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A shift in perspective: Decentering through mindful attention to imagined stressful events

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ABSTRACT

Ruminative thoughts about a stressful event can seem subjectively real, as if the imagined event were happening in the moment. One possibility is that this subjective realism results from simulating the self as engaged in the stressful event (immersion). If so, then the process of decentering—disengaging the self from the event—should reduce the subjective realism associated with immersion, and therefore perceived stressfulness. To assess this account of decentering, we taught non-meditators a strategy for disengaging from imagined events, simply viewing these events as transient mental states (mindful attention). In a subsequent neuroimaging session, participants imagined stressful and non-stressful events, while either immersing themselves or adopting mindful attention. In conjunction analyses, mindful attention down-regulated the processing of stressful events relative to baseline, whereas immersion up-regulated their processing. In direct contrasts between mindful attention and immersion, mindful attention showed greater activity in brain areas associated with perspective shifting and effortful attention, whereas immersion showed greater activity in areas associated with self-processing and visceral states. These results suggest that mindful attention produces decentering by disengaging embodied senses of self from imagined situations so that affect does not develop.

1. Introduction

1.1. Stress and its consequences

Perseverating about difficult events through rumination and worry elicits bodily stress responses that can affect one's health adversely (Brosschot et al., 2006; Keller et al., 2012). As much research demonstrates, chronic stress responses translate into wear and tear on the body and brain, together with reductions in psychological well-being (Black and Garbutt, 2002; Ganzel et al., 2010; Hänsel et al., 2010; McEwen, 1998; Juster et al., 2010; Rodrigues et al., 2009; Rozanski et al., 1999, 2005; Schiffrin and Nelson, 2010; Zautra, 2003). Because of the many negative consequences associated with chronic stress, it is important to understand the mechanisms that, first, produce stressful thoughts and, second, reduce their negative impact. In a neuroimaging experiment, we examined the neural mechanisms that underlie stressful thoughts and a brief decentering intervention for regulating them (mindful attention).

1.2. Why some thoughts are stressful

Much of the stress literature is devoted to establishing why some thoughts are stressful and others are not (e.g., Almeida, 2005; Lazarus, 1993, 1999; Scherer, 2001). One definition suggests that stress occurs when a mismatch takes place between an event one anticipates in the world and what actually happens (Ursin and Eriksen, 2004). Together with this expectation violation, a combination of additional factors contributes to making an event

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stressful, in particular: perceived self-threat, perceived inability to cope effectively (inefficacy), the objective severity of the stressor, the individual's resilience and vulnerability, negative emotion, and the associated neuroendocrine response (Almeida, 2005; Almeida et al., 2002; Lazarus, 1993, 1999; Scherer, 2001). In recent work, we have similarly found that an imagined event appears stressful when inability to cope effectively with a threatening situation is experienced such that negative emotion and perseveration result (Lebois et al., 2015 also see Brosschot (2010); Brosschot et al. (2005); Dickerson et al. (2004); Higgins (1989)).

Here we further propose that immersion plays a central role in stressful thoughts. By *immersion* we mean that people experience a strong sense of self-engagement with an imagined situation. As a consequence of self-engagement, people often experience vivid sensory details, emotions, feelings, and physical sensations, as if they were entering into a vivid daydream that they experience fully. As a further consequence, the imagined event seems *subjectively real*, as if it were happening in the present moment via mental time travel (Papies et al., 2012, 2015; also see *cognitive fusion* in Acceptance and Commitment Therapy or ACT, Hayes (2004)). Once immersion in a stressful situation produces subjective realism, negative emotion, bodily stress responses, and rumination are likely to result.

1.2.1. Neurobiology of stressful thinking

Research on the neural bases of stress and other emotional states finds that a consistent set of neural regions tends to become active during stressful thoughts. The anterior insula, amygdala, orbitofrontal cortex (OFC), and their reciprocal connections to sensory areas help determine the relevance of a stimulus for an individual (Barrett et al., 2007; Ganzel et al., 2010). Specifically, the OFC may initially categorize an event as stressful and can facilitate its perseveration in working memory (Dedovic et al., 2009a,b). In turn, the anterior cingulate cortex (ACC), amygdala, and dorsomedial and ventromedial prefrontal cortex (dmPFC and vmPFC, respectively) contribute to appraisals related to personal significance, emotional intensity, and valence (Barrett et al., 2007; Dedovic et al., 2009b,c; Ganzel et al., 2010).

Through connections with the hypothalamus and brainstem, the aforementioned brain regions initiate physiological, hormonal, and behavioral responses to stress (Barrett et al., 2007; Chida and Hamer, 2008; Dedovic et al., 2009a; Greenberg et al., 2002). Several additional areas regulate the neuroendocrine stress response via the hypothalamic–pituitary–adrenal axis (HPA axis). The hippocampus, for example, helps evaluate the extent to which the stressor affects one's goals and self (Dedovic et al., 2009a). Additionally, activation of the hippocampus, together with the mPFC, can inhibit the HPA axis (Dedovic et al., 2009a). Conversely, when the hippocampus and mPFC deactivate, the HPA axis is disinhibited, thereby initiating the cascade of stress hormone release. In contrast to the inhibitory role of the hippocampus and mPFC, the amygdala potentiates HPA axis activation (Dedovic et al., 2009a; Rodrigues et al., 2009). The amygdala, however, is not always consistently active during stressful cognition, with some contexts being more likely to activate it than others (Ganzel et al., 2010).

1.3. Mindfulness

Mindfulness offers one method for intervening on the neurobiological and cognitive mechanisms that produce stress, where mindfulness is often characterized as present-centered non-evaluative awareness of one's thoughts, emotions, and other experiences in the moment (Bishop et al., 2004; Kabat-Zinn, 1990). Research increasingly documents the benefits of mindfulness across diverse domains of well-being, including reductions in perceived stress, stress symptoms, rumination, negative thought avoidance, and emotional reactivity, coupled with enhanced attention and emotion regulation (for reviews see Bishop et al. (2004), Brown et al. (2007), Chiesa and Serretti (2010), Gard et al. (2014), Keng et al. (2011), Lutz et al. (2008), Tang et al. (2012)). Clinical interventions have incorporated aspects of mindfulness to improve functioning in mood, attention, and eating disorders (including ACT, Mindfulness Based Stress Reduction or MBSR, Dialectical Behavioral Therapy or DBT, and Mindfulness Based Cognitive Therapy or MBCT; for reviews see, Grossman et al. (2004), Rubia (2009), Hofmann et al. (2010)).

Neural mechanisms associated with mindfulness can vary widely across expertise and training regimen. Novices and intermediate practitioners of mindfulness, for example, typically activate brain areas associated with voluntary effortful attention (e.g., lateral prefrontal cortex lPFC, parietal cortex PC), whereas experts typically exhibit reduced activity in these areas and in the default mode network (e.g., medial prefrontal cortex mPFC, posterior cingulate cortex PCC), while at the same time exhibiting greater activity in dorsal anterior cingulate cortex (dACC), left insula, and striatum (Brefczynski-Lewis et al., 2007; for reviews see, Chiesa and Serretti (2010), Fox et al. (2014), Tang et al. (2012), Vago (2014)). Regarding training regimens, meditators whose practices focus on body awareness (e.g., Vipassana) often show increased functional activity and structural differences in the insula, whereas practices that lack this focus do not (see Fox et al. (2014) for a recent review).

1.3.1. Exploring brief mindfulness interventions

Most research has focused on experts and experienced practitioners who have at least completed an extended mindfulness course (e.g., 8 weeks of MBSR). Of primary interest has been how these interventions change psychological states and the underlying neural activity. Participants in an MBSR course, for example, exhibited reductions in perceived stress, together with less gray matter density in the amygdala (Hölzel et al., 2009). MBSR participants have also demonstrated reduced neural reactivity to sadness, especially in cortical midline areas associated with self-referential processing, relative to a wait list control group (Farb et al., 2010).

Much less research addresses relevant cognitive abilities that already exist in individuals before mindfulness training that contribute to acquiring mindfulness skills during an intervention. Does mindfulness draw on preexisting cognitive abilities, or is it completely acquired in meditation training? Various contemplative approaches assume that individuals have natural contemplative abilities waiting to be uncovered through relevant training and experience (e.g., Dzogchen and Mahamudra in Tibetan Buddhism; Thrangu, 1996; Nyima, 2004). Several researchers have also made this claim (Brown and Ryan, 2003; Brown et al., 2007; Kabat-Zinn, 2003; Taylor et al., 2011).

In particular, Bishop et al. (2004) proposed that pre-existing cognitive abilities underlie two basic components of mindfulness: attentional awareness and perspective shifting. The attention component makes it possible to maintain focus on present experience by regulating attention and inhibiting elaborative processing. The perspective shifting component makes it possible to approach thoughts and reactions with curiosity, openness, and acceptance – observing all reactions without efforts to change their content.

An important outcome of shifting perspective is an insight known as *decentering*: The realization that thoughts, feelings, and reactions are transitory patterns of mental activity, that they are not necessarily true representations of the self and events, and that they are not actually happening (Bishop et al., 2004; Brown et al., 2007; Teasdale et al., 1995; also see “reperceiving,” Shapiro et al. (2006); “cognitive defusion,” Hayes (2004)). Adopting this

perspective makes it possible for individuals to view their thoughts and reactions to events as arising and dissipating in the moment, without becoming engaged in sustained affective responses to them (Kross and Ayduk, 2008). From our perspective, decentering prevents subjective realism by disengaging a person's sense of self from an imagined situation, thereby decreasing immersion and mental time traveling.

Consistent with the pre-existence of basic mindfulness abilities, increasing research demonstrates that brief mindfulness interventions can produce immediate benefits via the attention component and/or the decentering/perspective shifting component. First, consider studies that have examined brief interventions for training the attention component (Arch and Craske, 2006; Delizonna et al., 2009; Dickenson et al., 2013; Ditto et al., 2006; Farb et al., 2007). In Dickenson et al. (2013), for example, a brief breath-focused meditation recruited more areas involved in internal state awareness (insula) and in attentional control and shifting (dlPFC, angular gyrus (AG)) compared to a mind wandering condition, especially in participants high in trait mindfulness. In Farb et al. (2007), a simple attentional shift to more present-centered awareness decreased activation in areas associated with self-referential (posterior cingulate cortex, mPFC) and visceral state processing (subgenual ACC).

Other brief intervention research has examined both attention and decentering together (Alberts and Thewissen, 2011; Broderick, 2005; Lutz et al., 2014; Singer and Dobson, 2007; Zeidan et al., 2010a,b,c). In several related studies, 20 min of mindfulness practice for 3–4 days improved sustained attention, visuospatial processing, working memory, and executive functioning, while reducing fatigue, anxiety, heart rate, and subjective experiences of pain compared to controls and sham meditation groups (Zeidan et al., 2010a,b,c). After training a mindfulness group with brief written instructions before a functional magnetic resonance imaging (fMRI) scan session, Lutz et al. (2014) found that mindfulness was associated with greater emotion regulation (increased superior mPFC) in anticipation of negative pictures, and decreased emotional responding during perception of emotional pictures (decreased amygdala and parahippocampal gyrus activity) compared to a control group.

Only a handful of brief intervention studies have emphasized decentering explicitly (Erisman and Roemer, 2010; Kross et al., 2009; Papies et al., 2012, 2015; Tincher et al., in press). In Papies et al. (2012, 2015), a 15 min mindful attention induction modulated implicit approach responses toward desirable, unhealthy foods, and also choices to consume them. In Tincher et al. (2015), a 20 min mindful attention induction modulated stereotype biases to in-group and out-group members. In Kross et al. (2009), less self-referential, emotional, and visceral state integration occurred in mPFC and sgACC for negative autobiographical memories in a mindful condition compared to a ruminative condition.

The majority of the work just described, however, is behavioral, with relatively little emphasis on the underlying neural mechanisms. In the experiment reported here, we assessed the neural mechanisms underlying immersion in stressful thoughts, together with the neural mechanisms underlying disengagement from such thoughts. We adapted a brief mindfulness intervention—mindful attention—from Papies et al. (2012) that utilizes the perspective shifting mechanism of mindfulness, specifically, decentering. Previous mindfulness interventions, reviewed above, often lack this specific focus on decentering, and none has emphasized decentering in the context of stressful cognition. By contrasting the cognition associated with immersion vs. mindful attention in a neuroimaging paradigm, we hoped to establish the neural mechanisms that make imagined events seem subjectively real and stressful, and conversely, the mechanisms that make it possible to disengage from these immersion experiences.

1.4. Experiment overview

During a brief initial instruction, participants learned a mindful attention strategy for disengaging from imagined events (decentering), and also practiced an immersion strategy for engaging with imagined events (mentally time travelling). During a subsequent fMRI session, in a completely repeated measures design, participants performed blocks using the *mindful attention* strategy and blocks using the *immersion* strategy. Within each mindful attention and immersion block, participants imagined experiencing *stressful events* in one sub-block (e.g., Your professor just accused you of cheating on an exam) and non-*stressful events* in a second sub-block (e.g., Your professor just passed out lecture notes in preparation for the next class). Within the initial *reading period* of each trial, participants read and comprehended a stressful or non-stressful event, and then, during the subsequent *strategy period*, performed either the mindful attention or immersion strategy for that event. Finally, participants rated their ability to perform mindful attention or immersion during the trial.

Of interest was the neural activity that each *strategy* (mindful attention vs. immersion) exhibited over the course of each *period* (reading vs. strategy) in each *event* condition (stressful vs. non-stressful). Most generally, we predicted that immersion would utilize brain areas that produce sensorimotor simulation of an event, together with areas that contribute to the experience that the event is subjectively real, including areas associated with self, emotion, and visceral states. In contrast, we predicted that mindful attention would utilize brain areas that contribute to disengaging the self from the simulated event, including areas associated with perspective shifting, effortful attention, and regulatory processing.

Because trials for immersion and mindful attention were blocked, it is possible that mindful attention and immersion processing operated across entire blocks, thereby entering into both the reading and strategy period on every trial. Rather than only being restricted to the strategy period, the strategy could be distributed across both periods. If, for example, mindful attention down-regulates affect associated with stressful events, then much initial regulatory activity during the reading period could be followed by less affective activity during the strategy period. Conversely, if immersion in an event increases across the reading and strategy periods, then neural activity might also increase.

Finally, we expected that mindful attention and immersion would differ more in neural activity for stressful events than for non-stressful events. Because stressful events generate strong affective responses, they are likely to produce strong experiences of immersion, and thus afford salient responses that can be regulated via mindful attention (see Papies et al., 2015, for related proposals and findings). In contrast, non-stressful events might not offer the same opportunities for differentially applying the two strategies, such that neural activity would be more similar.

2. Method

2.1. Design and participants

2.1.1. Design

The scanning session contained three independent variables—*strategy* (mindful attention vs. immersion) *X event* (stressful vs. non-stressful) *X period* (reading vs. strategy)—in a completely crossed repeated-measures design. As Fig. 1 illustrates, four critical conditions occurred in the strategy *X* event sub-design (associated once with the reading period and once with the strategy period): (1) mindful attention stressful, (2) mindful attention non-stressful, (3) immersion stressful, (4) immersion non-stressful. For reasons explained shortly, each of these four conditions contained 30

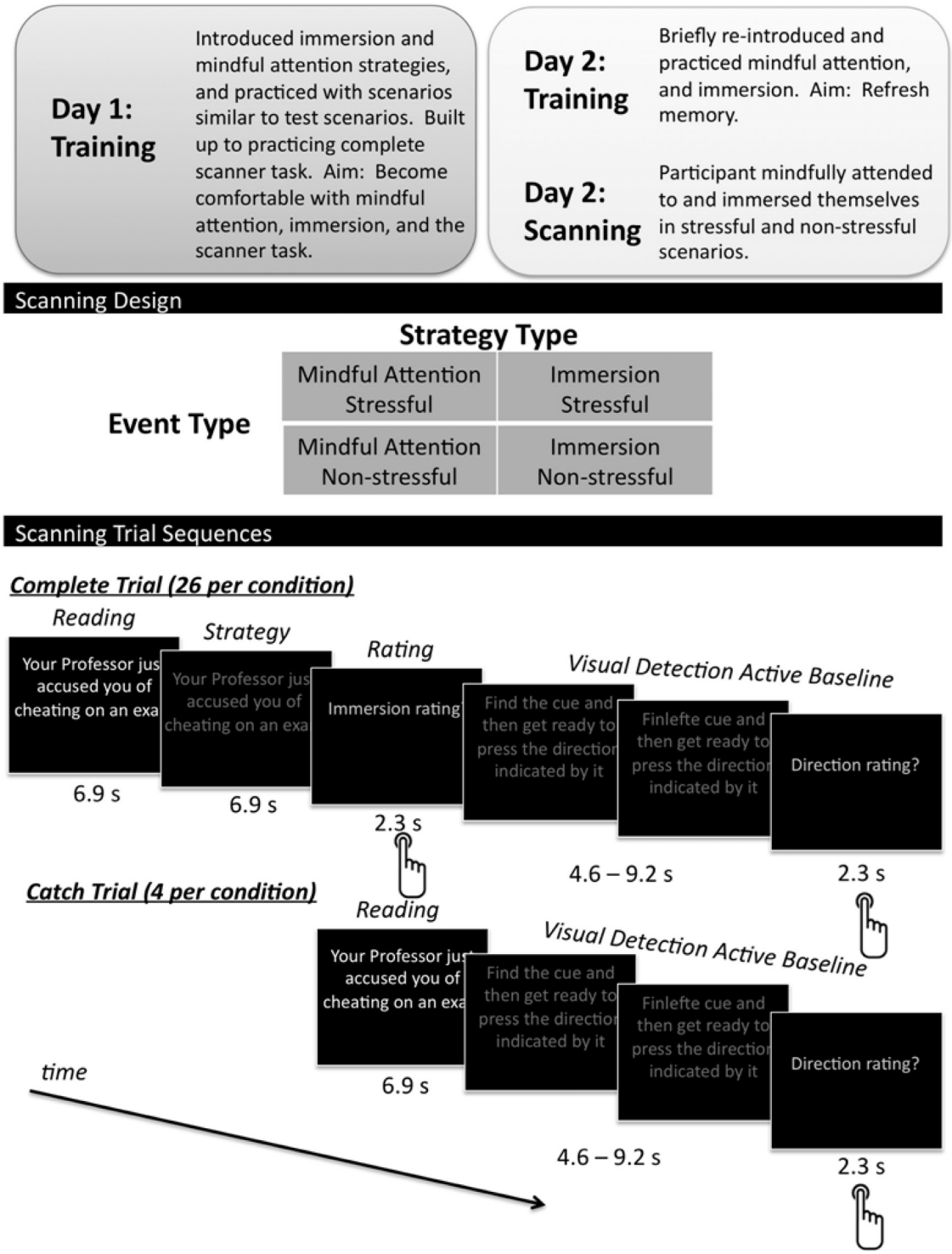

Fig. 1. The experimental design. The top panel summarizes the training procedure. The middle panel presents the four event types in the design, which occured in both the reading and strategy periods. The bottom panel describes the trial sequence using the immersion stress condition as an example. Mindful attention trials and non-stress trials followed the same procedure. The first sequence depicts a complete trial. The second sequence depicts a catch trial.

reading period trials and 24 strategy period trials. Although many mindfulness experiments include a mindfulness group and separate control group in a between-groups manipulation, we chose a repeated-measures design after piloting both designs. Specifically, pilot participants reported finding it easier to learn the immersion and mindful attention strategies together (contrasting them with each other) rather than alone (without the other).

A mix of complete trials and catch trials allowed us to separate BOLD activations during the reading period from those during the strategy period (details provided later). Catch trials constituted 20% of the total trials, enough to successfully isolate activations during the two adjacent periods (Ollinger et al., 2001a, 2001b). Each of the 4 critical conditions defined above contained 24 complete trials and 6 catch trials.

An active baseline task (visual detection) was used instead of a resting state baseline (details provided later). Because participants had to press a button to respond on the baseline task, it was analogous to the critical task that also required a button press. By

subtracting the active baseline from the critical conditions, we removed uninteresting activations associated with visual and motor processing that were not central to the event and strategy activations of interest. If we had used a resting baseline instead, it would likely have produced mind wandering associated with self-related processing (e.g., Mason et al., 2007). Because self-related processing is central to stress (e.g., Dedovic et al., 2009a; Dickerson and Kemeny, 2004), a resting baseline would have removed potentially germane activations from later analyses (e.g., cortical midline activity; Mason et al., 2007). An active baseline, therefore, was deemed more appropriate.

2.1.2. Participants

Thirty participants (15 female) were drawn from the student populations of Emory University and Georgia Institute of Technology, with this sample size providing sufficient power to test our hypotheses (Mumford and Nichols, 2008). Participants were 18–23 years old, including 50% Caucasian, 20% Asian, 17% other, 10% African American, and 3% Native American (1 individual also identified as Hispanic or Latino). Three participants were dropped due to excessive head movement in the scanner, and one participant was dropped after disclosing failure to follow instructions (during the exit interview). These 4 participants were replaced to maintain a 30-participant sample that exhibited the aforementioned demographics. Typical imaging exclusion criteria were enforced. Any individuals who were left-handed, had metal implants, or claustrophobia were excluded, as were individuals who were currently taking psychotropic medication, or who had experienced significant head injury associated with loss of consciousness. Participants also had to be native English speakers with normal or corrected vision. Additionally, we excluded individuals with meditation experience, as we wanted to examine the mechanisms underlying mindful attention in non-meditators. The Emory Institutional Review Board approved the protocol, and informed consent was obtained from all participants. Participants received $80 compensation for their time.

2.2. Materials

2.2.1. Scenarios

Critical events were 120 one-sentence scenarios (60 stressful, 60 non-stressful) that averaged 15 words in length. Each scenario contained second person ("you") references to promote self-engagement. Stressful scenarios all included interpersonal tensions relevant to college life, for example, "You have to tell your parents you failed a class and need to take summer school," "Your roommates had a party while you were gone, and now your landlord is threatening to evict you," and "Your professor asks for take-home midterms, and you realize you left yours at home." Non-stressful scenarios were written to match scene and character details from the stressful scenarios, but with non-threatening social interactions, for example, "You tell your parents you're considering taking a class over the summer to free up your fall schedule," "Your roommate says they decided to stay home while you went away last weekend," and "Your professor asks everyone to talk amongst themselves while taking a quick phone call outside."

To make the scenarios more ecologically valid, we drew ideas for events from a nation-wide database of stressful events (Almeida et al., 2002), and from undergraduate research assistants. In total, 572 stressful and non-stressful scenarios (286 each) were constructed and normed by 12 participants in a separate behavioral study for stressfulness, self-threat, perseverative thought, expectation violation, efficacy, experience, familiarity, plausibility, valence, arousal, and certainty (Lebois et al., 2015). The 60 most stressful scenarios with the least amount of variance in stressfulness were selected for use in the imaging experiment, along with their 60 matched non-stressful scenarios. Stressful and non-stressful scenarios did not differ in sentence length (stressful $M=15.33$, $SD=3.07$; non-stressful $M=15.52$, $SD=2.46$; $t(59)=-.39$, $SE=.47$, $p>.250$). On a Likert scale of 1 (low) to 7 (high), stressful scenarios were higher in perceived stressfulness ($M=5.86$, $SD=.37$) compared to non-stressful scenarios ($M=1.34$, $SD=.29$; $t(59)=75.01$, $SE=.06$, $p<.001$). Stressful scenarios were also significantly different on core features that predict stress, including, threat, arousal, perseveration, negative valence, bodily imagery, violation of expectations, efficacy, and positive valence (Lebois et al., 2015). The Supplementary Materials (SM) report the details of these additional norming results.

2.3. Procedure

As Fig. 1 illustrates, each participant performed two training sessions, one scanning session, and a post-scan question period. Each is addressed in turn.

2.3.1. Training session 1

Training session 1 was approximately 1.5 h in duration from initial self-report questionnaires to final task practice. Participants first completed self-report measures of absorption, rumination, and mindfulness. The results for these measures do not bear on the current analyses and are not discussed further.

To ensure that participants fully understood and were comfortable performing mindful attention and immersion, a detailed instruction protocol was followed (see the SM for more complete details). We adapted key concepts for this instruction from previous research (Lebois et al., 2015; Papies et al., 2012; Wilson-Mendenhall et al., 2011). Papies et al. (2012) elicited reliable behavioral differences between mindful attention and immersion on an implicit approach–avoidance task using a similar but more concise instruction.

First, we introduced the concept of immersion, provided a definition, and presented examples. As described earlier, participants were asked to become completely absorbed in the experience of the scenarios, as if they were happening in the moment. They were to mentally time travel and experience the sensory details, physical sensations, feelings, emotions, and bodily states associated with engaging in the scenario vividly. Participants practiced immersing themselves in presented scenarios through a series of tasks that built up to the timing and procedure of the critical task.

Second, participants learned the distinction between complete and catch trials. As Fig. 1 illustrates, complete trials contained a reading period, a strategy period, and a rating period (details provided later). During the reading period, participants were instructed to comprehend a presented event; during the strategy period, participants were instructed to perform either immersion or mindful attention (as described shortly) on the event; during the rating period, participants rated how well they were able to perform the strategy. As Fig. 1 further illustrates, catch trials were exactly the same as the complete trials except that they only consisted of the reading period, with the strategy and rating periods excluded. Following instruction, participants practiced performing both complete and catch trials to become comfortable with each.

Third, participants received instructions on the left-right visual detection task that served as the active baseline (details provided later). Participants then practiced the baseline task so that they would be comfortable performing it later in the context of complete and catch trials.

Fourth, we introduced the concept of mindful attention, provided a definition, and presented examples, following the same structure as the immersion instruction. Participants were asked to remain aware of their current physical location while thinking

about the scenarios. They were further asked to notice the kinds of reactions that they normally have during immersion, but rather than 'living' the event, they were instructed to simply observe their thoughts and reactions to it in the present moment. Participants were asked to perceive their thoughts about the stimuli as transitory mental states, not as parts of the scenarios, but as their psychological responses to them. Essentially, we briefly taught participants the decentering component of mindfulness, allowing them to disengage from the events being imagined.

Lastly, participants practiced one run of the experimental task, including complete trials, catch trials, and the active baseline task. All these elements had been practiced previously in training, but had not yet been implemented together. The practice run contained 1 block of 10 immersion trials mixed with baseline trials, and 1 block of 10 mindful attention trials also mixed with baseline trials (16 complete trials, and 4 catch trials). Each block contained a mini-block of 5 stressful scenarios and a mini-block of 5 non-stressful scenarios, counterbalanced for order.

At the onset of a 10-event block, participants received a cue, "IMMERSION" or "MINDFUL," presented in white font on a black background that lasted for 2.3 s followed by 2.3 s of a black screen. Cues only occurred at the beginning of a strategy block, not before each trial, nor when participants switched between stressful and non-stressful scenario mini-blocks within a strategy block.

As Fig. 1 illustrates, a complete trial consisted of the following events. (1) During the *reading period*, a one-sentence scenario was presented visually in white font on a black background for 6.9 s. During this period, the task was simply to read and understand the sentence. (2) During the *strategy period*, the sentence changed to a dark gray font, cuing participants to adopt either the mindful attention or immersion strategy for 6.9 s, depending on the type of block. (3) During the rating period, the screen switched to "Immersion rating?" or "Mindful rating?" for 2.3 s in a lime green font on a black background. Participants' task was to rate their ability to immerse (or mindfully attend) on a scale of 1 (not at all) to 5 (high). On catch trials, only the reading period occurred, not followed by the strategy and rating periods. One trial in each mini-block of five trials was randomly chosen to be a catch trial.

After every complete trial or catch trial, a left–right visual detection trial occurred (i.e., the active baseline task). For a randomly jittered interval of 4.6–9.2 s, the following sentence appeared on the black screen in a dark gray font, "Find the cue and then get ready to press the direction indicated by it." This sentence was of comparable length to the critical scenarios. At a random point during the variable interval, the word "left" or "right" appeared somewhere within the sentence, occluding letters within the sentence (e.g., "Finlefte cue and then get ready to press the direction indicated by it." where "left" occludes part of "Find the"). A rating screen then appeared for 2.3 s with the word "Direction?" in lime green font. Participants pressed the left-most button on the response box if they saw the word "left," the right-most button if they saw the word "right," and the middle button if they missed the direction word. The rating screen was followed by 2.3 s of a blank black screen before proceeding to the next trial. A 6.9 s black screen appeared between the immersion and mindful attention blocks, and a 16 s black screen occurred at the end of each run. All cues, stimuli, and rating requests appeared in the center of the screen.

2.3.2. Training session 2

Participants were not asked to practice any of the strategies outside of the lab training sessions. Training session 2 occurred 1–2 days after the first session. The total duration of day two from training to post-scan rating was approximately 2.5 h. During training, participants reviewed the immersion and mindful attention strategies, completed one more practice run, and then proceeded immediately to the MRI scanner.

2.3.3. Scanning session

In the scanner, participants completed six runs that followed the same procedure as the aforementioned practice run. To avoid repetition effects, participants viewed novel scenarios during the experimental task in the scanner not seen during practice. The scan session lasted approximately 1 h, including one T1 anatomical scan and 54 min of critical functional scans on the experimental task. While in the scanner, measures of heart rate, respiration, and electrodermal activity were also collected. These physiological data will be reported in a later manuscript.

Each of six runs, lasting about 9 min each, contained two strategy blocks, one for mindful attention and one for immersion. Each strategy block contained one mini-block of 5 stressful events and one mini-block of 5 non-stressful events, with each mini-block containing 4 complete trials and 1 catch trial, randomly ordered. Within each strategy block, the assigned strategy always remained constant across the two mini-blocks (e.g., mindful attention was performed first for stressful or non-stressful events and then for the other type of event). Eight different versions of the experiment were constructed, counterbalancing run order, block order, mini-block order, and the assignment of each event to mindful attention or immersion (each participant only saw a given event once, performing either mindful attention or immersion on it).

2.3.4. Post scan session

As a manipulation check, participants rated the critical scenarios for overall stressfulness on a 1 (not at all stressful) to 7 (highly stressful) scale. Finally, participants completed an exit interview in which they described what they were doing during each strategy, and how difficult it was for them.

2.4. Scan sequence

All scans were completed on a Siemens 3T Trio scanner with a 32-channel head coil. The functional scans were acquired with a whole-brain multiband slice-accelerated gradient-echo echo planar imaging (EPI) sequence (Feinberg et al., 2010; Moeller et al., 2010): TR/TE/FA = 1150 ms/24 ms/45°, FOV = 220 mm × 220 mm; image acquisition matrix = 74 × 74; 64 slices with thickness of 2 mm for a 3 mm × 3 mm × 2 mm voxel resolution. The high-resolution anatomical scans were acquired with a sagittal 3D T1-weighted MPRAGE sequence (FOV = 240 mm × 240 mm; TR/TI/TE/FA = 2250 ms/900 ms/3 ms/9° image acquisition matrix = 256 × 256 × 160; 0.9 mm × 0.9 mm × 1 mm resolution). Sequences were chosen to reduce susceptibility artifacts.

2.5. Image preprocessing and statistical analyses

AFNI was used to perform standard preprocessing including skull stripping and slice time correction (Cox, 1996). FSL (Smith et al., 2004) was used to correct spatial intensity variations (Zhang et al., 2001) and to perform spatial normalization and co-registration (Andersson et al., 2010; Jenkinson and Smith, 2001; Jenkinson et al., 2002). See the SM for further details on various aspects of the preprocessing and analyses described below.

During preprocessing, data for individual participants were temporally shifted, registered to a base volume, co-registered to an anatomical volume, spatially normalized to MNI152 template space, resampled to 3x3x3 voxels, and smoothed with an isotropic Gaussian (FWHM = 6 mm) kernel. Multiple linear regression analysis was then performed on individual participant's data. Regressors were constructed using a vector of onset time points for each respective condition. These blocks of stimulus times were convolved with a gamma-variate function. Each block was then rescaled to have an amplitude of 1 multiplied by the estimated

stimulus type beta-weight. For each voxel, the signal was modeled as the weighted sum of the aforementioned convolutions, the 3rd order polynomial drifts, and the constant baseline.

The 29 regressors (beta weights) included 4 during the reading period for the 4 critical conditions (mindful attention stress, mindful attention non-stress, immersion stress, immersion non-stress conditions), 4 during the strategy period for the same 4 critical conditions, 1 for the fixation cue, 6 for motion parameters, 6 for the 6 rest periods, and 8 for the 8 strategy and baseline rating periods (removing the regressors for the rest and rating periods had no effect on the results).

Each individual's beta coefficients for the 8 critical conditions were entered into a random effects whole brain ANOVA to obtain group level maps. All group-level maps mentioned in the conjunction and contrast analyses to follow were thresholded at a voxel-wise level of $p < .005$ and a corrected extent threshold of $p < .05$ (26 3 mmx3 mm $\times$ 3 mm voxels), estimated using AFNI's Monte Carlo 3dClustsim program. All x y z coordinates reported

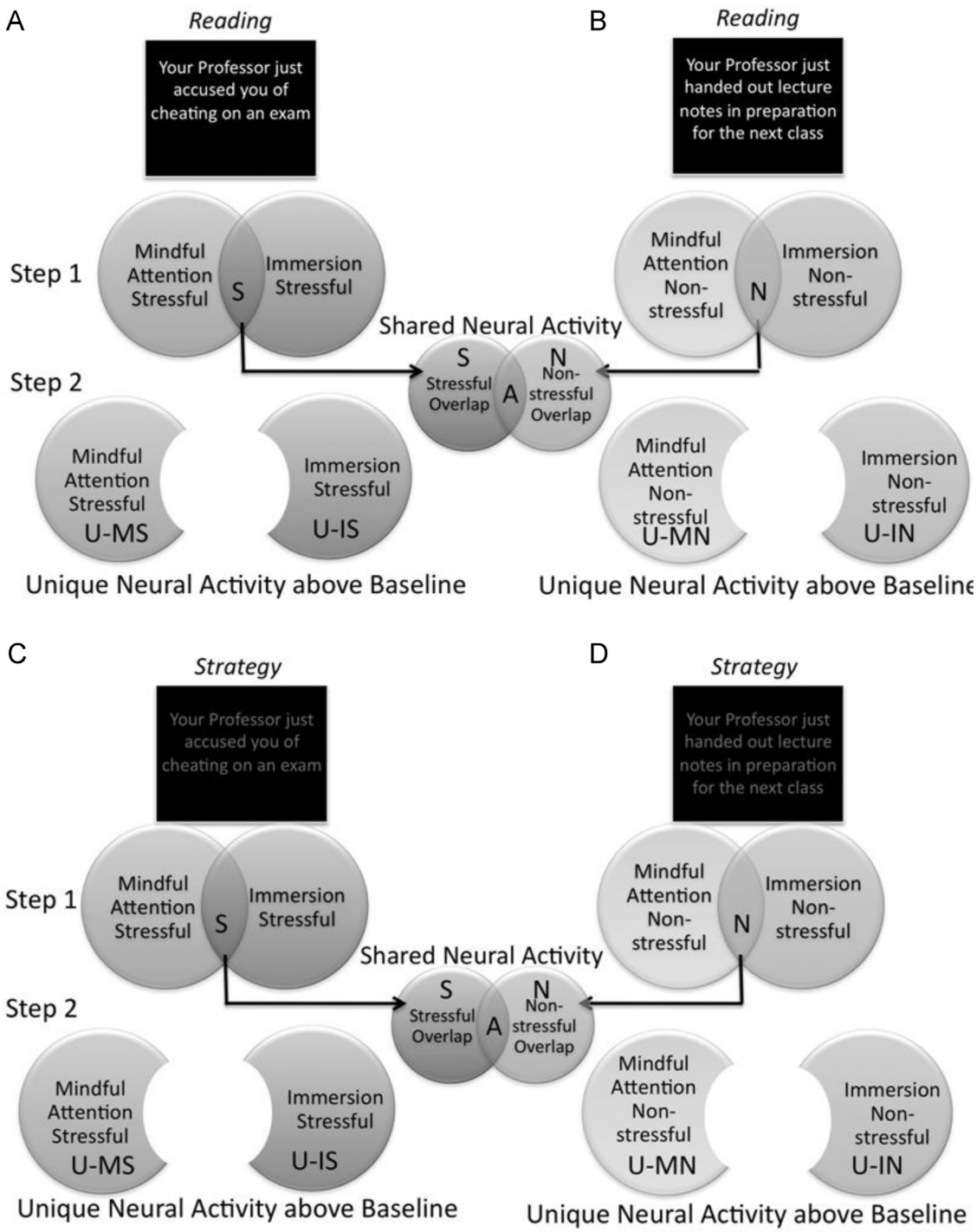

Fig. 2. The conjunction analysis procedure. Step 1 across Panels A and B illustrates the two initial conjunction analyses that each identified neural activity common across stressful (S) and non-stressful events (N) during the reading period. The arrows point to a third conjunction analysis of the voxels in S and N to establish the neural activity common across both stressful and non-stressful events during reading (A). In Step 2, we removed the common activity to extract the unique neural activity during reading in each of the four conditions: mindful attention stressful (U-MS), immersion stressful (U-IS), mindful attention non-stressful (U-MN), and immersion non-stressful (U-IN). Panels C and D specify the same procedures for the strategy periods.

are in Talairach space.

2.5.1. Conjunction analyses

As Fig. 2 illustrates, the eight condition maps in the period X strategy X event design (relative to the active baseline) were examined in a series of conjunction analyses. Significance in all conjunction analyses was established using the $p<.005$ level for individual voxels and the $p<.05$ level for spatial extent just described. A primary interest was to examine the neural activity in each condition relative to baseline across the reading and strategy periods. How much did mindful attention and immersion alter neural activity relative to baseline during the reading and strategy periods? During each period, what brain areas became active above baseline for each strategy? What activations did the strategies have in common? What activations were unique?.

To assess these issues, we first performed two conjunction analyses for the reading period, one for the two stressful conditions (mindful attention stressful, immersion stressful), and one for the two non-stressful conditions (mindful attention non-stressful, immersion non-stressful). As Step 1 across Panels A and B of Fig. 2 illustrates, these two initial conjunction analyses identified neural activity common across stressful events (S in Fig. 2) and across non-stressful events (N in Fig. 2) during the reading period. We then performed a third conjunction analysis of the voxels common across stressful events (S) and across non-stressful events (N) to establish the neural activity common across all events during reading (A in Fig. 2). Finally, in Step 2, we removed all common activity to extract the unique neural activity during reading in each of the four critical conditions: mindful attention stressful, immersion stressful, mindful attention non-stressful, and immersion non-stressful (in Fig. 2, U-MS, U-IS, U-IN, U-MN, respectively).

As Fig. 2 further illustrates in Panels C and D, three analogous conjunction analyses were performed for the strategy period. Again, shared voxels for stressful events (S), non-stressful events (N), and all events (A) were established, as were unique voxels for the four critical conditions (U-MS, U-IS, U-IN, U-MN).

As described in the Results section, assessing these 6 sets of shared voxels and 8 sets of unique voxels allowed us to characterize changes in brain activity relative to baseline for each condition. As we will see in the unique activation results, mindful attention and immersion differed significantly in how neural activity changed relative to baseline across the reading and strategy periods for stressful and non-stressful events.

We also examined the shared voxel sets and each of the eight unique voxel sets for the extent to which they contained voxels from important neural networks. Using masks that Yeo et al. (2011) established from a large-scale resting state study, we counted the number of voxels in each voxel set that resided in Yeo et al.'s visual, somatosensorimotor, limbic, default mode, fronto-parietal control, ventral attention, and dorsal attention networks. Of interest was the extent to which these seven networks were present in neural activity across the eight critical conditions.

2.5.2. Linear contrast analyses

Finally, we performed linear contrasts within the reading period and the strategy period. Of interest during each period was whether neural activity differed significantly between the mindful attention vs. immersion strategies.

3. Results

3.1. Behavioral results

Participants' task ratings during the scan session on the 1 to 5 scale indicated that they were able to perform the mindful attention and immersion strategies effectively (mindful attention stressful: $M=3.75$, $SD=.70$, bootstrapped 95% CI [3.50, 4.01]; mindful attention non-stressful: $M=3.89$, $SD=.63$, bootstrapped 95% CI [3.66, 4.12]; immersion stressful: $M=3.85$, $SD=.73$, bootstrapped 95% CI [3.59, 4.09]; immersion non-stressful: $M=3.77$, $SD=.71$, bootstrapped 95% CI [3.51, 4.02]). The lack of main effects for strategy type and event type indicate that both strategies were performed equally easily for both event types (strategy type: $F(1, 29)=.06$, $p>.250$, $\eta p^2=.002$; event type: $F(1, 29)=.13$, $p>.250$, $\eta p^2=.132$; interaction, $F(1, 29)=2.28$, $p=.142$, $\eta p^2=.073$).

Participants' event ratings during the post-scan session rating on the 1 to 7 scale indicated that when the scenarios occurred on mindful attention trials, they were rated as significantly less stressful ($M=3.57$, $SD=2.13$, bootstrapped 95% CI [3.47, 3.66]) than when they occurred on immersion trials ($M=3.66$, $SD=2.11$, bootstrapped 95% CI [3.57, 3.74]), $F(1, 118)=4.77$, $p=.031$, $\eta p^2=.039$, indicating that the instruction had a small sustained effect on self-report ratings of stress. Not surprisingly, the stressful scenarios were rated higher in stressfulness ($M=5.66$, $SD=.50$, bootstrapped 95% CI [5.55, 5.78]) than the non-stressful scenarios ($M=1.56$, $SD=.38$. bootstrapped 95% CI [1.45, 1.68]), $F(1, 118)=2561.82$, $p<.001$, $\eta p^2=.96$.

During the exit interview, participants provided accurate verbal descriptions of the immersion and mindful attention strategies, and generally reported being able to perform both. A majority of participants experienced immersion as producing more vivid experiences of the imagined scenarios, especially with bodily sensations of tension, compared to mindful attention. Most found mindful attention more effortful than immersion, and in contrast, those who reported more difficulty with immersion often expressed finding it unpleasant to project themselves into stressful scenarios.

3.2. Unique activations in the conjunction analyses

As Step 1 of Fig. 2 illustrates, conjunction analyses established shared activations across all four conditions during the reading and strategy period (labeled A in Fig. 2). Additional conjunction analyses established shared activations for just the stressful events (S) and non-stressful events (N). The SM describe these shared activations in detail (SM Tables 1 and 2, SM Figs. 1, 2, and 3).

As Step 2 of Fig. 2 further illustrates, all shared clusters were removed to establish the unique clusters that became active above baseline in each condition (voxels labeled U-MS, U-IS, U-MN, U-IN in both panels of Fig. 2). Of interest was how much mindful attention and immersion significantly increased neural activity above baseline during the reading and strategy periods, and what brain areas became active for each strategy.

As Fig. 3 illustrates, the four conditions differed in their respective distributions of unique neural activity across the reading and strategy periods (where “unique neural activity” is the total number of voxels across significantly active clusters). As Fig. 4 further illustrates, the four conditions also exhibited large differences in the neural networks active across these periods. Tables 1 and 2 provide the complete lists of unique clusters that became active above baseline in each condition, for the reading and strategy periods, respectively. Fig. 5 illustrates examples of these unique activations (panels A–D).

3.2.1. Stressful events

During mindful attention to stressful events, participants exhibited much more unique neural activity above baseline during the reading period than during the strategy period (Fig. 3, top left). The immersion condition exhibited the opposite pattern, showing much more unique neural activity during the strategy period for

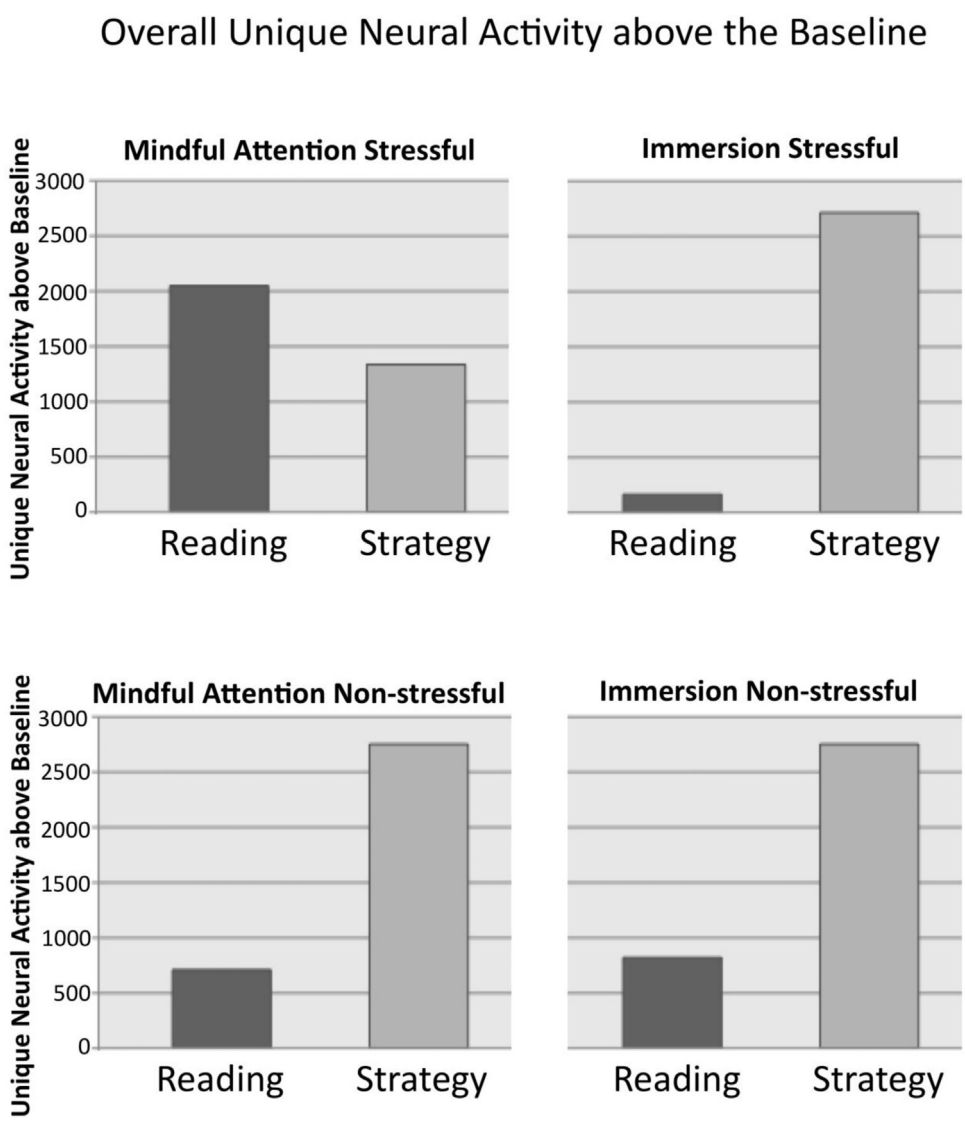

Fig. 3. Total unique neural activity for each of the four strategy-event type conditions from conjunction analyses illustrated in Fig. 2 (as measured in total voxels across significantly active clusters relative to the active baseline). All shared activations across mindful attention and immersion have been removed.

the stressful events (Fig. 3, top right). Thus, the distributions of unique activity above baseline across the reading and strategy periods differed significantly for mindful attention vs. immersion, $\chi^2(1)= 2247$, $p<.001$.

3.2.2. Non-stressful events

For the non-stressful events, more processing generally occurred during the strategy period for both mindful attention and immersion (Fig. 3, bottom left and right). Thus, the distributions of unique neural activity for mindful attention across the reading and strategy periods differed for stressful vs. non-stressful events, $\chi^2(1)= 1568$, $p<.001$.

3.3. Network analysis of the unique activations

Using the seven resting state networks established in Yeo et al. (2011), we examined the unique clusters above baseline in the visual, somatosensorimotor, limbic, default mode, frontoparietal control, ventral, and dorsal attention networks. As Fig. 4 illustrates, unique activations in these networks varied considerably across the four conditions.

3.3.1. Stressful events

For mindful attention to stressful events, the distribution of unique clusters across the seven networks differed significantly between the reading and strategy periods, $\chi^2(6)=455$, $p<.001$. Initially during the reading period, large amounts of unique activity occurred in the somatosensorimotor, visual, and limbic networks, with some dorsal attention network activity. During the strategy period, these activations decreased. Mindful attention to stressful events also produced large amounts of default mode network (DMN) activity during both the reading and strategy periods.

For immersion in stressful events, the reading and strategy periods also exhibited large differences in the distributions of unique neural activity across networks, $\chi^2(6)=476$, $p<.001$. During the strategy period, large increases in neural activity relative to the reading period occurred in the somatosensorimotor, limbic, default mode, and ventral attention networks.

3.3.2. Non-stressful events

For mindful attention to non-stressful events, the distribution of unique neural activity differed across the reading and strategy periods, $\chi^2(6)=715$, $p<.001$. During the strategy period, visual activity decreased while somatosensorimotor activity increased.

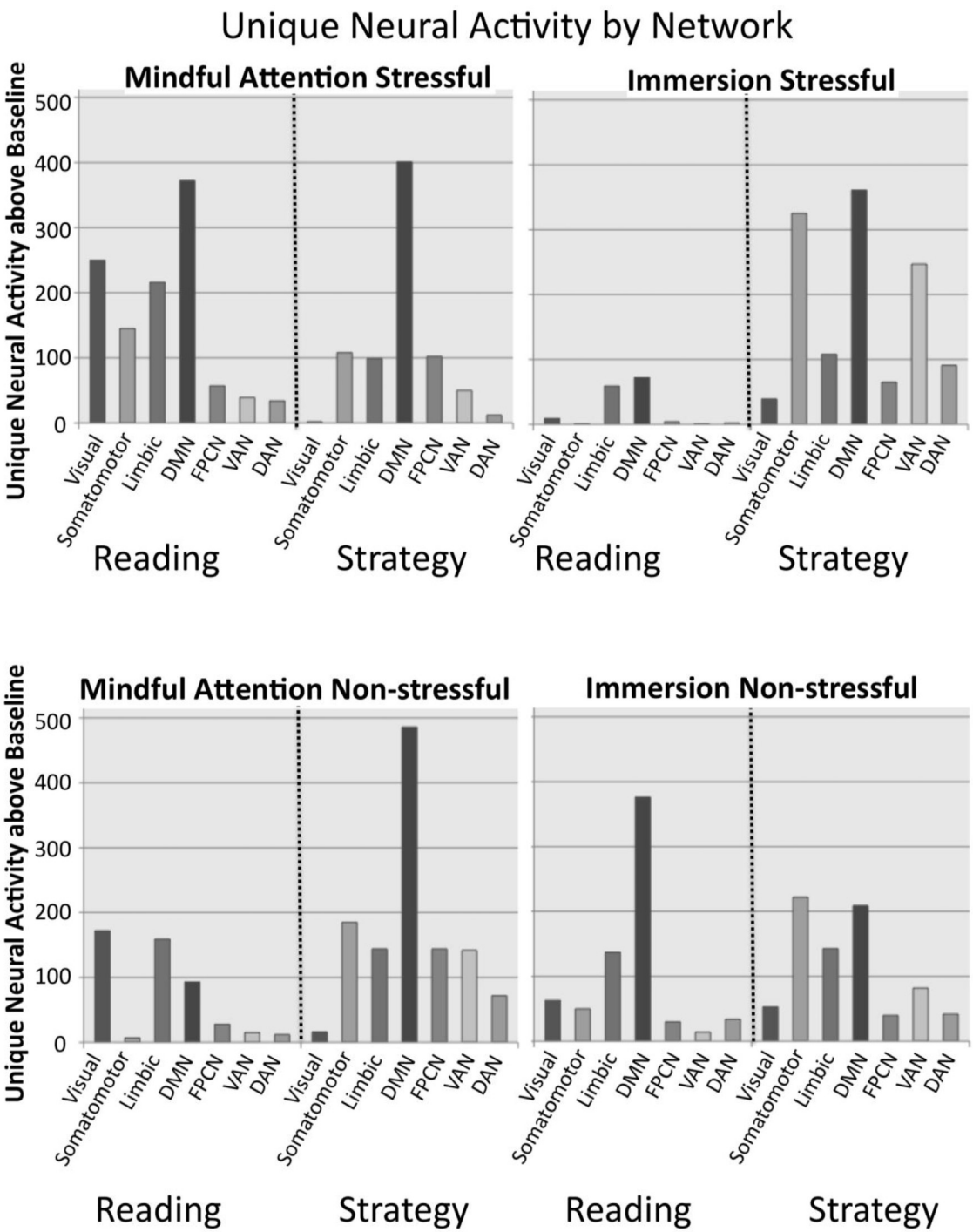

Fig. 4. Total unique neural activity for each of the four strategy-event type conditions lying within the Yeo et al. (2011) network masks from conjunction analyses illustrated in Fig. 2 (as measured in total voxels across significantly active clusters relative to the active baseline). All shared activations across mindful attention and immersion have been removed. Abbreviations for the Yeo et al. networks are: Visual = visual network, Somatomotor = somatosensorimotor network, limbic = limbic network, DMN = default mode network, FPCN = frontoparietal control network, VAN = ventral attention network, DAN = dorsal attention network.

Activity in the DMN, the frontoparietal control network, and both attention networks also increased during the strategy period.

For immersion in non-stressful events, the distribution of unique neural activity again differed across the reading and strategy periods, $\chi^2(6)=248$, $p<.001$. Similar to mindful attention, somatosensorimotor activity increased, but unlike mindful attention, DMN activity decreased. Similar to immersion in stressful events, activity in the ventral attention network increased.

3.3.3. Critical comparisons between conditions

A first pair of critical comparisons demonstrates how differently mindful attention and immersion operated for stressful events across the reading and strategy periods (Fig. 4). During the reading period, the distributions of network activity differed substantially between mindful attention and immersion for the stressful events, $\chi^2(6)=369$, $p<.001$. Specifically, mindful attention exhibited much more activity in the visual, somatosensorimotor, and limbic networks than did immersion. Mindful attention also exhibited greater activity in the DMN, frontoparietal

Table 1
Uniquely active clusters for mindful attention and immersion for stressful events during the reading and strategy periods (from two conjunction analyses, one for each period).

Cluster	Brain region	Brodmann area	Spatial extent	Peak		Center	
				t	x	y	z
Reading Period: Mindful Attention (Stressful Events)							
1	R MTG	21	633	7.07	48	3	−21
	R STS						
	R STG	22, 39					
	R ITG	20					
	R Temporal Pole	38					
	R Fusiform Gyrus	20					
	R PHG	36, 35					
	R lOFC	47					
	R Amygdala						
	R Culmen						
	R Tuber						
	R Cerebellar Tonsil						
	R Inf Semi-Lunar Lobule						
	R Pyramis						
	R Uvula						
2	L ITG	20	570	7.43	−42	−9	−30
	L Temporal Pole	38					
	L STS						
	L MTG	21					
	L Fusiform Gyrus	36, 37					
	L IOG	18					
	L Lingual Gyrus	19					
	L Uncus	20, 36					
	L PHG	35, 28					
	L Hippo-campus						
	L Thalamus						
	B PCC	31					
	B Precuneus	7					
	L Culmen						
	L Declive						
3	R SFG	9	134	6.57	−3	54	−18
	R dmPFC	9					
	B vmPFC	10					
	B mOFC	11					
	B vACC	32					
4	B Cerebellar Tonsil		92	5.05	12	−42	−42
5	R Precentral Gyrus	4	67	4.51	36	−24	45
6	R IOG	18	65	4.39	30	−93	0
	R Lingual Gyrus	18, 17					
7	R SFG/FEF	8	65	4.77	12	36	54
	R SMA	6					
8	R MFG	46	57	4.64	−51	24	24
	R dlPFC/MFG	9					
9	L Pyramis		50	4.68	−24	−75	−33
	L Inf Semi-Lunar Lobule						
10	L Lingual Gyrus	18, 17	49	4.67	−12	−96	−12
11	B Brainstem		48	4.61	−9	−21	−30
12	L MFG	6	47	4.73	−36	15	45
13	L STG	22	42	4.76	−54	−45	15
14	B SMA	6	42	4.29	−12	0	60
	L dACC	32					
15	R STG	41	34	5.68	42	−21	12
	R Posterior Insula	13					
16	B SMA	6	27	3.59	−6	−21	57
17	L Frontopolar Cortex	10	26	3.97	−18	45	39

Table 1 (*continued*)

Cluster	Brain region	Brodmann area	Spatial extent	Peak		Center	
				t	x	y	z
Reading Period: Immersion (Stressful Events)							
1	B Culmen		98	4.79	−15	−33	−9
	B Brainstem						
2	B vACC	32	39	5.56	−3	24	−6
	B sgACC	25					
	B mOFC	11					
3	B dmPFC	9	28	4.43	0	45	30
Strategy Period: Mindful Attention (Stressful Events)							
1	L vlPFC	10	281	5.59	−3	54	−15
	L mOFC	11					
2	L STG	39	188	6.17	−51	−60	39
	L AG	39					
	L IPL	40					
	L Precuneus	19					
3	L Precentral Gyrus	4	164	5.32	−15	−18	63
	L SMA	6					
	B Paracentral Lobule						
4	L ITG	20	148	5.12	−63	−42	−9
	L MTG	21					
5	L vlPFC	44, 45	88	4.46	−36	18	6
	L Anterior Insula	13					
6	R lOFC	47	77	4.77	42	24	−12
	R Temporal Pole	38					
7	B Brainstem		62	4.16	15	−36	−36
	R Cerebellar Tonsil						
8	R Pyramis		60	5.82	33	−78	−33
9	B dmPFC	9	59	5.15	−3	48	42
	B MFG/FEF	8					
10	L PHG		54	5.65	−15	−36	6
	L Thalamus						
11	R Precentral Gyrus	4	42	3.76	39	−24	48
	R Postcentral Gyrus	3, 40					
12	L Brainstem		41	4.43	−18	−36	−33
	L Cerebellar Tonsil						
13	L Lentiform Nucleus		40	4.20	−21	3	12
	L Lateral Glo-bus Pallidus						
	L Thalamus						
14	R Inf Semi-Lunar Lobule		32	4.15	24	−69	−42
Strategy Period: Immersion (Stressful Events)							
1	L mOFC	11	796	6.55	−12	−24	39
	B vmPFC	10					
	B dACC	32					
	B MCC	24					
	B SMA	6					
	B Paracentral Lobule						
	R dmPFC	9					
2	L Fusiform Gyrus	20, 37	376	8.01	−39	−30	−12
	L PHG	36, 34					
	L Uncus						
	L Amygdala						
	L Culmen						
3	R STG	22	278	6.11	57	−66	9
	R MTG	21					
4	L Postcentral Gyrus	2	221	5.34	−36	−18	45
	L Precentral	4					

Table 1 (*continued*)

Cluster	Brain region	Brodmann area	Spatial extent	Peak	Center		
				t	x	y	z
	Gyrus						
	L SMA	6					
5	L Putamen		178	7.32	−12	15	9
	L Caudate						
	L Lateral Globus Pallidus						
	L vACC/vmPFC	32, 10					
	L mOFC	11					
6	B RSC	29, 30	166	5.78	−12	−51	12
	B Precuneus	31, 7					
	B dPCC	31					
	R PCC	23					
7	R Putamen		140	5.69	18	12	9
	R Caudate						
8	R PHG		111	4.85	21	−12	−18
	R Mid Insula	13					
	R Claustrum						
9	R MTG	21	80	5.02	42	21	−24
	R Temporal Pole	38					
10	L Uvula		59	5.18	−24	−75	−30
	L Pyramis						
	L Inf Semi-Lunar Lobule						
11	L MFG/vlPFC	10	57	5.16	−30	42	27
	L SFG/dlPFC	9					
12	L MTG	37, 19	56	4.32	−42	−78	27
	L SOG	19					
13	R Cerebellar Tonsil		46	4.90	45	−45	−42
14	L Cerebellar Tonsil		34	5.04	−42	−60	−33
15	R v Anterior Premotor Cortex	44	31	5.33	60	9	12
16	R Fusiform Gyrus	20	30	4.77	42	−24	−3
	R STG	22					
	R PHG	36					
17	L Temporal Pole	38	29	4.83	−48	9	−6
	L Anterior Insula	13					
18	L Temporal Pole	38	26	3.89	−36	18	−27
	L lOFC	47					

Note. Clusters were thresholded at a voxel-wise level of $p<.005$ and a corrected extent threshold of $p<.05$ (26 3 mmx3 mmx3 mm voxels). L=left, R=right, B=bilateral, ACC=anterior cingulate cortex, AG=angular gyrus, d=dorsal, FEF=frontal eye fields, Inf=inferior, IOG=inferior occipital gyrus, IPL=inferior parietal lobule, ITG=inferior temporal gyrus, l=lateral, m=medial, MCC=middle cingulate gyrus, MFG=middle frontal gyrus, Mid=middle, MTG=middle temporal gyrus, OFC=orbitofrontal, PCC=posterior cingulate cortex, PFC=prefrontal cortex, PHG=parahippocampal gyrus, RSC=retrosplenial cortex, SFG=superior frontal gyrus, SFG=superior frontal gyrus, sg=subgenual, SMA=supplemental motor area, SOG=superior occipital gyrus, STG=superior temporal gyrus, STS=superior temporal sulcus, v=ventral.

control networks, and both attention networks.

The distributions of network activity for mindful attention and immersion also differed substantially during the strategy period for stressful events, $\chi^2(6)=562$, $p<.001$. Whereas somatosensorimotor activity was higher for immersion, DMN activity was higher for mindful attention. Activity in both attention networks was also higher during immersion.

A second critical pair of comparisons demonstrates how differently mindful attention operated for stressful vs. non-stressful events (Fig. 4). During the reading period, mindful attention was associated with higher activity across all seven networks for the stressful events than for the non-stressful events, $\chi^2(6)=831$, $p<.001$. In particular, mindful attention especially engaged areas associated with processing stressful situations both physically (visual, somatosensorimotor) and internally (limbic, DMN). Conversely, during the strategy period, greater network activity generally occurred for the non-stressful events, $\chi^2(6)=338$, $p<.001$.

3.4. Linear contrast analyses

In the conjunction analyses just presented, we focused on how neural activity increased significantly above baseline differently across conditions. As we saw, mindful attention and immersion differed considerably in their distributions of neural activity across the reading and strategy periods for the stressful and non-stressful events. Next we address direct differences between mindful attention and immersion in neural activity, rather than contrasting the two strategies with respect to differences in significant neural activity above baseline. Specifically, we report the results of linear contrasts between mindful attention and immersion, first in the reading period, and then in the strategy period. In the results reported here, we collapsed across event type, given that the individual contrasts for stressful and non-stressful events were comparable but weaker (SM Table 3 presents the individual contrasts).

3.4.1. Reading period

The contrast between mindful attention and immersion during the reading period exhibited one small cluster with greater activity for mindful attention in the right inferior occipital gyrus (BA 18, spatial extent=27, peak $t=3.75$, center=27, −81, −9). No other significant clusters emerged.

Notably, the relative lack of direct significant differences between mindful attention and immersion during the reading period contrasts with the large differences in significant neural activity above baseline reported earlier in Figs. 3 and 4 (also in Tables 1 and 2). Although mindful attention and immersion differed considerably in how neural activity increased significantly above baseline in the conjunction analyses, they did not differ as much in their overall levels of neural activity when contrasted against each other.

Examination of activation levels across conditions suggests that the following explanation underlies this pattern of results. In the conjunction analyses, activation typically increased above baseline for *both* mindful attention and immersion in similar brain areas. Interestingly, however, these activations above baseline were often large enough to achieve significance for *either* mindful attention or immersion, but *not* for both (i.e., the significantly active clusters Tables 1 and 2; as SM Tables 1 and 2 illustrate, however, many additional clusters reached significance for *both* strategies). Most importantly, mindful attention sometimes activated brain areas significantly above baseline, with activity in the same areas also above baseline for immersion, but not significantly so (and vice versa). As a consequence, direct contrasts between activation levels for mindful attention and immersion often did not reach significance, because both had increased above baseline. Consistent with this conclusion, additional clusters became significant in the linear contrasts when voxel and/or spatial extent thresholds were lowered.

Thus, our results offer two perspectives on the neural activity associated with mindful attention and immersion. On the one hand, the two strategies differed considerably in the neural clusters that they activated significantly above baseline. On the other hand, they engaged similar brain areas, such that direct contrasts between them were often not significant at standard thresholds.

Table 2
Uniquely active clusters for mindful attention and immersion for non-stressful events during the reading and strategy periods (from two conjunction analyses, one for each period).

Cluster	Brain region	Brodmann area	Spatial extent	Peak		Center	
				t	x	y	z
Reading Period: Mindful Attention (Non-stressful Events)							
1	R Temporal Pole	38	237	6.40	33	12	−30
	R MTG	21					
	R ITG	20					
	R PHG	35, 28					
	R Uncus						
	R Amygdala						
	R Culmen						
2	L MTG	21	138	6.17	−45	6	−27
	L ITG	20					
	L Uncus	20					
	L PHG						
	L Hippo-campus						
	L Amygdala						
	L Culmen						
3	L IOG	18	90	4.42	−36	−75	−18
	L Fusiform Gyrus	18					
	L Lingual Gyrus	18, 17					
	L Declive						
4	R IOG	18	73	4.64	27	−87	0
	R Lingual Gyrus	18, 17					
	R Declive						
5	B Cerebellar Tonsil		54	4.17	3	−51	−42
6	R Pyramis		50	5.65	24	−72	−39
	R Inf Semi-Lunar Lobule						
7	L MFG/dlPFC	46, 8	38	4.39	−42	15	24
8	L PHG	36	31	4.10	−9	−30	−6
	L Culmen						
Reading Period: Immersion (Non-stressful Events)							
1	B vmPFC	10	150	4.68	−9	66	9
	L dmPFC	9					
2	L SFG/FEF	8	99	5.68	−36	15	51
	L Premotor Cortex	6					
3	R MTG	39	92	4.85	51	−66	21
	R STG	22, 39					
4	R Fusiform Gyrus	20, 37	67	6.63	36	−30	−18
	R PHG	36					
	R Uncus	20					
5	L PHG	36, 28	59	5.86	−12	−33	−18
	L Culmen						
6	L lOFC	47	51	5.47	−27	18	−27
	L Temporal Pole	38					
7	R Tuber		49	4.95	24	−63	−30
	R Cerebellar Tonsil						
8	R Postcentral Gyrus	3	44	4.98	39	−21	45
	R Precentral Gyrus	4					
9	R ITG	21	42	5.05	66	−6	−12
	R STS						
10	B mOFC	11	42	5.30	0	30	−21
11	L Culmen		33	4.30	−15	−42	−6
12	L AG	39	32	5.02	−30	−78	39
	L Precuneus	19					
	L SOG	19					
13	R Temporal Pole	38	31	5.74	48	3	−39
14	L Culmen		30	5.20	−42	−36	−27
	L Tuber						

Table 2 (*continued*)

Cluster	Brain region	Brodmann area	Spatial extent	Peak		Center	
				t	x	y	z
Strategy Period: Mindful Attention (Non-stressful Events)							
1	L ITG	20	1140	7.57	−48	6	−24
	L MTG	21					
	L STS						
	L STG	22, 39					
	L Fusiform Gyrus	20					
	L Temporal Pole	38					
	B PHG	35					
	L Uncus						
	L Hippo-campus						
	L Amygdala						
	L Supramar-ginal Gyrus	40					
	L AG	39					
	L IPL	39, 40					
	L Precuneus	19					
	L MFG/vlPFC	46					
	L Anterior Insula	13					
	L lOFC	11, 47					
	B Brainstem						
	B Culmen						
	L Cerebellar Tonsil						
	L Fastigium						
2	L Premotor Cortex	6	750	5.67	−18	15	48
	L Precentral Gyrus	4					
	B SFG/MFG	6					
	L Postcentral Gyrus	3					
	L dmPFC	9					
	B dACC	32					
	L MCC	24					
	B Paracentral Lobule						
	B SMA	6					
3	R Cerebellar Tonsil		301	8.89	18	−78	−33
	R Inf Semi-Lunar Lobule						
	R Pyramis						
	R Uvula						
4	L MFG/vlPFC	46, 10	175	5.93	−18	57	3
	L vmPFC	10					
5	L Inf Semi-Lu-nar Lobule		80	4.93	−18	−78	−36
6	R STS		78	5.32	57	−21	−3
	R MTG	21					
	R Fusiform Gyrus	20					
	R PHG	36					
7	L MFG/FEF	8	55	5.01	−36	18	39
8	L Mid Insula	13	32	3.74	−33	−6	9
	L Claustrum						
	L Putamen						
9	R Postcentral Gyrus	2, 3, 40	30	3.48	33	−24	45
10	R Cerebellar Tonsil		29	4.87	9	−45	−39
11	L mOFC	11	27	4.19	−3	45	−18
12	L Putamen		27	4.13	−15	9	−6
	L Caudate						
13	R IFG/vlPFC	45	27	4.00	57	21	6
Strategy Period: Immersion (Non-stressful Events)							
1	L Paracentral Lobule		175	5.19	−6	−18	39
	L MCC	24					

Table 2 (*continued*)

Cluster	Brain region	Brodmann area	Spatial extent	Peak	Center		
				t	x	y	z
2	B vmPFC	10	156	5.42	−6	27	−12
	B mOFC	11					
	B sgACC						
3	R MTG	37, 39	101	4.93	57	−60	6
	R MOG	37					
4	R Temporal Pole	38	77	4.80	42	6	−39
5	L PHG	20, 36, 37	71	5.16	−30	−39	−12
	L Culmen						
6	L Thalamus		63	5.10	−15	−30	3
	L PHG	30					
	L Lingual Gyrus	18, 19					
	L RSC	30, 29					
7	L lOFC	47	58	4.47	−18	3	12
	L Anterior Insula	13					
	L Claustrum						
	L Putamen						
8	R MTG	21	55	5.32	57	−6	−9
	R STS						
9	R RSC	29, 30	55	4.73	6	−51	9
	R dPCC	31					
10	R Fusiform Gyrus	20	53	5.24	27	−12	−18
	R PHG	36					
	R Hippo-campus						
11	R Precentral Gyrus	4	46	4.36	36	−18	54
	R Postcentral Gyrus	3					
12	R lOFC	47	44	4.44	42	27	−12
	R Anterior Insula	13					
13	R SFG	9	44	4.13	9	63	24
	R dmPFC	9					
14	R dACC	33, 24	33	3.97	12	15	39
15	L Posterior Insula	13	30	3.95	−33	−30	12
	L Claustrum						
16	R Caudate		27	4.43	18	6	6
	R Putamen						
	R Lateral Glo-bus Pallidus						
17	R STG	22	27	4.19	57	−42	15
18	L Uncus		26	5.92	−21	−6	−24
	L PHG						

Note. Clusters were thresholded at a voxel-wise level of $p<.005$ and a corrected extent threshold of $p<.05$ (26 3 mmx3 mmx3 mm voxels). L=left, R=right, B=bilateral, ACC=Anterior Cingulate Cortex, AG=Angular Gyrus, d=dorsal, FEF=Frontal Eye Field, IFG=Inferior Frontal Gyrus, Inf=Inferior, IOG=Inferior Occipital Gyrus, IPL=Inferior Parietal Lobule, ITG=Inferior Temporal Gyrus, l=lateral, m=medial, MCC=Middle Cingulate Cortex, MFG=Middle Frontal Gyrus, Mid-=Middle, MOG=Middle Occipital Gyrus, MTG=Middle Temporal Gyrus, OFC=Orbitofrontal Gyrus, PCC=Posterior Cingulate Cortex, PFC=Prefrontal Gyrus, PHG=Parahippocampal Gyrus, RSC=Retrosplenial Cortex, SFG=Superior Frontal Gyrus, sg=Subgenual SMA=Supplemental Motor Area, SOG=Superior Occipital Gyrus, STG=Superior Temporal Gyrus, STS=Superior Temporal Sulcus, v=ventral.

When direct contrasts *were* significant, they indicated especially large differences between the two strategies. The results reported next for the strategy period illustrate such differences.

3.4.2. Strategy period

The contrast between mindful attention and immersion for the strategy period exhibited the differences listed in Table 3 and illustrated in Fig. 5E. Brain areas more active for mindful attention than for immersion included lPFC, mPFC (BA 8), AG, and inferior and middle occipital gyrus. Conversely, areas more active for immersion than for mindful attention included the subgenual cingulate cortex (sgACC), ventral anterior cingulate cortex (vACC), and ventromedial prefrontal cortex (vmPFC) / medial orbitofrontal cortex (mOFC).

4. Discussion

As described earlier, chronic stress can produce wear and tear on the brain and body, thereby negatively affecting physical and psychological well-being (Keller et al., 2012; McEwen, 1998). As also described earlier, one factor that makes thoughts about difficult situations feel stressful is the sense of immersion, that is, the sense that one has mentally time traveled into the imagined situation. As a result of immersion, the self becomes engaged with the situation and has the experience of 'living it' (*subjective realism*; Papies et al., 2012·, 2015). We predicted that the neural correlates of immersion would include brain areas associated with sensorimotor simulations of an event, together with areas associated with affect and a visceral sense of self. Finally, subjective realism can be blocked through the process of decentering – realizing that thoughts, feelings, and reactions are just transitory patterns of mental activity, such that the experience of 'living' the event dissipates (Papies et al., 2012, 2015). From our perspective, decentering prevents subjective realism by disengaging a person's sense of self from an imagined event. We predicted that the neural correlates of decentering in our meditation-naïve sample would include brain areas that contribute to perspective shifting, effortful attention, and regulatory processing.

4.1. Mindful attention prevents affective responses from developing whereas immersion produces up-regulation

Using conjunction analyses to establish neural activity significantly above an active baseline, we found major differences between mindful attention and immersion over time. During mindful attention to stressful events, participants exhibited much more unique neural activity above baseline during the reading period than during the strategy period (Fig. 3, top left). Although participants had been instructed to only read events during the reading period (and then to apply mindful attention during the strategy period), they appeared to begin applying the strategy while reading. Because mindful attention aims to regulate immersion in stressful events, mindfully attending while comprehending stimuli during the reading period could prevent strong affective and embodied responses from developing later. As a further consequence, less neural activity may have occurred during the strategy period, because the stressful events had already been regulated during the reading period. The brain areas active in the network analysis, discussed shortly, support this account.

During immersion, participants appeared to minimize processing of the stressful events initially, waiting to begin simulating the situated details of these events until the strategy period (Fig. 3, top right). Whereas mindful attention immediately engaged brain areas associated with simulation, regulation, and perspective shifting while reading about stressful events, immersion waited to up-regulate neural activity until the strategy period (see Kavanagh et al., 2005, for a similar role of elaborated mental imagery in desire). By operating quickly, mindful attention may down-regulate potentially stressful affective and bodily responses, making them less likely to develop (Brown et al., 2012; Hoge et al., 2013). This pattern of results may reflect a willingness to engage immediately with unpleasant states, and it may also reflect a reduction in emotional reactivity via rapid decentering (Bränström et al., 2010; Brown et al., 2007; Keng et al., 2011; also see desensitization, Baer, 2003). Indeed, actively engaging with negative

experience has the potential to reduce experiential avoidance, a key goal in DBT and ACT (Hayes et al., 2006; Keng et al., 2011).

Interestingly, mindful attention exhibited different distributions of neural activity for stressful vs. non-stressful events (Fig. 3, left). During the reading period, more neural activity occurred above baseline for stressful events, suggesting that they afford salient affective and bodily responses that mindful attention can regulate (Papies et al., 2015). Conversely, non-stressful events produced greater neural activity during the strategy period, suggesting that greater effort was required to generate appropriate thoughts relevant for applying mindful attention. Similarly, for immersion, participants again appeared to delay immersing themselves in the non-stressful events until the reading period, as they had done for the stressful events.

Analyses using Yeo et al.'s (2011) seven resting state networks corroborated the results for the conjunction analyses just described. For mindful attention to stressful events, the distribution of unique clusters across Yeo et al.'s networks changed significantly from the reading period to the strategy period (Fig. 4, top left). Initially during the reading period, large amounts of unique activity occurred in somatosensorimotor, visual, and limbic networks, with some activity in the dorsal attention network, suggesting that participants were simulating the scenarios (Damasio, 1999; Ganis et al., 2004), and attempting to regulate responses to them by shifting attention (Corbetta and Shulman, 2002; Froeliger et al., 2012). During the strategy period, these activations decreased, suggesting that participants were no longer simulating the scenarios and emotional reactions to them as vividly, given that they had been down-regulated during the reading period (consistent with the results in Fig. 3, top left).

Mindful attention to stressful events also produced large amounts of default mode network (DMN) activity during both the reading and strategy periods. Other mindfulness research only demonstrates decreased activation in DMN hubs (e.g., mPFC, PCC) for expert meditators, or sometimes for novices at lower thresholds (Farb et al., 2007). Because the DMN is implicated in internal goal-directed activity (e.g., Spreng et al., 2010), it may be highly engaged when first learning mindfulness practices.

For immersion in stressful events, the reading and strategy periods also exhibited large differences in the distributions of unique neural activity across networks (Fig. 4, top right). Relative to the reading period, large increases occurred during the strategy period in the somatosensorimotor, limbic, default mode, and ventral attention networks. As suggested earlier, participants may have waited until the strategy period to immerse themselves in the stressful events, simulating both the external situations and their internal reactions to them, especially personal salience.

For mindful attention to non-stressful events, the distribution of unique neural activity differed across the reading and strategy periods (Fig. 4, bottom left). During the strategy period, visual activity decreased while somatosensorimotor activity increased, suggesting that participants increasingly imagined acting in the non-stressful events. Increased activity in the DMN, the frontoparietal control network, and both attention networks during the strategy period further suggests that self-referential (Buckner et al., 2008) and effortful goal oriented processing (Spreng et al., 2013) increased as well. Because the non-stressful events did not readily afford emotional and bodily reactions, participants may have worked harder to produce thoughts relevant for mindful attention.

For immersion in non-stressful events, the distribution of unique neural activity again differed across the reading and strategy periods (Fig. 4, bottom right). Similar to mindful attention, somatosensorimotor activity increased, suggesting increased action engagement in the non-stressful situations. Similar to immersion in stressful events, activity in the ventral attention network increased, suggesting that effortful processing related to personal salience increased, perhaps working to generate affective and bodily responses. Unlike mindful attention, DMN activity decreased, perhaps reflecting a greater focus on the physical situation for immersion than on mental states for mindful attention (Buckner et al., 2008).

4.2. Mindful attention promotes perspective shifting and regulatory activity whereas immersion engages a visceral sense of self

Direct contrasts between mindful attention and immersion found, first, that both strategies activated many similar areas, and second, that a small subset of areas were significantly more active for one strategy vs. the other (Table 3 and Fig. 5E). Specifically, the brain areas more active for mindful attention than for immersion are associated with perspective shifting (AG; Seghier, 2013), executive and attentional control (lPFC; Spreng et al., 2013), augmented inhibitory control (mPFC, BA 8; Tang et al., 2012), and visual processing (inferior and middle occipital gyrus). Lack of expertise with mindful attention may have required greater shifts in perspective than did the more natural and familiar process of immersion. To implement this newly-learned mode of perspective shifting, participants may have needed to exert greater effort during mindful attention than during immersion, thereby engaging executive and regulatory areas. Higher visual activity may have reflected increased attention on imagined situations.

Conversely, areas more active for immersion than for mindful attention included the subgenual cingulate cortex (sgACC), ventral anterior cingulate cortex (vACC), and ventromedial prefrontal cortex (vmPFC)/medial orbitofrontal cortex (mOFC). As established elsewhere, these areas are often involved when integrating visceral states (Vogt, 2005), monitoring and processing reward (Elliot et al., 2000), attending to feelings (Kross et al., 2009), and labeling stimuli as self-relevant (Northoff and Bermpohl, 2004). Thus, immersion appeared to engage stronger self, bodily, and affective responses than did mindful attention, consistent with engaging oneself in events physically, becoming immersed in them, and experiencing them as subjectively real.

Overall, the results for these contrasts are consistent with the following conclusion: During the strategy period, mindful attention caused a shift in perspective that disengaged an embodied sense of self from simulated events (decentering). On the one hand, activations in AG, lPFC, and mPFC suggest that mindful attention shifted perspective through the use of regulatory processes. On the other hand, decreased activations in sgACC, vACC, vmPFC, and mOFC suggest that an embodied sense of self was less active for imagined events during mindful attention than during immersion. As a consequence, imagined events were experienced as transitory mental states in the current moment. An important goal for future research is to examine this pattern of neural activity further, establishing whether a causal relation exists between perspective shifting and reductions in self-engagement.

4.3. Relations to previous neuroimaging findings

As mentioned above, relative to immersion, mindful attention exhibited significantly less neural activity in sgACC, vmPFC, and mOFC. As previous research shows, these areas are associated with integrating visceral, autonomic, and affective states, representing the reward value of stimuli, and establishing self-relevance (e.g., Ressler and Mayberg, 2007; Kross et al., 2009; Greicius et al., 2007; Northoff and Bermpohl, 2004). Together, these areas may contribute to the experience of subjective realism. Several recent studies have similarly found that mindfulness is associated with low activity in these areas (e.g., Farb et al., 2007; Kross et al., 2009; Westbrook et al., 2013). Thus, our findings suggest that mindful

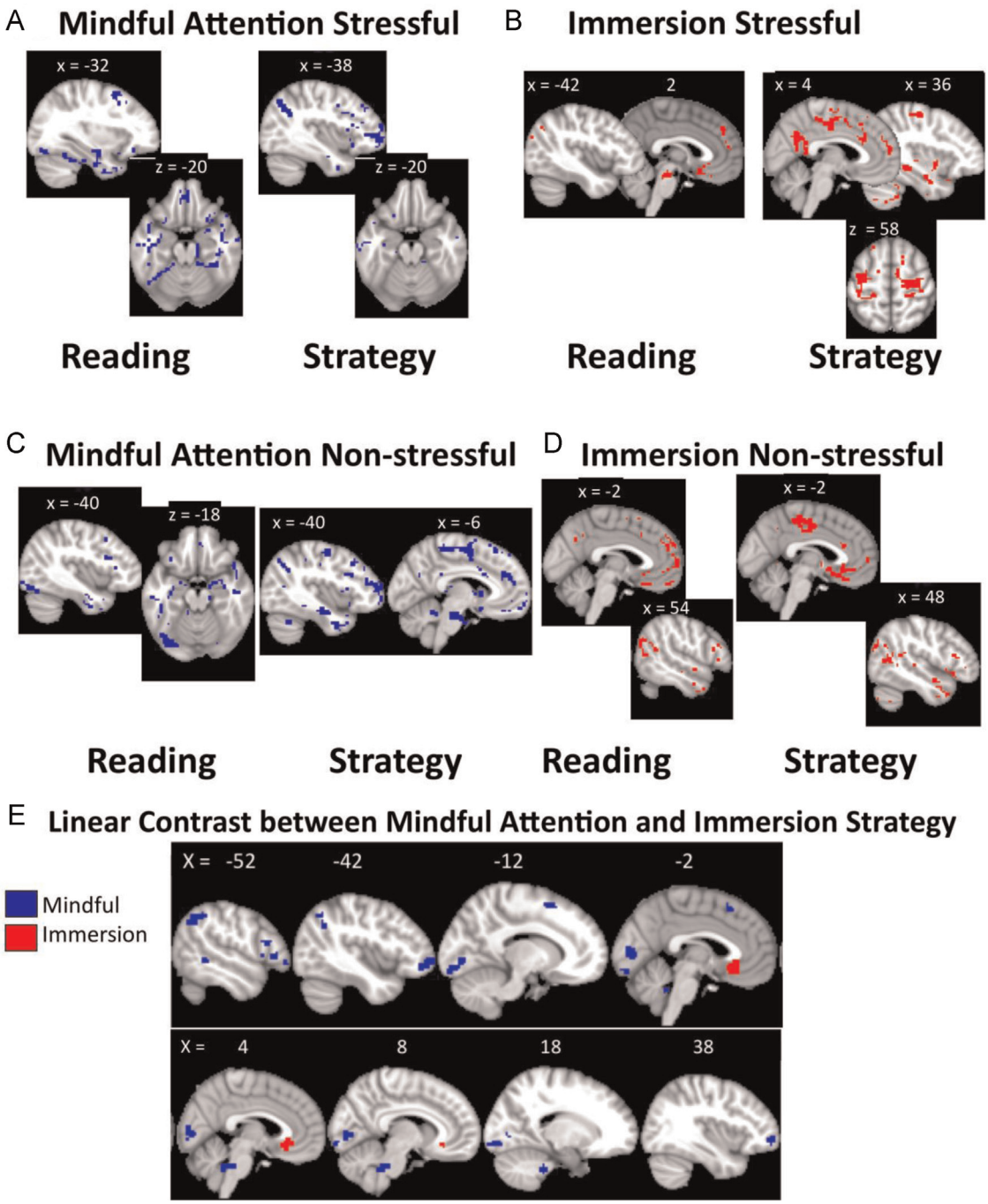

Fig. 5. Panels A–D illustrate unique activations from the conjunction analyses across mindful attention and immersion reported in Tables 1 and 2 and Figs. 4 and 5 (A. Mindful Attention Stressful; B. Immersion Stressful; C. Mindful Attention Non-stressful; D. Immersion Non-stressful). Panel E illustrates activations from the linear contrast between mindful attention and immersion during the strategy period, collapsed across stressful and non-stressful events.

attention, too, is associated with lower activity in these areas, consistent with our conclusion that decentering results from disengaging the self from imagined situations.

Conversely, mindful attention produced higher activations than immersion in brain areas associated with executive processing (lPFC) and inhibitory control (mPFC, BA 8). Activity in these regions is increasingly recognized as a hallmark of mindfulness in less experienced meditators, requiring more effort than for experts (e.g., Creswell et al., 2007; Farb et al., 2007, 2010; Tang et al., 2012). Likewise, several activations for mindful attention overlapped with the frontoparietal control network (e.g., lPFC, dmPFC, AG) and the dorsal attention network (e.g., superior frontal, frontal eye fields, middle temporal, occipital cortex). Whereas the frontoparietal control network facilitates goal-directed cognition through executive control, the dorsal attention network controls externally directed attention (Spreng et al., 2013).

Greater activity for mindful attention also occurred in parietal cortex (AG, inferior parietal lobule IPL). Similar areas are associated with high trait mindfulness (Dickenson et al., 2013), and with increased gray matter following MBSR (Hölzel et al., 2011). AG activity is also associated with transferring attention to relevant targets (Gottlieb, 2007; Seghier, 2013), and with shifting between first and third person bodily perspectives (Blanke et al., 2005). Interestingly, our AG coordinates are closest to those for activity associated with external agency attribution (Seghier, 2013; Sperduti et al., 2011), again suggesting that decentering may

Table 3
Clusters significantly active in a linear contrast between mindful attention vs. immersion during the strategy period (collapsed across stressful and non-stressful events).

Cluster	Brain region	Brodmann area	Spatial extent	Peak	Center		
				t	x	y	z
Mindful Attention > Immersion (Strategy Period)							
1	B IOG	18, 17	261	3.95	−3	−90	−12
	L MOG	18					
	B Lingual Gyrus	18, 17					
2	L vlPFC	10	144	4.69	−42	45	−12
3	L vlPFC	45	93	4.84	−54	30	3
	L v Anterior Premotor Cortex	44					
4	L IPL	40, 39	82	4.14	−48	−57	39
	L AG	39					
5	B Cerebellar Tonsil		80	4.61	9	−39	−36
	B Brainstem (Pons)						
6	L MTG	21	72	3.89	−60	−45	−6
7	L SFG/FEF	8	40	3.80	−15	9	57
	L mPFC	8					
8	R vlPFC	10	29	4.65	36	54	−3
Immersion > Mindful Attention (Strategy Period)							
1	B mOFC/ vmPFC	11	75	−5.33	0	24	−12
	B vACC	24, 32					
	B sgACC	25					

Note. Clusters were thresholded at a voxel-wise level of $p < .005$ and a corrected extent threshold of $p < .05$ (26 3m mx3 mmx3 mm voxels). L=left, R=right, B=bilateral, ACC=Anterior Cingulate Cortex, AG=Angular Gyrus, FEF=Frontal Eye Field, IOG=Inferior Occipital Gyrus, IPL=Inferior Parietal Lobule, l=lateral, m=medial, MOG=Middle Occipital Gyrus, MTG=Middle Temporal Gyrus, OFC=Orbitofrontal Gyrus, PFC=Prefrontal Gyrus, SFG=Superior Frontal Gyrus, sg=Subgenual, v=ventral.

disengage the self from simulated events.

Additionally, activity for mindful attention occurred in the brainstem and cerebellum. Hölzel et al. (2011) reported increased gray matter in both these regions after extended mindfulness training. Whereas the brainstem contributes to arousal and mood (Singleton et al., 2014), the cerebellum contributes to emotion regulation (Schmahmann et al., 2007). Thus, activity in these areas may reflect participants attempting to down-regulate affect (although see recent meta-analysis in which structural changes in the brainstem due to meditation training are not replicated consistently; Fox et al., 2014).

4.3.1. Inconsistencies with earlier findings

The contrast analyses between mindful attention and immersion did not demonstrate differential activity for internally-oriented self-referential processing in the DMN (e.g., mPFC, PCC; Buckner and Carroll, 2007). Although many meditation studies demonstrate reduced DMN activity, this reduction occurs primarily for expert meditators, or sometimes for novices at lower thresholds (e.g., Farb et al., 2007; Taylor et al., 2011; Brefczynski-Lewis et al., 2007). Many novice studies actually report higher activation in mPFC relative to experts, perhaps reflecting greater regulation of thought (Brefczynski-Lewis et al., 2007; Hölzel et al., 2007; Taylor et al., 2011) and emotion (Modinos et al., 2010; Ochsner et al., 2002; Ochsner and Gross, 2005).

Additionally, other studies report increased activity and structural changes in mOFC and vACC for meditators (e.g., Klimecki et al., 2012; see Fox et al. (2014) for a review). In contrast, we observed decreased activity in mOFC/vmPFC and vACC for mindful attention, together with greater activity in these regions and in sgACC for immersion. Two factors could underlie this discrepancy: (1) Because the peak activation for our immersion cluster was in sgACC, it is possible that nearby OFC and vACC activity resulted from smoothing during preprocessing; (2) Structural and functional differences in these areas may often reflect practice effects, such that novice meditators exhibit less activity in these areas than do experts (Fox et al., 2014).

The contrast analyses also did not demonstrate differential activity in insular cortex or in the hippocampus, areas sometimes related to mindfulness in other research (e.g., Dickenson et al., 2013; Farb et al., 2007). Structural differences in the hippocampus between meditators and controls demonstrate a modest correlation with meditation experience, suggesting that brief decentering instruction may not engage this area (Fox et al., 2014). Structural differences in the insula between meditators and controls may result from practicing body-focused meditation techniques (e.g., Vipassana/insight meditation; Fox et al., 2014), thereby explaining the lack of insula activation when learning decentering in isolation.

4.4. Implications for interventions and limitations related to extended practice

Consistent with research described earlier, we found that brief mindful attention instruction produced immediate changes in how people process stressful events. Such rapid acquisition of a metacognitive strategy suggests that all individuals possess the basic decentering mechanism associated with mindfulness. The findings reported here further suggest that decentering can happen relatively quickly when first representing an event, and that it operates most effectively on highly affective events (also see Papies et al., 2015). Additionally, our results suggest that decentering draws on regulatory and perspective shifting resources in the brain, which, in turn, down-regulate neural areas associated with an embodied sense of self. As a consequence of perspective shifting, the self becomes decentered from the imagined event.

We hasten to add, however, that the decentering skill demonstrated here for non-meditators may lie on the earliest part of the learning curve. Some research suggests that time spent in meditation practice correlates with a variety of behavioral and neural changes, and with well-being (Carmody and Baer, 2008; Chiesa and Serretti, 2010; Hölzel et al., 2011, although see Fox et al., 2014, for problems with replication). An important goal for future work is to better understand how these initial skills develop, together with the trajectory of changes that occur with greater practice. Nevertheless, it appears that a wide variety of mindfulness interventions in lay and clinical settings can capitalize on a preexisting skill for decentering.

Author contributions

LAML, LWB, EKP, LFB, KG, and KQ developed the initial study concept and design. LAML played the primary role in implementing, running, and analyzing the experiment in the Barsalou Lab at Emory University. LWB played central roles in implementing the experiment, analyzing the results, and managing the project. KG and RC also played central roles in implementing the procedure. KG played a leading role in developing and implementing the analyses. VK assisted with programming related to a preliminary imaging preprocessing analysis. KQ and RC played central roles in analysis and interpretation of peripheral physiological data not reported in this manuscript. LAML, LWB, EKP, LFB, and KG contributed to the interpretation of the results. LAML, and

LWB drafted the manuscript, and all authors contributed to revising it. LWB and LFB are joint senior authors. All authors approved the final version for submission.

Declaration of conflicting interests

The authors declared that they had no conflicts of interest with respect to their authorship or the publication of this article.

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Appendix A. Supplementary Materials

Supplementary materials associated with this article can be found in the online version at http://dx.doi.org/10.1016/j.neuropsychologia.2015.05.030.

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