/mmHg. By contrast, BRS may also be assessed using the spectral technique yielding values in both low- and high-frequency bands. Compared to spectral methods, an advantage of the sequence method is that it allows for distinct assessment of baroreflex activity during increasing and decreasing arterial pressure (specifying interbeat interval changes induced by baroreceptor stimulation or deactivation, respectively).

Although BRS measurements are used much more frequently in medical research than in studies of psychological constructs, relatively consistent findings linking anxiety to reduced BRS warrant additional investigations of anxiety using this autonomic measure. For example, a study examining several cardiovascular measures during stressors revealed reductions in BRS in response to both physical and psychological stressors. Moreover, BRS was more strongly responsive to the stressors than other cardiovascular indices obtained in the study (Anderson et al., 2016). Research suggests that exploring individual differences in BRS may provide important insight into the role of autonomic functioning in dispositional anxiety. TA reflects a relatively stable tendency to attend to and report worries, fears, and anxiety across a wide array of situations, and is therefore an ideal target variable for examination.

### **3. Current Study**

#### **3.1. Overall Aims**

Ample literature describes the importance of interoception in anxiety. Some literature reveals the relevance of BRS in emotional processes (e.g. anxiety). Yet much remains unknown regarding the interrelation among these variables, as no known study has yet examined this in a single investigation. The primary purpose of the project was to narrow the gap between these two foci and to link these factors in a way that will ultimately generate downstream information for treatment of anxiety disorders, which are notably related to afferent physiology. This work is envisioned to aid in explicating latent mechanisms involved in the pathogenesis of anxious symptomatology.

In light of recent theoretical accounts of interoception (i.e. predictive coding and dimensional models of interoception, the current study aims to extend the work of Garfinkel et al. (2015) (Three-Dimensional Model of Interoception) and Paulus & Stein (2010) (Altered Interoceptive Predictive Coding Model). This investigation examined the unknown relationships between the stated interoceptive dimensions to TA. The study also aimed to investigate the contribution of a cardiovascular measure (BRS) in these associations. BRS is a known indicator of baro-afferent signal transmission which is importantly linked to interoceptive processing. BRS was anticipated to relate to interoceptive variables by virtue of its vital role in cardiovascular afferent feedback that modulates heart rate and blood pressure responses. The present study also examined BRS changes in relation to acute stress reactivity, specifically examining BRS during an anticipatory anxiety manipulation. It is well established that stress modulates cardiovascular responses that may alter afferent neural information received from the cardiovascular system (Appleyard, Marks, Kobayashi, Okana, Low, Andresen, 2007; Schulz et al., 2010).

IS was indexed in two ways: One measure was self-reported confidence on heartbeat tracking task. A separate measure of IS was assessed self-report on the Multidimensional

Assessment of Interoceptive Awareness (MAIA; Mehling, 2012; See Appendix I). IAC was indexed via objective performance on a heartbeat tracking task. Although using the MCS task for this purpose may have been ideal, there were insufficient funds for this method, and so the Schandry (1982) heartbeat tracking task was used, including added methodological controls which are further discussed in the Methods section (e.g. Dunn et al., 2010b). Additionally, as previously stated, the Schandry task is found to be more sensitive to individual differences than tone detection methods. IAW was measured as average of the within-trial correspondences between IS and IAC.

### 3.2. Specific Aims and Hypotheses

1. **Aim:** To explore the relationships among the three dimensions of interoception (IS, IAC, and IAW) in an attempt to further empirically validate the Garfinkel (2015)'s model.

**Hypothesis:** IS and IAC will be independent, suggesting distinct and dissociable interoceptive domains. IAC was expected to be significantly associated with IAW due to the existence of IAC as a theoretical component of IAW.

2. **Aim:** To assess the degree to which IS, IAC, IAW, and baseline BRS predict trait anxiety (TA).

**Hypothesis:** Higher IS and IAC, and lower IAW and BRS will significantly predict higher TA.

3. **Aim:** To examine BRS, IS, IAC, and IAW across two in-lab "conditions" (resting, during a speech preparation task (a potent anticipatory anxiety manipulation)) among high and low TA subjects. **Hypothesis:** BRS will decrease from baseline to task for both groups. Higher TA will be associated with lower BRS in both conditions compared to lower TA subjects. This aligns with findings of reduced cardiac regulatory control in anxiety.

Among higher TA subjects, IAC will decrease from baseline to task whereas IS (this time indexed via self-reported confidence on the heartbeat tasks) will increase from baseline to task.

**3.2.1. Exploratory analyses.** a) To test associations between Anxiety Sensitivity (AS), and interoceptive domains. b) To test associations between responses on the Brief Fear of Negative Evaluation Scale and interoceptive domains c) To examine correlations between mean HF-HRV and BRS during rest, and during the anticipatory anxiety manipulation. d) To examine correlations between mean heart rate and IAC during each heartbeat tracking task. e) To explore potential sex differences in physiological and psychological data.

### 3.3. Method

**3.3.1. Subjects.** Sixty students were recruited (for 0.95 power at  $\alpha=0.05$ ; mean age=19.35 years; SD=1.07; 37 female) from Virginia Tech. Exclusion criteria included history of cardiovascular, metabolic, neurological diseases or disorders, as well as history or current diagnosis of affective, psychotic, or developmental psychological disorders. Those with anxiety disorder diagnoses were included in the sample; however, anxiety diagnoses were assessed via self-report. Exclusion criteria included chronic alcoholism and smoking within the past year; having sustained a concussion or other brain injury causing cognitive or visual symptoms, and use of pharmacological agents with known psychotropic or cardiovascular effects (including those taking selective serotonin reuptake inhibitors (SSRI's)). For other participant characteristics, see Tables 1-3.

Eligibility was determined based on responses from the Mind-Body Lab Health History screening questionnaire (HHQ; See Appendix D), which was a prerequisite for ability to sign up

for the study. Researchers obtained approval of the study by the Virginia Tech Institutional Review Board prior to recruitment of participants. Course extra credit as well as a random chance to win a \$50 or \$25 Visa card served as compensation for participation. Recruitment strategies involved placement of flyers as well as use of Virginia Tech's SONA online recruitment system.

**3.3.2. Physiological Measures.** All physiological signals were acquired in real-time using BIOPAC Systems, Inc. software and MP160 hardware (BIOPAC Systems Inc., Goleta, CA). For the purpose of controlling for respiration values in HF-HRV measures, respiration values were obtained. A BIOPAC effort transducer TP-TSD-201 respiration belt was used for this purpose. Physiological data were recorded using BIOPAC AcqKnowledge 5.0 software. An ECG signal was obtained using ConMed Suretrace conductive Ag/Ag chloride adhesive pre-gelled electrodes (#1800).

**3.3.2.1. Heart rate and heart rate variability.** The *Find Cycle* function for R-wave onset in AcqKnowledge was applied to the ECG signal. The signal was visually inspected and artifacts were removed. Interbeat intervals (IBI)'s (distance between two consecutive R-waves) were imported into Kubios software (Version 2.2, 2004, University of Eastern Finland) for both heart rate and heart rate variability (HRV) measures. HF-HRV values were collected to examine relations with BRS indices. HRV values were attained using spectral analysis of the ECG signal and yielded variability in the high-frequency spectrum corresponding to respiration (0.12-0.40 Hz). A Fast-Fourier Transform function was performed for the IBI time series to derive power ( $\text{ms}^2$ ) in this high-frequency band. Calculations were then converted with a natural logarithm transformation.

**3.3.2.2. Blood pressure (BP).** Following attachment of BP equipment to the non-dominant arm, the arm was placed on a foam block in front of the subject for heart-level measurement of the signal. Non-invasive systolic and diastolic BP measurements were collected continuously, in a beat-to-beat fashion, and the signal was amplified using the CNAP® Monitor 500 and BIOPAC NIBP100D system (BIOPAC Systems Inc., Goleta, CA).

**3.3.2.3. Baroreflex sensitivity (BRS).** Measures of arterial BRS were derived via BIOPAC AcqKnowledge 5.0 software's baroreflex analysis routine using the sequence method (Kuusela, 2010; Reyes del Paso, 1994). Adaptive template matching was applied in order to identify each cardiac cycle, marking components of the cycle (P, Q, R, S, & T) on the ECG waveform as well as systolic and diastolic points on the BP signal. BP and ECG signals were then visually inspected for accuracy and appropriate corrections were applied.

The sequence method involves analysis of systolic blood pressure and interbeat interval/heart rate values and identification of locations of defined time ranges for analysis that fit a set of criteria (sequences) (Reyes del Paso, 1994). Specifically, ascending and descending sequences were identified and included in analyses (Parati et al., 1995). Ascending sequences were defined as consecutive cardiac cycles with sequential increases in systolic blood pressure which are immediately followed by successive lengthening of interbeat intervals. Conversely, descending sequences were defined as consecutive cardiac cycles with sequential decreases in systolic blood pressure which are immediately followed by successive shortening of interbeat intervals.

In accordance with Reyes del Paso (1994)'s recommendations, a rising (or ascending) sequence was defined as a time range involving at least  $n$  consecutive data points/cardiac cycles  $i \in \{j, k\}$  which exhibit  $RR(i+2) - RR(i+1) > RR_{threshold}$  and  $SBP(i+1) - SBP(i) > SBP_{threshold}$ . A

falling (or descending) sequence was defined as a time range involving at least  $n$  consecutive data points/cardiac cycles  $i \in \{j, k\}$  which exhibit  $RR(i+2) - RR(i+1) < RR_{threshold}$  and  $SBP(i+1) - SBP(i) < SBP_{threshold}$ . In other words, this description refers to BP and heart rate signals increasing (for ascending sequences) or decreasing (for descending sequences) by at least their thresholds in between consecutive data points. The following criteria were applied for both sequence types:  $n=3$ ,  $RR_{threshold}=1$  ms,  $SBP_{threshold}=0.5$  mmHg (Kuusela, 2010). Time intervals included were required to consist of at least 3 samples but extended until the first sample in which the signals decreased/the increase was below the SBP threshold (for ascending sequences) and in which the signals increased/the decrease was below the SBP threshold (for descending sequences).

BRS for each of these identified time intervals/sequences involved calculation of the best linear fit for the sequence, with SBP and heart rate as  $x$  and  $y$  coordinate, respectively. The local BRS reflected the slope of this line of best linear fit. The minimal degree of correspondence ( $r$  values) for each sequence was required to be greater than or equal to .75 for inclusion in analyses. Separate mean BRS values for the first and second baseline periods and speech preparation were computed across sequences contained within the epochs.

**3.3.2.4. Respiration rate.** Respiration rate values were obtained to control for possible respiratory effects on HRV parameters. A BIOPAC respiration belt with TP-TSD201 Respiratory Effort transducer was wrapped around the subject at the sternum and fastened close but comfortably (Etzel et al., 2006). The respiration waveform was resampled at 62.5 samples per second and transformed using a digital band pass filter with low- and high-frequency cutoffs fixed at .05 and 1.0 Hz, respectively. The waveform was fixed at 5000 coefficients, based on

guidelines suggesting number of coefficients at  $4 \times (\text{Waveform Sampling Rate} / \text{Lowest Frequency Cutoff for Filter})$  (BIOPAC Systems Inc., AcqKnowledge Software Guide).

**3.3.3. Self-report measures.** The Mind-Body Lab Health History Questionnaires (MBL-HHQ) assisted primarily in determining whether subjects will be included or excluded from study participation. The Patient Health Questionnaire (PHQ-9; Kroenke, Spitzer, & Williams, 2001) is a 9-item self-report diagnostic measure assessing the presence of depressive disorders. The PHQ-9 has acceptable psychometric properties, with good internal reliability ( $\alpha$  ranges from .86 to .89) and excellent test-retest reliability. ROC analyses showed area under the curve (AUC) for diagnosing major depression was .95 (Kroenke et al., 2001).

The State-Trait Anxiety Inventory (STAI; Spielberger, 1983) consists of two subscales: State and Trait. The Trait subscale evaluates relatively stable individual differences in tendency to experience anxiety in anticipation of subjectively threatening situations. The STAI-Trait is comprised of 20 items and internal consistency coefficients ranging from .86 to .95 and test-retest reliability coefficients ranging from .65 to .75 over a 2-month period (Spielberger et al., 1983). The STAI-State 6 item questionnaire (STAI: Y-6 item; Marteau & Bekker, 1992) is a 6-item short form version of Spielberger et al.,'s (1983) questionnaire. This measure was designed to assess current anxiety, and items inquire about how subjects "feel right now, at this moment". The STAI: Y-6 item measure demonstrates acceptable reliability ( $\alpha=.82$ ) and validity, and has been shown to produce scores similar to those obtained using the full 20-item STAI (Marteau & Bekker, 1992).

The Multidimensional Assessment of Interoceptive Awareness (MAIA; Mehling et al., 2012) is a multidimensional 32-item self-report instrument measuring body awareness and is

comprised of the following eight subscales: *Noticing*, *Not-distracting* (reverse coded), *Not-worrying* (reverse coded), *Attention Regulation*, *Emotional Awareness*, *Self-regulation*, *Body Listening*, and *Trusting*. The MAIA shows good construct validity and internal-consistency reliability of the eight subscales of  $\alpha$ 's greater than .65 (Mehling et al., 2012). The instrument also demonstrates the ability to detect differences between individuals who are less experienced and highly experienced concerning somatic awareness (Mehling et al., 2012).

The Anxiety Sensitivity Index-Revised (ASI-R; Taylor & Cox, 1998) is a 36-item measure containing six subscales assessing the following domains: *Fear of cardiovascular symptoms*, *Fear of respiratory symptoms*, *Fear of gastrointestinal symptoms*, *Fear of publicly observable anxiety reactions*, *Fear of dissociative neurological symptoms*, *Fear of cognitive dyscontrol*. The ASI-R has excellent internal consistency ( $\alpha=.95$ ) and psychometrically acceptable content validity (Deacon, Abramowitz, Woods, & Tolin, 2003).

The Brief Fear of Negative Evaluation Scale- Revised (FNE-II) is a 12-item instrument assessing general discomfort with the possibility of negative social evaluation from others (Carleton et al., 2006). The FNE-II demonstrates excellent internal consistency ( $\alpha=.96$ ) and factor analyses support a unitary solution (Carleton et al., 2006). Finally, the Confidence Judgment/Self-rated Accuracy questionnaire gauged subjects' self-perception of accuracy for heartbeat tracking task trials.

**3.3.4. Baseline videos.** Five-minute non-stimulating videos displaying aquatic were played during acquisition of physiological measures during baseline epochs. This commonly used assessment technique is based on recommendations that allow for superior generalizability and stability to traditional "resting" baseline measures and lengthier baseline periods (Jennings,

Kamarck, Stewart, Eddy, & Johnson, 1992; Yang, Jennings, & Friedman, 2017). Videos were muted to avert potential interference from auditory stimuli with variables of interest.

**3.3.5. Missing data.** Data from some subjects were omitted from specific analyses due to equipment malfunctioning, absent data, or poor clarity of physiological signals. Specifically, blood pressure and BRS data for one subject were absent during the second baseline period and speech preparation period. Another subject had missing data for the speech preparation period only. Also, there were some periods where despite clear data, no qualified BRS sequences occurred. Insufficient STAI-T responses for one subject permitted inclusion of TA data. One subject's heartbeat tracking accuracy data was omitted due to failure to record several self-reported heartbeat counts.

### **3.4. Procedure**

Sessions were run within a similar window of time every day (early to late-afternoon). Subjects entered the laboratory following a six-hour caffeine abstinence, 24-hour abstinence from alcohol, and two-hour abstinence from eating or vigorously exercising. Subjects were requested to sleep for approximately eight hours on the previous night.

Following the reading and signing of a consent form, the aforementioned requests were confirmed via verbal self-report on the Mind-Body Lab Recent Health History Questionnaire (R-HHQ; See Appendix E). Researchers then attached physiological recording equipment to subjects for continuous recording, which first consisted of electrode placement on the torso for collection of an electrocardiography (ECG) signal using a standard Lead II configuration (See Section 3.3.3 “Physiological Measures” and Appendix L). Subsequently, a respiration belt was

placed around the chest. Following this, subjects were seated in front of a computer and remained seated for the remainder of the study.

The following self-report measures were then administered electronically: Mind-Body Lab Health History Questionnaire; Patient Health Questionnaire-9 (PHQ-9; Kroenke, Spitzer, & Williams, 2001; See Appendix F). State Trait Anxiety Inventory-Trait Subscale (STAI; Spielberger et al., 1983; See Appendix G) State-Trait Anxiety Inventory-State (STAI: Y-6 item; Marteau & Bekker, 1992; See Appendix H). Multidimensional Assessment of Interoceptive Awareness (MAIA; Mehling, et al., 2012; See Appendix I); Anxiety Sensitivity Index-Revised (ASI-R); Taylor & Cox, 1998; See Appendix J); Brief Fear of Negative Evaluation (FNE-II; Carleton, McCreary, Norton & Asmundson, 2006; See Appendix K).

Subsequently, researchers attached a blood pressure (BP) cuff to the non-dominant arm with cuff placed over the brachial artery as well as a double-finger cuff to the ipsilateral hand, to noninvasively acquire a continuous BP signal (See Appendix M). Successively, a five-minute baseline period was employed for the collection of resting physiological measures. During baseline epochs, subjects viewed engaging but minimally stimulating videos displaying marine life (Coral Sea Dreaming; Plankton Productions and MLJ).

Following this, subjects performed a heartbeat tracking task. The BP monitor was paused during heartbeat tracking tasks, since the closeness of the finger cuffs surrounding the fingers during BP measurement would have allowed subjects to feel their pulse in their fingers. In accordance with the mental tracking task paradigm (Ehlers & Breuer, 1992; Schandry, 1981), instructions were asked to silently count their heartbeats by closely attending to their bodies-particularly to the activity of their heart, without taking their pulse nor feeling any surface of their body. The onset and offset of each heartbeat counting trial was cued by the words “GO”

and “STOP”, which were presented on the computer screen (e.g. Ainley, 2014). Trial lengths were 25s, 30s, 35s, 40s, 45s, 50s. A total of 6 trials were presented in random order. Intertrial intervals lasted ten seconds in duration (Appendix N for schematic depiction of task).

Directly after each trial, self-reported task performance was acquired. This involved rating confidence in perceived accuracy of the response. Subjects were instructed to circle a whole number on a paper form with a visual analogue scale spanning from 1 to 10 (“No heartbeat awareness/Complete guess” to “Full perception of heartbeat/Complete confidence”) (Garfinkel et al., 2015; See Appendix O). Prior to participation in the “scored” task, subjects began by completing three practice trials (which were clearly labeled as such) in order to familiarize themselves with general completion of the task.

Immediately following completion of the first heartbeat task, a three-minute recovery period ensued in which the subject was asked to sit quietly. BP readings then resumed. Subsequently, after a second five-minute baseline epoch, the researcher re-entered the room to instruct the subject to prepare a brief five-minute speech in which they were going to talk continuously about why they would be a good candidate for their ideal job. It was also noted that this speech was going to be recorded via the web camera attached to the computer and viewed by a panel of judges trained in public speaking. They were told that they would be allotted a total of five minutes to prepare the speech and that their performance was going to be rated on apparent confidence, public speaking skills, and knowledge about the topic. Additionally, there were instructed to prepare for the speech “mentally” and not to write anything down during this time. The researcher also mentioned that no questions about the speech could be answered at this time, in order to keep consistency across participants. The researcher then cued the start of the preparation period. This manipulation was designed to elicit anticipatory anxiety.

Immediately, following the conclusion of the speech preparation period, the researcher informed the subject that due to a technical issue, the speech was still in the process of being set up. At this point, the subject was asked to complete the second heartbeat task in the meantime, for the sake of time efficiency. Subjects were not yet informed they were not in fact going to deliver a speech.

The BP monitor was paused once more prior to administration of a second heartbeat tracking task where specifications were identical to the first heartbeat tracking task, with the exception of interval duration presentation order, which was re-randomized. Additionally, no further familiarization trials took place prior to task completion. At the conclusion of the second heartbeat task, the researchers then revealed the deception of the speech preparation task, briefly explaining that subjects would not in fact be required to perform a speech.

To control for the potential confound of biased guesses based on prior knowledge of average resting heart rate, researchers asked subjects to estimate the length of three randomly presented intervals (19s, 37s, and 49s) and to provide an estimate of their current resting heart rate (Ainley, 2014; Dunn et al., 2010<sup>b</sup>). Briefly, subjects were verbally asked about their state fatigue (“How sleepy or drowsy do you feel? How able were you to concentrate on the tasks?”). Response options ranged from one to five; 1= Very, 5=Not at all. Subjects were then asked how believable the speech preparation task was. (“How convinced were you that you would actually be required to deliver a speech during the session?” Options for a response were: *Completely convinced, somewhat convinced, slightly doubtful, and completely doubtful.*) Researchers then obtained height and weight measurements for body mass index (BMI) calculations.

Finally, a debriefing about the study was given before subjects exited the lab. This included an explanation of the deception of the speech preparation manipulation. Additionally,

researchers urged subjects not to reveal the procedures of the study to anyone else, including the deceptive aspect of the speech manipulation task, as this may have invalidated the efficacy of the manipulation for future participants (Refer to Appendix P for a schematic overview of the in-lab experimental protocol).

### 3.5. Data Reduction and Analyses

All physiological measures were individually averaged across each epoch (Baseline, Heartbeat tracking task, Recovery). For indexing interoceptive accuracy (IAC), heartbeat tracking task data were reduced as follows: Following BIOPAC Acqknowledge 5.0 software and visual/manual inspection of ECG waveform for artifacts, which were corrected for if detected, the number of R-wave peaks for each trial were calculated by the software. IAC was calculated as  $(1/6 \sum (1 - (|\text{recorded heartbeats} - \text{counted heartbeats}| / \text{recorded heartbeats})))$  (Schandry, 1981). Higher scores reflect higher IAC (Ainley et al., 2014). IAC was examined on a continuous scale, rather than using classification of individuals as *good* or *poor* heartbeat detectors.

In order to assess interoceptive sensibility (IS), mean responses on the MAIA Noticing subscale were used. Future research may examine possible associations among scores on specific subdomains and the physiological variables under examination; however this would extend beyond the specific aims of the study. An alternative measure of IS was also gauged using mean values of heartbeat task confidence.

For central analyses, interoceptive awareness (IAW) (i.e. confidence-accuracy correspondence) was indexed via within-person Pearson correlation,  $r$ , between within trial IAC and IS (trial by trial self-rated confidence on heartbeat tracking task trials). Six individual values

were obtained for each subject for each task, and mean values across each task were computed. Resting IAW was defined as IAW during the first heartbeat tracking task.

As a control for the possible confound of subjects' potentially biased guessing (i.e. counting seconds), a calculation was performed in order to assess the subjects' ability to estimate the duration of an elapsed interval. This value, termed the "time estimation accuracy", is equal to  $(1/3\sum (1(|\text{estimated elapsed time} - \text{actual elapsed time}|/\text{actual elapsed time}))$  (Dunn et al., 2010<sup>b</sup>). Values for each participant were averaged across the three time intervals (19s, 37s, 49s). Estimated resting heart rate accuracy is calculated using the following equation:  $(1/3\sum (1(|\text{estimated heart rate} - \text{actual heart rate}|/\text{actual heart rate}))$ . The actual heart rate value was a mean value and reflected a 30 second period (the 15 seconds preceding and 15 seconds following the given estimate).

**3.5.1. Statistical Analyses.** Partial Pearson's correlation analyses were employed in order to assess the relationships between the three interoceptive dimensions at rest (during the first heartbeat tracking task). BMI, birth control use, heart rate estimation accuracy, and time estimation accuracy were entered into the analysis as control variables. Separate correlation analyses were performed for IAC and IS (assessed via task 1 confidence ratings), IAC and IS (assessed via responses on MAIA Noticing subscale), and IAC and IAW (mean within-person, within-trial correspondence between IS and IAC).

A stepwise linear regression approach was used to examine explanatory variance for interoceptive subdomains and baseline BRS in prediction of TA. The first original regression equation was as follows:  $TA = b_0 + b_1IAC + b_2IS + b_3BRS + b_4BRS*IAC + b_5BRS*IS + e$ . Due to issues of multicollinearity, a separate regression equation for IAW was also performed:  $TA = b_0 + b_1IAW + b_2BRS + b_3IAW*BRS + e$ .

To examine BRS, IS, IAC and IAW across the two in-lab conditions in relation to TA, separate 2-factor mixed model repeated measures ANOVA tests were employed for each dependent measure (BRS, IS, IAC, and IAW). The within-subjects factor was Condition: (Resting, Speech Preparation). TA was included in the model as a between-subjects factor following categorization of TA scores into “high” and “low” using a median split. Greenhouse-Geisser corrections were used to address sphericity assumptions.

Pharmacological contraceptive use, BMI, time estimation accuracy, and estimated resting heart rate accuracy were controlled for in statistical analyses by treating them as covariates. Prior to inclusion in analyses, birth control use was dummy coded (0= non-use, 1=use).

**3.5.2. Exploratory analyses.** Additional partial correlation analyses were used to examine the bivariate relationships among AS and the three interoceptive domains; as well as between FNE-II and MAIA responses. Partial correlations between mean HF-HRV, and BRS values during the baseline epochs and speech preparatory phases were calculated in order to explore the associations between these two measures that assess cardiac control in this sample. Additional partial correlation analyses were performed to examine a potential relationship between mean heart rate and IAC during each heartbeat tracking task. BMI, birth control use, test estimation accuracy, and heart rate estimation accuracy were control variables. Finally, independent samples t-tests were performed to assess sex differences in all physiological measures during the first baseline period and also during the speech preparation period. Independent samples t-tests were also performed to assess sex differences in self-report data.

## **3.6. Results**

### **3.6.1. Primary Results**

**3.6.1.1. Relation between interoceptive facets at rest.** Controlling for BMI, birth control use, time estimation accuracy, and heart rate estimation accuracy, partial correlations between IAC and IS (assessed via confidence ratings during the first heartbeat tracking task (during rest)) did not show a significant association ( $r = .155, p = .13$ ). IAC and IS (assessed via responses on the MAIA Noticing subscale) also failed to show a significant correlation ( $r = -.058, p = .34$ ). IAC and IAW were not significantly correlated ( $r = .138, p = .16$ ). Additionally, the two indices of IS were not significantly correlated with one another ( $r = -.067, p = .31$ ). (See Table 4 and Figure 2).

**3.6.1.2. Interoceptive facets and resting BRS in prediction of TA.** Controlling for BMI, birth control use, heart rate estimation and time estimation, a stepwise multiple linear regression analysis performed for the prediction of TA failed to identify resting IS (mean confidence ratings during the first cardioceptive task), IAC, and  $BRS_{\text{ascending}}$  (mean BRS for ascending sequences during the first baseline period) as significant predictors in the model ( $p$ -values for each independent variable exceeded .05). Interaction terms  $BRS * IS$  and  $BRS * IAC$  were also removed from the model due to non-significance in prediction of TA. In addition, a separate stepwise multiple linear regression performed for the prediction of IAW, mean  $BRS_{\text{ascending}}$  and  $BRS * IAW$  with the same aforementioned control variables failed to show significant predictions onto TA.

Partial correlations performed alongside the regression analyses showed  $BRS_{\text{ascending}}$  during the second baseline and  $BRS_{\text{descending}}$  during the speech preparation period were positively correlated with TA [(marginal trend  $r = .20, p = .08$ ), and ( $r = .26, p = .03$ ), respectively]. (See Figure 3). Finally, controlling for birth control use and BMI, IAC during the first and second cardioceptive tasks were both significantly positively correlated with TA [( $r = .25, p = .03$ ), and ( $r = .23, p = .04$ ), respectively]. (See Figure 4).

**3.6.1.3. BRS and interoceptive facets during anticipatory anxiety.** A two-factor repeated measures mixed ANOVA analyses found no significant main effect of condition (Resting, following speech preparation) on IAC [ $F(1,54)=.07, p=.79$ ]. While this difference was non-significant for within-subjects effects, post-hoc pairwise comparisons showed significantly greater mean IAC scores immediately following the SP than during the task at rest ( $p=.01$ ). Tests of between-subjects effects failed to show a significant effect of TA group on IAC as a function of condition [ $F(1,54)=.72, p=.40$ ].

No significant effect of condition on resting IS (mean confidence ratings during task 1) was found [ $F(1,54)=1.28, p=.26$ ]. Additionally, resting IS was not significantly affected by TA group [ $F(1,54)=.01, p=.91$ ]. No significant effect of condition was found for IAW [ $F(1,53)=2.4, p=.13$ ] nor was TA significantly associated with IAW during the two conditions [ $F(1,53)=.41, p=.53$ ]. No significant effect of condition (second baseline versus speech preparation) on mean  $BRS_{\text{ascending}}$  or  $BRS_{\text{descending}}$  values was found [ $F(1,47)=0.43, p=.71$ ], [ $F(1,47)=.11, p=.74$ ], respectively. Finally, no condition-related TA group differences were found for BRS variables.

### 3.7.2. Exploratory analyses

**3.7.2.1. Self-report.** Partial correlations between mean ASI-R responses and interoceptive subdomains showed a significant negative correlation with IS (mean confidence ratings) during the second heartbeat tracking task ( $r = -.27, p=.02$ ). No significant correlations between AS and overall mean measures for the subdomains were found. However, a significant negative correlation between AS and IS was found with respect to the MAIA subdomain *Not Worrying* ( $r = -.59, p=.00$ ) and a positive correlation was found for *Emotional Awareness* ( $r=.27, p=.02$ ). In addition, a marginal negative correlation was found for *Attention Regulation* ( $r = -.20, p=.07$ ). Similarly, partial correlations between FNE-II scores and broader interoceptive dimensions did

not show significant associations, however, FNE-II responses were significantly negatively correlated with MAIA subscales *Attention Regulation* ( $r = -.27, p = .02$ ) and *Not Worrying* ( $r = -.31, p = .01$ ). (See Tables 6 and 7 for correlation matrices for TA and self-report measures).

**3.7.2.2. Physiological indices.** Partial correlations showed significant positive associations between mean HF-HRV indices and  $BRS_{\text{ascending}}$  as well as  $BRS_{\text{descending}}$  during the second baseline epoch ( $r = .43, p = .00$  and  $r = .38, p = .00$ ), respectively. HF-HRV measures were also positively correlated with  $BRS_{\text{ascending}}$  and  $BRS_{\text{descending}}$  during the speech preparation period ( $r = .36, p = .00$  and  $r = .46, p = .00$ ), respectively.

When controlling for BMI and birth control use, partial correlations between mean heart rate and IAC during each heartbeat tracking task showed marginal negative trends. Mean heart rate was negatively associated with IAC during the first task ( $r = -.20, p = .07$ ) as well as during the second task ( $r = -.18, p = .08$ ).

**3.7.2.3. Sex differences.** Sex differences were found for mean HR, HF-HRV, respiration rate, DBP, and BRS ascending values during the first baseline period. Results from an independent samples t-test showed significantly greater HF-HRV and BRS ascending values among men versus women. [HF-HRV for men ( $M = 7.36, SD = 1.03$ ) versus women ( $M = 6.60, SD = .98$ ),  $t(58) = -2.14, p = .04$ ]. [ $BRS_{\text{ascending}}$  for men ( $M = 20.31, SD = 13.94$ ) versus women ( $M = 13.07, SD = 8.23$ ),  $t(53) = -2.32, p = .03$ ]. Significantly greater HR, DBP, and respiration rate were found for women versus men. [HR for women ( $M = 75.74, SD = 10.43$ ) versus men ( $M = 67.11, SD = 9.12$ ),  $t(58) = 3.27, p = .00$ ; DBP for women ( $M = 66.21, SD = 7.32$ ), versus men ( $M = 59.81, SD = 6.59$ ),  $t(58) = 3.42, p = .00$ ; Respiration rate for women ( $M = 16.79, SD = 2.97$ ) compared to men ( $M = 14.97, SD = 2.86$ ),  $t(48.2) = 3.50, p = .00$ , equal variances not assumed].

During the speech preparation period, significant sex differences were found for all physiological measures. Specifically, t-tests showed higher HF-HRV, and BRS values among male subjects [HF-HRV for men: (M=7.18, SD=.91),  $t(58) = -2.14, p = .04$ ; for women: (M=6.59, SD=1.10)]. [BRS<sub>descending</sub> for men: (M=21.57, SD=13.26),  $t(54) = .02$ ; for women: (M=13.47, SD=10.99)]. Results showed higher mean HR, SBP, and DBP among female subjects. [HR for women: (M= SD=), HR for men: (M=SD=),  $t(58) = 3.24, p = .00$  ; SBP and DBP for women (M=110.98, SD=14.04; M=72.18, SD=9.53, respectively) and for men (M=102.57, SD=12.53; M=64.16, SD=9.68, respectively),  $t(56) = 2.32, p = .02$ ;  $t(56) = 3.11, p = .00$ , respectively].

For self-report data, women (M=5.32, SD=4.26) showed marginally greater PHQ-9 scores than men (M=3.78, SD=2.84);  $t(57.63) = 1.68, p = .10$  and marginally greater ASI-R scores (M=79.86, SD=17.55) than men (M= 71.00, SD=21.24),  $t(58) = 1.75, p = .09$ . Sex differences were also found for MAIA subscales. Men (M=3.35, SD=.64) reported significantly higher scores on the *Attention Regulation* subscale of the MAIA than women (M=2.61, SD=.85),  $t(55.61) = -3.82, p = .00$ . (See Table 8 for summarized data stratified by sex).

**3.7.3. Descriptive Statistics.** Refer to Tables 1-3, and 5 for demographic data, mean physiological values during rest and speech preparation task, self-report data, and data by sex, respectively. Refer to Tables 9 for mean baseline physiological data and Table 10 for partial correlations among resting physiological variables.

### 3.8. Discussion

This is the first known investigation to examine cardioception in a multidimensional fashion in relation to TA. It is also the first known study to explore baroreflex activity in contribution to the specific facets of cardioception. The central aims and hypotheses were as

follows: First, to provide additional empirical validation for Garfinkel & Critchley's 2013 model of interoception. IAC and IS at rest were predicted to be independent, due to theoretical differences between the constructs. IAC was expected to be significantly associated with IAW due to the existence of IAC as mathematical component of IAW. Secondly, a central aim of the study was to assess the degree to which IS, IAC, IAW and BRS at rest predict TA. Based on a large body of research as well as recent interoceptive predictive coding models (e.g. Paulus and Stein, 2010), TA was expected to be positively predicted by IS and IAC, and negatively predicted by IAW and resting BRS. It was also of special interest to explore how these independent variables may be affected by acute stress, namely, anticipatory anxiety, since this reflects a gap in the literature.

### **3.8.1. Relations between interoceptive facets at rest**

In accordance with hypotheses, resting interoceptive facets IAC and IS were uncorrelated, suggesting that they reflect distinct constructs. This suggestion was also supported by findings from Garfinkel et al., (2015). A lack of a significant correlation between resting IAC and IAW was unexpected, due to the contribution of IAC to IAW. However, this may be explained by the fact that IAW reflects a mean calculation of within-subject, within-trial correspondence between IAC and IS (task confidence ratings), whereas resting IAC was defined as mean cardioceptive accuracy across trials of the task. However, within-subject correlations between IAC and IAW would be expected to be significant.

### **3.8.2. Trait anxiety, cardioceptive dimensions, and BRS at rest**

The second major aim was to examine the potential for cardioceptive dimensions and resting BRS (BRS during the first baseline period) to predict trait anxiety (TA). Contrary to

hypotheses, the regression models failed to identify these factors as significant independent predictors of TA. However, results still suggest a link between BRS and TA. Specifically, partial correlations controlling for BMI, birth control use, heart rate estimation, and time estimation performed alongside the regression model revealed that ascending BRS during the second baseline and descending BRS during the speech preparation were positively associated with TA.

These seemingly divergent results likely reflect differences in the specific aspects and indices of baroreflex function as well as differences in affective state. BRS does not constitute an inflexible index of cardiac vagal control, but rather the sensitivity of the baroreflex system is subject to situational and temporal changes (e.g. Virtanen et al., 2003; Hossman, Fitzgerald, & Dollery, 1980). Moreover, results suggest that increased specificity of BRS measurements provides more informative than more general measures of baroreflex activity. For example, it is well-known that ascending and descending baroreflex responses are at times asymmetrical (La Rovere et al., 2008). Ascending BRS sequence measures reflect reflex cardiac interbeat interval changes induced by baroreceptor stimulation, whereas descending BRS sequence measures reflect baroreceptor deactivation (Parati et al., 2000).

Correlation results show a positive association between TA and IAC, controlling for BMI and birth control use. This finding aligns with hypotheses and much of the literature, which finds superior performance on cardioceptive tasks among highly anxious (typically clinically anxious) individuals (Dunn et al., 2010<sup>a</sup>; Wiens, Mezzacappa, & Katkin, 2000). Based on results of the current study, this heightened IAC may be related to increased BRS activity. Contrary to theoretical models of anxiety and to a substantial body of literature, the present study failed to identify IS (self-rated confidence on cardioceptive task performance) as significant corollary or predictor of TA. IAW was also not significantly related to TA in the current study, which

conflicts with hypotheses. This failure could reflect the issue of restricted range of responses on the STAI-T. Expected results may have emerged with a greater number of highly TA subjects.

### **3.8.3. Cardioceptive facets and BRS during anticipatory anxiety**

The third primary aim involved examination of within-person differences in BRS as well as interoceptive facets between two affective conditions: during rest (second baseline period), and during a five-minute speech preparation task. Existing literature generally shows reductions in BRS during acute stressors (Watkins et al., 1999). Potential differences in these relationships as a function of TA were also assessed. While the speech preparation manipulation significantly induced cardiovascular stress responses (i.e. significantly increased heart rate from baseline; See Figure 5), overall, no significant difference in interoceptive facets or BRS variables between the first and second heartbeat tasks was found. This unexpected occurrence may be explained by the temporal distance between the onset of the speech preparation manipulation and the subsequent heartbeat tracking task. Subjects' anticipatory anxiety may have waned as they refocused attention away from the aversive task. It is possible that focus on the second heartbeat tracking task may have been used an emotion regulation strategy, although lacking HF-HRV responses do not suggest this. Finally, the failure to identify effects of the anticipatory anxiety manipulation on the second heartbeat tracking task cannot be explained by the notion that subjects were skeptical about whether they would have to deliver a speech. The vast majority of subjects reported that they were completely convinced that they would have to deliver a speech.

The failure to find TA-related differences in IS, IAC, IAW and BRS in the two different conditions may not necessarily refute the existence of TA-related differences in emotional responses during the second task. The underlying factors relating to this finding were not

specifically investigated in the current study. For example, those higher in TA have been shown to exhibit biased attention to threat in early stages of processing, followed by avoidance of threatening stimuli (Koster et al., 2006). In other words, the cardioceptive task could conceivably reflect the use of the second heartbeat tracking task as a means of avoidance. Interestingly, despite the aforementioned findings, significant pairwise comparison results suggested that across individuals, greater mean IAC scores occurred following the speech preparation manipulation than during the first cardioceptive task.

### **3.8.4. Exploratory analyses**

**3.8.4.1. Self-report.** Exploratory analyses revealed interesting results that may inform the central findings in the current study. Anxiety sensitivity (AS), the fear of bodily sensations associated with the experience of anxiety, reflects a common fear among trait anxious individuals, though AS varies considerably across anxious phenotypes (Taylor, Koch, & Crockett, 1991). Nevertheless, AS is likely to play an important role in potentially dysregulated cardioception relating to anxiety (Domschke et al., 2010). Therefore, AS was expected to be a likely corollary of the interoceptive facets.

Despite failure to identify significant associations of AS to overall resting cardioceptive dimensions, associations with certain MAIA subdomains provide valuable and more specific insight into the link between anxiety and IS, relationships that may not emerge when examining the broader constructs of TA and IS. MAIA subdomains reveal behavioral patterns and interpretive biases and appraisal or subjectively assigned valence to physiological sensations that may be more informative for models of anxiety and interoception (as in interoceptive predictive coding models, e.g. Seth, 2013).

In the present study, AS scores were significantly negatively correlated with the *Not Worrying* subscale, described as the tendency not to worry or experience emotional distress with sensations of pain or discomfort. This was expected due to the very nature of the experience of AS. Also, AS was positively linked with *Emotional Awareness*, the connection between bodily sensations and emotional states. This finding aligns well with the tendency for anxiety sensitive, and anxious individuals more broadly, to be more interoceptively attuned (i.e. to have higher IS) but importantly, to experience negative affect more intensely (Wiens et al., 2000).

Interestingly, a marginal trend revealed a negative association between AS and *Attention Regulation*. While this finding may seem to run counter to putative literature concerning IS, this subscale is conceptually distinct from overall tendency to attend to internal physiological signals (or IS) insofar as its focus concerns the ability to sustain and control attention to bodily sensations. Given the possibility that anxious individuals tend to avoid threat (both internal and external) at later stages of stimulus processing, as well as the presence of attentional or working memory deficits associated with enduring heightened anxiety, this finding is conceivable (Koster et al., 2006) .

Considering that social anxiety and fear of negative evaluation commonly occur among trait anxious individuals, and given the nature of the anxiety manipulation used in the current study, it was deemed important to investigate the link between interoceptive constructs and fear of negative evaluation. Since fear of negative evaluation and anxiety sensitivity are theoretically closely linked in the context of social anxiety (i.e. fear of physiological reactions being noticed by others), it was expected that similar relationships may emerge (Dixon, Kemp, Farrell, Blakey, & Deacon, 2015). FNE-II scores were significantly negatively associated with *Attention Regulation* and *Not Worrying*, which may be a reflection of the relative difficulty that socially

anxious individuals have with sustaining attention, even attention focused on subjectively threatening physiological responses (such as increased heart rate).

**3.8.4.2. Physiological indices.** In the view of the importance of vagal functioning to BRS activity, it was deemed relevant to explore associations between BRS and HF-HRV at rest and during anticipatory anxiety (Duschek et al., 2013). Significant contributions of both BRS and HF-HRV to cardiac vagal control have been supported by multiple findings, specifically in the context of spontaneous BP changes. For example, much research has confirmed that both  $BRS_{\text{ascending}}$  and  $BRS_{\text{descending}}$  measures strongly correlate with HF-HRV, which is expected due to the factors comprising the measure of time-domain BRS (simultaneous changes in BP and interbeat intervals) (e.g. Milic et al, 2009). In the present investigation, mean BRS ascending and descending sequences during the second baseline period were each positively correlated with HF-HRV. This was also true during the speech preparation period. It is possible that the limited length of measurement of BRS may explain the lack of significant correlations for all BRS measurements during both time periods.

Finally, it has been proposed that cardiac measures such as heart rate should be considered a fourth facet of cardioception (Forkmann et al., 2016). Despite the logical contributions to cardioception, surprisingly, relatively minimal research has been devoted to investigation of the role of tonic autonomic activity or reactivity on IAC. It is generally assumed that increased heart rate leads to increased IAC. However, empirical studies do not equivocally support this notion (e.g. Stewart, Buffett-Jerrott, & Kokaram, 2001). Interestingly, in the current study, a brief examination of this topic showed a marginal trend toward a negative association between heart rate and IAC. This pattern appeared during both heartbeat tracking tasks.

**3.8.5. Sex differences.** Overall, for resting and anticipatory periods, men showed higher mean HF-HRV and BRS values, and lower HR and BP values versus women. Overall, these findings only partially align with the literature. In accordance with the majority of studies, resting BRS is generally greater among males as compared to females, likely due to differences in sex steroid hormones (Huikuri et al., 1996; Laitinen et al., 1998). Women also tend to show higher HR responses to acute stress due to greater  $\beta$ -adrenergic (compared to  $\alpha$ -adrenergic) influences than their male counterparts. However, diverging from the current results, general findings in the literature show significantly greater resting HF-HRV among women, reflecting enhanced vagal mediation of cardiac control (Thayer, Sollers, Friedman, & Koenig, 2016). Men typically demonstrate more predominant sympathetic influences on vascular responses than women (Evans et al., 2001). Evidence of increased BP responses to acute stress among men versus pre-menopausal women is well-documented (Reckelhoff, 2001).

Sex differences also emerged for self-reported psychological measures. Women reported greater scores on assessments of anxiety sensitivity and depression than men, which aligns with most extant literature (e.g. Stewart, Taylor, & Baker, 1997; Kessler, McGonagle, Swartz, Blazer, & Nelson, 1993). It is plausible that the unanticipated autonomic sex differences may be partially explained by overall greater anxious responses to the laboratory environment and/procedures among women. This notion would align specifically with evidence of increased anxiety sensitivity among women in the sample compared to men. The nature of the procedures in the study (i.e. heartbeat perception tasks) lends to increased state anxiety among those fearful of potentially negative cardioceptive cues.

**3.8.6. Limitations.** A potential limitation of the current study lies in the recruitment of a non-clinically anxious sample, and lacking focus on specific anxious phenotypes. Only one

subject in the sample reported having an anxiety disorder (generalized anxiety). Recruitment of a highly anxious sample was also likely to have been limited by the required mention of a speech in the recruitment materials for the study.

The current results suggest that perhaps more specific measures of anxiety and of interoceptive factors would be more informative. However, the examination of TA and anxiety sensitivity aids in the investigation of ways in which interoceptive patterns may occur in subclinical anxious traits and across various anxious sub-types. Such investigation may be informative in its own right.

Another study limitation was the fact that neither general attention nor working memory were specifically manipulated or measured though performance on the heartbeat tracking tasks requires ability to sustain attention. While this is true, the Likert scale question regarding self-reported ability to concentrate provides some degree of information about subjects' self-perceived ability to sustain attention during the tasks (See Table 2). Lastly, as previously discussed, a major limitation of the present investigation involves the seeming reduction in anticipatory anxious stress responses from the speech preparation period to the second heartbeat tracking task, which was designed to assess the interoceptive facets during anticipatory anxiety.

**3.8.7. Future Directions.** With increased understanding of the basic autonomic nervous processes involved in cardioception in anxiety, the elucidation of underlying mechanisms may eventually prove useful for applied clinical purposes. Following results from the current investigation, further research will be required to clarify the role of the baroreflex in interoception and relations to anxiety, possibly using various indices of baroreflex functioning. For instance, the baroreflex effectiveness index (BEI) is a measure which accounts for the number of baroreflex sequences in a given time window (DiRienzo et al., 2001). BEI specifies

the *rate* at which the baroreflex is able to progressively change cardiac activity in response to short-term sequential SBP changes.

Future directions also include use of interdisciplinary and multi-method approaches to empirically test recent theories of interoception in anxiety (e.g. Paulus & Stein, 2010; Garfinkel et al., 2015). For instance, use of CMS paradigms and fMRI approaches could be used in concert with cardiovascular approaches to study interoceptive processes associated with anxiety across multiple physiological systems.

In addition, further work is required to specify the degree to which specific interoceptive aberrations are reliably associated with anxious phenotypes. For example, social anxiety is associated with increased self-focused attention and self-monitoring. This may not be equally the case for other anxious tendencies (Rapee & Heimberg, 1997).

It would also be of utility to investigate the degree to which interoceptive abnormalities may be a predisposing and/or characteristic feature of clinical anxiety. It also remains to be identified whether cardiac interoceptive acuity is an independent risk or protective factor in the development of anxious pathologies. This may depend on the degree of associated interoceptive dimensions as well as autonomic (e.g. cardiovascular) factors. Understanding these relationships would eventually bear considerably on determination of the appropriateness of interoceptive therapies in treating excessive anxiety.

Finally, future work may further incorporate the presumably crucial roles of emotion regulation, self-referential schemas in subjective interpretation of cardiac signals, general attentional capacities, and patterns of state attention to internal signals. For example, the extent to which increased IAC among TA individuals is due primarily to threat-related working

memory/state attentive functions or to the actual ability to feel cardiac sensations with each heartbeat is unknown. The inclusion of autonomic variables in this research will be vital. Interoceptive models with increased predictive power will undoubtedly continue to be modified, as empirical research continues to narrow the gaps in the literature.

### **3.8.8. Conclusions**

Results from the current study support the existence of distinct interoceptive facets, and the importance of examining various anxious traits. Overall, results underscore the complexity of both conscious and implicit psychological and physiological factors that contribute to cardioception. TA, though common across anxious phenotypes, reflects a more general construct that may not consistently reveal systematic contributions of baroreflex activity. The relationship between TA and overall measures of BRS was somewhat unclear; however, TA was marginally positively associated to BRS during the second baseline. Although this finding runs counter to most existing findings, it could reflect the superior IAC relating to TA that emerged in select analyses. Results could insinuate that BRS may contribute to cardioceptive accuracy. Furthermore, effects of anticipatory anxiety on cardioceptive dimensions must be further clarified.

Importantly, the present study reveals method variance with regard to interoceptive subdomains (e.g. meaningful distinctions between IS assessed using confidence judgments during heartbeat tracking tasks or using self-report questionnaires). Moreover, operational definitions of the subconstructs may or may not appropriately reflect the self-report instruments used to assess them. These methodological and conceptual issues may have important implications for conceptual models such as Garfinkel's three-dimensional model, and more

broadly, for methodological assessment of interoceptive facets. These issues underscore the importance of increased descriptive specificity in interoceptive research, as well as the need for greater consistency in measurement of both behavioral and self-report proxy indices of interoception.

Though the aims of the study were basic in nature, rather than applied, increased understanding of basic processes pertaining to cardioception in anxiety remains crucial. Therefore, implications and empirical contributions following from the current study are significant. Anxiety disorders are among the most prevalent of mental disorders, with a 12-month prevalence of 18.1% of the U.S. adult population (Kessler, 2005). Superior treatment of debilitating anxiety will, for many patients, ultimately depend upon increased understanding of interoceptive facets in association with specific autonomic and psychological factors.

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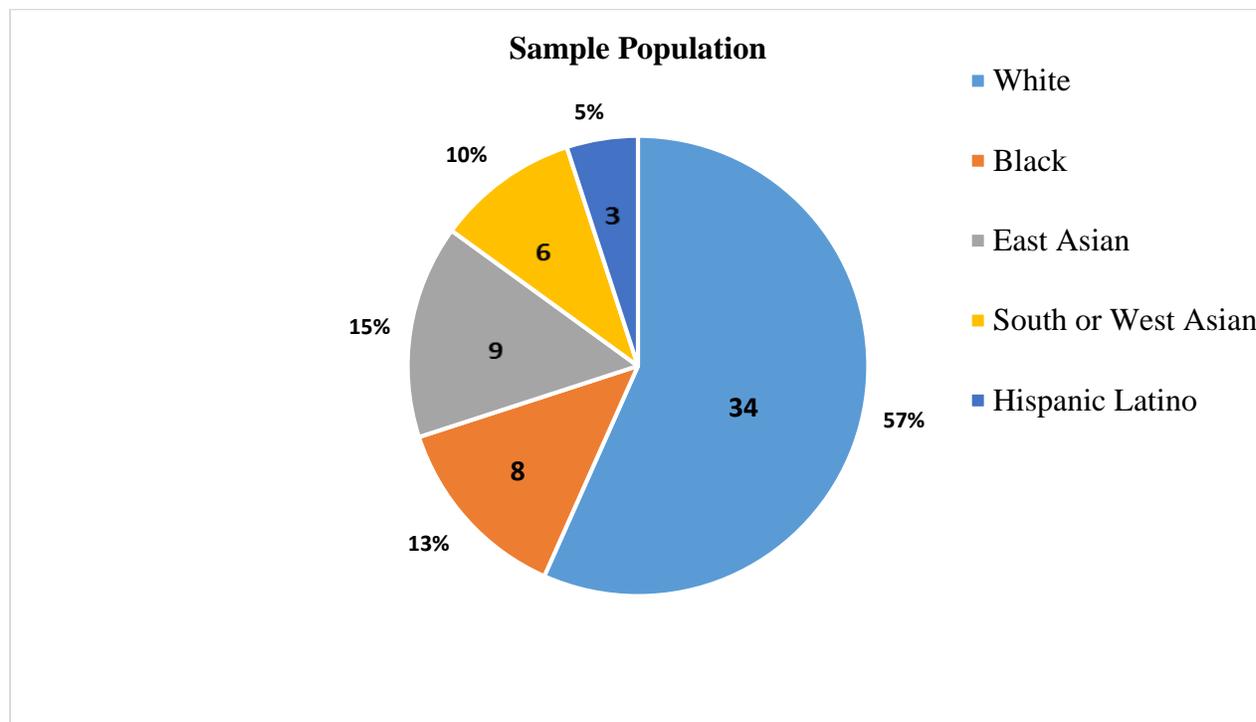
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## Figures and Tables

*Figure 1.* Self-reported Race and Ethnicity of Sample



*Note:* Internal numbers reflect the number of subjects for each demographic group

Table 1. *Mean Values and Percentages for BMI and Birth Control Use*

	<u>Male</u>	<u>Female</u>	<u>N</u>
<b>BMI</b>	24.06(3.89)	22.96(4.47)	60
<b>Birth control use</b>		<u>Percentage</u>	
Yes	N/A	54.05%	20
No	N/A	45.95%	17

Table 2. *Participant Characteristics and Brief Self-report*

	<b>Mean(SD)</b>	<b>N</b>
Fatigue	2.85(0.97)	60
Ability to concentrate	3.68(0.77)	60
Heart rate estimate accuracy	73.68(19.74)	60
Time estimate accuracy	79.55(13.88)	60
Speech believability	<u>Percentage</u>	
<i>Completely convinced</i>	70.00%	42
<i>Somewhat convinced</i>	18.33%	11
<i>Slightly doubtful</i>	10.00%	6
<i>Completely doubtful</i>	1.67%	1

Table 3. *Mean Questionnaire Data*

Questionnaire / Subscale	Mean (SD)	N
STAI-TRAIT	44.25(7.96)	59
STAI- STATE	32.89(8.45)	60
PHQ-9	4.73(3.83)	60
ASI-R	76.47(19.37)	60
BFNE-II	35.17(10.23)	60
MAIA <i>Noticing</i>	3.40(0.78)	60
MAIA <i>Not Distracting</i>	1.88(0.97)	60
MAIA <i>Not Worrying</i>	2.49(1.08)	60
MAIA <i>Attention Regulation</i>	2.89(0.85)	60
MAIA <i>Emotional Awareness</i>	3.25(0.93)	60
MAIA <i>Self-Regulation</i>	2.82(0.94)	60
MAIA <i>Body Listening</i>	2.06(1.12)	60

Table 4. Mean Interoceptive Facets

Physiological Measure	Mean(SD)		Mean(SD)	
	<u>Baseline 1</u>	<u>N</u>	<u>Speech Prep</u>	<u>N</u>
IAC	64.23(17.05)	60	68.59(16.70)	60
IS (Confidence Ratings)	4.27(1.64)	60	4.31(1.61)	60
IS (MAIA <i>Noticing</i> ) <sub>1</sub>	3.40(0.78)	60	N/A	
IAW	0.22(0.46)	60	0.26(0.43)	59

<sub>1</sub>Completed once, during questionnaire battery at the beginning of the study, and not during the baseline

#### 4. Facet

Table 5. Mean Physiological Data Stratified by Epoch

Physiological Measure	Mean(SD)					
	<u>Baseline 1</u>	<u>HBT 1</u>	<u>Recovery</u>	<u>Baseline 2</u>	<u>Speech Prep</u>	<u>HBT 2</u>
HR (bpm)	72.43(10.74)	73.47(10.31)	74.67(10.87)	72.66(10.44)	78.47(10.85)	72.55(10.39)
Ln HF-HRV (ms <sup>2</sup> )	6.89(1.06)	6.79(1.01)	6.83(.99)	6.75(1.05)	6.82(1.06)	6.97(.96)
SBP (mmHg)	116.28(13.33)	N/A	N/A	116.18(12.03)	107.64(13.98)	N/A
DBP (mmHg)	63.76(7.66)	N/A	N/A	66.71(9.70)	69.00(10.30)	N/A
BRS <sub>ascending</sub> (ms/mmHg)	15.97(11.82)	N/A	N/A	16.22(9.47)	19.25(12.91)	N/A
BRS <sub>descending</sub> (ms/mmHg)	16.00(1.28)	N/A	N/A	17.03(11.24)	16.80(12.52)	N/A
RR (bpm)	16.09(3.04)	15.91(2.76)	15.71(2.71)	16.40(2.93)	16.71(2.77)	15.49(3.01)

*Notes.* HBT 1= First heartbeat tracking task; HBT 2= Second heartbeat tracking task.

HR= heart rate; HF-HRV= high frequency heart rate variability; SBP= systolic blood pressure; DBP= diastolic blood pressure; BRS<sub>ascending</sub>= ascending sequences of baroreflex activity; BRS<sub>descending</sub>= descending sequences of baroreflex activity; RR= respiration rate

Table 6. *Partial Correlations between Responses on MAIA Subscales and Trait Anxiety*

Measures/Subscales	1	2	3	4	5	6	7	8	9
1. STAI Trait	—								
2. Noticing	-.06	—							
3. Body Listening	.08	.46**	—						
4. Not Distracting	-.19~	.14	.25*	—					
5. Not Worrying	-.29*	-.12	-.10	-.20~	—				
6. Attention Regulation	-.17	.36**	.23*	.10	.24*	—			
7. Emotional Awareness	-.03	.63**	.37**	.09	-.23*	.19	—		
8. Self-Regulation	-.12	.49**	.34**	.04	-.04	.52**	.47**	—	
9. Trusting	-.31**	.44**	.35**	.20	.00	.44**	.53**	.45**	—

Notes. Controlling for BMI and birth control use.

Sig. (one-tailed) at \*\*\* $p < .00$ ; \*\* $p < .01$ ; \* $p < .05$ ; ~ Marginal trend

Table 7. *Partial Correlations between Questionnaire Responses and Trait Anxiety*

Table 7

*Partial Correlations Between Questionnaire Responses and Trait Anxiety*

Measures	1	2	3	4	5
1. STAI Trait	—				
2. STAI State	.18~	—			
3. PHQ-9	.39**	.37**	—		
4. ASI-II	.26*	.34**	.42**	—	
5. BFNE-II	.34**	.31*	.13	.46**	—

Notes. Controlling for BMI and birth control use.

Sig. (one-tailed) at \*\*\* $p < .00$ ; \*\* $p < .01$ ; \* $p < .05$ ; ~ Marginal trend



<b><u>Baseline 1 Physiological Measure</u></b>	<b><u>Male</u></b>	<b><u>N</u></b>	<b><u>Female</u></b>	<b><u>N</u></b>
HR (bpm)	67.10 (9.12)***	23	75.74(10.43)***	37
Ln HF-HRV (ms <sup>2</sup> )	7.36(1.03)*	23	6.60(0.98)*	37
SBP (mmHg)	114.66(13.94)	23	117.29(13.04)	37
DBP (mmHg)	59.81(6.59)***	23	66.21(7.32)***	37
BRS <sub>ascending</sub> (ms/mmHg)	20.31(14.94)*	22	13.07(8.23)*	33
BRS <sub>descending</sub> (ms/mmHg)	17.40(9.60)	22	15.05(9.35)	32
RR (bpm)	14.97(2.86)***	23	16.79(2.97)***	37
<b><u>Questionnaire</u></b>	<b><u>Male</u></b>	<b><u>N</u></b>	<b><u>Female</u></b>	<b><u>N</u></b>
STAI-Trait	45.65(7.58)	23	43.36(8.17)	36
STAI-State	31.74(7.78)	23	33.60(8.87)	37
PHQ-9	3.78(2.84)~	23	5.32(4.26)~	37
ASI-R	71.00(21.24)~	23	79.86(17.55)~	37
FNE-II	32.48(9.62)	23	36.84(10.37)	37
MAIA <i>Noticing</i>	3.42(0.88)	23	3.38(0.73)	37
MAIA <i>Not Distracting</i>	1.80(0.94)	23	1.94(1.00)	37
MAIA <i>Not Worrying</i>	2.91(0.87)	23	2.23(1.13)	37
MAIA <i>Attention Regulation</i>	3.35(0.64)***	23	2.61(0.85)***	37
MAIA <i>Emotional Awareness</i>	3.12(1.03)	23	3.32(0.87)	37
MAIA <i>Self-Regulation</i>	3.20(0.82)	23	2.58(0.95)	37
MAIA <i>Body Listening</i>	2.38(1.22)	23	1.86(1.01)	37
MAIA <i>Trusting</i>	4.07(0.90)	23	3.63(1.00)	37

*Notes.* HR= heart rate; HF-HRV= high-frequency heart rate variability; SBP= systolic blood pressure; DBP= diastolic blood pressure; BRS<sub>ascending</sub>= ascending sequences of baroreflex activity; BRS<sub>descending</sub>= descending sequences of baroreflex activity; RR= respiration rate.

\*\*\*Sig. at  $p < .00$ ; \*\*Sig. at  $p < .01$ ; \*Sig. at  $p < .05$ ; ~ Marginal trend.

Table 9. *Mean Baseline Values of Physiological Data*

<b>Physiological Variable</b>	<b>Mean(SD)</b>	<b>N</b>
HR (bpm)	72.54(10.51)	60
Ln HF-HRV (ms <sup>2</sup> )	6.82(.99)	60
SBP (mmHg)	116.09(10.08)	60
DBP (mmHg)	65.22(7.76)	60
BRS <sub>ascending</sub> (ms/mmHg)	16.26(8.16)	59
BRS <sub>descending</sub> (ms/mmHg)	17.25(9.51)	59
BRS <sub>mean</sub> (ms/mmHg)	16.88(7.64)	60
RR (bpm)	16.25(2.78)	60

*Notes.*  
Physiological  
l values

reflect averages across the two baseline epochs. BRS<sub>mean</sub>=average BRS, including both ascending and descending values.

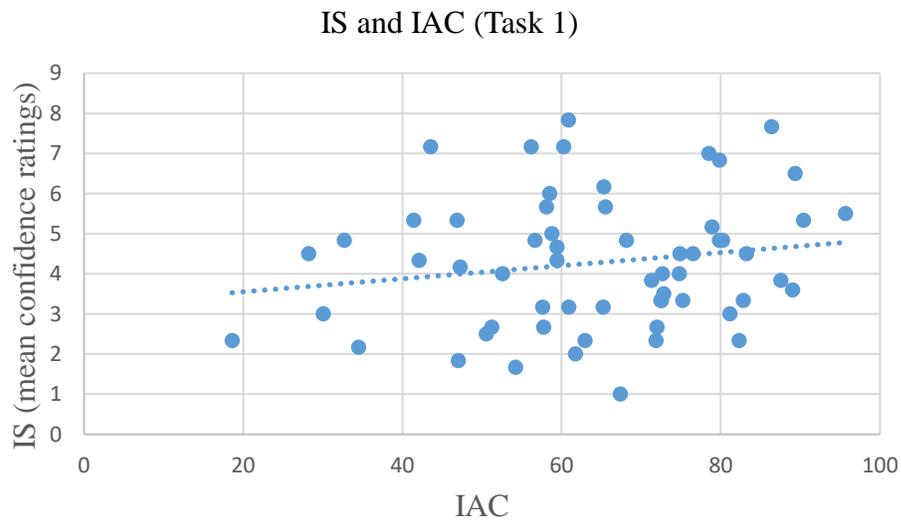
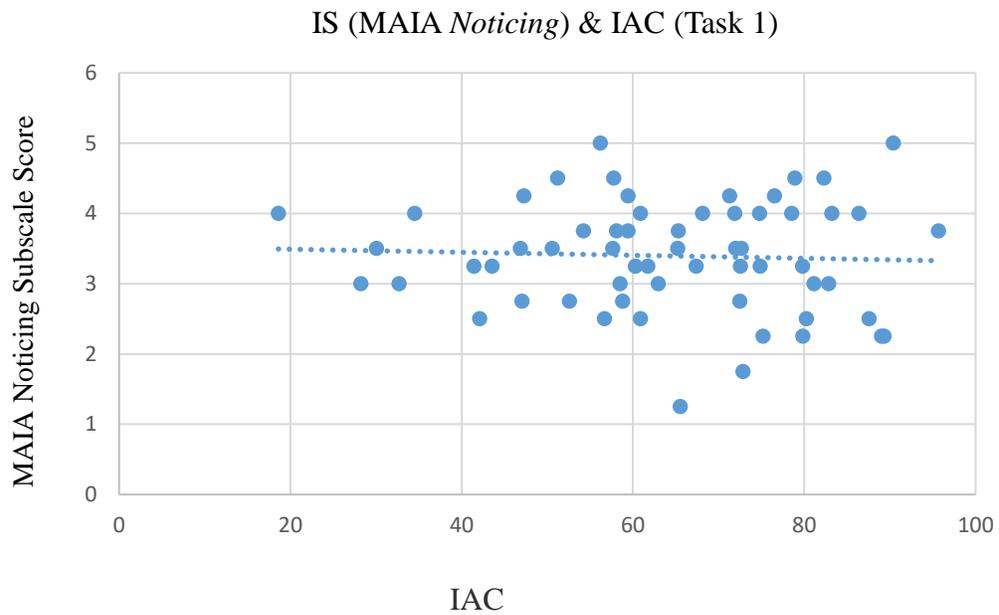
Table 10. *Partial Correlations among Resting Physiological Variables*

Physiological Variable	1	2	3	4	5	6	7
1. HR	—						
2. LN HF-HRV	-.50***	—					
3. SBP	.05	-.05	—				
4. DBP	.44***	-.41**	.45***	—			
5. BRS <sub>ascending</sub>	-.40**	.51***	-.45**	-.37**	—		
6. BRS <sub>descending</sub>	-.50***	.44**	-.21	-.19	.52***	—	
7. RR	-.06	-.04	.11	.12	-.07	.04	—

*Notes.* Partial correlation table reflecting relationships among physiological variables at rest. Baseline values were averages across the two baseline epochs. Controls: BMI and birth control use. HR= heart rate; HF-HRV= high-frequency heart rate variability; SBP= systolic blood pressure; DBP= diastolic blood pressure; BRS<sub>ascending</sub>= ascending sequences of baroreflex activity; BRS<sub>descending</sub>= descending sequences of baroreflex activity; RR= respiration rate

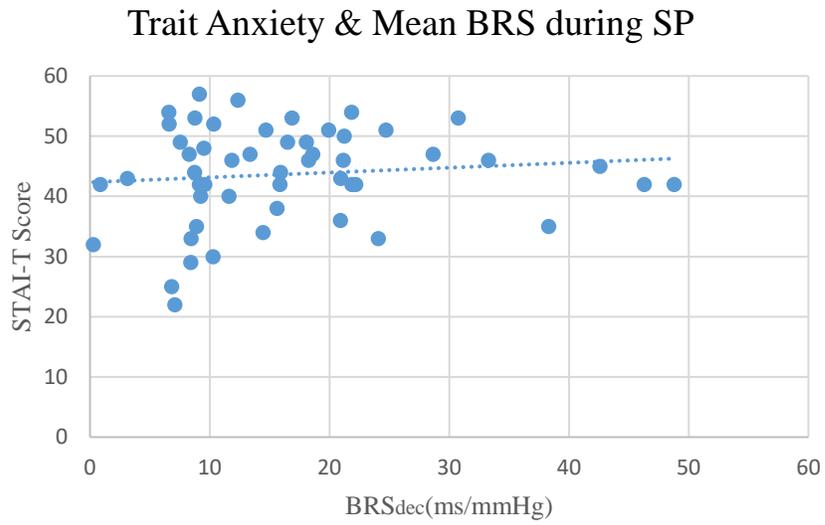
Sig. (two-tailed) at \*\*\* $p < .00$ ; \*\* $p < .01$ ; \* $p < .05$ ; ~Marginal trend

Figure 2. Independence among Interceptive Facets



Note. Scatterplots depict the non-significant correlations between IS and IAC. ( $p > .05$ )

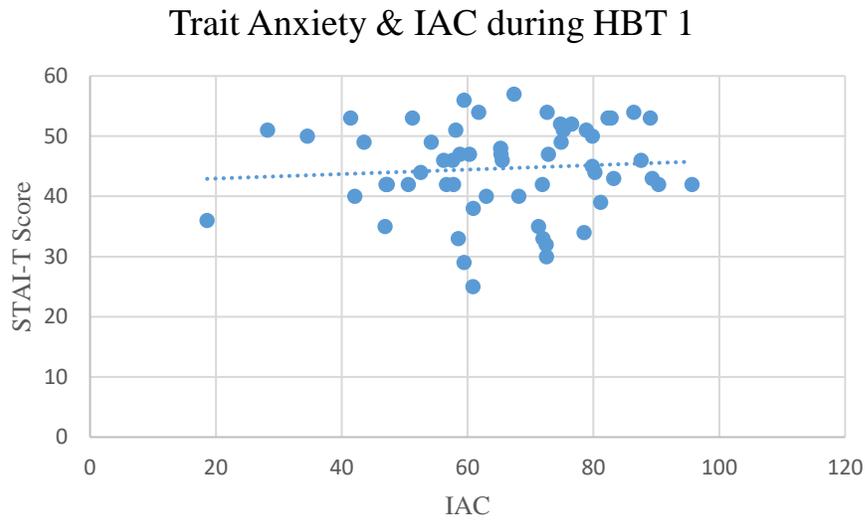
Figure 3. Association of Trait Anxiety to BRS



Note. SP= Speech preparation task; BRS<sub>dec</sub>= Mean value of descending BRS sequences

Marginal trend at  $p < .10$

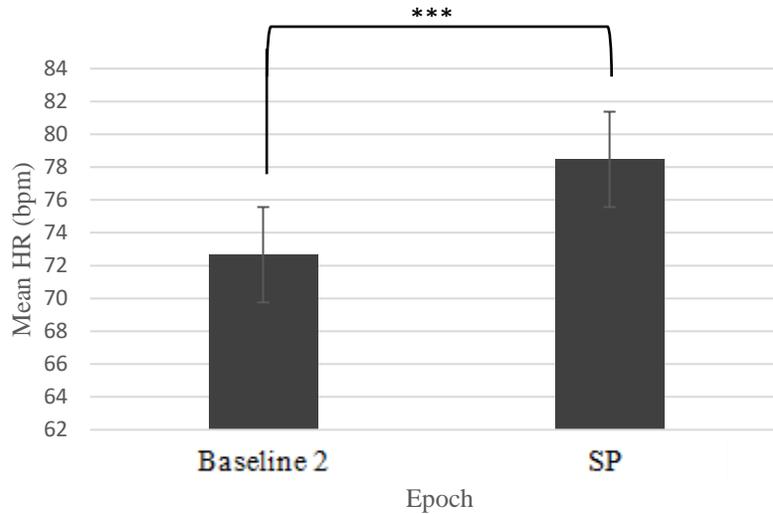
Figure 4. Association of Trait Anxiety to IAC



Note. HBT 1= First heartbeat tracking task (during rest).

Marginal trend at  $p < .10$

Figure 5. Mean HR during Baseline and Speech Preparation

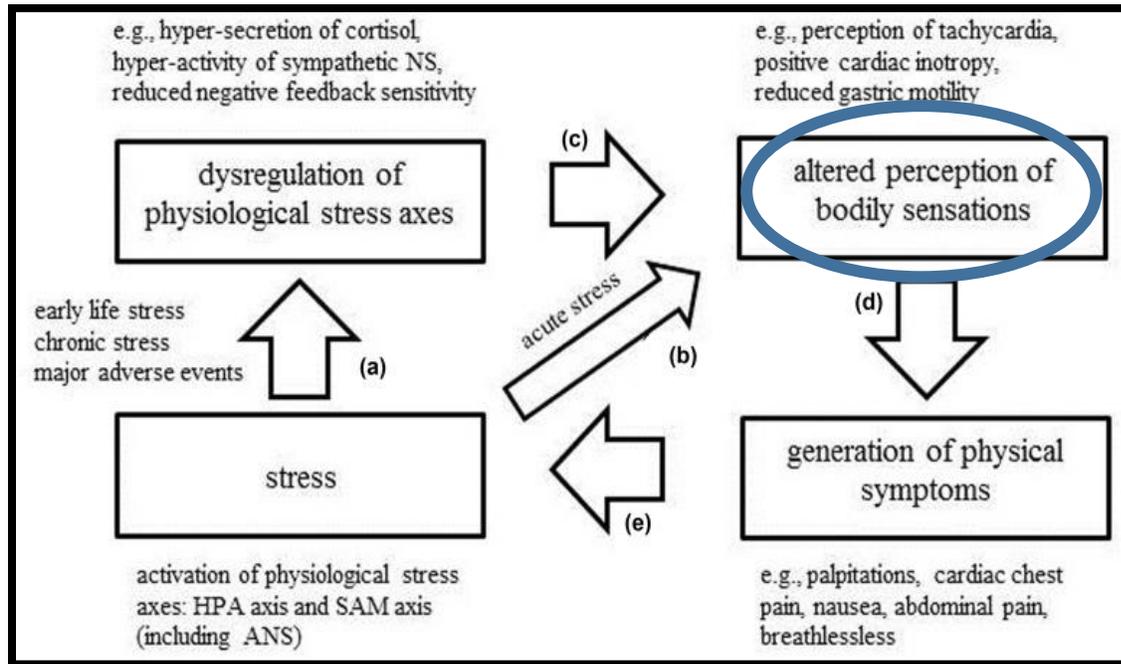


*Note.* Paired samples T-test showed significant differences between mean HR during the second baseline epoch and speech preparation period; SP= Speech Preparation

$t(60)=-8.69$

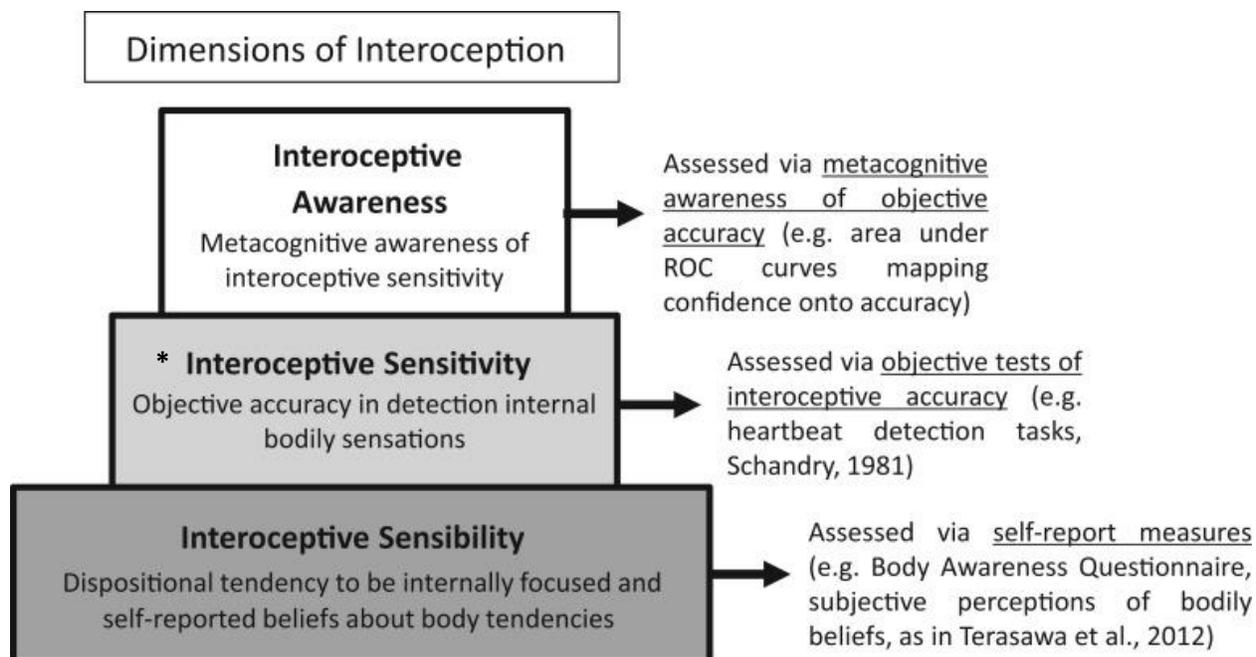
\*\*\*Sig. at  $p<.000$

**Appendix A**  
**Conceptual Model (Schulz & Vogele, 2015)**



“Synthesis of findings on acute and chronic stress, dysregulation of physiological stress axes, altered interoception and the generation of physical symptoms into model comprising a positive feedback loop” (Schulz & Vogele, 2015). Altered interoception (e.g. perception of tachycardia, positive cardiac inotropy, reduced gastric motility) is an important mediator in the relationship between dysregulation of physiological stress axes and generation of physical symptoms of anxiety.

**Appendix B**  
**Conceptual Model (Garfinkel & Critchley, 2013; 2015)**

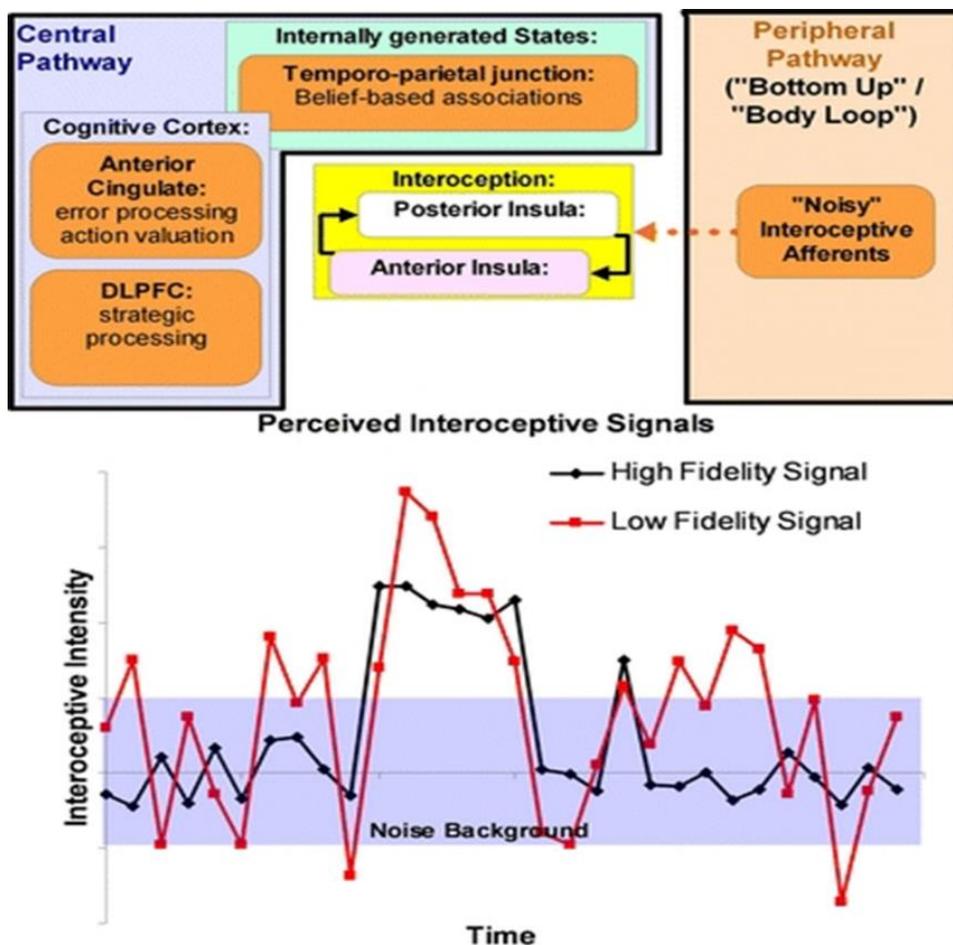


“Dimensions of interoception: Schematic figure depicting layered representation of internal bodily state and sensation. These facets may have distinct and dissociable contributions to affective behavior. Approaches for assessment these facets are suggested to the right hand side” (Garfinkel & Critchley, 2013. Also referenced in Garfinkel & Critchley, 2015).

Note. *Interoceptive Sensitivity* is now termed *Interoceptive Accuracy*.

### Appendix C

#### Conceptual Model: (Paulus & Stein, 2010)



“Proposed alterations in brain circuitry (top) and the resulting process abnormalities in anxiety and depression. Briefly, “noisy” afferent interoceptive information results combined belief-based associations lead to an attempt of the cognitive control apparatus to differentiate predictive from non-predictive signals. The resulting experience (bottom) consists of amplified interoceptive afferents that are associated with carry poor differentiation of stimuli that carry predictive outcomes and create constant uncertainty for the future” (Paulus & Stein, 2010).

**Appendix D**  
**Mind-Body Laboratory Health History Questionnaire (HHQ)**

A very brief medical history must be obtained as part of the experimental protocol. It is very important that you be completely honest. This information will be kept strictly confidential.

1. What is your age, height, weight, and gender?

Age: \_\_\_\_\_ years

Height: \_\_\_\_\_ feet, \_\_\_\_\_ inches

Weight: \_\_\_\_\_ pounds

Sex: \_\_\_M \_\_\_F

2. Since birth, have you ever been hospitalized or had any major medical problems?

\_\_\_ Yes \_\_\_ No

If Yes, briefly explain:

3. Have you ever experienced a concussion or lost consciousness due to a blow to the head?

\_\_\_ Yes \_\_\_ No

If Yes, briefly explain:

4. Have you ever had problems that required you to see a counselor, psychologist, or psychiatrist?

\_\_\_ Yes \_\_\_ No

If Yes, briefly explain:

5. Do you use tobacco products of any kind?

\_\_\_ Yes \_\_\_ No

If Yes, describe what kind how often/much:

6. Have you ever been diagnosed with a psychological disorder?

\_\_\_ Yes \_\_\_ No

If Yes, briefly explain:

7. Do you currently have or have you ever had any of the following?

\_\_\_ Yes \_\_\_ No    Strong reaction to cold weather

\_\_\_ Yes \_\_\_ No    Circulatory problems

\_\_\_ Yes \_\_\_ No    Tissue disease

- Yes  No Skin disorders (other than facial acne)
- Yes  No Arthritis
- Yes  No Asthma
- Yes  No Lung problems
- Yes  No Cardiovascular disorder/disease
- Yes  No Auditory deficiency that noticeably affects your ability to hear
- Yes  No Tinnitus (ringing in your ears)
- Yes  No Pulsatile tinnitus (hearing “whooshing” sound in timing w/ your pulse)
- Yes  No Diabetes
- Yes  No Hypoglycemia
- Yes  No Hypertension (high blood pressure)
- Yes  No Hypotension (low blood pressure)
- Yes  No Hepatitis
- Yes  No Neurological problems
- Yes  No Epilepsy or seizures
- Yes  No Brain disorder
- Yes  No Stroke

If you responded Yes to any of the above conditions, briefly explain:

8. Have you ever been diagnosed as having:

- Yes  No Learning deficiency or disorder
- Yes  No Reading deficiency or disorder
- Yes  No Attention deficit disorder
- Yes  No Attention deficit hyperactivity disorder
- Yes  No Autism spectrum disorder or Asperger syndrome

9. Have you ever been diagnosed with:

- Yes  No Claustrophobia (extreme fear of small closed spaces)
- Yes  No Blood phobia (extreme fear of needles or blood)

- Yes  No Fear of medical settings (e.g. hospital or doctor)
- Yes  No Health anxiety (extreme fear of serious but undiagnosed medical condition)
- Yes  No Phobia of any type (if Yes, briefly explain:)
- Yes  No Generalized anxiety disorder
- Yes  No Social anxiety disorder
- Yes  No Post-traumatic stress disorder
- Yes  No Panic disorder
- Yes  No Obsessive Compulsive Disorder
- Yes  No Anxiety disorder of any type (if Yes, briefly explain:)

If you responded Yes, briefly explain here:

10. Have you ever been diagnosed with:

- Yes  No Major depressive disorder
- Yes  No Bipolar disorder
- Yes  No Seasonal affective disorder
- Yes  No Affective disorder of any type

If you responded Yes, briefly explain here:

11. Do you currently take selective serotonin reuptake inhibitors (SSRI's)? (Some examples: Prozac, Paxil, Zoloft, Luvox, Lexapro, Celexa).

Yes  No

If you responded Yes, briefly explain here:

12. Do you currently take hormonally-based contraception (including birth control pills, skin patches, or vaginal rings)?

13. List any over-the-counter or prescription medications you are currently taking:

14. If any medications are listed in Question 13, list the symptoms that these drugs are treating

15. List any other medical conditions that you have or have had in the past:

16. What is your average daily caffeine consumption (approximate number of cups/glasses of coffee, tea, or caffeinated soda)?

17. What is your average weekly alcohol consumption (approximate number of alcoholic beverages)?

18. How many hours of sleep do you average per night?

19. On average, how often do you engage in physical activity for at least 30-minute sessions?  
(Circle one)

*a- Never; b- Rarely; c- One to two times per month; d- One to two days per week;  
e- Three to four days per week; f- Five to six days per week; g- Seven days per week*

20. Do you regularly use a FitBit or other similar device to keep track of your heart rate?

21. Have you ever fainted? If so, explain. (When, what was likely to have caused it, how often does this occur?)

**Appendix E**  
**Mind-Body Laboratory Recent Health Behaviors Questionnaire (R-HHQ)**

A very brief medical history must be obtained as part of the experimental protocol. It is very important that you be completely honest. This information will be kept strictly confidential.

1. When was the last time that you have had any alcohol before the study began?
2. When was the last time you have had a caffeinated beverage before the study began (if today)?
  - a. What caffeinated beverage did you consume? (Type & size).
3. When was the last time that you ate before the study began?
4. What phase of the menstrual cycle are you currently in (beginning, middle, end, or N/A)?
5. How many hours of sleep did you get last night?
6. Did you engage in vigorous exercise within the last 2 hours?

## Appendix F

### Patient Health Questionnaire (PHQ-9; Kroenke et al., 2001)

#### PATIENT HEALTH QUESTIONNAIRE (PHQ-9)

NAME: \_\_\_\_\_ DATE: \_\_\_\_\_

Over the last 2 weeks, how often have you been bothered by any of the following problems?  
(use "✓" to indicate your answer)

	Not at all	Several days	More than half the days	Nearly every day
1. Little interest or pleasure in doing things	0	1	2	3
2. Feeling down, depressed, or hopeless	0	1	2	3
3. Trouble falling or staying asleep, or sleeping too much	0	1	2	3
4. Feeling tired or having little energy	0	1	2	3
5. Poor appetite or overeating	0	1	2	3
6. Feeling bad about yourself—or that you are a failure or have let yourself or your family down	0	1	2	3
7. Trouble concentrating on things, such as reading the newspaper or watching television	0	1	2	3
8. Moving or speaking so slowly that other people could have noticed. Or the opposite—being so fidgety or restless that you have been moving around a lot more than usual	0	1	2	3
9. Thoughts that you would be better off dead, or of hurting yourself	0	1	2	3

add columns  +  +

(Healthcare professional: For interpretation of TOTAL, TOTAL:   
please refer to a accompanying scoring card).

10. If you checked off any problems, how difficult have these problems made it for you to do your work, take care of things at home, or get along with other people?	Not difficult at all	_____
	Somewhat difficult	_____
	Very difficult	_____
	Extremely difficult	_____

## Appendix G

### State Trait Anxiety Inventory (STAI-Trait Subscale; Spielberger, 1983)

#### DIRECTIONS

A number of statements which people have used to describe themselves are given below. Read each statement and then circle the appropriate number to the right of the statement to indicate how you generally feel. There are no right or wrong answers. Do not spend too much time on any one statement but give the answer which seems to describe how you generally feel.

	ALMOST NEVER	SOMETIMES	OFTEN	ALMOST ALWAYS
21. I feel pleasant.....	1	2	3	4
22. I feel nervous and restless .....	1	2	3	4
23. I feel satisfied with myself.....	1	2	3	4
24. I wish I could be as happy as others seem to be .....	1	2	3	4
25. I feel like a failure .....	1	2	3	4
26. I feel rested .....	1	2	3	4
27. I am "calm, cool, and collected".....	1	2	3	4
28. I feel that difficulties are piling up so that I cannot overcome them.....	1	2	3	4
29. I worry too much over something that really doesn't matter.....	1	2	3	4
30. I am happy .....	1	2	3	4
31. I have disturbing thoughts .....	1	2	3	4
32. I lack self-confidence.....	1	2	3	4
33. I feel secure .....	1	2	3	4
34. I make decisions easily .....	1	2	3	4
35. I feel inadequate.....	1	2	3	4
36. I am content .....	1	2	3	4
37. Some unimportant thought runs through my mind and bothers me .....	1	2	3	4
38. I take disappointments so keenly that I can't put them out of my mind.....	1	2	3	4
39. I am a steady person.....	1	2	3	4
40. I get in a state of tension or turmoil as I think over my recent concerns and interests .....	1	2	3	4

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## Appendix H

### Spielberger State-Trait Anxiety Inventory (STAI: Y-6 item)

**Measure:**

Name ..... Date .....

*A number of statements which people have used to describe themselves are given below. Read each statement and then circle the most appropriate number to the right of the statement to indicate how you feel right now, at this moment. There are no right or wrong answers. Do not spend too much time on any one statement but give the answer which seems to describe your present feelings best.*

	Not at all	Somewhat	Moderately	Very much
1. I feel calm .....	1	2	3	4
2. I am tense .....	1	2	3	4
3. I feel upset .....	1	2	3	4
4. I am relaxed .....	1	2	3	4
5. I feel content .....	1	2	3	4
6. I am worried .....	1	2	3	4

**Calculation:**

To calculate the total STAI score (range 20 - 80):

- reverse scoring of the positive items (calm, relaxed, content) so 1=4, 2=3, 3=2 and 4=1;
- sum all six scores;
- multiply total score by 20/6;
- refer to Spielberger's manuals to interpret scores (a 'normal' score is approx. 34 - 36) or Bekker HL, Legare F, Stacey D, O'Connor A, Lemyre L. *Is anxiety an appropriate measure of decision aid effectiveness: a systematic review?* Patient Education and Counselling. 2003; 50: 255-262.



Below you will find a list of statements. Please indicate how often each statement applies to you generally in daily life.

	Circle one number on each line					
	Never					Always
1. When I am tense I notice where the tension is located in my body.	0	1	2	3	4	5
2. I notice when I am uncomfortable in my body.	0	1	2	3	4	5
3. I notice where in my body I am comfortable.	0	1	2	3	4	5
4. I notice changes in my breathing, such as whether it slows down or speeds up.	0	1	2	3	4	5
5. I do not notice (I ignore) physical tension or discomfort until they become more severe.	0	1	2	3	4	5
6. I withdraw myself from sensations of discomfort.	0	1	2	3	4	5
7. When I feel pain or discomfort, I try to power through it.	0	1	2	3	4	5
8. When I feel physical pain, I become upset.	0	1	2	3	4	5
9. I start to worry that something is wrong if I feel any discomfort.	0	1	2	3	4	5
10. I can notice an unpleasant body sensation without worrying about it.	0	1	2	3	4	5
11. I can pay attention to my breath without being distracted by things happening around me.	0	1	2	3	4	5
12. I can maintain awareness of my inner bodily sensations even when there is a lot going on around me.	0	1	2	3	4	5
13. When I am in conversation with someone, I can pay attention to my posture.	0	1	2	3	4	5
14. I can return awareness to my body if I am distracted.	0	1	2	3	4	5
15. I can refocus my attention from thinking to sensing my body.	0	1	2	3	4	5
16. I can maintain awareness of my whole body even when a part of me is in pain or discomfort.	0	1	2	3	4	5

Please indicate how often each statement applies to you generally in daily life.

	Circle one number on each line				
	Never				Always
17. I am able to consciously focus on my body as a whole.	0	1	2	3	4 5
18. I notice how my body changes when I am angry.	0	1	2	3	4 5
19. When something is wrong in my life I can feel it in my body.	0	1	2	3	4 5
20. I notice that my body feels different after a peaceful experience.	0	1	2	3	4 5
21. I notice that my breathing becomes free and easy when I feel comfortable.	0	1	2	3	4 5
22. I notice how my body changes when I feel happy / joyful.	0	1	2	3	4 5
23. When I feel overwhelmed I can find a calm place inside.	0	1	2	3	4 5
24. When I bring awareness to my body I feel a sense of calm.	0	1	2	3	4 5
25. I can use my breath to reduce tension.	0	1	2	3	4 5
26. When I am caught up in thoughts, I can calm my mind by focusing on my body/breathing.	0	1	2	3	4 5
27. I listen for information from my body about my emotional state.	0	1	2	3	4 5
28. When I am upset, I take time to explore how my body feels.	0	1	2	3	4 5
29. I listen to my body to inform me about what to do.	0	1	2	3	4 5
30. I am at home in my body.	0	1	2	3	4 5
31. I feel my body is a safe place.	0	1	2	3	4 5
32. I trust my body sensations.	0	1	2	3	4 5

**Appendix J**  
**Anxiety Sensitivity Index- Revised (ASI-R) (Taylor & Cox, 1998)**

**Rate: 1 to 5**

**(1 = strong disagreement; 5 = strong agreement)**

1. When I feel like I'm not getting enough air I get scared that I might suffocate
2. Smothering sensations scare me
3. It scares me when I become short of breath
4. When my chest feels tight, I get scared that I won't be able to breathe properly
5. It scares me when I feel faint
6. When my throat feels tight, I worry that I could choke to death
7. It scares me when my heart beats rapidly
8. When my breathing becomes irregular, I fear that something bad will happen
9. It scares me when I feel "shaky" (trembling)
10. When I have trouble swallowing, I worry that I could choke
11. It frightens me when my surroundings seem strange or unreal
12. It scares me when my body feels strange or different in some way
13. It is important for me not to appear nervous
14. I believe it would be awful to vomit in public
15. I think it would be horrible for me to faint in public
16. I worry that other people will notice my anxiety
17. When I tremble in the presence of others I fear what people might think of me
18. When I begin to sweat in a social situation, I fear people will think negatively of me
19. It scares me when I blush in front of people
20. When I feel a strong pain in my stomach, I worry it could be cancer
21. When my head is pounding I worry I could have a stroke
22. When ... my heart is beating rapidly, I worry that I might have a heart attack
23. When my face feels numb, I worry that I might be having a stroke
24. When I feel pain in my chest, I worry that I'm going to have a heart attack
25. When I feel dizzy, I worry there is something wrong with my brain
26. When my stomach is upset, I worry that I might be seriously ill
27. When I notice my heart skipping a beat, I worry ... seriously wrong with me
28. When I get diarrhea, I worry that I might have something wrong with me
29. It scares me when I am nauseous
30. It scares me when I feel tingling or prickling sensations in my hands
31. When I feel "spacey" or spaced out I worry that I may be mentally ill
32. When my thoughts seem to speed up, I worry that I might be going crazy
33. When I have trouble thinking clearly, I worry ... there is something wrong with me
34. When I cannot keep my mind on a task, I worry that I might be going crazy
35. It scares me when I am unable to keep my mind on a task
36. When my mind goes blank I worry there is something terribly wrong with me

**Appendix K**  
**Brief Fear of Negative Evaluation – II (FNE-II; Carleton et al., 2006)**

ASDP BFNE-II 1 of 1

ID #: \_\_\_\_\_

Date: \_\_\_\_\_

## Brief Fear of Negative Evaluation-II

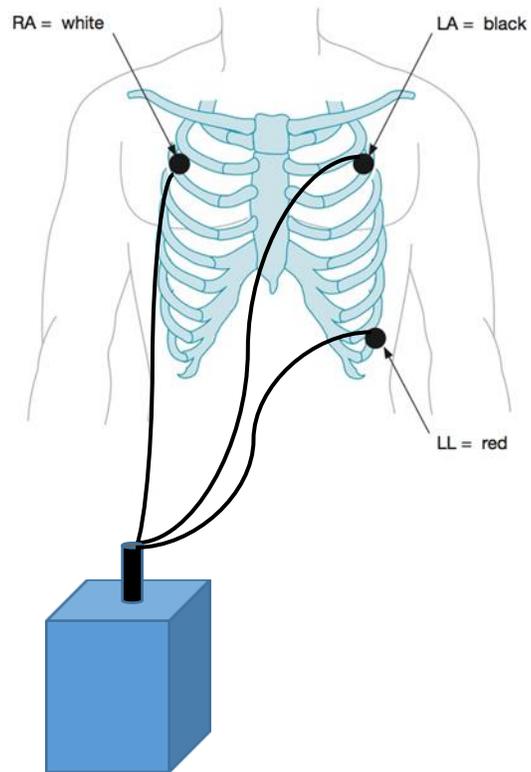
(Carleton, McCreary, Norton, & Asmundson, 2008)

Please circle the number that best corresponds to how much you agree with each item.

	Not at all characteristic of me	A little characteristic of me	Somewhat characteristic of me	Very characteristic of me	Entirely characteristic of me
1. I worry about what other people will think of me even when I know it doesn't make any difference.	1	2	3	4	5
2. It bothers me when people form an unfavourable impression of me.	1	2	3	4	5
3. I am frequently afraid of other people noticing my shortcomings.	1	2	3	4	5
4. I worry about what kind of impression I make on people.	1	2	3	4	5
5. I am afraid that others will not approve of me.	1	2	3	4	5
6. I am afraid that other people will find fault with me.	1	2	3	4	5
7. I am concerned about other people's opinions of me.	1	2	3	4	5
8. When I am talking to someone, I worry about what they may be thinking about me.	1	2	3	4	5
9. I am usually worried about what kind of impression I make.	1	2	3	4	5
10. If I know someone is judging me, it tends to bother me.	1	2	3	4	5
11. Sometimes I think I am too concerned with what other people think of me.	1	2	3	4	5
12. I often worry that I will say or do wrong things.	1	2	3	4	5

Carleton, R. N., McCreary, D. R., Norton, P. J., & Asmundson, G. J. (2006). Brief fear of negative evaluation scale—revised. *Depression and Anxiety, 23*(5), 297-303.

## Appendix L Electrocardiography (ECG) Leadset Configuration



Derived from an image on [www.lifeinthefastlane.com](http://www.lifeinthefastlane.com)

## Appendix M

### Setup for BIOPAC Non-invasive Blood Pressure Monitor (NIBP 100D)



Finger cuff around the index and middle finger, along with an upper arm cuff.

## Appendix N



Heartbeat Perception Task (Schandry, 1981). The onset and offset of each heartbeat counting trial was cued by the words “GO” and “STOP”, which were presented on the computer screen (e.g. Ainley, 2014). Trial lengths were 25s, 30s, 35s, 40s, 45s, 50s. Intertrial intervals lasted ten seconds in duration. Subjects completed the task twice: once during rest and once during anticipatory anxiety (immediately following the speech preparation period). A total of 6 trials, presented in random order, were completed during each task epoch.

## Appendix O

### Counted Heartbeats & Confidence Judgment

Instructions: Please rate your confidence in perceived accuracy of your responses in the last trial. Circle a single whole number below. Options span from 1 (“No heartbeat awareness/Complete guess”) to 10 (Full perception of heartbeat/Complete confidence”).

TRIAL 1:

No heartbeat awareness/  
Complete guess

1

2

3

4

5

6

7

8

Full perception of heartbeat/  
Complete confidence

9

10

TRIAL 2:

No heartbeat awareness/  
Complete guess

1

2

3

4

5

6

7

8

Full perception of heartbeat/  
Complete confidence

9

10

TRIAL 3:

No heartbeat awareness/  
Complete guess

1

2

3

4

5

6

7

8

Full perception of heartbeat/  
Complete confidence

9

10

TRIAL 4:

No heartbeat awareness/  
Complete guess

1

2

3

4

5

6

7

8

Full perception of heartbeat/  
Complete confidence

9

10

TRIAL 5:

No heartbeat awareness/  
Complete guess

1

2

3

4

5

6

7

8

Full perception of heartbeat/  
Complete confidence

9

10

**TRIAL 6:**

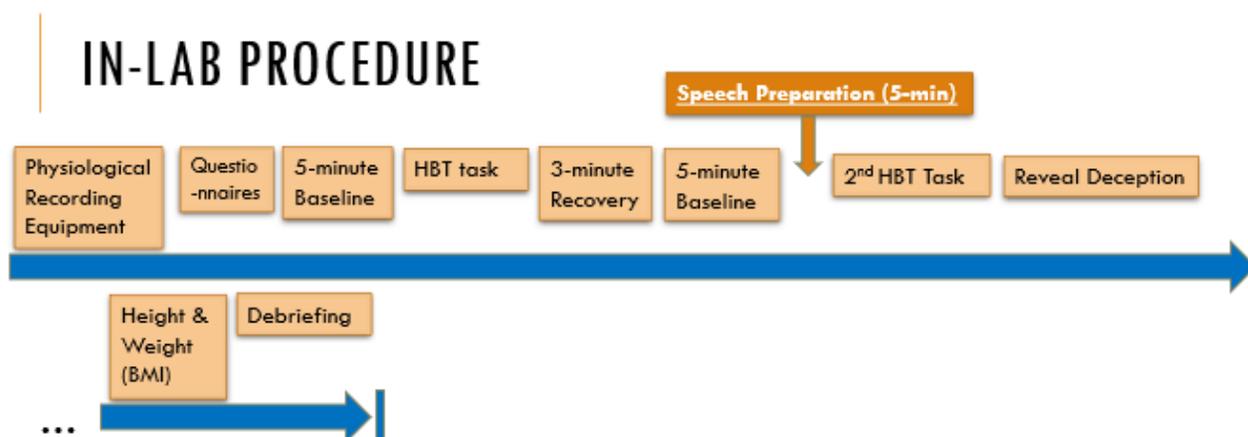
No heartbeat awareness/  
Complete guess

**1****2****3****4****5****6****7****8**

Full perception of heartbeat/  
Complete confidence

**9****10**

## Appendix P Study Schematic



**\*Heartbeat tracking task (HBT):** Assesses IAC (Schandry, 1981)- Constructed with E-Prime

- Silently count heartbeats by closely attending to your body, w/o taking pulse; “Go” & “Stop” on computer screen
- 6 trials of randomly presented lengths (25s, 30s, 35s, 40s, 45s, 50s); Intertrial intervals: 10 secs; 3 practice trials
- Self-reported performance after each HBT trial: Confidence 1-10 (“complete guess”→”complete confidence”)
- $IAC = (1/6 \sum (1 - (|\text{recorded heartbeats} - \text{counted heartbeats}| / \text{recorded heartbeats}))$
- To control for potential confound of biased guessing: *Time estimation accuracy* =  $(1/3 \sum (1 - (|\text{estimated elapsed time} - \text{actual elapsed time}| / \text{actual elapsed time})))$ . *Resting heart rate estimation accuracy* =  $(1/3 \sum (1 - (|\text{estimated heart rate} - \text{actual heart rate}| / \text{actual heart rate})))$ . (19s, 37s, and 49s intervals).

**\*Speech preparation:** Subjects were informed that they must prepare 5-min speech in which they talk continuously about why they would be a good candidate for their ideal job. Subjects were given 5 minutes to prepare the speech. They were told that they will be later rated on confidence, public speaking, and knowledge; and that the speech would be recorded via webcam and viewed by 3 judges trained in public speaking. No actual speech was given.