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ABSTRACT

A MULTI-MEASURE EXAMINATION OF INTEROCEPTION IN PEOPLE WITH SELF-INJURIOUS BEHAVIORS

by

Lauren N. Forrest

Introduction: Every year millions of people engage in self-injurious behaviors. Despite research advances, rates of self-injury remain high while prediction remains weak. Novel, robust self-injury correlates must be identified. One potential self-injury correlate is impaired interoception—i.e., inaccurately detecting the body's physiological sensations. The current study examined whether interoceptive accuracy (the ability to accurately monitor sensations) and self-reported interoceptive abilities (judgment of one's typical ability to perceive sensations) for cardiac sensations, pain, and fear differed between people with and without self-injurious behaviors. **Method:** Fifty-five adults with no history of self-injurious thoughts and behaviors (72.7% women) and 54 adults with recent self-injury (nonsuicidal self-injury at least once in the past year [n = 39] or a suicide attempt within the past two years [n = 15]; 88.9% women) participated in the study. Interoceptive accuracy for cardiac sensations was assessed using the heartbeat tracking task and interoceptive accuracy for pain and fear were assessed with metrics developed for the current study. Self-reported interoceptive abilities for cardiac sensations, pain, and fear were assessed with self-report measures. **Results:** Participants with and without self-injurious behaviors exhibited similar interoceptive accuracy for cardiac sensations and self-reported similar interoceptive abilities for cardiac sensations, pain, and fear. However, self-injurious behavior group status was associated with lower interoceptive accuracy for pain and fear. **Conclusion:** People with and without self-injury did not differ on their self-reports of their interoceptive abilities for cardiac sensations, pain, or fear. While groups also exhibited similar interoceptive accuracy for cardiac sensations, interoceptive accuracy for pain and fear—i.e., sensations relevant to self-injury—was diminished among people with self-injury. Overall, interoceptive impairment may vary by domain and sensation type. Diminished interoceptive accuracy for sensations relevant to the pathophysiology of self-injury may be a novel correlate or risk factor for self-injurious behaviors.

A MULTI-MEASURE EXAMINATION OF INTEROCEPTION IN PEOPLE WITH SELF-INJURIOUS BEHAVIORS

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by

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DEDICATION

This dissertation is dedicated to people persevering and finding a way through.

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Self-injurious behaviors, which include nonsuicidal self-injury (NSSI) and suicide attempts, are global public health problems. Suicide is the second leading cause of death among adolescents and young adults worldwide (Center for Disease Control and Prevention, 2015; World Health Organization, 2015). Over 800,000 people die by suicide every year and millions more engage in nonfatal suicide attempts and NSSI (Center for Disease Control and Prevention, 2015; Klonsky, 2011; World Health Organization, 2015). Decades of research have yielded important advances in the understanding of self-injurious behaviors (Joiner, 2005; Muehelenkamp, 2012; Nock & Prinstein, 2004; Van Orden, Cukrowicz, Witte, Braithwaite, Selby, & Joiner, 2010), yet these advances have not significantly reduced self-injurious behavior rates (Nock, Borges, Bromet, Cha, Kessler, & Lee, 2008) or improved the accuracy of self-injurious behavior prediction (Fox, Franklin, Riberio, Kleiman, Bentley, & Nock, 2015; Franklin et al., 2017; Ribeiro, Franklin, Fox, Bentley, Kleiman, Chang, & Nock, 2015). For instance, prior suicide attempts are believed to strongly predict future attempts (Joiner, 2005; Ribeiro et al., 2015; Van Orden et al., 2010) but meta-analytic findings indicate that prior suicide attempts are only weak prospective predictors of attempts (Franklin et al., 2017; Ribeiro et al., 2015). In fact, established suicide risk factors (e.g., prior NSSI, prior attempts) have extremely low predictive power (Franklin et al., 2017; Ribeiro et al., 2015). For example, prior NSSI is the strongest predictor of attempts, though NSSI increases the odds of a future attempt by only 0.013 (Ribeiro et al., 2015). Further complicating the prediction of suicidal behavior, the prediction of NSSI is also weak (Fox, Franklin, Ribeiro, Kleiman, Bentley, & Nock, 2015). Clearly, novel risk factors for self-injurious behaviors must be identified.

Emerging research suggests that disrupted interoception—an impaired ability to accurately perceive the emotional and physiological condition of the entire body (Craig, 2002)—may be necessary for self-injurious behaviors to occur (Forrest, Smith, White, & Joiner, 2015; Franklin, Aaron, Arthur, Shorkey, & Prinstein, 2012; Muehlenkamp, 2012; Rogers, Hagan, & Joiner, 2018; Ross, Heath, & Toste, 2009). Interoception is a multifaceted construct (Garfinkel, Seth, Barrett, Suzuki, & Critchley, 2015; Khalsa et al., 2018) and different modes of interoception may be dysregulated in people with self-injurious behaviors. However, prior research has measured only self-reported interoceptive abilities. Self-reports assess the judgment of one's physiological condition without assessing the accuracy of the judgments. In order to examine the extent of disrupted interoception in people with self-injurious behaviors, multiple domains of interoceptive processing must be considered (Garfinkel et al., 2015; Khalsa et al., 2018). The present study will test whether two forms of interoceptive processing—interoceptive accuracy and self-reported interoceptive abilities—differentiate individuals with self-injurious behaviors from people without self-injurious behaviors.

Interoception and Self-Injurious Behaviors

Interoception is the cognitive process of detecting and becoming aware of the body's many visceral cues, such as cardiac sensations, pain, and emotions (Craig, 2002). Interoception is believed to influence self-*protective* behaviors, given that perceiving pain, for instance, motivates withdrawing from a pain-inducing stimulus (Craig, 2002). Relatedly, impaired interoception is believed to influence self-*injurious* behaviors (Forrest et al., 2015; Muehlenkamp, 2012), given that being unable to experience pain would not promote withdrawing from a pain-inducing stimulus. In other words, when interoceptive processing is inaccurate, people are disconnected from their internal sensations. This disconnection can lead to viewing the body more as an object than a living being (Ainley & Tsakiris, 2013; Tsakiris, Taiadura-Jiménez, & Constantini, 2011). Just as it is easier to harm an object versus a feeling body, if one is disconnected from one's body and more likely to view it as an object, one may be more able to harm the body (Forrest et al., 2015; Muehlenkamp, 2012).

Indeed, people who have engaged in NSSI self-report interoceptive deficits—i.e., low awareness of sensations—for pain and emotions (Franklin et al., 2012; Ross et al., 2009). Further, in my own work, my colleagues and I found that people who had attempted suicide self-reported greater interoceptive deficits for emotions than people who had thought about suicide but never attempted (Forrest et al., 2015). In a second study, we found that clinical outpatients who had attempted suicide self-reported greater interoceptive deficits for emotions than clinical outpatients who had not attempted suicide (Forrest et al., 2015). In a third study, we compared self-reported interoceptive deficits for emotions among eating disorder patients with and without self-injurious behaviors. Those with self-injurious behaviors had higher interoceptive deficits relative to those without self-injurious behaviors (Smith, Forrest, & Velkoff, 2018). Together, findings indicate that people with self-injurious behaviors self-report interoceptive deficits, suggesting that interoceptive impairment may be a correlate of self-injurious behaviors.

Domains of Interoceptive Processing

Notably, interoception is a multifaceted process that encompasses many features (Garfinkel et al., 2015; Khalsa et al., 2018). Self-reported interoceptive abilities are one such feature, and assess the trait-level perception and judgment of one's previous interoceptive states. Another feature is interoceptive accuracy, which measures the ability to accurately monitor changes in one's current interoceptive states. These various features of interoceptive processing are thought to be more distinct than they are similar, because they are not often correlated with one another (Baranauskas, Grabauskaite, & Grikova-Bulanova, 2017; Garfinkel et al., 2015). For this reason, these features of interoception are thought to map onto unique neural pathways (Baranauskas et al., 2017; Khalsa et al., 2018).

As described above, the only studies that support impaired interoception as a correlate for self-injurious behaviors have assessed interoception through self-reports. While assessing self-reported interoceptive abilities has merit, self-reports alone are insufficient to fully understand whether and how interoceptive processing is disrupted in relation to self-injury. This is because if people experience dysregulated interoceptive abilities, asking them to accurately report on the extent of their interoceptive impairment—without any objective data about the sensations being transmitted—may be quite difficult, akin to asking someone who experiences color blindness to differentiate various shades of red and green. Accordingly, additional features of interoception must be assessed. For instance, interoceptive accuracy is measured through a person performing an interoceptive task while physiological (i.e., objective) data are collected. At the same time as physiological data are recorded, a person is simultaneously tracking their interoceptive sensations. Then, to index interoceptive accuracy, one's self-monitored sensations are compared to the physiologically-recorded sensations. Greater differences indicate lower interoceptive accuracy. In other words, assessing interoceptive accuracy measures how tightly linked one's physiological sensations are with one's perception of those bodily states (Garfinkel et al., 2015; Khalsa et al., 2018). Because interoceptive accuracy assesses the actual physiological sensations and the in-vivo perceived sensations, some of the limitations of self-report assessments of interoceptive abilities are overcome.

One of the most widely used measures of interoceptive accuracy is called the heartbeat tracking test, which assesses interoceptive accuracy for cardiac sensations (Schandry, 1981). In the heartbeat tracking test, participants mentally count each heartbeat they sense while electrocardiography measures participants' actual number of heartbeats. While participants are counting their heartbeats, they are instructed not to take their pulse but to simply listen to their bodies. After the test is completed, a difference score is computed between mentally-counted and electrocardiography-recorded heartbeats. As described above, greater differences indicate more impaired interoceptive accuracy.

In addition to measuring interoceptive accuracy, recent work indicates that assessing people's knowledge of how well they performed an interoceptive accuracy task can also yield important interoceptive information. That is, Garfinkel and colleagues (2015) assessed the relation between interoceptive accuracy and confidence in heartbeat tracking test performance (i.e., a visual analog scale where participants rated their responses along the spectrum of *total guess/no heartbeat awareness* to *complete confidence/full perception of heartbeat*) among a sample of university staff and students, categorized as having high or low interoceptive abilities (determined via median split). In their study, interoceptive accuracy and confidence in heartbeat tracking test performance were positively associated only among people with high interoceptive abilities (Garfinkel et al., 2015). These results were interpreted to indicate that correspondence between interoceptive accuracy and interoceptive confidence may provide an additional metric of interoceptive processing, as correspondence between the measures would be expected only if people have generally in-tact and accurate interoceptive processing to begin with.

Interoceptive accuracy is almost exclusively assessed for cardiac sensations, because interoception for cardiac sensations was long believed to be a general measure of interoception for all sensory modalities (Craig, 2002; Craig, 2015). However, interoceptive processing may vary across sensory modalities (Khalsa et al., 2018) and across contexts, such as at rest versus when in an emotionally salient situation (e.g., mealtime for people with eating disorders, experiencing elevated heartrate [e.g., when intensely exercising] for people with panic disorder; Khalsa & Lapidus, 2016). In the context of self-injury, assessing interoceptive abilities for self-injury-specific situations holds great promise in advancing the understanding of self-injurious behavior pathophysiology (Glenn, Cha, Kleiman, & Nock, 2017). Specifically, situations that elicit pain and fear hold clinical and theoretical relevance to self-injury (Joiner, 2005; Van Orden et al., 2010). Physiologically, self-injury should be painful, yet individuals with self-injurious behaviors report relief and analgesia during self-injury (Franklin, Lee, Hanna, & Prinstein, 2013; Koenig, Thayer, & Kaess, 2016). Similarly, the prospect of death should elicit fear (given the evolutionary benefit of fearing death), yet individuals who engage in suicidal behaviors exhibit *diminished* neural responses to threat in general (Weinberg, May, Klonsky, Kotov, & Hajcak, 2017) and report diminished fear of death specifically (Dhingra, Boduszek, & Klonsky, 2016; Smith, Stanley, Joiner, Sachs-Ericsson, & Van Orden, 2016; though see Forrest & Smith, 2017). Considering that (1) interoception encompasses awareness of pain and emotions and (2) the brain structures responsible for interoceptive processing overlap considerably with the neural structures responsible for pain and affective processing (Khlasa et al., 2018), impaired interoception for pain and fear may contribute to abnormal pain processing and fearlessness among people with self-injurious behaviors. Indeed, the right insula is widely implicated in interoceptive processing (Craig, 2002; Khalsa et al., 2018) and has been proposed as one of the brain regions underlying pain tolerance and fearlessness about death (i.e., capability for suicide; Deshpande, Baxi, Witte, & Robinson, 2016). Taken together, since people with self-injurious behaviors self-report greater interoceptive deficits than people without self-injurious behaviors, people with self-injurious behaviors may also *exhibit* more severe interoceptive impairments, particularly in the experience of pain and fear.

The current study sought to test theoretically-informed hypotheses about aberrant cognitive processes that may contribute to self-injurious behavior engagement. Specifically, the study assessed two domains of interoceptive processing—interoceptive accuracy and self-reported interoceptive abilities—for cardiac sensations, pain, and fear among people with and without self-injurious behaviors. Because cardiac sensations are assumed to be a general metric of interoceptive abilities, and because literature to date has established that people with self-injurious behaviors report interoceptive deficits, I predict that people with self-injurious behaviors will exhibit and report more severe interoceptive impairments for cardiac sensations, relative to people without self-injurious behaviors. Because disrupted interoception may contribute to impaired pain and fear perception, I predict that people with self-injurious behaviors will exhibit and report more severe interoceptive impairments for pain and fear, relative to people without self-injurious behaviors.

Method

Participants

Adult men and women with and without self-injurious behaviors were recruited. The inclusion criterion for participants with self-injurious behaviors was either (1) engaged in NSSI at least once in the past year or (2) attempted suicide within the past two years (see Measures section below). This timeframe for attempts was chosen because following an initial attempt, risk for subsequent attempts is greatest within the first two years (Chu, Klein, Buchman-Schmitt, Hom, Hagan, & Joiner, 2015). Sixty-six individuals were screened for inclusion in the Self-Injurious Behavior group. Eleven were ineligible to participate due to reporting NSSI > 1 year prior to screening or reporting a suicide attempt > 2 years prior to screening. Fifty-five participants met inclusion criteria for the Self-Injurious Behavior group, though one participant elected to not participate in the interoceptive tasks. This participant was therefore not included in analyses, resulting in a total sample size of 54 for the Self-Injurious Behavior group. Thirty-nine reported past-year NSSI and 15 reported suicide attempts within the past two years. Almost all participants in the Self-Injurious Behavior group reported lifetime NSSI (96.3%). The frequency of lifetime NSSI ranged from 2 to 2000 (*mean* = 142.0 [*SD* = 332.0], *median* = 30). In addition to the 15 participants with a recent suicide attempt, 19 participants reported a suicide attempt that occurred more than two years prior to enrollment, for a total of 63.0% reporting a lifetime suicide attempt. The frequency of lifetime suicide attempts ranged from 1 to 9 (*mean* = 2.7 [*SD* = 2.3], *median* = 2). Demographic characteristics are provided in Table 1. Most participants in the Self-Injurious Behavior group identified as women (88.9%), white (77.8%), and non-Hispanic (96.3%). Roughly half identified as straight (51.9%). Most reported that their highest level of education was some college (83.3%). Mean age was 20.6 years (*SD* = 5.6).

The MINI International Neuropsychiatric Interview (Sheehan et al., 1998) was administered to participants in the Self-Injurious Behaviors group to determine whether they met criteria for current and lifetime psychopathology. All but one participant in the Self-Injurious Behavior group met criteria for a psychiatric disorder. The most commonly reported diagnoses were anxiety disorders (64.8%) and depressive disorders (64.8%; see Table 1).

Participants in the Self-Injurious Behavior group were recruited via (1) posting flyers around the Butler County community, including on Miami University's Oxford campus, the Miami University Psychology Clinic, and Miami University's Student Counseling Service; (2)

emails sent to Miami University Reserve Officer Training Corps students[1] and randomly selected Miami University students; and (3) through the Psychology Department's mass screening procedures. Participants recruited via flyers or emails contacted the investigator to complete an online screening survey. If they reported NSSI within the past year or a suicide attempt within the past two years (assessed via selected questions from the Self-Injurious Thoughts and Behaviors Interview [SITBI]; Nock, Holmberg, Photos, & Michel, 2007; see below), they were invited to participate in the full study. Participants recruited via mass screening completed screening questions selected from the SITBI assessing the lifetime presence and recency of NSSI and suicide attempts. If participants reported NSSI within the past year or a suicide attempt within the past two years, they were invited to participate in the full study. Participants in the Self-Injurious Behavior group were compensated for participation through receiving partial course credit or $25.

Inclusion criteria for participants without self-injurious behaviors were reporting no lifetime self-injurious thoughts or behaviors, reporting a score of 0 on two measures of current suicidal ideation (Beck Scale for Suicide Ideation [Beck, Kovacs, & Weissman, 1979] and the Depressive Symptoms Inventory–Suicidality Subscale [Joiner, Pfaff, & Acres, 2002]), and reporting that they had never received treatment for a mental health problem. One-hundred seventy individuals were screened for inclusion in the No Self-Injurious Behavior group. Ninety reported lifetime self-injurious thoughts or behaviors and 25 reported (1) a non-zero Beck Scale for Suicidal Ideation score, (2) a non-zero Depressive Symptoms Inventory–Suicidality Subscale score, and/or (3) receiving lifetime treatment for a mental health problem. Excluding these participants resulted in a final sample size of 55 for the No Self-Injurious Behavior group. Most No Self-Injurious Behavior group participants identified as women (72.7%), white (92.7%), non-Hispanic (94.5%), and straight (98.2%; see Table 1). Most reported that their highest level of education was some college (96.4%). Mean age was 19.0 years (*SD* = 1.2).

Participants in the No Self-Injurious Behavior group were recruited through (1) the Psychology Department's mass screening procedures and (2) emails sent to Miami University Reserve Officer Training Corps students. Participants recruited via mass screening were invited to participate in the study if they reported no lifetime self-injurious thoughts or behaviors, which were assessed using selected questions from the SITBI. These participants were compensated via course credit. Participants recruited via emails sent to Miami University Reserve Officer Training Corps students contacted the investigator to complete an online screening survey. If they reported no lifetime self-injurious thoughts or behaviors (also assessed via items from the SITBI), they were invited to participate in the study and they were compensated financially for participation ($5). Financial compensation for participants in the No Self-Injurious Behavior group was lower relative to the Self-Injurious Behavior group because participants in the Self-Injurious Behavior group completed multiple follow-up surveys as part of a secondary study aim.

Measures

Self-injurious behaviors. The SITBI (Nock et al., 2007) is a structured, clinician-administered interview that assesses current and lifetime experiences, frequencies, and characteristics of suicide ideation, suicide plans, suicide gestures, suicide attempts, thoughts of

[1] Reserve Officer Training Corps students were targeted specifically because the overarching study had a secondary aim of comparing interoceptive accuracy between Reserve Officer Training Corps students and the general student body. However, only one Reserve Officer Training Corps student met criteria for inclusion in the Self-Injurious Behavior group and only one Reserve Officer Training Corps student met criteria for inclusion in the No Self-Injurious Behavior group. These low numbers prevented the ability to examine this secondary aim.

NSSI, and engagement in NSSI. The SITBI was administered to all participants with self-injurious behaviors to determine whether they met criteria for inclusion in the Self-Injurious Behavior group.

While the SITBI was originally designed to be administered verbally, a self-report version has been developed and used in previous studies (e.g., Franklin et al., 2016). Participants in the No Self-Injurious Behavior group completed the self-report version of the SITBI, as a second check to ensure that they reported no current or lifetime self-injurious thoughts or behaviors. Only participants who passed this second check were included in analyses.

Cardiac interoceptive accuracy. Cardiac interoceptive accuracy was assessed with the heartbeat tracking test (Schandry, 1981). Four heartbeat tracking trials were completed, with counterbalanced trial intervals of 25, 35, 45, and 100 seconds. In each trial participants mentally counted each heartbeat they sensed, without taking their pulses, while electrocardiography measured actual heartbeats. To index interoceptive accuracy, a difference score was computed between the mentally-counted and electrocardiography-recorded heartbeats with the following formula: $\frac{1}{4} \Sigma$ [1 – (|electrocardiography heartbeats – reported heartbeats| / electrocardiography heartbeats)] (Schandry, 1981). Lower values indicated more impaired cardiac interoceptive accuracy. Cronbach's alpha for the heartbeat tracking trials was excellent ($\alpha = .94$).

Self-reported interoceptive abilities for cardiac sensations. The Body Perception Questionnaire (Porges, 1993) is a self-report measure assessing awareness of 45 different physiological sensations, such as muscle tension, stomach pains, and heartbeats. For each physiological sensation presented, participants are asked to indicate their typical awareness of the sensation using a scale ranging from 1 (*never*) to 5 (*always*). Responses for all items were averaged into a general awareness score. Lower scores indicate less awareness of physiological sensations. This scale is frequently used in conjunction with the heartbeat tracking test to index individuals' self-reported interoceptive abilities (e.g., Garfinkel et al., 2015; Garfinkel, Tiley, O'Keeffe, Harrison, Seth, & Critchley, 2016). To mirror previous research, the Body Perception Questionnaire total score was the first metric of self-reported interoceptive abilities for cardiac sensations, and Cronbach's alpha was excellent ($\alpha = .97$). However, to more specifically assess self-reported interoceptive abilities for cardiac sensations, the Body Perception Questionnaire item assessing awareness of heartbeats was used as a second metric of self-reported interoceptive abilities for cardiac sensations.

Pain interoceptive accuracy. Pain interoceptive accuracy was assessed with a pain perception test, developed for the current study. The development of this task mirrored the heartbeat tracking test, where the goal was to quantify the difference between an objectively-recorded sensation and an in-vivo perceived sensation. The task consisted of perpendicularly applying a handheld pressure algometer to the skin at the first dorsal interosseous muscle (i.e., behind the first knuckle of the index finger) of the right hand during three practice trials and three test trials. In the practice trials, an experimenter applied one, two, and three pounds of pressure to the hand, respectively, and told the participant how many pounds of pressure were applied. Participants then completed three counterbalanced test trials where the algometer was applied at a steady rate until reaching 3.5, 4.2, and 4.9 pounds of pressure. Trials were separated by 90-second intervals to prevent habituation. After each trial, participants estimated the pounds of pressure they experienced while the actual pounds of pressure were recorded. Pain interoceptive accuracy was computed by creating a difference score between the estimated and actual pounds of pressure, with the following formula: $\frac{1}{3} \Sigma$ [1 – (|actual pounds – estimated pounds| / actual pounds)] (c.f., Schandry, 1981). Lower values indicated more impaired pain interoceptive accuracy. Cronbach's alpha for the pain perception trials was excellent (α = .90).

Self-reported interoceptive abilities for pain. The Pain Tolerance Examination Questionnaire (Rokke, Fleming-Ficek, Simens, & Hegstand, 2004) is a 12-item self-report measure used to index self-reported pain tolerance. The scale presents 12 different painful scenarios, such as cutting one's skin, having a headache, and breaking a bone. Respondents indicated a percentage of how well they could tolerate pain from these situations relative to people of the same age and sex. For instance, a male providing a score of 12% indicates that he could tolerate the pain better than 12% of same-aged males; a female providing a score of 80% indicates that she could tolerate the pain better than 80% of same-aged females. The percentages provided for all items were averaged into a total self-reported pain tolerance score. Higher scores indicate greater pain tolerance. Cronbach's alpha was good (α = .82).

For the purposes of the current study, greater pain tolerance was used as a proxy for more diminished self-reported interoceptive abilities for pain. This decision was based on research finding that cardiac interoceptive accuracy is inversely associated with pain tolerance, such that people with low interoceptive accuracy report higher pain tolerance compared to people with high interoceptive accuracy (Pollatos, Füstös, & Critchley, 2012). However, the relation between interoceptive accuracy and pain tolerance may be moderated by some variables, as another study identified that cardiac interoceptive accuracy was negatively correlated with pain tolerance among university students and staff but positively correlated among people with somatoform disorders (Weiss, Sack, Henningsen, & Pollatos, 2014). While self-reported pain tolerance is an imperfect measure of self-reported interoceptive abilities for pain, to my knowledge, such measures do not exist, which required using a proxy measure.

Fear interoceptive accuracy. A metric of fear interoceptive accuracy was developed for the current study, as no such measures exist to my knowledge. Because indexing interoceptive accuracy quantifies the relationship between the objectively-recorded sensation and the perceived sensation, the goal was to identify both an objective measurement and a perceived metric of fear. However, unlike operationalizing cardiac or pain interoceptive accuracy, where the objectively-recorded sensation and the perceived sensation share the same metric (i.e., heart rate, pounds of force), no shared metrics exist for fear. Thus, fear interoceptive accuracy was indexed by assessing respiratory sinus arrhythmia and self-reported fear intensity while viewing a film clip. Respiratory sinus arrhythmia is a physiological indicator of adaptive emotion regulation, where higher respiratory sinus arrhythmia is associated with greater and more adaptive regulation (Beauchaine, 2015; Vasilev, Crowell, Beauchaine, Mead, & Gatzke-Kopp, 2009). Further, respiratory sinus arrhythmia has been linked to the specific emotion regulation strategy of clearly recognizing emotions (Williams, Cash, Rankin, Bernardi, Koenig, & Thayer, 2015), which is conceptually and empirically related to interoceptive deficits for emotions (Stasiewicz et al., 2012). The relation between respiratory sinus arrhythmia and emotion recognition was the primary reason respiratory sinus arrhythmia was selected as the objectively-recorded sensation for fear in the current study. Respiratory sinus arrhythmia was expected to be negatively related to self-injurious behaviors, given that low respiratory sinus arrhythmia has been observed among people with self-injurious behaviors (Beauchaine, 2015; Crowell, Beauchaine, McCauley, Smith, Stevens, & Sylvers, 2005), who often self-report poor emotion regulation and low emotional awareness (Franklin et al., 2012).

Respiratory sinus arrhythmia can be assessed through recording electrocardiography and respiration. For this study, electrocardiography and respiration were recorded while participants viewed a 3.5-minute clip from the film *Misery* (Nicolaides, Reiner, Scheinman, & Stott, 1990). The clip shows a man being held captive while his captor breaks his ankles to prevent him from moving. This clip was chosen because it has been shown to elicit fear (Schaefer, Nils, Sanchex, & Philippot, 2010). After viewing the clip, participants used a visual analog scale to rate their fear intensity ranging from 0 (*no reaction*) to 100 (*extreme reaction*; Rottenberg, Ray, & Gross, 2007). Self-reported fear intensity while watching the film was the indicator of the perceived sensation of fear. Intensity of five other emotions (amusement, happiness, disgust, anger, and sadness) was also assessed using the same 0–100 visual analog scale as a manipulation check (Rottenberg et al., 2007). Throughout the rest of this document, the film-related procedures are referred to as the *emotion rating task.*

Because respiratory sinus arrhythmia and fear intensity do not share the same metric, fear interoceptive accuracy was indexed by entering respiratory sinus arrhythmia and fear intensity as simultaneous predictors of group status in a logistic regression (see below; c.f. Schandry, 1981). Considering that people with self-injurious behaviors would be expected to experience lower respiratory sinus arrhythmia (Beauchaine, 2015; Crowell et al., 2005) and lower fear intensity (Van Orden et al., 2010) relative to people without self-injury, for the purposes of the current study, respiratory sinus arrhythmia and fear intensity being *negatively* related to group status (0 = No Self-Injurious Behavior, 1 = Self-Injurious Behavior), when adjusting for the influence of one another, would indicate diminished fear interoceptive accuracy.

Self-reported interoceptive abilities for fear. The Acquired Capability for Suicide Scale–Fearlessness about Death (Ribeiro et al., 2014) is a seven-item self-report measure that assesses respondents' degree of fear about dying. Respondents indicated on a scale ranging from 0 (*not at all like me*) to 4 (*very much like me*) how similar each item's description is to respondents' experiences. Example items include, *The fact that I am going to die does not affect me,* and *It does not make me nervous when people talk about death.* Items were summed to a total, where higher scores indicate greater fearlessness about death. For the current study, greater fearlessness about death was used as a proxy for more diminished self-reported interoceptive abilities for fear. Cronbach's alpha was good ($\alpha = .87$).

Table 2 summarizes the metrics of interoceptive accuracy and self-reported interoceptive abilities for cardiac sensations, pain, and fear.

Confidence in interoception tasks. Participants in the Self-Injurious Behavior group completed several additional measures, as these measures were added after participants in the No Self-Injurious Behavior group had been enrolled. Specifically, after completing each of the interoceptive tasks (i.e., heartbeat tracking, pain perception, and emotion rating), participants reported on a visual analog scale their confidence in the responses they gave in the task. The visual analog scale ranged from 0 (*total guess/no [heartbeat, pain, emotion] awareness*) to 100 (*complete confidence/full perception of [heartbeat, pain, emotion]*). These questions were included so that the relation between interoceptive accuracy and confidence could be assessed, which would provide an additional metric for whether interoceptive accuracy was impaired among people with self-injurious behaviors.

Procedure

The study included a single study visit, which took place in the laboratory. After informed consent was obtained, the MINI and SITBI were administered to participants in the Self-Injurious Behavior group. Participants in the No Self-Injurious Behaviors group completed the self-report version of the SITBI. Next, all participants completed the Beck Scale for Suicide

Ideation and a suicide risk assessment was conducted as needed. One participant being screened for the No Self-Injurious Behavior group required a risk assessment, and this participant was therefore discontinued from the study. Nineteen participants in the Self-Injurious Behavior group required risk assessments but this was expected given the recency of many participants' self-injury; these participants were not discontinued from the study. Electrocardiography and respiration were recorded during a five-minute baseline task. Electrocardiography was collected by placing gelled Ag–AgCl Biopac EL503 electrodes in a standard lead II configuration. Respiration was collected using a respiration belt placed around the upper abdomen. Electrocardiography and respiration were recorded at a 1000 Hz sampling rate with a Biopac MP150 system (Biopac Systems Inc.) and its data processing software, AcqKnowledge (Biopac Systems Inc.). All participants completed the heartbeat tracking test, pain perception test, and the emotion rating task in a counterbalanced order. Electrocardiography was measured during the heartbeat tracking test and both electrocardiography and respiration were measured during the emotion rating task.

Data Cleaning and Analytic Plan

Data cleaning. Respiratory sinus arrhythmia data cleaning procedures adhered to established guidelines (Lewis, Furman, McCool, & Porges, 2012; Quintana, Alvares, & Heathers, 2016). Specifically, electrocardiography and respiration signals were read into Mindware's Heart Rate Variability analysis software (Mindware Technologies). R peaks were detected using the maximum expected difference–minimum expected difference artifact detection algorithm. Additionally, data were inspected visually to identify and remove artifacts and misidentified beats, which can occur due to participant movement or software glitches (Quintana et al., 2016). Any participant data that contained more than 10% artifacts was discarded (n = 3). After visual inspection, 60-second interbeat interval (i.e., interval between successive heart beats) epochs were tapered using a Hanning window. A fast Fourier transformation then integrated power at the 0.12–0.40 Hz bandwidth, to derive respiratory sinus arrhythmia (ms^2/Hz; Bernston, Quigley, & Lozano, 2007). All respective 60-second respiratory sinus arrhythmia epochs were natural-log transformed, because respiratory sinus arrhythmia is consistently skewed (Lewis et al., 2012), and averaged to provide a single respiratory sinus arrhythmia value (ms^2/Hz) for the emotion rating task.

Missing data. Prior to imputation, data were inspected for outliers through creating boxplots. Outliers were defined as any values outside 1.5 times the interquartile range above the upper quartile or below the lower quartile. Inspection of the data revealed a single outlier for pain interoceptive accuracy within the Self-Injurious Behavior group and five outliers for respiratory sinus arrhythmia—two within the No Self-Injurious Behavior group and three within the Self-Injurious Behavior group. These outliers were removed from the data.[2] After removing these outliers, missing data ranged from 0.9% (Body Perception Questionnaire, Pain Tolerance Examination, and Fearlessness about Death) to 6.4% (respiratory sinus arrhythmia while viewing *Misery*). Little's Missing Completely at Random test indicated that data were consistent with a pattern of missing completely at random, χ^2 (29) = 27.88, p = .53. Missing data were handled with multiple imputation with fully conditional specification (m = 20) in SPSS (IBM Corporation, 2015). Data were then aggregated to use in analyses. To inspect imputation

[2] Analyses were recalculated while retaining the outliers. Results were highly similar to those reported here, which do not include outliers. Given the similarity in results and that fewer assumptions were violated when removing the outliers, results are presented without outliers.

accuracy, all analyses were rerun on five randomly-selected imputation data sets (i.e., 25% of the imputation data sets). Results were identical to those reported here.

Software. Except where noted otherwise, all analyses were performed using R software (R Core Team, 2013), using the following packages: car (Fox et al., 2018), corrr (Jackson, Cimentada, & Ruiz, 2019), ggplot2 (Wickham et al., 2019), multcomp (Hothorn, Bretz, Westfall, Heiberger, Schetzenmeister, & Scheibe, 2019), nlme (Pinheiro et al., 2019), ppcor (Kim, 2015), and stats (R Core Team, 2013).

Film manipulation check. Skew and kurtosis were computed and the Shapiro-Wilk test was performed to assess whether emotion ratings in response to viewing *Misery* were normally distributed. Skew ranged from –0.59 (disgust) to 3.11 (happy) and kurtosis ranged from –1.41 (sad) to 10.16 (happy). Shapiro-Wilk tests revealed that all emotion ratings were non-normally distributed (ps < .001). Accordingly, a non-parametric repeated measures Group × Emotion analysis of variance (ANOVA) was used to determine whether emotion intensities in response to viewing the *Misery* clip differed by group (between-subjects factor) or emotion type (within-subjects factor). Specifically, in line with recommendations (Baguley, 2012), data were rank-transformed and then a nonlinear mixed effects model was fit to the rank-transformed data. Planned contrasts then identified whether participants reported greater fear intensity relative to all other emotions.

Assumption checks for interoceptive accuracy and self-reported interoceptive abilities. To identify the most appropriate tests to identify group differences on measures of interoceptive accuracy and self-reported interoceptive abilities, skew and kurtosis were computed and the Shapiro-Wilk test was performed to assess whether the assumption of normality was violated. In addition, Levene's test was used to inspect whether the assumption of homogeneity of variance was violated. The results of these tests are shown in Table 3. All variables exhibited mild skew and kurtosis (skew range: –1.06 to 0.57, kurtosis range: –0.78 to 1.82). Shapiro-Wilk tests revealed that cardiac interoceptive accuracy, the Body Perception Questionnaire heartbeat item, pain interoceptive accuracy, respiratory sinus arrhythmia, fear intensity, and confidence in the emotion rating task showed significant deviations from normality (ps ≤ .01). In addition, the Body Perception Questionnaire total score exhibited significant heterogeneity of variance ($p < .001$; see below for how these violations were handled for each individual test).

Relations among interoception measures. Bivariate correlations among interoceptive accuracy and self-reported interoceptive abilities for cardiac sensations, pain, and fear were computed within the No Self-Injurious Behavior and Self-Injurious Behavior groups.

Among the Self-Injurious Behavior group only, one sample *t*-tests were used to identify whether interoceptive confidence for the heartbeat tracking test and pain perception test significantly differed from 100, which was the value indicating complete confidence, and from 50, which was the value indicating chance-level confidence. Given the non-normal distribution for confidence in the emotion rating task, a one-sample Wilcoxon test was used to determine whether confidence in the emotion rating task significantly differed from 100 (complete confidence) and from 50 (chance confidence). Next, a non-parametric repeated measures ANOVA was used to compare whether interoceptive confidence differed among the three tasks (within-group factor). Confidence ratings were rank-transformed and then a nonlinear model was fit to the rank-transformed data. Then, pairwise comparisons were performed to identify any differences in confidence by task. These contrasts used the multcomp package's "free" adjustment to correct for multiple comparisons.

Finally, the correlation between interoceptive task confidence and accuracy were computed for cardiac sensations, pain, and fear. Because a single fear interoceptive accuracy metric was not available (and was instead indicated by respiratory sinus arrhythmia and fear intensity while viewing the *Misery* clip), two partial correlations were computed for emotion confidence: the first assessed the correlation between emotion task confidence and respiratory sinus arrhythmia when adjusting for fear intensity, and the second assessed the correlation between emotion task confidence and fear intensity when adjusting for respiratory sinus arrhythmia.

Group differences in interoceptive accuracy and self-reported interoceptive abilities. Given that the assumption of normality was violated for cardiac interoceptive accuracy, the Body Perception Questionnaire heartbeat item, and pain interoceptive accuracy, two-sample Wilcoxon tests were used to identify group differences on these measures. Given that the assumption of equal variance was violated for the Body Perception Questionnaire total score, a two-sample *t*-test with a Welch correction was used to identify group differences on this measure. Two-sample *t*-tests were used to identify group differences on self-reported interoceptive abilities for pain and fear.

As described above, a metric for fear interoceptive accuracy was not obtained. Instead of a two-sample *t*-test or Wilcoxon test, a logistic regression was used to examine whether respiratory sinus arrhythmia or fear intensity were associated with Self-Injurious Behavior group status, when adjusting for the influence of one another. The beta values and 95% confidence intervals were exponentiated. Exponentiated betas are conceptually similar to odds ratios, where values < 1 indicate a negative relation, values of 1 indicate no relation, and values > 1 indicate a positive relation. As an exploratory analysis, I also completed two-sample Wilcoxon tests to examine whether groups differed on respiratory sinus arrhythmia and fear intensity, without adjusting for the influence of one another.

Results

Film Manipulation Check

The non-parametric Group × Emotion ANOVA revealed a non-significant main effect of group ($F[1, 108] = 1.02$, $p = .31$) but a significant main effect of emotion type ($F[5, 540] = 91.34$, $p < .001$) on emotion intensities, see Figure 1. Planned contrasts revealed that fear intensity was greater than the intensity of amusement (estimate = 198.53, 95% CI [153.30, 243.75], $z = 11.02$, $p < .001$), happiness (estimate = 288.89, 95% CI [243.67, 334.12], $z = 16.04$, $p < .001$), anger (estimate = 172.42, 95% CI [127.20, 217.65], $z = 9.57$, $p < .001$), and sadness (estimate = 98.64, 95% CI [4753.42, 143.87], $z = 5.48$, $p < .001$). The intensities of fear and disgust were similar (estimate = –27.74, 95% CI [–72.96, 17.49], $z = –1.54$, $p = .40$). Taken together, these results suggest that viewing the film *Misery* effectively elicited the intended emotional response (i.e., fear) in both groups.

Relations among Interoception Measures

Bivariate correlations. The bivariate correlations among interoceptive accuracy measures and self-reported interoceptive abilities for cardiac sensations, pain, and fear are shown in Tables 4 and 5. Overall, interoceptive accuracy metrics demonstrated small and nonsignificant associations with one another, though respiratory sinus arrhythmia demonstrated a moderate, positive correlation with cardiac interoceptive accuracy (in both groups, *r*s = .35 and .48, *p*s < .001). The self-report measures of interoceptive abilities also demonstrated small and nonsignificant associations with one another (*r*s = –.17 to .23, *p*s > .05), though self-reported interoceptive abilities for pain and fear were positively associated in the Self-Injurious Behavior group ($r = .29$, $p < .05$). Finally, interoceptive accuracy and self-reported interoceptive abilities for each sensation type also demonstrated mostly small and nonsignificant associations (cardiac *r*s = –.12 to .05, pain *r*s = –.20 to .20, fear *r*s = –.35 to .27), though self-reported interoceptive abilities for fear were positively associated with respiratory sinus arrhythmia ($r = .27$, $p < .05$) and negatively associated with fear intensity ($r = –.35$, $p < .001$) in the No Self-Injurious Behavior group. Respiratory sinus arrhythmia was also negatively associated with fear intensity ($r = –.33$, $p < .05$) in the No Self-Injurious Behavior group.

Interoceptive confidence and accuracy. The one-sample *t*-tests and Wilcoxon test revealed that interoceptive confidence in the heartbeat tracking, pain perception, and emotion rating tasks were significantly lower than 100 (*p*s < .001, see Table 6 and Figure 2), indicating that participants reported less than complete confidence in their interoceptive test performance. The tests assessing whether participants had chance-level confidence (i.e., a score of 50) in interoceptive test performance yielded mixed results (see Table 6): interoceptive confidence in the heartbeat tracking test was significantly less than 50 ($p = .002$, 95% CI [35.57, 46.60]), interoceptive confidence in the pain perception test was not significantly different from 50 ($p = .49$, 95% CI [42.64, 53.57]), and interoceptive confidence in the emotion rating task was significantly greater than 50 ($p < .001$, 95% CI [65.50, 85.00]).

Next, the non-parametric repeated measures ANOVA revealed that confidence significantly differenced by task, $F[2, 106] = 124.62$, $p < .001$. Post-hoc comparisons revealed that confidence in the heartbeat tracking test was lower than confidence in the pain perception test (estimate = 12.62, 95% CI [0.65, 24.59], $z = 2.47$, $p = .04$) and emotion rating task (estimate = 75.21, 95% CI [63.25, 87.18], $z = 14.74$, $p < .001$). Confidence in the pain perception test was also lower than confidence in the emotion rating task (estimate = 62.59, 95% CI [50.63, 74.56], $z = 12.27$, $p < .001$).

Interoceptive confidence in the heartbeat tracking test and cardiac interoceptive accuracy were significantly and positively correlated, $r = .53$, $p < .001$ (see Figure 3A). However, interoceptive task confidence in the pain perception test and pain interoceptive accuracy exhibited a small, negative, non-significant correlation, $r = –.07$, $p = .61$ (see Figure 3B). Interoceptive confidence in the emotion rating task also exhibited small, nonsignificant partial correlations with respiratory sinus arrhythmia (partial $r = –.19$, $p = .17$, when adjusting for fear intensity) and fear intensity (partial $r = .04$, $p = .77$, when adjusting for respiratory sinus arrhythmia) while viewing *Misery* (see Figure 3C and 3D).

Group Differences in Interoceptive Abilities

Group means, standard deviations, and group comparisons are shown in Table 7.

Cardiac sensations. Group means for interoceptive accuracy and self-reported interoceptive abilities for cardiac sensations are displayed in Figure 4. A two-sample Wilcoxon test revealed similar cardiac interoceptive accuracy between the No Self-Injurious Behavior and Self-Injurious Behavior groups (difference = 0.00, 95% CI [–0.06, 0.07], $p = .94$, Figure 4A). A Welch-corrected two sample *t*-test revealed similar self-reported interoceptive abilities for body sensations in general, as indicated by the Body Perception Questionnaire total score (difference = 0.08, 95% CI [–0.39, 0.23], $p = .59$, Figure 4B). A two-sample Wilcoxon test also revealed similar self-reported interoceptive abilities for heartbeats, as indicated by the Body Perception Questionnaire heartbeat item (difference = 0.00, 95% CI [–0.99, 0.00], $p = .45$, Figure 4C).

Pain. Group means for interoceptive accuracy and self-reported interoceptive abilities for pain are displayed in Figure 5. The two-sample Wilcoxon test revealed that the Self-Injurious Behavior group displayed significantly lower interoceptive accuracy for pain relative to the No Self-Injurious Behavior group (difference = 0.07, 95% CI [0.01, 0.13], $p = .02$, Figure 5A). A two-sample t-test revealed similar self-reported interoceptive abilities for pain between the No Self-Injurious Behavior and Self-Injurious Behavior groups (difference = 3.25, 95% CI [–1.87, 8.37], $p = .21$, Figure 5B).

Fear. Results of the exploratory two-sample Wilcoxon test revealed similar respiratory sinus arrhythmia while viewing *Misery* among the No Self-Injurious Behavior and Self-Injurious Behavior groups (difference = 0.05, 95% CI [0.00, 0.10], $p = .05$; Table 7). Results of the exploratory two-sample Wilcoxon test revealed that the Self-Injurious Behavior group reported significantly lower fear intensity while viewing *Misery* relative to the No Self-Injurious Behavior group (difference = 13.00, 95% CI [5.00, 24.00], $p = .003$; Table 7). However, results of the logistic regression revealed that respiratory sinus arrhythmia (exp[B] = 0.03, 95% CI [0.00, 0.52], $p = .02$) and fear intensity (exp[B] = 0.97, 95% CI [0.95, 0.99], $p = .001$) were significantly and negatively related to group status (0 = No Self-Injurious Behavior, 1 = Self-Injurious Behavior; see Table 8). The 95% CI for respiratory sinus arrhythmia spanned 0, though, and was relatively wide, indicating that this parameter lacked precision. A two-sample t-test revealed similar self-reported interoceptive abilities for fear between the No Self-Injurious Behavior and Self-Injurious Behavior groups (difference = 0.27, 95% CI [–2.97, 2.44], $p = .85$, Figure 6). A summary of the results comparing interoceptive accuracy and self-reported interoception for cardiac sensations, pain, and fear is provided in Table 9.

Discussion

The current study assessed two types of interoceptive processing (interoceptive accuracy and self-reported interoceptive abilities) for three sensations (cardiac, pain, and fear) among people with and without self-injurious behaviors. Overall, results revealed no significant group differences in interoceptive accuracy or self-reported interoceptive abilities for cardiac sensations. Results also revealed no significant group differences in self-reported interoceptive abilities for pain and fear. However, Self-Injurious Behavior group status was associated with lower interoceptive accuracy for pain and fear—sensations that may be central to the pathophysiology of self-injurious behaviors. Overall, these findings indicate that interoceptive accuracy for clinically-relevant sensations may be impaired among people with self-injurious behaviors.

Self-Injurious Behaviors and Interoceptive Accuracy

Results indicated consistently that cardiac interoceptive accuracy was not diminished among people with self-injurious behaviors relative to people without self-injurious behaviors. Specifically, people with and without self-injurious behaviors exhibited similar performance on the heartbeat tracking test. The *mean* and *median* cardiac interoceptive accuracy scores for each group were similar to or above norms among non-clinical samples (e.g., *mean* = 0.66 [SD = 0.21] and *median* = 0.70 in Garfinkel et al., 2015; Study 1 *mean* = 0.50 [SD = 0.27] and Study 2 *mean* = 0.61 [SD = 0.32] in Nicholson, Williams, Grainter, Christensen, Calvo-Merino, & Gaigg, 2018; *mean* = 0.66 [SD = 0.15] in Pollatos et al., 2012). Moreover, confidence in the heartbeat tracking test was positively associated with cardiac interoceptive accuracy. Observing positive and statistically significant correspondence between different measures of cardiac interoceptive abilities supports a *lack* of cardiac interoceptive dysfunction among people with self-injurious behaviors (Garfinkel et al., 2015). This makes sense given that this relation is thought to emerge only if people have generally in-tact and accurate cardiac interoceptive processing (Garfinkel et al., 2015). However, even though interoceptive accuracy and confidence were correlated, and even though cardiac interoceptive accuracy was not impaired relative to people without self-injurious behaviors, people with self-injurious behaviors reported significantly lower confidence in their heartbeat tracking test performance relative to their confidence in the pain perception and emotion rating tasks. This could indicate that people with self-injurious behaviors underestimated the (objective) accuracy of their heartbeat perception. Similar results have been documented previously (Khalsa, Rudrauf, Damasio, Davidson, Lutz, & Tranel, 2008). Specifically, in a study comparing cardiac interoceptive accuracy between meditators and non-meditators, both groups exhibited similar cardiac interoceptive accuracy. However, non-meditators reported significantly lower confidence in their heartbeat perception relative to meditators (Khalsa et al., 2008). This underestimation of interoceptive abilities may explain why past work indicates that people with self-injurious behaviors self-report interoceptive deficits (Forrest et al., 2015; Franklin et al., 2012; Rogers et al., 2018; Ross et al., 2009), though future work is needed to identify why people may underestimate their interoceptive abilities despite exhibiting high cardiac interoceptive accuracy.

When considering sensations associated with self-injury, cardiac sensations are relatively neutral, whereas pain and fear are central. Multiple results suggested that lower interoceptive accuracy for pain and fear were associated with self-injurious behaviors. First, people with self-injurious behaviors exhibited significantly lower pain interoceptive accuracy than people without self-injurious behaviors. Second, confidence in the pain perception test and pain interoceptive accuracy were non-significantly associated. Third, respiratory sinus arrhythmia and fear intensity while watching *Misery* were negatively associated with Self-Injurious Behavior group status, when adjusting for the effect of one another. Negative relations were expected, given that respiratory sinus arrhythmia is typically diminished among people with self-injurious behaviors (Beauchaine, 2015; Crowell, et al., 2005) and that lowered fear is central in theoretical accounts of suicide (Dhingra et al., 2016; Joiner, 2005; Smith et al., 2016; Van Orden et al., 2010). Of note, when comparing group differences on respiratory sinus arrhythmia without adjusting for fear intensity, groups were found to be similar. Yet when adjusting for fear intensity, some signal emerged for respiratory sinus arrhythmia being negatively associated with group status.

Even though the respiratory sinus arrhythmia parameter was relatively unstable, confidence in the emotion rating test exhibited small and non-significant correlations with both respiratory sinus arrhythmia and self-reported fear intensity. Given that correspondence between interoceptive confidence and accuracy is expected only in the presence of accurate interoceptive abilities (Garfinkel et al., 2015), the lack of correspondence between interoceptive confidence and accuracy for pain and fear supports that people with self-injurious behaviors experience diminished interoceptive accuracy for these sensations. In other words, results indicated that compared to people without self-injurious behaviors, those who engaged in recent self-injury displayed reduced interoceptive accuracy for pain and fear.

Contemporary theoretical accounts may explain why interoceptive accuracy may be diminished for pain and fear among people with self-injurious behaviors. These theories propose that interoception occurs via predictive coding, which means that the brain continuously and automatically *constructs* interoceptive sensations (Ainley, Apps, Fotopoulou, & Tsakiris, 2016; Barrett, Quigley, & Hamilton, 2016; Barrett & Simmons, 2015; Friston, 2010; Khalsa et al., 2018; Seth, 2013). That is, interoception is not simply the result of the brain perceiving an afferent sensation. Rather, the brain constructs sensations by perceiving an afferent sensation and *comparing* the afferent sensation to a *predictive model* for that sensation. Predictive models are based on previous experiences, beliefs, and stimulus–response associations (Farb et al., 2015; Paulus, Feinstein, & Khalsa, 2019; Seth, 2013). Comparisons between the afferent sensation and predictive model are made on not only the characteristics of sensations (e.g., mild vs. extreme, pleasant vs. unpleasant) but also on the certainty (i.e., precision) of sensations. If the afferent sensation differs from the predictive model, interoceptive prediction errors occur.

Prediction errors are not adaptive and the brain will strive to minimize them, through either (1) assigning low certainty to the afferent sensation while assigning very high certainty to the predictive model (Paulus et al., 2019) or (2) updating the predictive model to be more in line with the afferent sensation (Farb et al., 2015; Seth, 2013). However, in the context of psychopathology, interoceptive predictive models are thought to be hyper-precise (i.e., assigning too much certainty to the predictions) and highly rigid, meaning that the predictive model does not easily incorporate model-incongruent information (Paulus et al., 2019). Hyper-precise and/or rigid predictive models are thought to cause interoceptive processing to become impaired, which may then exacerbate psychopathology. For example, if a person has repeatedly engaged in NSSI, they may possess a predictive model indicating that NSSI results in a positive and desirable physiological state (e.g., Nock & Prinstein, 2004). When engaging in NSSI, the brain may predict to experience this positive physiological state, yet the afferent sensations actually produced may be undesirable and painful, resulting in an interoceptive prediction error. To minimize the prediction error, the brain may assign more certainty to the predictive model and far less certainty and precision to the afferent sensation, which causes the person to actually perceive a desirable physiological state after engaging in self-injury (Paulus et al., 2019). While this approach minimizes the prediction error, it may simultaneously impair interoceptive processing and maintain psychopathological processes (Paulus et al., 2019).

Self-Injurious Behaviors and Self-Reported Interoceptive Abilities

No group differences were found for people with versus without self-injurious behaviors on self-reported interoceptive abilities for cardiac sensations, pain, and fear. On one hand, the lack of group differences for self-reported interoceptive abilities in the context of significant associations between interoceptive accuracy and self-injurious behaviors aligns with theories proposing that multiple, unique forms of interoceptive abilities exist (Garfinkel et al., 2015; Khalsa et al., 2018). If each type of interoceptive processing is driven by distinct neural processes, as is hypothesized (Garfinkel et al., 2015; Khalsa et al., 2018), then the fact that group differences emerged for only some forms of interoceptive processing sheds light on specific ways in which interoceptive processing is disrupted for people with self-injurious behaviors.

On the other hand, the lack of group differences on self-reported interoceptive abilities is inconsistent with research indicating that people with self-injurious behaviors self-report poorer interoceptive abilities than people without self-injurious behaviors (Forrest et al., 2015; Franklin et al., 2012; Rogers et al., 2018; Ross et al., 2009). However, this past literature has assessed self-reported interoceptive abilities using measures that are not sensation-specific, such as the Eating Disorders Inventory (Garner, Olmstead, & Polivy, 1983), which assesses awareness of general emotions and gut sensations (Forrest et al., 2015; Hagan, Rogers, Brausch, Muehlenkamp, & Joiner, 2019; Smith et al., 2018) or the Multidimensional Interoceptive Awareness Inventory (Mehling, Price, Daubenmier, Acree, Bartmess, & Stewart, 2012), which assesses one's general relationship with the body's sensations (Rogers et al., 2018). These sensation-general self-report assessments of interoceptive abilities may yield different information than sensation-specific assessments because if people truly have diminished interoceptive processing and inaccurately perceive their interoceptive sensations, asking them to report on the perception of specific sensations may require a level of detail and precision that they do not possess.

At the same time, though, the self-report assessments for interoception for pain and fear used in the current study were only proxies for interoceptive abilities, as to my knowledge, self-report assessments of interoception for pain and fear are not available. Even though pain tolerance and interoceptive abilities are conceptually and empirically associated (Khalsa et al., 2018; Pollatos et al., 2012; though see Dodd et al., 2018 and Hagan et al., 2019), and even though lack of perception of fear could contribute to fearlessness (about death), we have much to understand regarding the similarities and dissimilarities among these constructs.

Clinical Implications

As the field of clinical science moves toward dimensional approaches, where disorders are conceptualized more by their underlying biological and psychological mechanisms of dysfunction and less by their categorical symptoms (e.g., Insel et al., 2010; Kotov et al., 2017), transdiagnostic processes are highly relevant to advancing the understanding and treatment of psychopathology. Indeed, impaired interoception is implicated in the development and maintenance of multiple types of psychopathology, including depressive disorders (Harshaw, 2015; Paulus et al., 2019; Paulus & Stein, 2010), anxiety disorders (Paulus et al., 2019; Paulus & Stein, 2010), substance use disorders (Paulus, Tapert, & Schulteis, 2009), and eating disorders (Kaye, Fudge, & Paulus, 2009). Interoceptive dysfunction has only recently begun to be investigated among people with self-injurious behaviors. But considering that self-injurious behaviors are observed among people with virtually all forms of psychopathology (Nock et al., 2009; Nock, Hwang, Sampson, & Kessler, 2010), studying interoceptive abilities among people with self-injurious behaviors is highly compatible with dimensional approaches to psychopathology.

While interoceptive impairment may be a transdiagnostic construct, a challenge with traditional interoception research and interventions is that for some forms of psychopathology (e.g., panic disorder; De Cort et al., 2017; Graeff & Del-Ben, 2008), interoception is impaired because people are overly sensitive to their bodily signals, whereas for other forms of psychopathology (e.g., eating disorders; Klabunde, Acheson, Boutelle, Matthews, & Kaye, 2013; Pollatos et al., 2008) people are *in*sensitive to their bodily signals. The resultant conceptualizations of and treatments for interoceptive dysfunction therefore differ. In the context of over-sensitivity to sensations, interoceptive exposures may be used to teach people how to tolerate physiological sensations and differentiate contexts when heightened physiological sensations are and are not indicative of danger. In the context of insensitivity to sensations, though, interoception may be targeted by providing individuals with self-referent (Ainley, Maister, Brokfeld, Farmer, & Tsakiris, 2013), integrated interoceptive and exteroceptive feedback, such as looking at one's reflection in a mirror while counting one's heartbeats (Ainley, Tajadura-Jiménez, Fotopoulou, & Tsakiris, 2012) or viewing a projected outline of one's body that flashes to the beat of one's heart (Aspell, Heydrich, Marillier, Lavanchy, Herbelin, & Blanke, 2013).

While these interventions may be effective (Pompoli, Furukawa, Efthimiou, Imai, Tajka, & Salanti, 2018; Zucker et al., 2019), they are limited in the fact that they do not account for within-person contextual differences, where interoception may be diminished in some instances but heightened in others. For example, in the eating disorders field researchers and clinicians have reported for decades that people with anorexia nervosa experience reduced interoceptive abilities (e.g., Bruch, 1962; Pollatos et al., 2008), such that they are “tuned out” to their bodily sensations. However, Khalsa and colleagues (2015) assessed interoceptive accuracy for cardiac sensations and respiration among people with anorexia nervosa when they were anticipating consuming a meal—a context that produces acute increases in anxiety for this population. As meal consumption approached, people with anorexia nervosa continued to exhibit significant interoceptive impairment, but rather than being “tuned out” of their body sensations, they were acutely aware of their sensations, and much more aware than a healthy control group (Khalsa, Craske, Li, Vangala, Strober, & Feusner, 2015). These findings indicate that in the context of psychopathology, interoceptive processing may be impaired both at rest and in contexts that trigger symptomatic behaviors, but the direction of the impairment may shift dynamically.

Conceptualizing oversensitivity and insensitivity to sensations as different processes does not account for context-specific shifts in interoceptive processing. Moreover, if only one form of interoceptive disturbance is being targeted in treatment, then interventions may be only partially effective. These limitations can be overcome when viewing interoceptive dysfunction through the lens of the predictive coding framework, which suggests that a single mechanism is responsible for over- or under-sensitivity of bodily states—i.e., hyper-precise and rigid predictive models. This perspective is parsimonious, clearly identifies a single treatment target (e.g., correct predictive models through exposure), and may allow for the identification of transdiagnostic interventions. For example, interoceptive exposures are a common and effective panic disorder intervention, but a very uncommon component of eating disorder treatment (though for a novel interoceptive intervention in eating disorders see Zucker et al., 2019). Adopting this dimensional perspective of interoceptive dysfunction may allow for effective interventions typically used in the context of a specific disorder to be used more transdiagnostically and contribute to more favorable treatment outcomes across the board (Kotov et al., 2017).

Strengths and Limitations

The study’s strengths include that the participants in the Self-Injurious Behavior group had all engaged in recent self-injurious behaviors. Considering that the severity of interoceptive dysfunction is positively associated with the recency of self-injury (Forrest et al., 2015), the sample of people with recent self-injury was well suited to address the current research questions. Another strength is that two domains of interoceptive processing—accuracy and self-reported abilities—were assessed for three different sensations. This is the first study to go beyond the use of self-report assessments for interoceptive impairments in people with self-injurious behaviors, and this multidimensional approach extends the literature on interoceptive dysfunction and self-injurious behaviors. However, the assessments of interoceptive accuracy for pain and fear have simultaneous strengths and limitations. The strengths are that the pain perception test largely mirrored the heartbeat tracking test, and the emotion rating task used a psychophysiological indicator known to be associated with emotion regulation and awareness (Beauchaine, 2015; Vasilev et al., 2009; Williams et al., 2015). The limitations are that their construct validity cannot be established. Respiratory sinus arrhythmia (during the film) was positively correlated with cardiac interoceptive accuracy, which is expected given that respiratory sinus arrhythmia (at baseline) is positively associated with scores from the heartbeat tracking test (Knapp-Kline & Kline, 2005; Murphy, Brewer, Hobson, Catmur, & Bird, 2018).

However, pain interoceptive accuracy was not correlated with cardiac interoceptive accuracy or the two indicators for fear interoceptive accuracy. Moreover, interoceptive accuracy for pain and fear were not significantly correlated with most self-report measures of interoceptive abilities. However, we would not expect to observe correlations among these measures, given that (1) measures of interoceptive accuracy are not usually associated with self-reported measures of interoceptive abilities (e.g., Garfinkel et al., 2015) and (2) interoceptive abilities may vary by sensation (Khalsa et al., 2018).

It could also be argued that the two indicators of fear interoceptive accuracy—respiratory sinus arrhythmia and fear intensity—could be conceptualized as metrics of emotion regulation and reactivity, respectively. The results that respiratory sinus arrhythmia (i.e., regulation) demonstrated a negative—albeit unstable—relation to self-injury group status is in line with other research indicating that, when adjusting for the influence of emotion reactivity, people with self-injurious behaviors display diminished emotion regulation abilities as compared to people without self-injurious behaviors (e.g., Davis et al., 2014). The results that fear intensity (i.e., reactivity) was negatively related to self-injury group status is in line with theoretical accounts that people engaging in suicidal behavior exhibit diminished fear of death (Van Orden et al., 2010). Ultimately, because the validity of the pain and fear interoceptive accuracy metrics cannot be established by assessing correlations with other metrics of interoceptive accuracy or with self-report measures of interoceptive abilities (Garfinkel et al., 2015; Khalsa et al., 2018), neuroimaging studies are needed to identify whether brain regions known to be associated with interoceptive processing, such as the anterior insula and anterior cingulate (Craig, 2002; Khalsa et al., 2018), are activated during the pain perception test and emotion rating tasks employed here.

The *Misery* clip is also limited in that it elicited relatively high levels of fear and disgust, so it was not necessarily a pure elicitation of fear. In addition, fear and fear of death (as is central to suicide theories and as was assessed with the self-report measure of interoceptive abilities) are not necessarily synonymous, though evolutionarily, fear responses emerge because of a perceived or potential threat to one's existence (e.g., Adolphs, 2013).

The heartbeat tracking test itself also has several shortcomings. These include that heartbeat perception is possible through interoceptive or exteroceptive input (e.g., chest wall vibrations; Khalsa et al., 2009) and that task performance can be influenced by resting heart rate, knowledge of one's heart rate, and beliefs about one's heart rate (Khalsa et al., 2008; Murphy et al., 2018; Ring, Brener, Knapp, & Mailloux, 2015). Given these limitations, the mentally counted number of heartbeats may not actually reflect the number of counted heartbeats. Rather, it could reflect people's *beliefs* about or expectations of their heartbeats (Ring et al., 2015). Beliefs about one's sensations may certainly be related to interoceptive processing (e.g., Farb et al., 2015; Paulus et al., 2019; Seth, 2013) but beliefs are not a proxy for the perception of afferent sensations. Another limitation is that the interoceptive accuracy tasks for cardiac sensations, pain, and fear were assessed in a lab environment and do not capture interoceptive processes occurring in the moments before, during, or after self-injury. Ecologically valid assessments of interoceptive processing are an important direction for future interoception and self-injurious behaviors research (e.g., Khalsa et al., 2015).

The current results do not account for the effect that comorbid conditions may have had on interoceptive accuracy or self-reported interoceptive abilities for cardiac sensations, pain, or fear. For instance, several people in the Self-Injurious Behavior group met criteria for panic disorder, which is associated with over-perception of bodily sensations (e.g., De Cort et al., 2017; Graeff & Del-Ben, 2008), whereas several others met criteria for eating disorders, which are typically associated with under-perception of bodily sensations (e.g., Klabunde et al., 2013; Pollatos et al., 2008). For this reason, the metrics of interoceptive accuracy did not take into account the direction of the interoceptive impairment. While not accounting for the direction of interoceptive impairment is consistent with a transdiagnostic perspective and the interoceptive predictive coding framework (Ainley et al., 2016; Barrett et al., 2016; Barrett & Simmons, 2015; Friston, 2010; Khalsa et al., 2018; Seth, 2013), research may benefit from characterizing both the degree and direction of interoceptive impairment among people with self-injurious behaviors.

Conclusion

This study extends the knowledge of interoceptive processing and self-injurious behaviors by examining multiple facets of interoception among people with and without self-injurious behaviors. If impaired interoceptive processing is to be considered as a novel self-injury correlate or risk factor, interoceptive abilities must differ between people with and without self-injury (Kraemer, Kazdin, Offord, Kessler, Jensen, & Kupfer, 1997). Overall, the current results indicate that the relations between interoceptive processing and self-injurious behaviors may be both domain- and sensation-specific. That is, interoceptive accuracy, but not self-reported interoceptive abilities, was impaired for pain and fear among people engaging in self-injurious behaviors. However, for cardiac sensations, neither interoceptive accuracy nor self-reported interoceptive abilities differed between people with and without self-injurious behaviors. Given these results, statements indicating that “interoception is dysregulated among people with self-injurious behaviors” may by overly simplistic because they do not address the heterogeneity of interoceptive processes, which encompass interoceptive accuracy and self-reported interoceptive abilities (to only name a few features of interoception) for the body’s many sensory domains. In the context of psychopathology, sensation-specificity of interoceptive impairment may be important, considering that the sensations that are salient for the pathophysiology of specific disordered behaviors (e.g., gastrointestinal sensations in eating disorders, heart rate and respiration in panic disorder, and pain and fear in self-injury) are likely to be the sensations for which interoceptive predictive models are hyper-precise or rigid (Paulus et al., 2019). Continued investigations of aberrant interoceptive processing within people with self-injurious behaviors are needed, as disrupted interoceptive accuracy appears to show promise as a correlate or risk factor contributing to several forms of psychopathology.

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Table 1

Demographic characteristics for the No Self-Injurious Behavior and Self-Injurious Behavior groups

	No SIB (n = 55)	SIB (n = 54)		
	n (%)	n (%)	χ^2	p
Gender			9.09	.03
Man	15 (27.3)	4 (7.4)		
Woman	40 (72.7)	48 (88.9)		
Gender fluid	0 (0)	1 (1.9)		
Trans man	0 (0)	1 (1.9)		
Race			7.86	.16
White	51 (92.7)	42 (77.8)		
Asian	1 (1.8)	3 (5.6)		
American Indian/Alaska Native	0 (0)	2 (3.7)		
Black/African American	0 (0)	2 (3.7)		
Biracial or multiracial	3 (5.5)	3 (5.6)		
Other	0 (0)	2 (3.7)		
Ethnicity			0.19	.66
Hispanic/Latino	3 (5.5)	2 (3.7)		
Not Hispanic/Latino	52 (94.5)	52 (96.3)		
Sexual orientation			31.49	< .001
Straight	54 (98.2)	28 (51.9)		
Mostly straight	0 (0)	2 (3.7)		
Bisexual	1 (1.8)	15 (27.8)		
Gay	0 (0)	3 (5.6)		
Lesbian	0 (0)	2 (3.7)		
Queer	0 (0)	1 (1.9)		
Pansexual	0 (0)	2 (3.7)		
Unsure or unknown	0 (0)	1 (1.9)		
Highest level of education			34.90	< .001
High school graduate or GED	0 (0)	2 (3.7)		
Some college	53 (96.4)	45 (83.3)		
2-year degree	0 (0)	3 (5.6)		
4-year degree	2 (3.6)	2 (3.7)		
Professional degree	0 (0)	2 (3.7)		
Recent SIB type				
NSSI (past year)	–	39 (72.2)		
Attempt (past 2 years)	–	15 (27.8)		
Lifetime NSSI	–	52 (96.3)		
Recency: > 1 year ago	–	4 (7.4)		
Recency: Past year	–	23 (42.6)		
Recency: Past month	–	13 (24.1)		
Recency: Past week	–	12 (22.2)		

(continued)

Table 1 *(continued)*

	No SIB (n = 55)	SIB (n = 54)			
	n (%)	*n* (%)	χ^2	*p*	
Lifetime attempt	–	34 (63.0)			
Recency: > 1 year ago	–	23 (38.2)			
Recency: Past year	–	9 (16.4)			
Recency: Past month	–	2 (3.6)			
Recency: Past week	–	0 (0.0)			
Psychiatric diagnoses					
Anxiety disorder	–	35 (64.8)	–	–	
Depressive disorder	–	35 (64.8)	–	–	
Bipolar disorder	–	15 (27.8)	–	–	
Substance use disorder	–	2 (3.6)	–	–	
Posttraumatic stress disorder	–	9 (16.7)	–	–	
Obsessive–compulsive disorder	–	15 (27.8)	–	–	
Eating disorder	–	11 (20.4)	–	–	
Schizoaffective disorder	–	1 (1.9)	–	–	
	M (*SD*)	*M* (*SD*)	*t*	*p*	Difference (95% CI)
Age	19.0 (1.2)	20.6 (5.6)	–2.06	.04	–1.61 (–3.17, –0.04)

Note. SIB = self-injurious behavior; NSSI = nonsuicidal self-injury

Table 2

Summary of interoceptive accuracy indices and self-reported interoceptive abilities

	Interoceptive accuracy: Objective metric	Interoceptive accuracy: Perceived metric	Self-reported interoceptive abilities
Cardiac	Electrocardiography-recorded heartbeats	Mentally-counted heartbeats	Body Perception Questionnaire total score and heartbeat item
Pain	Actual pounds of pressure	Estimated pounds of pressure	Pain Tolerance Examination Questionnaire score
Fear	Respiratory sinus arrhythmia during film	Self-reported fear intensity during film	Acquired Capability for Suicide Scale–Fearlessness about Death subscale score

Table 3

Normality assumption checks

			Shapiro-Wilk		Homogeneity of variance	
	Skew	Kurt	*W*	*p*	*F*	*p*
Cardiac IA	–0.50	–0.45	0.96	.001	0.14	.71
Cardiac SR: BPQ total	0.13	–0.33	0.99	.38	16.45	< .001
Cardiac SR: BPQ HB	0.26	–0.61	0.91	< .001	2.16	.15
Cardiac confidence	–0.03	–0.78	0.98	.53	–	–
Pain IA	–0.61	–0.24	0.96	.002	0.53	.47
Pain SR	–0.02	–0.23	0.99	.90	1.46	.23
Pain confidence	–0.06	–0.59	0.97	.27	–	–
Fear IA1: RSA	0.57	0.19	0.97	.01	0.13	.72
Fear IA2: Intensity	–0.54	–0.73	0.93	< .001	2.65	.11
Fear SR	0.00	–0.67	0.98	.10	0.27	.61
Fear confidence	–1.06	1.82	0.92	.001	–	–

Note. IA = interoceptive accuracy, SR = self-report, BPQ = Body Perception Questionnaire, BPQ HB = BPQ item assessing awareness of heartbeats, RSA = respiratory sinus arrhythmia, kurt = kurtosis. Levene's tests of homogeneity of variances include 1 degree of freedom.

Table 4

Bivariate correlations among interoceptive accuracy and self-reported interoceptive abilities for cardiac sensations, pain, and fear in the No Self-Injurious Behaviors group

	1	2	3	4	5	6	7	8
1. Cardiac IA	–							
2. Cardiac SR: BPQ total	–.07	–						
3. Cardiac SR: BPQ HB	.05	.65**	–					
4. Pain IA	.08	.19	.25	–				
5. Pain SR	.20	–.12	.00	.25	–			
6. Fear IA1: RSA	.35**	.18	.16	–.01	.09	–		
7. Fear IA2: Intensity	–.21	–.05	–.04	.00	–.26	–.33*	–	
8. Fear SR	.25	–.17	–.04	.17	.23	.27*	–.35**	–

Note. IA = interoceptive accuracy, SR = self-report, BPQ = Body Perception Questionnaire, BPQ HR = BPQ item assessing awareness of heartbeat, RSA = respiratory sinus arrhythmia, * $p < .05$, ** $p < .01$

Table 5

Bivariate correlations among interoceptive accuracy and self-reported interoceptive abilities for cardiac sensations, pain, and fear in the Self-Injurious Behaviors group

	1	2	3	4	5	6	7	8
1. Cardiac IA	–							
2. Cardiac SR: BPQ total	–.12	–						
3. Cardiac SR: BPQ HB	.04	.53**	–					
4. Pain IA	–.20	–.06	–.17	–				
5. Pain SR	–.06	–.14	–.05	–.15	–			
6. Fear IA1: RSA	.48**	–.07	–.13	–.18	.12	–		
7. Fear IA2: Intensity	–.06	.10	.13	.13	–.26	–.21	–	
8. Fear SR	.32*	–.16	–.02	–.20	.29*	.14	–.06	–

Note. IA = interoceptive accuracy, SR = self-report, BPQ = Body Perception Questionnaire, BPQ HR = BPQ item assessing awareness of heartbeat, RSA = respiratory sinus arrhythmia, * $p < .05$, ** $p < .01$

Table 6

One sample t-test or Wilcoxon test to identify whether interoceptive confidence significantly differed from 100 (complete confidence) and 50 (chance-level confidence) among participants with self-injurious behaviors

					Complete confidence (100)		Chance-level confidence (50)	
	M (*SD*)	*Median*	One-sample test	95% CI	Test statistic	*p*	Test statistic	*p*
Cardiac	41.09 (20.21)	40.00	*t*-test	35.57, 46.60	t (53) = –21.43	< .001	t (53) = –3.24	.002
Pain	48.11 (20.01)	49.12	*t*-test	42.64, 53.57	t (53) = –19.06	< .001	t (53) = –0.70	.49
Fear	79.84 (12.80)	80.00	Wilcoxon test	65.50, 85.00	V = 0	< .001	V = 600.501	< .001

Table 7

Comparing interoceptive accuracy and self-reported interoceptive abilities for cardiac sensations, pain, and fear

		No SIB		SIB					
	Min–Max	*M* (*SD*)	*Median*	*M* (*SD*)	*Median*	Two-sample test	Test stat. (*df*)	*p*	95% CI
Cardiac IA	0.15–0.98	0.70 (0.18)	0.73	0.70 (0.19)	0.70	Wilcoxon test	*W* = 1497	.94	–0.06, 0.07
Cardiac SR: BPQ total	1.16–5.00	2.75 (0.98)	2.73	2.83 (0.60)	2.91	Welch *t*-test	*t*(89.71) = –0.54	.59	–0.39, 0.23
Cardiac SR: BPQ HB	1.00–5.00	2.78 (1.21)	3.00	2.93 (1.06)	3.00	Wilcoxon test	*W* = 1363.50	.45	–1.00, 0.00
Pain IA	0.31–0.98	0.76 (0.13)	0.79	0.69 (0.16)	0.72	Wilcoxon test	***W* = 187.50**	**.02**	**0.01, 0.13**
Pain SR	22.50–86.83	57.55 (14.10)	55.40	54.30 (12.80)	55.80	*t*-test	*t*(107) = 1.26	.21	–1.87, 8.37
Fear IA1: RSA	6.41–7.07	6.74 (0.14)	6.74	6.70 (0.15)	6.69	Wilcoxon test	*W* = 1804	.05	0.00, 0.10
Fear IA2: Intensity	0.00–100.00	62.90 (23.90)	70.00	47.60 (27.80)	59.00	Wilcoxon test	***W* = 1983**	**.003**	**5.00, 24.00**
Fear SR	0.00–28.00	14.30 (6.88)	13.00	14.60 (7.37)	14.00	*t*-test	*t*(108) = –0.19	.85	–2.97, 2.44

Note. SIB = self-injurious behavior, IA = interoceptive accuracy, SR = self-report, BPQ = Body Perception Questionnaire, BPQ HB = BPQ item assessing awareness of heartbeat, RSA = respiratory sinus arrhythmia, stat = statistic. Statistically significant findings are in bold text.

Table 8

Logistic regression results of respiratory sinus arrhythmia and fear intensity while viewing a clip from Misery *predicting group status (0 = No Self-Injurious Behavior, 1 = Self-Injurious Behavior)*

	B	*SE*	*p*	Exp(*B*)	Exp(95% CI)
Intercept	26.01	10.78	–	–	–
Respiratory sinus arrhythmia	–3.64	1.57	.02	0.03	0.00, 0.52
Fear	–0.03	0.01	.001	0.97	0.95, 0.99

Table 9

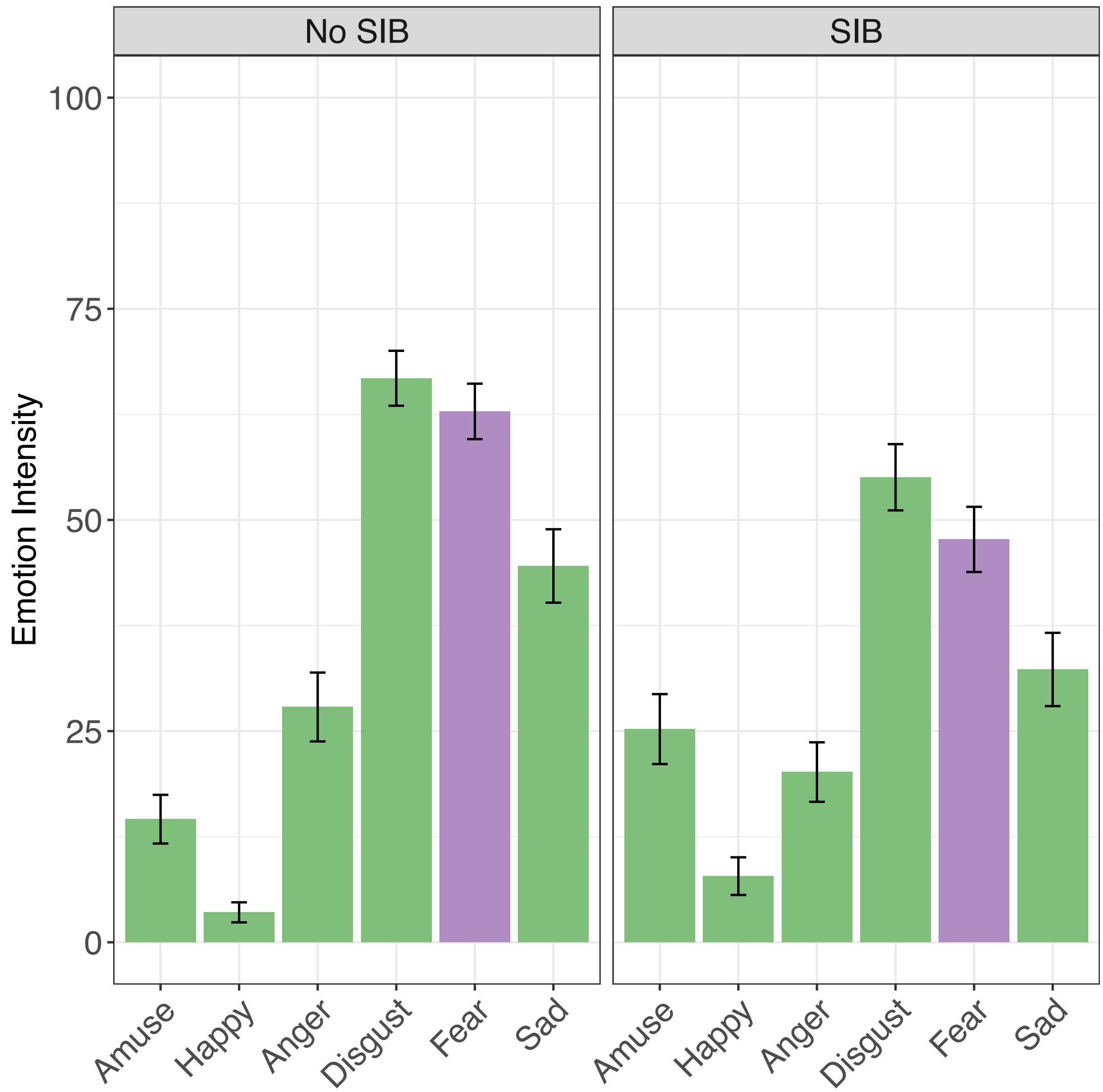
Summary of No Self-Injurious Behavior vs. Self-Injurious Behavior group comparisons on interoceptive accuracy and self-reported interoceptive abilities for cardiac sensations, pain, and fear

Sensation	Interoceptive Accuracy	Self-Reported Interoception
Cardiac	No SIB = SIB	No SIB = SIB
Pain	No SIB > SIB	No SIB = SIB
Fear	RSA and fear negatively associated with SIB	No SIB = SIB

Note. SIB = self-injurious behavior, RSA = respiratory

Figure 1

Intensities of emotional responses to viewing the clip from Misery *among the No Self-Injurious Behavior and Self-Injurious Behavior groups*



Note. SIB = self-injurious behavior.

Figure 2

Confidence in the cardiac, pain, and emotion interoceptive tasks among the Self-Injurious Behavior group

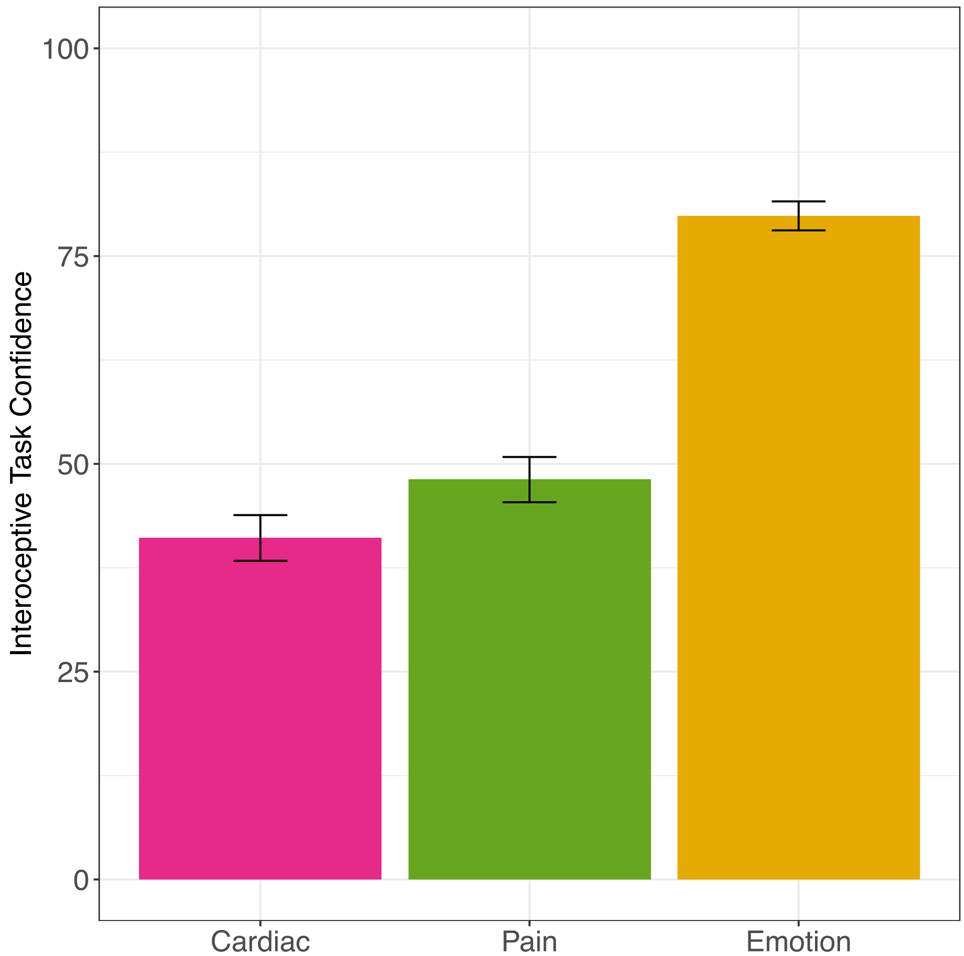
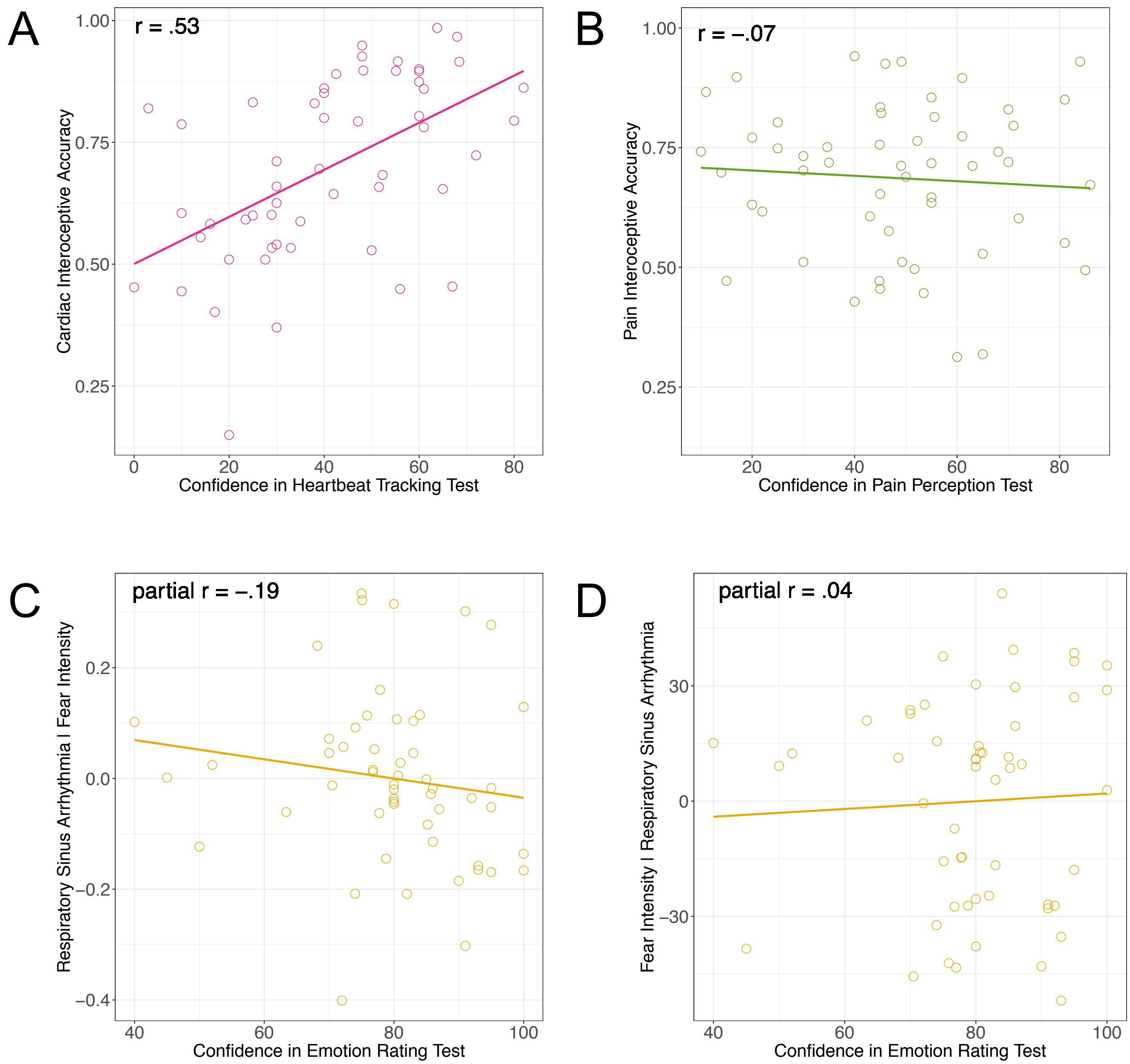


Figure 3

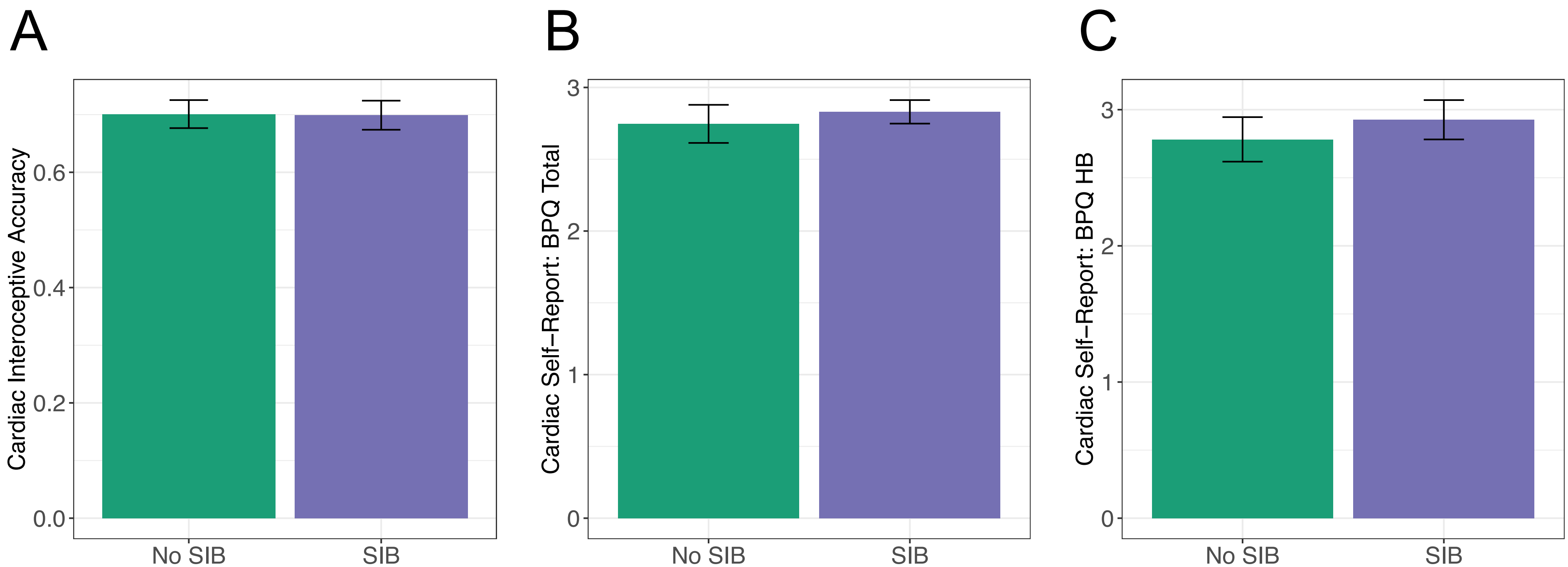
Correlations between interoceptive confidence and interoceptive accuracy for cardiac sensations, pain, and fear among the Self-Injurious Behavior group



Note. In panel C, the relation between confidence in the emotion rating task and respiratory sinus arrhythmia when adjusting for fear intensity is depicted. In panel D, the relation between confidence in the emotion rating task and fear intensity when adjusting for respiratory sinus arrhythmia is depicted.

Figure 4

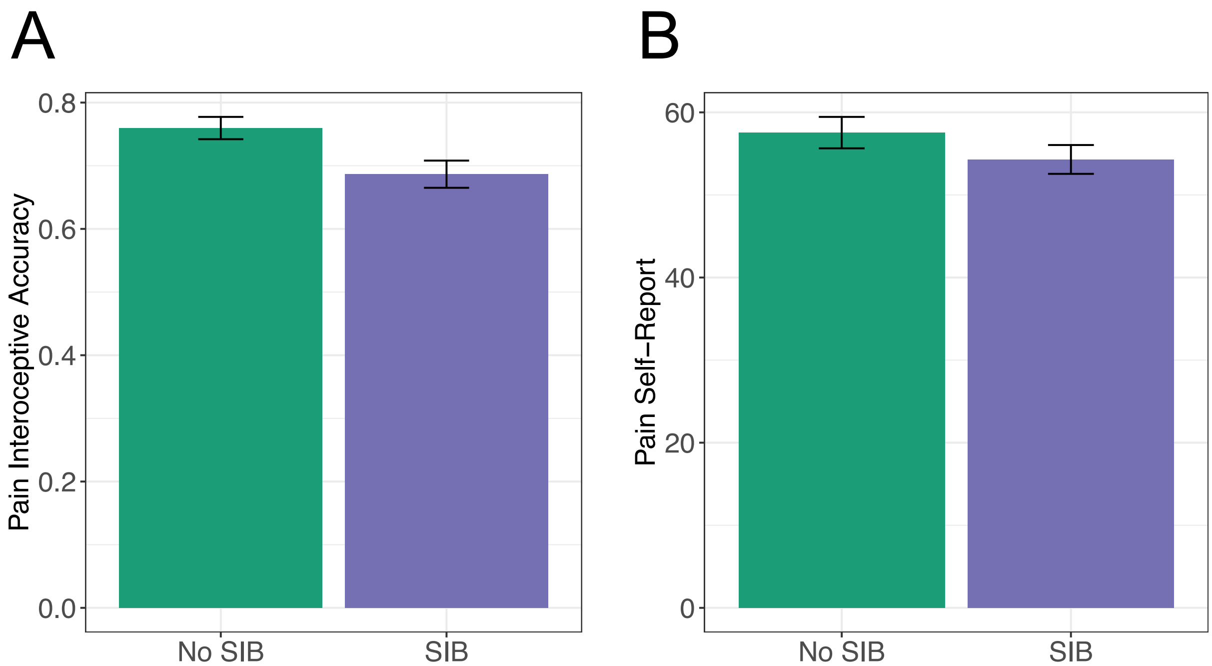
Interoceptive accuracy and self-reported interoceptive abilities for cardiac sensations among the No Self-Injurious Behavior and Self-Injurious Behavior groups



Note. SIB = self-injurious behavior, BPQ = Body Perception Questionnaire, BPQ HB = Body Perception Questionnaire assessing awareness of heartbeats. Cardiac interoceptive accuracy was assessed with the heartbeat tracking test. Self-reported interoceptive ability for cardiac sensations was assessed with the BPQ.

Figure 5

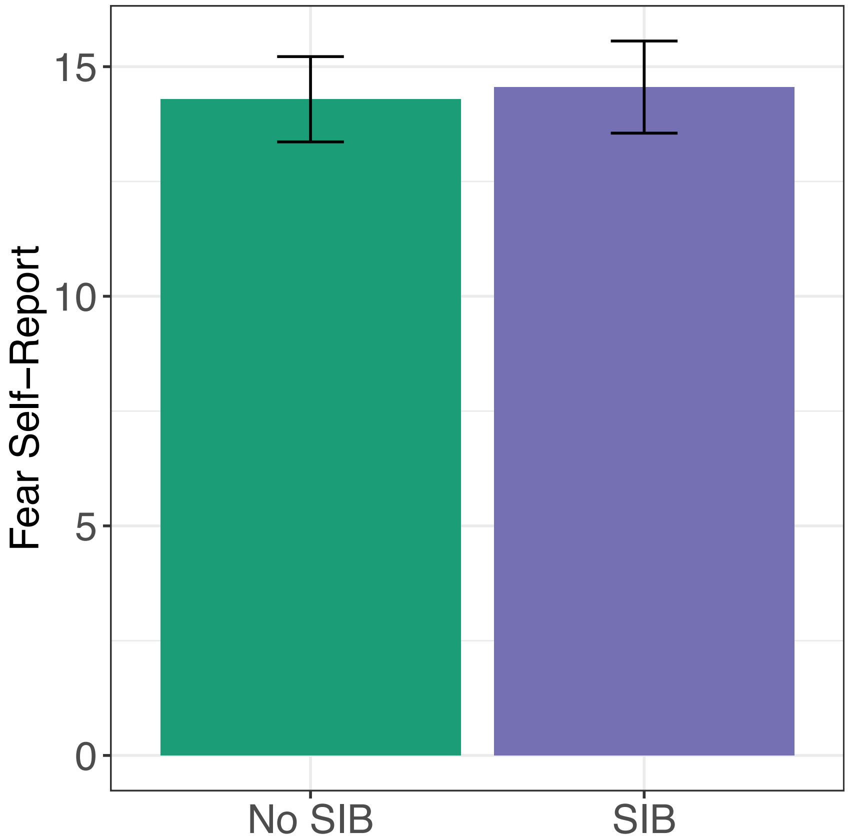
Interoceptive accuracy and self-reported interoceptive abilities for pain among the No Self-Injurious Behavior and Self-Injurious Behavior groups



Note. SIB = self-injurious behavior. Pain interoceptive accuracy was assessed with the pain perception test. Self-reported interoceptive ability for pain was assessed with the Pain Tolerance Examination Questionnaire.

Figure 6

Self-reported interoceptive abilities for fear among the No Self-Injurious Behavior and Self-Injurious Behavior groups



Note. SIB = self-injurious behavior. Self-reported interoceptive ability for fear was assessed with the Fearlessness about Death scale.