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Alterations in Affective Processing of Attack Images Following September 11, 2001

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The events of September 11, 2001 created unprecedented uncertainty about safety in the United States and created an aftermath with significant psychological impact across the world. This study examined emotional information encoding in 31 healthy individuals whose stress response symptoms ranged from none to a moderate level shortly after the attacks as assessed by the Impact of Event Scale-Revised. Participants viewed attack-related, negative (but attack-irrelevant), and neutral images while their event-related brain potentials (ERPs) were recorded. Attack images elicited enhanced P300 relative to negative and neutral images, and emotional images prompted larger slow waves than neutral images did. Total symptoms were correlated with altered N2, P300, and slow wave responses during valence processing. Specifically, hyperarousal and intrusion symptoms were associated with diminished stimulus discrimination between neutral and unpleasant images; avoidance symptoms were associated with hypervigilance, as suggested by reduced P300 difference between attack and other images and reduced appraisal of attack images as indicated by attenuated slow wave. The findings in this minimally symptomatic sample are compatible with the alterations in cognition in the posttraumatic stress disorder (PTSD) literature and are consistent with a dimensional model of PTSD.

The events of September 11, 2001 (9/11) were an unprecedented terrifying experience that posed tremendous uncertainty about safety in the United States and throughout the world. In response, 8–10% of the residents of New York City (NYC) reported symptoms consistent with a diagnosis of posttraumatic stress disorder (PTSD) and depression (Galea et al., 2002). In another study, over 40% of Americans across the country were reported to experience significant symptoms of stress related to the attacks (Lee, Isaac, & Janca, 2002; Schuster et al., 2002). The dramatic differences in the prevalence rates of PTSD symptoms in these studies are most likely due to the different cutpoints used by the authors to determine if someone fell into the clinically significant stress response category, but actual levels could well have been quite similar. Results such as these have continued the debate in the field as to whether posttrauma stress responses are better characterized as dimensional or categorical in nature, and inform the relationship between acute stress disorder (ASD) and PTSD.

Participants in the present study, like the rest of the world, varied in the severity of the reactions to the events of 9/11. The current study, however, was implemented in a unique sample of young, unmedicated, well-educated individuals who besides experiencing a range of stress reactions following media exposure to the attacks, do not share the confounding variables reported by participants in many studies of PTSD. Therefore, similar findings in these individuals as those typically found in the PTSD literature would provide some support for the position that high levels of symptoms are simply at the end of a dimensional construct rather than being a qualitatively different category.

This study was conducted within 1 week following 9/11, to determine how the events affected the manner in which otherwise healthy individuals encoded emotional information and event-related potentials (ERPs) of altered valence processing were

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related to specific stress symptoms. The ERP responses were prompted using affective pictures—attack-related, negative (but attack-irrelevant), and neutral images. Below we review three ERP components elicited during affective picture processing that may enhance our understanding of the cognitive effects of exposure to highly stressful events.

N200 (or N2), a negative-going wave peaking at around 200 ms after stimulus presentation, is generally thought to reflect early attention allocated to stimulus discrimination (Näätänen, 1982). In affective picture paradigms, N2 is also related to valence of the stimuli, such that unpleasant images elicit reduced N2 amplitude compared to pleasant or neutral images (Carretie, Hinojosa, Martin-Loeches, Mercado, & Tapia, 2004; Moser, Hupper, Duval, & Simons, 2008; Silvert, Nobre, Fragopanagos, Taylor & Eimer, 2007). N2 in the PTSD literature has been studied most often using auditory paradigms, where N2 for neutral targets is generally found to be delayed, suggesting slower stimulus discrimination (e.g., Felmingham, Bryant, Kendall, & Gordon, 2002; Galletly, Clark, McFarlane, & Weber, 2001; McFarlane, Weber, & Clark, 1993; Metzger et al., 2009). Visual N2 data in anxiety and PTSD are scarce, though normal N2 amplitude has been reported in an emotionally neutral sustained attention task (Shucard, McCabe, & Szymanski, 2008), while others have reported diminished N2 modulation by threat stimuli in high anxious subjects (Dennis & Chen, 2009), suggesting that attention may be attenuated as a defensive response in PTSD, resulting in emotional numbing (Menning, Renz, Seifert, & Maercker, 2008). These data are consistent with the behavioral findings that performance of participants with PTSD is compromised when emotional stimuli are used (see Banich et al., 2009 for a review). More N2 data are needed to evaluate the affective modulation of early attention in traumatic stress reactions and its relationship with specific symptoms.

P300, a positive-going wave occurring around 300 ms after stimulus onset, is thought to index attention (P3a, over the frontocentral region) and task-relevant memory update (P3b, over the parietal region; Polich, 2007). P300 elicited by images is often coupled with a later, sustained positivity and together are referred to as the late positive potential (LPP). P300/LPP is consistently larger to emotional than neutral pictures (Amrhein, Muhlberger, Pauli, & Wiedemann, 2004; Cuthbert, Schupp, Bradley, Birbaumer, & Lang, 2000). The affective P300/LPP effect is typically maximal over the parietal region and significantly correlated with hemodynamic activity in visual cortical structures (Sabatinelli, Lang, Keil, & Bradley, 2007). This leads researchers to believe that emotional images are processed automatically and can be considered natural targets in the visual scene due to their intrinsic motivational significance (see Hajcak, McNamara, & Olvet, 2010).

The large body of P300 literature in PTSD comprises mostly studies using oddball paradigms. The general finding highlights the importance of emotional information processing in PTSD: individuals with PTSD show reduced P3b to targets in nonemotional contexts, but enhanced P3b to neutral targets when the distractors contain trauma-related or threatening information (see Karl, Malta, & Maercker, 2006 for a review). In other words, when the context is perceived as innocuous, mental resources for updating short-term memory are reduced. In the facto of possible threat, however, mental resources are indiscriminately increased to monitor threat. This may explain the clinical observation of hypervigilance in PTSD.

There is some evidence that abnormal P3 responses are related to specific PTSD symptoms. For example, individuals with more severe numbing symptoms showed reduced overall P300 responses (Felmingham et al., 2002), whereas individuals high in hyperarousal and reexperiencing symptoms exhibited enhanced P300 to distractors (Shucard et al., 2008). It remains to be demonstrated whether previous P3 findings in PTSD and anxiety disorders can be generalized across tasks and perceptual modalities.

Slow wave (SW) is a late-latency ERP component thought to index more controlled, elaborative cognitive operations such as mental rehearsal (Ruchkin, Johnson, Grafman, Canoune, & Ritter, 1992). For example, in a stimulus discrimination paradigm, positive SW—particularly over frontal and parietal regions—reflects updating and rehearsal of working memory stores (Clark, Orr, Wright, & Weber, 1998). The SW in image-viewing paradigms occurs after 500 ms poststimulus onset and can last at least up to 6 s. Affective images elicit increased SW positivity compared to neutral images. Because elevated SW prompted by affective pictures is correlated with later better recall of these pictures (Dolcos & Cabeza, 2002), the SW is suggested to index mental rehearsal required for memory formation. The affective effect on SW is subject to the influences of top-down processes such as appraisal strategy (Hajcak, Moser, & Simons, 2006) and suppression of emotional reactions (Moser, Hajcak, Bukay, & Simons, 2006). The SW data in PTSD are scarce, most likely due to the prevalent use of brief stimulus presentation and short time epochs for ERP analyses. The only study we are aware of is Galletly et al. (2001), which found decreased frontal and posterior SW to targets and non-targets in a tone discrimination task among individuals with PTSD, suggesting disrupted executive processes and memory formation of affectively neutral information. Demonstrating a relationship between reduced SW during emotional information processing and specific aspects of stress response would provide a better neurophysiological understanding of altered mental operations caused by trauma exposure.

Based on the findings reviewed, we hypothesized that attack, negative, and neutral images would elicit differential N2, P300, and SW responses due to their differences in valence and arousal levels. Further, ERPs elicited by affective images, particularly attack images, would be correlated with all three PTSD symptom clusters as well as overall elevation of symptoms.

METHOD

Participants

A sample of 31 university students in Boston, Massachusetts (17 women, 14 men; 28 right-handed, 3 left-handed) not directly involved in the attacks and who had no immediate family or close friends involved, were recruited for the study within 1 week following 9/11. This was the first week of the academic year, and participants were recruited as part of a larger event for students interested in psychology studies. Therefore, exposure to the events was limited to media coverage and exchanges with others not directly affected by the attacks. Participants with major medical illness, history of mental illness, or on psychotropic medications were excluded using a screening questionnaire. Written informed consent was obtained from each participant after information of the study was provided in detail.

Procedures

Participants completed the Impact of Event Scale-Revised (IES-R; Weiss & Marmar, 1997), designating the traumatic event as the events of 9/11, and the Beck Depression Inventory (BDI; Beck, Steer, & Brown, 1996). Sums rather than the standard mean scoring was used for the IES-R. Following the viewing of the images, participants rated the valence (1 = *pleasant* through 9 = *unpleasant*) and arousal (1 = *calm* through 9 = *aroused*) of each of the images using the Self-Assessment Manikin (SAM; Bradley & Lang, 1994).

The passive picture-viewing task used in this study contained 90 images presented in random order, each presented for 2 s with an interstimulus interval of 12–18 s. Thirty were "attack" pictures (images taken from the media and directly related to the events of 9/11), 30 were selected to be negative but not involving 9/11 (images of other conflicts and natural disasters displayed in the contemporary media), and 30 were neutral (taken from the International Affective Picture System, IAPS; Lang, Ohman, & Vaitl, 1988). Due to the limited amount of time and pool of 9/11-related images available at the time, image characteristics (e.g., color, complexity, presence of people) were not explicitly matched between the three categories of images; the stimuli in both the attack and negative categories contained a range of complex images with and without people.

An electroencephalogram (EEG) was recorded from frontal (F3, F4, Fz), central (C3, C4, Cz), and parietal (P3, P4, Pz) sites using a Lycra stretchable cap (Electro-Cap International Inc., Eaton, OH) with Ag/AgCl electrodes positioned according to the International 10-20 system. Electro-oculogram (EOG) data were recorded from electrodes placed lateral to the outer canthi and at the left supraorbital and suborbital positions. Electrode impedances were kept below 5 kΩ. EEG was referenced to the left mastoid (M1) and re-referenced to average mastoids offline ([M1 + M2]/2). The EEG signals were amplified with a 37/64 channel amplifier (SA Instrumentation Company, CA) and were digitally sampled at the rate of 2000 Hz with a high-pass analog filter at 0.01 Hz and low-pass at 100 Hz.

The EEG data reduction was conducted using BrainAnalyzer software (BrainVision, Gmbh, Saarbrucken, Germany). Data were segmented into 2.5-s epochs (500-ms baseline, 2000-ms poststimulus) with respect to the stimulus onset. This was followed by the application of a 60-Hz notch filter and correction of eye-blink artifact using the Gratton, Coles, and Donchin (1983) regression algorithm. Individual trials exceeding ± 80 μV were automatically rejected. Data were subsequently subjected to visual inspection and manually scored to remove remaining artifact. Data were then baseline adjusted, and averaged across trials for each of the three valence conditions.

The ERP components were identified based on a literature review and principal component analysis (PCA) with an extraction criterion of eigenvalue > 1 and Varimax rotation. An ERP component was defined as a contiguous set of points with factor loadings ≥ .60 on a single principal component. Three distinctive ERP components were identified: N2 (150–340 ms), P300 (340–820 ms), and SW (820–2000 ms). The mean PCA score (i.e., product of brain potentials and component loadings) of each of these ERP components was used in analyses.

Statistical Analyses

Valence and arousal ratings of the images were analyzed separately using repeated-measures analysis of variance (ANOVA), with stimulus valence as the within-subjects variable. N200 was analyzed with a 3 (Valence: attack, negative, neutral) × 3 (Laterality: F3, Fz, F4) repeated-measures ANOVA. P300 was analyzed in the same manner, except that parietal (P3, Pz, P4) instead of frontal sites were used (Cuthbert et al., 2000). For SW, because it is unclear from the literature whether it has a specific topographic distribution for this paradigm, a 3-way 3 (Valence: attack, negative, neutral) × 3 (Laterality: left, midline, right) × 3 (Caudality: frontal, central, parietal) repeated-measures ANOVA was performed. For all ANOVAs, Huynh-Feldt adjustment was used in case of violation of the assumption of sphericity. Relations between the ERP measures and stress symptom clusters were examined with Pearson correlations.

RESULTS

Distress related to the attacks ranged from minimal to a few respondents endorsing a moderate level—total IES-R scores ranged from 5 to 41 ($M = 20.35$, $SD = 10.33$). The range of scores for the three IES-R subscales were as follows: Intrusion 1–16 ($M = 8.45$, $SD = 4.24$), Avoidance 2–18 ($M = 8.31$, $SD = 4.88$), and Hyperarousal 0–10 ($M = 3.59$, $SD = 3.12$). The BDI

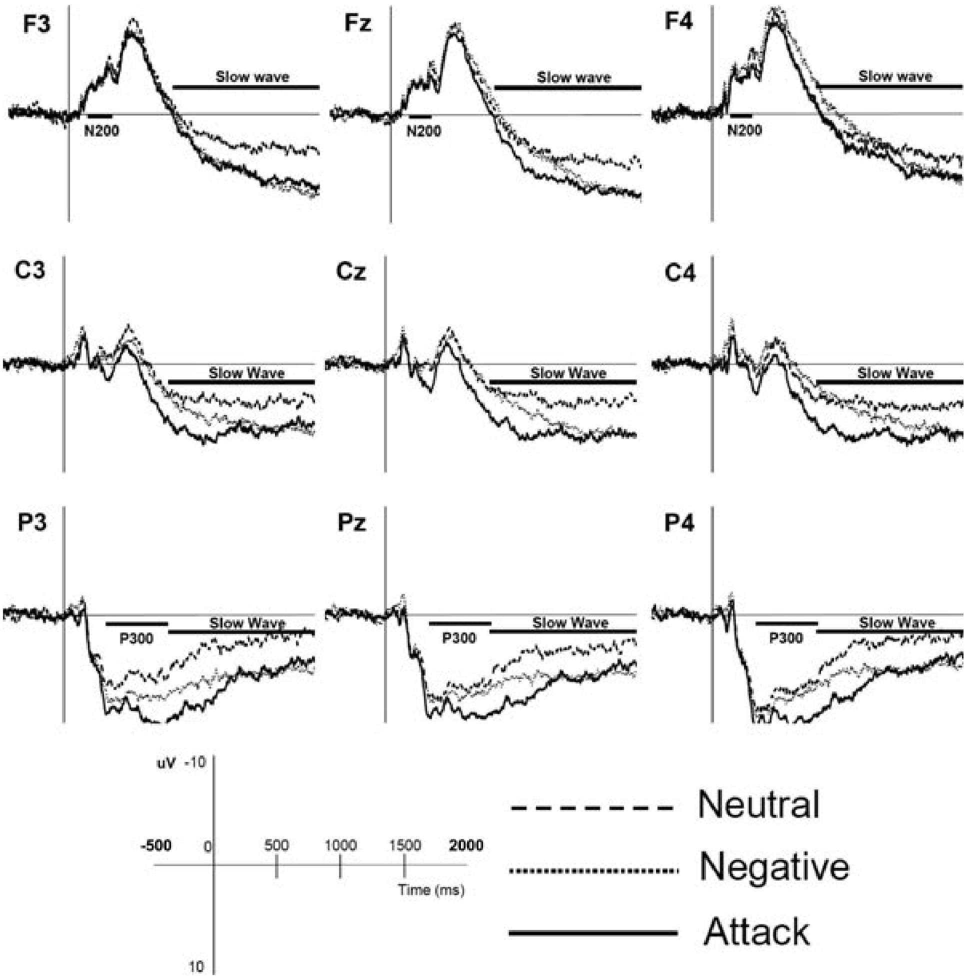

Figure 1. Event-related potentials evoked by Attack, Negative, and Neutral images. Stimulus onset occurred at 0 ms. Electrodes are displayed from most anterior (top) to most posterior (bottom) and from left to right as they were positioned on the scalp.

scores ranged from 0 to 14 ($M = 5.36$, $SD = 3.53$). The distress variables showed slightly skewed distributions.

Participants rated the attack images as more unpleasant than the negative images, ($M = 7.02$, $SD = 0.84$) versus ($M = 6.72$, $SD = 0.91$), which were in turn rated as more unpleasant than the neutral images ($M = 4.90$, $SD = 0.70$). The ANOVA yielded the following: $F(1.24, 33.49) = 61.98$, $p < .001$, partial $\eta^2 = .70$. Participants rated the attack ($M = 6.40$, $SD = 1.28$) and negative images ($M = 6.27$, $SD = 1.15$) as more arousing than the neutral images ($M = 3.23$, $SD = 1.62$); $F(1.23, 33.88) = 72.18$, $p < .001$, partial $\eta^2 = .73$; attack and negative images were not statistically different in arousal rating.

Grand average waveforms at each of the nine sites in the attack, negative, and neutral conditions are presented in Figure 1. N2 responses were not different across valence conditions, $F(2, 60) = 0.23$, $p = .794$, but were lateralized to the right ($M = -3.18$, $SD = 2.78$), $F(2, 60) = 5.10$, $p = .009$, partial $\eta^2 = .15$, with no significant difference ($p = .906$) between left ($M = -2.57$, $SD = 2.68$) and midline N2 ($M = -2.54$, $SD = 2.64$). The Valence × Laterality interaction was not significant.

For P300 there was a strong valence effect, $F(2, 60) = 8.77$, $p < .001$, partial $\eta^2 = .23$, where P300 response to attack images ($M = 7.71$, $SD = 3.84$) was larger than negative ($M = 6.56$, $SD = 4.43$) and neutral images ($M = 5.75$, $SD = 4.07$); negative and neutral images were not different ($p = .109$). Although P300 did not show an overall laterality effect, $F(2, 60) = 1.54$, $p = .222$, there was a Valence × Laterality interaction, $F(4, 120) = 3.77$, $p = .006$. Post hoc analyses revealed that emotional images (attack and negative) elicited larger P300 over the left hemisphere

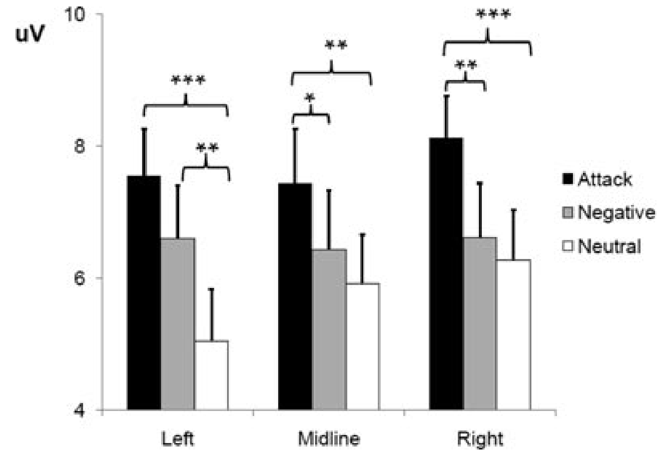

Figure 2. Valence × Laterality interaction of parietal P300 responses.
$^{*}p < .05$. $^{**}p < .01$. $^{***}p < .001$.

than neutral images did, and attack images elicited larger P300 at midline and right sites than attack-irrelevant (negative and neutral) images (see Figure 2).

There was also a strong valence effect for SW, $F(2, 60) = 7.25$, $p = .002$, partial $\eta^2 = .20$. Unlike the P300 valence effect, however, both attack ($M = 5.18$, $SD = 3.69$, $p = .001$) and negative images ($M = 4.61$, $SD = 3.05$, $p = .016$) elicited larger SW than neutral images ($M = 2.88$, $SD = 4.08$) did with no statistical difference between the two emotional conditions ($p = .320$). Neither of the laterality and caudality effects, nor any of the interactions between the within-subjects factors was significant.

The correlations between the three subscales on the IES-R and the ERP variables (frontal N2, parietal P300, and average SW across electrode sites) in each of the valence conditions (attack, negative, neutral) as well as ERP differences between each of the emotional conditions and the neutral condition (i.e., attack minus neutral, negative minus neutral, attack minus negative) are displayed in Table 1. Intrusion was inversely correlated with N2 negativity to neutral images and with neutral-minus-attack and neutral-minus-negative N2 differences. In other words, participants with more intrusion symptoms tended to show more N2 negativity to unpleasant stimuli than neutral stimuli; this could be due to their decreased N2 response to neutral stimuli. Avoidance was significantly correlated with decreased attack-minus-neutral and attack-minus-negative P300, decreased SW response to attack images, and decreased attack-minus-neutral SW. Hyperarousal was significantly correlated with decreased N2 negativity to neutral images.

The total IES-R score was significantly correlated with decreased N2 negativity to neutral images, and decreased neutral-minus-attack and neutral-minus-negative N2 negativity as well as with decreased attack-minus-neutral P300 and SW. Finally, IES-R symptoms were not correlated with valence or arousal ratings (all $ps > .15$), and the BDI was not significantly correlated with ERP measures (all $ps > .10$).

Table 1. Correlations Between Stress Response Symptoms and ERP Measures

	Impact of Event Scale-Revised			
	Intrusion	Avoidance	Hyperarousal	Total
N2[a]				
Attack	−.04	.04	−.21	−.06
Negative	−.17	−.07	−.34	−.21
Neutral	−.41*	−.19	−.45*	−.40*
Neutral-Attack[b]	−.43*	−.25	−.33	−.39*
Neutral-Negative[b]	−.45*	−.22	−.28	−.37*
Negative-Attack[b]	−.14	−.11	−.15	−.16
P300				
Attack	.07	−.02	.03	.03
Negative	.05	.18	.06	.13
Neutral	.23	.30	.22	.30
Attack-Neutral	−.26	−.49**	−.29	−.42*
Negative-Neutral	−.26	−.15	−.23	−.25
Attack-Negative	.01	−.36*	−.06	−.19
SW				
Attack	−.22	−.36*	−.09	−.29
Negative	−.24	−.07	−.14	−.17
Neutral	−.08	.12	.13	.06
Attack-Neutral	−.14	−.50**	−.24	−.37*
Negative-Neutral	−.11	−.18	−.25	−.20
Attack-Negative	−.02	−.35	.02	−.17

Note. $N = 31$. ERP = Event-related potential.
[a] For ease of interpretation, the sign of N2 was reversed in the computation of correlations, so that positive correlations indicate that higher symptom score is associated with increased N2 negativity. [b] Because N2 negativity, unlike P300 and SW, is normally larger to pleasant/neutral than to unpleasant stimuli, Neutral-Attack instead of Attack-Neutral (and similarly for differences between other valence conditions) was used in computing symptom correlations with N2.
$^{*}p < .05$. $^{**}p < .01$.

DISCUSSION

This study examined neural correlates of emotional information processing in a group of healthy individuals most of whom described minimal post-9/11 distress reactions, though there were a number whose ratings indicated moderate distress. The results indicate that psychophysiological responses during valence processing were related to distress level. The stress-related psychophysiological deviations were these: (a) diminished stimulus discrimination between unpleasant and neutral stimuli, as suggested by the reduced N2 difference between unpleasant and neutral images; (b) hypervigilant memory update, as suggested by the reduced P300 difference between unpleasant and neutral images, likely due to the increased P300 to neutral images; and (c) reduced appraisal of trauma-related images, as suggested by the attenuated SW to attack images. These deviations are analogous to the clinical phenomena and abnormal cognition observed in individuals with PTSD (Karl et al., 2006; Shipherd & Beck, 2005). Given that the participants in this study were young, unmedicated, highly functional individuals and their distress was clearly below clinical threshold, this finding is consistent with the notion that normal stress reactions may differ from those resulting in ASD or PTSD only quantitatively, but not qualitatively. This is consistent with the thesis that at least in the area of ERPs, the phenomena may be more appropriately conceptualized as a continuum and that clinically significant reactions to traumatic life events represent the upper end of a stress-response continuum rather than a discrete clinical syndrome (Broman-Fulks et al., 2006; Ruscio, Ruscio, & Keane, 2002). Considerably more evidence, however, would be needed to firmly establish this conceptualization.

In this study, N2 negativity did not show a valence effect, contrary to the common finding that neutral/pleasant images elicit larger N2 response than unpleasant images among healthy individuals (Carretie, Hinojosa, et al., 2004; Carretie, Mercado, Hinojosa, Martin-Loeches, & Sotillo, 2004; Silvert et al., 2007). This was likely due to the decreased N2 negativity to neutral images in those with higher stress reactions, particularly intrusion and hyperarousal symptoms. The correlation between reduced neutral-minus-unpleasant N2 difference and severity of stress reactions found in this study suggests that the normal attentional bias away from negative events (Bradley et al., 1997; Deldin, Keller, Gergen, & Miller, 2001) disappears as stress reactions become stronger. This is consistent with the neuroimaging finding (Bremner et al., 2004; Shin et al., 2001) that individuals with PTSD fail to recruit the anterior cingulate cortex (ACC)—a brain region to where the N2 response to affective images has been localized (Carretie, Mercado, et al., 2004)—to direct attention away from threats. This altered attentional process in subsyndromal hyperarousal and intrusion stress reactions may be analogous to the early protective inhibition for the sensitive nervous system in some individuals with PTSD suggested by Lewine et al. (2002). This potentially protective mechanism, nevertheless, may contribute to the maintenance of trauma-related stress symptoms, as it impairs one's ability to discriminate benign events from threatening ones, thus limiting the opportunity to develop positive emotions and to unlearn the associations between neutral stimuli and trauma memories. Executing cognitive control to redirect attentional resources toward benign information may be a critical way to recover from maladaptive stress reactions.

Attack images elicited substantially larger P300 response than both negative and neutral images. This was not surprising given that the attack images were rated as most unpleasant and arousing (Cuthbert et al., 2000). However, although negative images were rated as more unpleasant and arousing than neutral images, the magnitudes of P300 response elicited by these two types of images were not significantly different. Thus, there appeared to be a complex interaction between valence and arousal on P300; P300 response in this study may be appropriately thought to index the perceived salience of the stimuli. Obviously, the attack images were likely highly significant and anxiety-provoking to the participants given the recency of 9/11 at the time of the study. However, the positive relationship between P300 response and stimulus salience weakened with higher stress reactions; P300 response to neutral images was increased as stress reactions move from minimal to moderate. This indicates active memory update despite the trauma-irrelevant nature of the current information, perhaps analogous to hypervigilance observed in PTSD. Such a hyperactive signal detection system results in unnecessary contextual updating. Although hypervigilance may be protective in some situations, in the long run it taxes the individual through indiscriminate memory update, which potentially exhausts mental resources and results in an inability to protect self from danger and retraumatizing activities (cf. Orcutt, Erikson, & Wolfe, 2002).

Participants showed larger SW responses to attack and negative than neutral images, consistent with the literature that arousing visual material elicits more positive-going SW (see Olofsson, Nordin, Sequeira, & Polich, 2008 for a review). However, as avoidance stress symptoms increased from none to a little, SW to attack images decreased. It has been shown that affective effect on SW is subject to the influences of top-down processes such as appraisal strategy (Hajcak, Moser, & Simons, 2006) and suppression of emotional reactions (Moser, Hajcak, Bukay, & Simons, 2006). The reduced SW response to attack images in those with higher avoidance symptoms could be analogous to thought suppression or avoidance of appraisal of trauma-related information, a maladaptive coping strategy commonly observed in PTSD. It should be noted that because the image characteristics of the attack images were not able to be explicitly matched with the neutral and negative pictures, this finding should be interpreted with caution and further investigation is warranted.

Finally, the finding that different stress symptom clusters, but not symptoms of depression, showed different affective ERP correlates underscored the importance of examining emotional information processing in the investigation of stress reactions. In addition, because specific stress symptom clusters were significantly correlated with ERP measures but not self-report valence and arousal ratings of the stimuli, this indicates the value of psychophysiological measures in future similar studies.

This study has several limitations, including a largely asymptomatic and small sample size, exclusive use of college students, and uncorrected multiple comparisons/correlations. Replications using well-matched stimuli and larger and more representative samples, including participants with a much wider range of distress from traumatic exposure, would help confirm the ERP correlates of specific stress symptom clusters. It could also lend evidence to support the claim that at least some aspects of PTSD are dimensional in nature. Inclusion of a control group (e.g., depression) would also help to test if the findings are trauma-specific.

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