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The neural correlates of trait resilience when anticipating and recovering from threat

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Abstract

A facet of emotional resilience critical for adapting to adversity is flexible use of emotional resources. We hypothesized that in threatening situations, this emotional flexibility enables resilient people to use emotional resources during appropriately emotional events, and conserve emotional resources during innocuous events. We tested this hypothesis using functional magnetic resonance imaging (fMRI) in a repeated recovery from threat task with low and high trait resilient individuals (LowR and HighR, respectively, as measured by ER89 [Block & Kremen, 1996]). In an event-related design, 13 HighR and 13 LowR participants viewed ‘threat’ cues, which signaled either an aversive or neutral picture with equal probabilities, or ‘nonthreat’ cues, which signaled a neutral picture. Results show that when under threat, LowR individuals exhibited prolonged activation in the anterior insula to both the aversive and neutral pictures, whereas HighR individuals exhibited insula activation only to the aversive pictures. These data provide neural evidence that in threatening situations, resilient people flexibly and appropriately adjust the level of emotional resources needed to meet the demands of the situation.

Key Words: resilience, anticipation, recovery, emotion regulation, neuroimaging, threat

Resilience is the ability to cope effectively and adapt in the face of loss, hardship, or adversity (Block & Kremen, 1996). Resilient people endure less protracted grief symptoms after a loved one dies (Bonanno et al., 2002), report fewer depressive symptoms in response to a national crisis (Fredrickson et al., 2003), and experience less mental distress after combat (Florian, Mikulincer, & Taubman, 1995). One psychological mechanism hypothesized to underlie resilient people's ability to adapt successfully to ever-changing environments is emotional flexibility: the flexible use of emotional resources needed to precisely match the demands of the situation (Block & Block, 1980; Block & Kremen, 1996; Bonanno, Papa, Lalande, Westphal, & Coifman, 2004; Charney, 2004). For example, when faced with the prospect of having to give a public speech, both high and low resilient participants exhibited similar cardiovascular reactivity. However, when the threat of giving the speech was later removed, high resilient participants' cardiovascular reactivity recovered more quickly (Tugade & Fredrickson, 2004). Resilient participant's emotional flexibility is reflected by their use of physiological resources when needed (when facing the threat of giving a speech), and conservation of resources when no longer needed (the threat of the speech was over). A recent study confirmed that this emotional flexibility can indeed be a strategic process. Participants who were better able to both strategically enhance and suppress their emotions to match the demands of the situation experienced less distress in the aftermath of the September 11th terrorist attacks (Bonanno et al., 2004).

The benefit of emotional flexibility is especially apparent in unpredictable situations, such as those in which anticipated negative events are sometimes realized and other times not. In these repeated threat situations, the emotional flexibility hypothesis suggests that resilient people

should exhibit appropriate emotional and physiological responses when the negative events occur, and appropriate non-emotional responses when the negative events do not occur (Waugh, Fredrickson, & Taylor, 2008). For example, in a ‘repeated recovery from threat’ paradigm, participants viewed cues that signaled either a neutral picture (‘no-threat’) or signaled the equal probability of viewing an aversive or neutral picture (‘threat’). High resilient participants exhibited more complete self-reported affective recovery when anticipated negative events did not occur, but equivalent affective responses (relative to low resilient participants) when the negative events did occur (Waugh et al., 2008).

In the current fMRI study, we adopted the above ‘repeated recovery from threat paradigm’ to examine the neural correlates of the proposed emotional flexibility characteristic of trait resilience. Trait resilience was measured with the same ego-resilience questionnaire (ER89; Block & Kremen, 1996) used in the above studies (Tugade & Fredrickson, 2004; Waugh et al., 2008), designed to tap emotional flexibility. For example, the ER89 includes items such as “I enjoy dealing with new and unusual situations,” and “I quickly get over and recover from being startled.” The ER89 is also a well-validated measure of ecological resilience – those participants who scored high on this measure before the terrorist attacks on 9/11 exhibited fewer depressive symptoms post-9/11 (Fredrickson, Tugade, Waugh, & Larkin, 2003). Informed by our behavioral results in previous studies, we hypothesized that brain activation differences between high and low trait resilient participants would be most apparent in response to neutral stimuli that could have been aversive. It is on these trials that resilient participants’ emotional flexibility would be most beneficial, leading to decreased activation in affective regions in those moments when there is no longer the threat of a negative event.

The affective regions we specifically targeted for investigation included the insula, amygdala, and orbitofrontal cortex (OFC). Prior work, including several meta-analyses, have ascribed prominent roles to these structures in the generation and regulation of emotion (Phan, Wager, Taylor, & Liberzon, 2002; T. D. Wager et al., in press). The insula, particularly its anterior portion, has been associated with anticipatory anxiety (Carlsson et al., 2006; Nitschke, Sarinopoulos, Mackiewicz, Schaefer, & Davidson, 2006; Ploghaus, Berra, Borras, & Borsook, 2003), and activity in the insula is augmented in people high in anxiety (Chua, Krams, Toni, Passingham, & Dolan, 1999; Simmons, Strigo, Matthews, Paulus, & Stein, 2006), a trait associated with low resilience (Fredrickson et al., 2003). The insula's functions include both representing visceral states (particularly the ventral anterior and posterior portions), and conscious feeling states related to interoceptive processes (in the dorsal anterior region; Hugo D. Critchley, Wiens, Rotshtein, Ohman, & Dolan, 2004; Craig, 2003).

Activation of the amygdala is similarly associated with emotionally salient stimuli. The amygdala is responsive to potentially threatening context cues (Herry et al., 2007) and stimuli (Whalen et al., 1998), and serves as a key component in the physiological response to threat (Phelps & LeDoux, 2005). In addition, the amygdala has been shown in depressed people to exhibit sustained activity to emotional events (Siegle, Steinhauer, Thase, Stenger, & Carter, 2002). Portions of the amygdala have also been associated with relief from threat (Seymour et al., 2005), the interaction between positive affectivity and positive stimuli (Canli, Sivers, Whitefield, Gotlib, & Gabrieli, 2002), and both positive and negative expectancies (Paton, Belova, Morrison, & Salzman, 2006). Given its robust association with emotion, it is clear that the amygdala is a key region in which to examine our hypothesis that resilient people are characterized by a flexible use of emotional resources. However, we have no explicit hypotheses

regarding the direction of activation given the amygdala's association with both positive and negative emotional stimuli.

The OFC is a region implicated broadly in the integration of emotion and cognition (Rolls, 1999), and more specifically in the expectation of negative outcomes (O'Doherty, Kringelbach, Rolls, Hornak, & Andrews, 2001), especially when that outcome is relatively more negative than an alternative (Ursu & Carter, 2005). The lateral OFC tracks negative prediction error, exhibiting increased activation with expectation of an aversive stimulus, and sharp drops in activation when the expected aversive stimulus does not occur (Seymour et al., 2005). High and low resilient people have been shown to differ in their appraisals of impending stressful events (Tugade & Fredrickson, 2004), therefore the OFC may also be a key region to track these differences between high and low resilient participants in expectations of and recovery from threat.

The critical period for testing the emotional flexibility hypothesis is the response to neutral stimuli that could have been aversive, and we have hypothesized that differential activity between high and low resilient participants to these neutral stimuli may speak to the neural underpinnings of trait resilience. Past research has found that high and low trait resilient people differ in the duration but not magnitude of their cardiovascular responses after threat (Tugade & Fredrickson, 2004). It becomes important then to distinguish response generation from response duration, and we do so in the current study by separately estimating the height and width of the BOLD response (Bellgowan, Saad, & Bandettini, 2003; Lindquist & Wager, 2007). Although these separate parameters are not fully able to differentiate the underlying neural and/or psychological processes hypothesized to be associated with them (Lindquist & Wager, 2007),

there is evidence that the different components of psychological processes can be inferred from the different parameters of the BOLD response (Bellgowan et al., 2003).

Methods and materials

Participants

Healthy participants, without active medical or psychiatric illness, were recruited through community advertisements to complete a web-based screening. After answering questions about general eligibility to participate in an fMRI study (e.g., no metals inside body, no history of neurological disorders), 242 people completed the emotional resilience scale (ER89; Block & Kremen, 1996). Participants were contacted if they exhibited a score in the upper (raw score > 50) or lower (raw score < 42) quartiles of the sample¹. Potential participants were excluded for signs of current depression (scored > 25 on Center for Epidemiologic Studies Depression scale Radloff, 1977)². Of the 100 (45 high resilient, 55 low resilient) eligible subjects, 30 participated in the experiment (15 high resilient, 15 low resilient), matched on age, gender, ethnicity, education, and socioeconomic status (see Table 1 for details)³. This study was approved by the University of Michigan Institutional Review Board.

Written measures

Prior to entering the MRI scanner, participants completed several personality scales shown to correlate with the trait resilience measure (ER89) in previous studies, and/or shown in previous studies to be associated with affect regulation (S. E. Taylor et al., 2008). These scales included optimism (Scheier, Carver, & Bridges, 1994); neuroticism, extraversion, and openness (Costa & McCrae, 1992); behavioral activation sensitivity (BAS) and behavioral inhibition sensitivity (BIS; Carver & White, 1994); satisfaction with life (Diener, Emmons, Larsen, & Griffin, 1985); and an emotions questionnaire (Differential Emotions Scale; Izard, 1977;

Modified DES; Fredrickson et al., 2003), which asked participants to rate 20 different emotions terms to reflect how they have felt during the last two weeks. As has been found in previous studies, high trait resilience was associated with higher optimism, openness to experience, behavioral activation sensitivity, and positive feelings in the last two weeks, and lower neuroticism, behavioral inhibition and negative feelings (see Table 2 for means and correlation coefficients of these personality scales for participants included in study).

Task Design

The task consisted of **passively** viewing images from the International Affective Picture System (IAPS; Lang, Bradley, & Cuthbert, 1997), preceded by a cue (Figure 1). The ‘threat’ cue (2/3 of trials) could be followed by an aversive or neutral picture (50/50 frequency [participants were not informed of this ratio]); the ‘no-threat’ cue (1/3 of trials) was always followed by a neutral picture. We chose aversive pictures normatively rated as highly negative ($M = 2.01$, $SD = .65$) and arousing ($M = 6.42$, $SD = .57$) and relatively specific to disgust (Lang et al., 1997; Mikels et al., 2005). The neutral pictures were selected as being normatively rated as neutral and matched to the aversive pictures on brightness (Mikels et al., 2005). **The neutral pictures were randomly divided between the trials in which they were preceded by the threat cue (‘threat-neutral’) or no-threat cue (‘nonthreat-neutral’), resulting in each condition having equivalent valence ($M_s = 4.99$ and 5.36 , respectively), and arousal ($M_s = 2.85$ and 3.07 , respectively) ratings.**

After acquiring the structural MRI images, participants were provided with verbal descriptions of the cue-outcome associations and given several trials to train on these associations so that they had thoroughly learned the association before acquiring the functional images. We counterbalanced between participants whether the triangle or circle represented the

threat and nonthreat cues. The cue appeared for 4, 8 or 12 sec (equal frequencies, pseudorandomized to optimize design power), followed by picture presentation (3 sec), and an intertrial interval, also 4, 8 or 12 sec in length (pseudorandomized). The length of the cue and intertrial periods were jittered to enable deconvolution of the hemodynamic response for each epoch. Each run contained 18 trials, and there were 5 total runs for each participant's session for a total of 90 trials. The participants were reminded of the cue-outcome association before each run. After participants completed the task in the scanner, they were debriefed on the purpose of the study, paid according to the amount of time the experiment had taken, and thanked.

fMRI Technical Specifications

We measured blood oxygenation level (BOLD) in a 3T GE scanner. For the functional images, we collected 40 oblique-axial slices (FOV = 20, slice thk/sp = 3/0), prescribed to be approximately parallel to the AC-PC line (same locations as structural scans), using a T2*-weighted, single-shot, reverse spiral acquisition, (Noll, Cohen, Meyer, & Schneider, 1995; gradient-recalled echo, TR = 2000, TE = 30, flip angle = 90°, 64 x 64), a sequence designed to enable good signal recovery in areas of high susceptibility artifact, (e. g. orbitofrontal cortex; Yang et al., 2002). The slices were acquired contiguously to optimize the effectiveness of the movement post-processing algorithms. Offline image reconstruction included processing steps to remove distortions caused by magnetic field inhomogeneity and other sources of misalignment to the structural data. Prior to acquisition of functional data, high resolution T1 SPGR images were acquired to enable anatomic normalization.

Image analysis

Images were first realigned and corrected for movement. Next, the realigned images were normalized to a standard single subject T1 template and then smoothed with a [8 8 8] mm kernel.

Four subjects were excluded from the data analysis because of excessive movement, or the inability to warp their anatomic images to stereotactic space (2 high resilient and 2 low resilient; leaving 9 females in both groups). SPM2 (Wellcome Department of Cognitive Neurology) was used, along with custom routines, to estimate the hemodynamic response (HRF) to each event in each voxel. We used a finite impulse response (FIR) model of the HRFs to estimate responses without assuming a pre-defined hemodynamic response shape (Glover, 1999). Using the FIR estimated HRFs in each voxel, we estimated the height (H), width (W), and time-to-peak (T) of the fitted HRF for the cues and pictures separately (Bellgowan et al., 2003; Lindquist & Wager, 2007).

To estimate H, T, and W, HRFs for each condition were de-convolved from the BOLD timeseries using a (FIR) model with a 32 s kernel and 2 s bins. FIR estimates within the first 12 seconds of the response were smoothed with a 6s exponential kernel from which H, T, W were estimated from the fitted responses using a simple peak-finding algorithm (Lindquist & Wager, 2007). Next, we calculated contrasts in H and W for four contrasts: ['threat' – 'nonthreat' cue], ['aversive' – 'nonthreat-neutral' picture], ['aversive' – 'threat-neutral' picture], ['threat-neutral' – 'nonthreat-neutral' picture].

For the group analysis, we used robust regression at the 2nd level (Tor D. Wager, Keller, Lacey, & Jonides, 2005) to perform random effects analyses on response parameter contrasts (e.g., ['threat height' – 'nonthreat height' cue]) and contrast magnitude x resilience interactions. Robust regression minimizes the influence of outliers, at a small cost in power relative to ordinary least squares when statistical assumptions are met. Resilience between observers was contrast coded ([1 -1]) so that the intercept of the 2nd level model tested the response parameter in the group, and the resilience regressor tested the effect of resilience on the response

parameters. To restrict our analyses to potential sites of interest and also minimize Type II errors, we used an ‘emotional brain’ mask derived from a meta-analysis of emotion and fMRI studies (T. D. Wager et al., in press), and separate ROIs for the insula, amygdala, and orbitofrontal cortex, which were created from voxels that overlapped between the emotional brain mask and ROI masks from the AAL library (Tzourio-Mazoyer et al., 2002). Results were thresholded by using Monte Carlo simulations to establish the minimum cluster size of voxels ($p < .005$) for each ROI that exceeded a corrected p-value of .05 (Ward, 2000). This led to a minimum cluster size of 29 voxels for the ‘emotional brain’ mask and 11, 5, 13 voxels for the insula, amygdala, and OFC ROIs respectively.

Results

Height and width differences to threat-neutral pictures

To test our hypothesis that emotional flexibility in high resilient participants would lead to less brain activation in affective regions when recovering from threat, we compared high and low trait resilient participants’ response to the threat-neutral pictures, i.e. neutral pictures following a threat cue, in comparison to the nonthreat-neutral pictures. Across all participants, regions exhibiting a higher response peak to the threat-neutral pictures were the left lateral prefrontal cortex (LPFC), and left middle temporal gyrus (see Table 3).

Trait resilience did not predict differences in response height, but it did predict differences in response width to the threat-neutral (vs. nonthreat-neutral) pictures. Consistent with predictions, low trait resilient participants exhibited greater insula response width in response to the threat-neutral (vs. nonthreat-neutral) pictures (Figure 2). To further explore this resilience difference, we extracted the average width in the insula cluster for each participant in each condition. **Separate within-group t-tests suggest that this interaction can be explained by**

low resilient participants exhibiting wider responses to the threat-neutral (vs. nonthreat-neutral) pictures, $t(12) = 4.24$, $p = .001$, and to a lesser extent high resilient participants exhibiting narrower responses to the threat-neutral (vs. nonthreat-neutral) pictures, $t(12) = 3.1$, $p < .01$ (Figure 2). There were no differences in response height between the resilient groups at this threshold; however, it is still a possibility that sub-threshold differences in response height could partially explain the difference in response width. To examine this possibility, we extracted the average height of the response in the insula cluster for each participant, and subjected these average responses to a 2 (Group: low resilient, high resilient) x 2 (Picture: nonthreat-neutral, threat-neutral) ANOVA. At a lower threshold, there was a significant main effect of group, such that low resilient participants (vs. high resilient participants) exhibited a significantly higher response peak across both pictures, $F(1,24) = 4.53$, $p < .05$ (Figure 2c); however, there was no interaction between group and picture type. In addition, the relationship between trait resilience and width of insula response remained significant in an ANCOVA with insula response height as the covariate, $F(1, 23) = 26.8$, $p < .0001$, suggesting that the insula response width difference was not due to differences in response height.

To further characterize this response width difference in the insula, we extracted the cluster average in each participant for time-to-peak, time-to-half peak (rise) and time-to-half peak (fall; Figure 2b,2e), and subjected each of these measures to a repeated-measures ANOVA with picture type (nonthreat-neutral, threat-neutral) as the within-subjects variable and trait resilience as the between-subjects variable. For time-to-peak, there was only a main effect of picture type, $F(1, 24) = 11.89$, $p < .003$: both low and high resilient participants exhibited earlier peaks to threat-neutral than nonthreat-neutral pictures, $ts = 2.92, 2.08$, $ps = .01, .06$, respectively. For time-to-half peak (rise) times, there was an interaction with trait resilience, $F(1, 24) = 4.6$, p

< .05: low resilient participants exhibited earlier time-to-half peak (rise) times to the threat-neutral vs. nonthreat-neutral pictures, $t(12) = 4.72, p < .001$. For time-to-half peak (fall) times, there was a marginal interaction with resilience, $F(1, 24) = 3.48, p = .074$, characterized by high resilient participants exhibiting earlier time-to-half peak (fall) times to the threat-neutral vs. nonthreat-neutral pictures, $t(12) = 2.62, p < .03$. These results suggest that the insula response width difference may have been due to both an earlier response onset for low resilient participants, and an earlier response offset for high resilient participants.

Responses to anticipatory threat

To test for possible trait resilience differences during anticipation, we examined height responses to the threat vs. nonthreat cue⁴. Across all participants, a region in the right posterior lateral orbitofrontal cortex (OFC; 44, 31, -15) exhibited a higher response peak to the threat cue than to the nonthreat cue (Table 4; Figure 3). Two additional, non-overlapping regions were moderated by trait resilience; an additional region in the lateral OFC (38, 38, -18), slightly anterior to the previously mentioned region, and another region in the anteroventral insula (38, 9, -12). Specifically, low trait resilient people showed a similar differentiation in response height (high during the threat cue, low during the nonthreat cue) in these additional regions of the right lateral OFC and anteroventral insula as they did in the posterior portion of the lateral OFC. In contrast, high trait resilient participants showed a reverse pattern of activation (nonthreat cue > threat cue) in the anterior lateral OFC and anteroventral insula (Figure 3).

Responses to aversive stimuli

Next, we assessed the regions that were responsive to the aversive stimuli to verify that our experiment elicited regions similar to previous experiments using these stimuli, and to test the second portion of the emotional flexibility hypothesis which predicts there to be little to no

differential activation by trait resilience in response to the aversive stimuli. Consistent with previous findings, across all participants there were several regions that exhibited higher response peak to the aversive pictures than to the nonthreat-neutral pictures, including amygdala, occipital cortex, bilateral insula, left inferior frontal gyrus (IFG), lateral OFC, and dorsomedial prefrontal cortex (dMPFC; see Table 5). The occipital cortex also exhibited wider responses to the aversive pictures. Supporting the emotional flexibility hypothesis, trait resilience did not predict differences in height or width of activity to the aversive stimuli.

Personality correlates of insula response width

Lastly, we tested whether the relationship between trait resilience and the insula response width to the threat-neutral vs. nonthreat-neutral pictures could be explained by more basic personality traits. We found that when entered in regression equations separately, several personality traits did predict insula response width, including optimism, BAS – reward responsiveness, and BAS – fun seeking (β s = -.45, -.40, -.44, respectively; all $ps < .05$), as well as positive and negative feelings experienced in the last two weeks (β s = -.41, .43, respectively). However, resilience remained a significant predictor of insula response width controlling for each of these trait or emotion indices, suggesting that this finding is explained better by the meta-construct resilience that incorporates portions of each of these more core traits, rather than by any of the traits alone.

Discussion

These studies provided neural evidence in support of the hypothesis that trait resilience may be characterized in part by emotional flexibility. After being threatened with the possibility of viewing an aversive picture, the emotional flexibility characteristic of high trait resilient participants was reflected by appropriate responses in affective regions (insula, amygdala) to the

aversive pictures and an appropriate lack of response in these regions to the neutral pictures (threat-neutral). On the other hand, the emotional inflexibility of low trait resilient participants was reflected by responses in affective regions both to the aversive and neutral pictures. The main contrast of interest showed that low trait resilient participants exhibited greater insula response width to the threat-neutral pictures than high trait resilient participants. This differential width response seemed to be explained by two patterns: A. low resilient participants exhibited an earlier rise in activation suggesting that their response to these threat-neutral pictures was characterized by an earlier spike in insula activity; and B. high resilient participants exhibited an earlier fall of their activation suggesting that their response to these threat-neutral pictures was characterized by insula activity more quickly returning to baseline. Although response time-to-onset can be an unreliable parameter to estimate (Miezen, Maccotta, Ollinger, Petersen, & Buckner, 2000), this pattern of neural data is consistent with psychophysiological and behavioral findings showing that after being threatened with a possible negative experience, high resilient people recover quicker (Tugade & Fredrickson, 2004) and more completely (Waugh, Fredrickson, & Taylor, in press) than low trait resilient people.

The current insula finding is striking given that the differential insula responses were to neutral pictures. The insula has been associated with processing affective stimuli including pain (Chua et al., 1999; Ploghaus et al., 1999), disgust faces (Phillips et al., 1997), and pictures (Wright, He, Shapira, Goodman, & Liu, 2004), with the anterior insula being important for representing the conscious awareness of the visceral states associated with these emotions (Craig, 2002; H. D. Critchley, 2005; Hugo D. Critchley et al., 2004; Singer et al., 2004). However, in this study, the differential insula responses were to neutral stimuli that could have been aversive, raising the possibility that activation in the insula reflected integration of prior

expectations with subsequent outcomes. Negative expectations may have produced affective responses in the insula to otherwise nonaffective stimuli – an interpretation consistent with data showing that affective responses in the insula can be influenced by prior expectations (Nitschke, Dixon et al., 2006; Sarinopoulos, Dixon, Short, Davidson, & Nitschke, 2006). An alternative, more speculative, explanation for the insula findings may be that when viewing a neutral picture that could have been aversive, low resilient participants imagined or remembered an aversive scene that they might have seen. Support for this alternative explanation is provided by the fact that we used disgusting scenes as our aversive stimuli and the insula is strongly activated in response to disgust stimuli (Phillips et al., 1997; Wright et al., 2004). Although intriguing, we caution that both the ‘insula as integrating expectations’ and ‘insula as imagining alternatives’ explanations are post-hoc and should be subject to further investigation.

During the anticipatory period, high and low trait resilient participants showed different patterns of activation in two regions of the lateral OFC and the anteroventral insula. Previous research implicates both the OFC and anterior insula in anticipating possible negative events (Porro et al., 2002; Carlsson et al., 2006; Herwig, Kaffenberger, Baumgartner, & Jancke, 2007), with the OFC also being involved in calculating the probability of some event occurring (Knutson, Taylor, Kaufman, Peterson, & Glover, 2005), and generating expectancies in the face of an uncertain outcome (H. D. Critchley, Mathias, & Dolan, 2001). Besides generating expectancies, the lateral OFC has also been associated with emotion regulation (Lieberman et al., 2007; Phillips, Ladouceur, & Drevets, 2008) via its connections with lateral prefrontal cortices and the amygdala (Stein et al., 2007). However, in our study there was no amygdala activation during the anticipation period, suggesting that the OFC’s role in generating expectancies may be a more parsimonious explanation for the current results. Low trait resilient participants showed

higher response peak in all three regions to the threat vs. nonthreat cue, suggesting that they recruited these regions only during expectations of threat. Although high trait resilient participants showed similarly higher threat vs. nonthreat cue response peak in the posterior OFC, they exhibited the opposite pattern (nonthreat vs. threat) of activation in the anterior OFC and the anteroventral insula, suggesting that high trait resilient participants recruited sub-regions of the lateral OFC to represent both expectations of threat and safety. This additional representation of safety for the high resilient participants is consistent with findings showing that high resilient people can co-activate positive and negative appraisals of a stressful situation (Folkman & Moskowitz, 2000; Fredrickson et al., 2003; Ong, Bergeman, Bisconti, & Wallace, 2006; Tugade & Fredrickson, 2004), leading to faster physiological recovery from stress (Tugade & Fredrickson, 2004), and better mental health outcomes during chronic stress (Folkman & Moskowitz, 2000).

The only significant activation in the amygdala was in response to aversive pictures. This finding is unsurprising given the amygdala's central role in affective processing (LeDoux, 1996), including determining salience (Fitzgerald, Angstadt, Jelsone, Nathan, & Phan, 2006), heightening vigilance to possible threats (Herry et al., 2007), and emotional memory (Dolcos, LaBar, & Cabeza, 2005). What is perhaps surprising is that resilience did not moderate amygdala activity given the finding that resilience moderated insula activity to the pictures that could have been aversive. Although it is difficult to interpret null findings, one possible explanation is that if the amygdala is responsible for tracking the emotional salience of a stimulus or context, the difference between high and low resilient participants was not in the perceived emotional salience of the neutral pictures, but rather in their integration of negative expectations or imagining of negative alternatives – functions perhaps more associated with the insula.

It is also important to note that no regions exhibited differences in activation between high and low resilient participants in response to the aversive pictures. This finding further supports the emotional flexibility hypothesis by suggesting that the difference between high and low trait resilient people is not a blunted response to affective stimuli – a conclusion consistent with data showing that even when high resilient individuals exhibit faster cardiovascular recovery from a threat, they do not differ from low resilient individuals in the degree of experienced adversity while the threat is still present (Tugade & Fredrickson, 2004).

The current study presents a novel way of studying emotional responding in fMRI by examining the width of the hemodynamic response separate from the height of that response. Width of response in this study was measured by fitting a parameter to the hemodynamic response function (HRF) that represented the width (in TRs) of the HRF curve at half of the peak height. Although there is slightly biased parameter estimation in the FIR model (Lindquist & Wager, 2007), separately estimating these parameters presents a unique way of examining the neural correlates of emotion that seems to be more consistent with how emotion theorists conceptualize emotions as having both intensity and duration (Frijda, Ortony, Sonnemans, & Clore, 1992). In addition to providing greater theoretical specificity (Bellgowan et al., 2003), deconvolving the HRF also provides a more flexible model of the data, the accuracy of which is less influenced by task and brain region differences in the shape of the HRF (Lindquist & Wager, 2007). However, much is still unknown about the relationship between these different parameters and brain function. For example, it is not clear whether the time scale with which we measured width of the hemodynamic response in the current study (seconds) captures true behavioral/physiological differences between high and low trait resilient participants. This small difference in the duration of neural activity may be sufficient to influence thinking, feeling, and

downstream physiological responding. Our study was designed to introduce this possibility, not necessarily to answer the question. Future work is needed to extend the current results and more specifically examine the functional relationship between the height and duration of brain activation and emotional phenomena and traits.

The primary limitation of the current study was that we did not measure behavioral responses or subjective feeling states during the fMRI task. We elected to have participants view the stimuli passively in light of the previous evidence that responses in core emotional areas such as the amygdala and insula can be attenuated by attention-demanding tasks (Pessoa, Padmala, & Morland, 2005), and are thus strongest during passive viewing of emotional stimuli (S. F. Taylor, Phan, Decker, & Liberzon, 2003). As a result, although our results were consistent with behavioral findings from different samples (Waugh et al., 2008), in the current sample we were unable to correlate behavioral data with brain activations. Also, the neutral and aversive stimuli were not matched for faces and figures, differences that may have confounded differences in BOLD signal. Yet, because our main contrast of interest was between two sets of neutral stimuli, our principal findings should not be affected. Finally, although our self-report measure of resilience did predict insula response width controlling for other more 'core' personality traits such as optimism and BAS, this measure as well as our repeated recovery from threat paradigm examine only a limited slice of the meta-construct 'resilience.' Future studies will need to examine possible implications of laboratory findings such as these for how resilient people navigate both major and minor real-life stressors.

In summary, the present study adds neural data to the literature on the mechanisms underlying resilience. We investigated differences in brain activations between low and high trait resilient people when viewing innocuous events in the midst of threat. The overall pattern of data

is consistent with previous studies and suggests that what differentiates high from low trait resilient people in times of threat is their flexible use of emotional resources. This neural evidence provides valuable insight into the cognitive and emotional foundations of resilience under threat and lays the groundwork for future research on this consequential individual difference variable. This study also highlights the value of including measures of BOLD activation width in addition to the oft-studied activation magnitude when studying emotional phenomena and traits.

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Footnotes

¹ Although a shortcoming of this approach is that it does not provide information on the center of the distribution (Preacher, Rucker, MacCallum, & Nicewander, 2005), we chose to limit the sample to extreme groups to maximize power given the small sample sizes available in neuroimaging studies (Kagan, Snidman, & Arcus, 1998). Subsequent studies with larger sample sizes are needed to investigate whether effects generalize to participants who scored in the middle portion of the scale.

² We did not assess lifetime psychiatric disorders.

³ Adding participant's gender as a covariate did not influence the pattern of any of the reported results, so is not reported any further.

⁴ We do not report response width to anticipation, because unlike pictures which were presented for 3s, the anticipatory period consisted of the entire period from cue to picture presentation, and the duration of this period varied randomly throughout the experiment making the width of the response relatively uninterpretable.

Table 1

Demographics and screening data for participants

	High resilient (n = 15)	Low resilient (n = 15)
ER89 (SD)	50.4 (1.4)	37.8 (2.3)
Age (SD)	20.2 (1.37)	20.5 (2.0)
Gender	5 M, 10 F	5 M, 10 F
Education	15 College	14 College, 1 Graduate Student
Depression (CESD)	14.8 +/- 2.6	16.4 +/- 3.8
Family Income	6.64 (~65,000)	5.96 (~60,000)

Note. ER89 = ego-resilience measure. ER89 is only index above on which groups differed significantly, $t(28) = 17.8, p < .001$.

Table 2

Means of personality variables for high and low resilient participants and correlation between personality variables and resilience scale (ER89).

<i>Personality variable</i>	ER89 (n = 26)	High resil (n = 13)		Low resil (n = 13)	
	<i>r</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>
Optimism	.64**	3.2 _a	.51	2.2 _b	.62
Extraversion	.37	3.8 _a	.62	3.4 _a	.43
Neuroticism	-.53**	2.2 _a	.57	2.8 _b	.50
Openness	.38	3.8 _a	.87	3.4 _a	.48
BIS	-.09	2.8 _a	.50	2.9 _a	.49
BAS – reward responsiveness	.53**	3.7 _a	.34	3.4 _b	.31
BAS - drive	.44*	3.3 _a	.38	2.8 _b	.42
BAS – fun-seeking	.43*	3.4 _a	.46	2.9 _b	.43
Positive feelings (last 2 weeks)	.50**	3.1 _a	.55	2.4 _b	.53
Negative feelings (last 2 weeks)	-.53**	0.5 _a	.28	1.0 _b	.49
Satisfaction with life	.24	4.6 _a	.95	4.0 _a	.92

Note: For correlation coefficients, ** $p < .01$, * $p < .05$. For high and low resilient (high and low ER89, respectively) groups, means in the same row that have different subscripts are significantly different from each other at $p < .05$.

BIS – Behavioral Inhibition Sensitivity. BAS – Behavioral Activation Sensitivity.

Table 3.

Height and Width Activations for Threat-neutral vs. Nonthreat-neutral Pictures

Region of Activation	Coordinates				Volume (mm ³)	Z score
	Brodmann's Area	x	y	z		
HEIGHT						
<i>Threat-neutral > Nonthreat-neutral</i>						
Inferior Frontal Gyrus	9	-44	12	24	967	4.36
Middle Temporal Gyrus	22	-50	-34	0	850	4.61
<i>Hi > Low resilient</i> – no clusters						
<i>Low > Hi resilient</i> – no clusters						
<i>Nonthreat-neutral > Threat-neutral</i>						
No clusters at threshold						
<i>Hi > Low resilient</i> – no clusters						
<i>Low > Hi resilient</i> – no clusters						
WIDTH						
<i>Threat-neutral > Nonthreat-neutral</i>						
No clusters at threshold						
<i>Hi > Low resilient</i> – no clusters						
<i>Low > Hi resilient</i>						
Anterior Insula	13	38	22	3	381	3.65
<i>Nonthreat-neutral > Threat-neutral</i>						
No clusters at threshold						
<i>Hi > Low resilient</i> – no clusters						
<i>Low > Hi resilient</i> – no clusters						

Table 4.

Activations for Threat vs. Nonthreat cue

Region of Activation	Coordinates			Volume (mm ³)	Z score	
	Brodmann's Area	x	y			z
<i>Threat > Nonthreat</i>						
Posterior LOFC	47	44	31	-15	498	4.50
<i>Hi > Low resilient</i>						
No clusters at threshold						
<i>Low > Hi resilient</i>						
Anterior LOFC	11	38	38	-18	381	4.13
<i>Nonthreat > Threat</i>						
No clusters at threshold						
<i>Hi > Low resilient</i>						
Anteroventral Insula	13	38	9	-12	439	5.83
<i>Low > Hi resilient</i>						
No clusters at threshold						

Table 5

Height and width activations in Aversive vs. Nonthreat-neutral pictures

Region of Activation	Coordinates				Volume (mm ³)	Z score
	Brodmann's Area	x	y	z		
HEIGHT						
<i>Aversive > Nonthreat-neutral</i>						
DMPFC	9	6	56	30	1143	6.08
LOFC	47	44	25	-9	850	3.98
OFC/Inferior Insula	47	-41	19	-12	3018	4.77
Inferior Frontal Gyrus	9	-47	9	27	1084	4.21
Anterior Insula	13	38	9	-9	2871	4.66
Middle Insula	13	-38	0	3	850	4.30
Amygdala	NA	31	-3	-15	352	4.17
Thalamus/Midbrain	NA	6	-19	0	7178	5.47
Occipitotemporal Cortex	37	50	-66	-3	11719	6.31
Occipitotemporal Cortex	37	-47	-69	3	12803	7.05
Middle Temporal Gyrus	39	53	-69	12	469	4.89
Occipital Cortex	17	-6	-97	-9	2344	3.94
<i>Hi > Low resilient – no clusters</i>						
<i>Low > Hi resilient – no clusters</i>						
<i>Nonthreat-neutral vs. Aversive</i>						
No Clusters at threshold						
<i>Hi > Low resilient – no clusters</i>						
<i>Low > Hi resilient – no clusters</i>						

WIDTH

Aversive vs. Nonthreat-neutral

Inferior Occipital Gyrus	17	-12	-100	0	967	5.29
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Hi vs. Low resilient – no clusters

Low vs. Hi resilient – no clusters

Nonthreat-neutral vs. Aversive

No clusters at threshold

Hi vs. Low resilient – no clusters

Low vs. Hi resilient – no clusters

Figure Captions

Figure 1. Participants received one of two cues; a ‘threat’ cue indicated that an aversive picture might appear (0.5 probability, unknown to participants), or a neutral (*threat-neutral*) picture might appear instead. The ‘nonthreat’ cue signified that the participants would see a neutral (*nonthreat-neutral*) picture (1.0 probability).

Figure 2. Width of activation in the right anterior insula (38, 22, 3) differentiates high and low trait resilient participants. **A.** Low trait resilient participants show prolonged activation in the insula in response to the threat-neutral pictures (vs. nonthreat-neutral pictures), whereas **D.** high trait resilient participants do not. **B and E.** Temporal characteristics of the insula activation including width, time to half-peak (rise), time to peak, and time to half-peak (fall). The differential width effect in the insula (time at half-peak [fall – rise]) seems to be due to both **B.** low resilient participants exhibiting earlier times at half-peak (rise), and **E.** high resilient participants exhibiting earlier times at half-peak (fall). **C.** There was only a main effect of resilience on insula activation height across all pictures. *The HRF estimates are deconvolved, and this figure shows the estimates of the HRF response in % BOLD signal change. Bars are standard error of the mean.

Figure 3. A. Height of peak activation in two sub-regions of the lateral orbitofrontal cortex (pLOFC; 44, 31, -15; aLOFC; 38, 38, -18 – each image plane taken at the orthogonal coordinate) and anteroventral insula (38, 9, -12) during the threat cue (vs. nonthreat cue). Low resilient participants showed significantly higher peak activation to the threat cue vs. nonthreat cue in all three subregions. High resilient participants showed a similar threat vs. nonthreat cue height activation difference in the pLOFC, but the reverse pattern (nonthreat vs. threat cue) in the aLOFC and anteroventral insula. Bars are standard error of the mean.