Biological Psychology 113 (2016) 37–45

Contents lists available at ScienceDirect

Biological Psychology

journal homepage: www.elsevier.com/locate/biopsycho

When the brain does not adequately feel the body: Links between low resilience and interoception

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ARTICLE INFO

Article history:
Received 4 February 2015
Received in revised form 26 August 2015
Accepted 13 November 2015
Available online 28 November 2015

Keywords:
Resilience
fMRI
Interoception
Insula

ABSTRACT

This study examined neural processes of resilience during aversive interoceptive processing. Forty-six individuals were divided into three groups of resilience Low (LowRes), high (HighRes), and normal (NormRes), based on the Connor-Davidson Resilience Scale (2003). Participants then completed a task involving anticipation and experience of loaded breathing during functional magnetic resonance imaging (fMRI) recording. Compared to HighRes and NormRes groups, LowRes self-reported lower levels of interoceptive awareness and demonstrated higher insular and thalamic activation across anticipation and breathing load conditions. Thus, individuals with lower resilience show reduced attention to bodily signals but greater neural processing to aversive bodily perturbations. In low resilient individuals, this mismatch between attention to and processing of interoceptive afferents may result in poor adaptation in stressful situations.

1. Introduction

Resilience can be conceptualized as one's ability to positively adapt to stress, trauma, and adversity (Luthar, Cicchetti, & Becker, 2000), that is, the ability to utilize cognitive, emotional, and physiological resources in response to a stressor, and conservation of these resources once the stressor is removed (Block & Kremen, 1996; McEwen & Gianaros, 2011; Ong, Bergeman, Bisconti, & Wallace, 2006). These components of resilience may work together for an individual to adequately cope with traumatic events (Kok, Herrell, Thomas, & Hoge, 2012) and prevent the development of psychopathology (Haglund, Nestadt, Cooper, Southwick, & Charney, 2007). Surprisingly, however, relatively little is known how resilience is implemented in the brain. Of particular interest are the neural processing characteristics of low resilient individuals because they provide a brain-based rationale to develop targeted interventions to strengthen inadequate processing of stressors. Moreover, a more comprehensive understanding of the facets that contribute to low resilience is necessary to create biomarkers of change in intervention studies aimed at increasing stress resilience.

A central goal of recovery from stress is to maintain homeostasis of critical bodily functions such as temperature, blood pH, and blood glucose. To that end, the brain needs to be able to sense the state of the body to effectively engage in actions that can reduce imbalances and thus better regulate homeostasis. Interoception (Craig, 2002, 2003) is the process of sensing body-state relevant information within the context of homeostasis. For example, a person will approach a heat source in a cold environment but avoid it when the ambient temperature is high. Interoception provides an anatomical and physiological framework for identifying pathways focused on the modulating the internal state of the individual. This framework comprises peripheral receptors (Vaitl, 1996), c-fiber afferents, spino-thalamic projections, specific thalamic nuclei, posterior and anterior insula as the limbic sensory cortex, and anterior cingulate cortex (ACC) as the limbic motor cortex (Augustine, 1996; Craig, 2007). The insula is thought to be the central nervous system hub for interoceptive processing, such that body-state relevant affer-

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http://dx.doi.org/10.1016/j.biopsycho.2015.11.004
0301-0511/

ents enter the posterior insula, are integrated with the internal state in the mid-insula, and re-represented as complex feeling state within the anterior insula (Gu, Hof, Friston, & Fan, 2013).

Interoception is an important process for resilience because it links the perturbation of internal state, including stressors, to goal-directed action that can restore the homeostatic balance of the body (Paulus et al., 2009). Highly resilient individuals (e.g., elite athletes, special operations forces) demonstrate attenuated insular and ACC activation during emotional processing and aversive interoceptive stimulation (Paulus et al., 2012; Paulus et al., 2010; Simmons et al., 2012; Thom et al., 2012), findings suggesting that the ability to perform well under stress may modulate neural systems important for processing interoceptive information. Despite recent work demonstrating brain patterns linked to high resilience (Paulus et al., 2012; Waugh, Wager, Fredrickson, Noll, & Taylor, 2008), less work has examined neural processes reflective of low resilience. Available research indicates that low-resilient individuals exhibit heightened anterior insula activation to threatening and aversive stimuli, whereas high-resilient individuals only show anterior insula increases to aversive emotion, suggesting that low resilience is linked to inappropriate evaluation of threat (Waugh et al., 2008). Moreover, attenuated recruitment of the medial prefrontal cortex (mPFC) has been linked to high resilience (Amodio & Frith, 2006; Thom et al., 2012), likely because mPFC mediates adaptations to stress (Maier & Watkins, 2010). It is unknown whether low resilience is characterized by attenuated or amplified processing of body-relevant information, which may lead to inadequate responses to stressful situations.

2. The present study

To examine how the body and brain responds to an aversive stimulus, we employed an aversive inspiratory breathing load task to study individual differences in resilience during functional magnetic resonance imaging (fMRI). Breathing is an interoceptive process that has both peripheral (Adriaensen & Timmermans, 2011) and central (Davenport & Vovk, 2009) pathways. Changes in breathing serve as a source of threat and result in increased anxiety (von Leupoldt, Chan, Bradley, Lang, & Davenport, 2011). An effective method of inducing experimental breathing change is by providing resistance during breathing inspiration. Our inspiratory breathing load task reliably activates brain regions involved in interoceptive processing, namely the insula, ACC, and medial prefrontal cortex (mPFC) (Paulus et al., 2012). Thus, the inspiratory breathing load task is an ideal method to assess the degree to which low-resilient and high-resilient individuals physiologically bounce back from stress.

We hypothesized that, compared to normal and high resilient individuals, low resilient individuals will exhibit greater activation in ACC, insular, and prefrontal cortices, linked to greater resources needed to regulate stress responses. For example, if the anterior insular cortex plays an important role in helping to predict perturbations in the internal body state and the ACC computes various types of error signals to help establish the selection of action, one would hypothesize that heightened activations in these structures are associated with less effective stress adaptation.

3. Methods

3.1. Participants

This study was conducted at the University of California, San Diego (UCSD) and was approved by the UCSD Institutional Review Board. All subjects were recruited from the community, signed informed consents, and received $50 compensation. Participants were categorized on the basis of their scores on the Connor-Davidson Resilience Scale (CD-RISC) (Connor & Davidson, 2003), a 10-item scale that measures the ability to cope with stress and adversity. Prior studies of the original CD-RISC support its internal consistency, test-retest reliability, and convergent and divergent validity (Campbell-Sills & Stein, 2007). Forty six eligible subjects, all right handed as assessed by the Edinburgh Handedness Inventory (Oldfield, 1971), were separated into three groups: (1) low resilience (LowRes, $n = 16$; CD-RISC score $\leq$ 20th percentile); (2) normal resilience (NormRes, $n = 12$; CD-RISC score between 21st–79th percentiles); and (3) high resilience (HighRes, $n = 18$; CD-RISC score $\geq$80th percentile).

Participants were matched for age, education, and gender (see Table 1 for study demographics). The following were exclusion criteria for all groups: (1) incorporated metal or any other factor that precludes use of fMRI; (2) current drug and/or alcohol dependence; (3) history of severe traumatic brain injury with loss of consciousness >30 min; (4) current use of antipsychotic medication or mood stabilizers, or other drugs that can acutely affect the hemodynamic response; (5) any diagnosed neurological disorder (including attention deficit hyperactivity disorder); and (6) history of schizophrenia, bipolar disorder, obsessive compulsive disorder, or antisocial personality disorder. No restrictions were placed on the consumption of caffeine-containing beverages; none of the subjects were smokers. Subjects then completed an fMRI session consisting of a continuous performance task with a breathing load manipulation (described below).

3.2. Neuroimaging involving aversive interoceptive processing

Prior to the fMRI scan, participants completed measures of self-reported interoceptive awareness, the Body Awareness Questionnaire (BAQ), assessing attentiveness to normal bodily processes

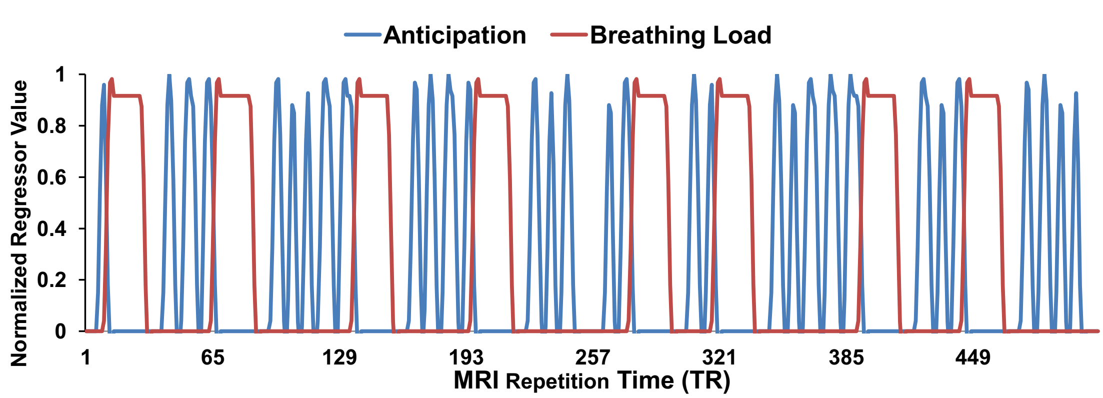

Fig. 1. Aversive inspiratory breathing load task regressors of interest.