ABSTRACT
BACKGROUND: Posttraumatic stress disorder (PTSD) is linked to elevated arousal and alterations in cognitive processes. Yet, whether a traumatic experience is linked to neural and behavioral differences in selective attentional tuning to traumatic stimuli is not known. The present study examined selective awareness of threat stimuli and underlying temporal-spatial patterns of brain activation associated with PTSD.

METHODS: Participants were 44 soldiers from the Canadian Armed Forces, 22 with PTSD and 22 without. All completed neuropsychological tests and clinical assessments. Magnetoencephalography data were collected while participants identified two targets in a rapidly presented stream of words. The first target was a number and the second target was either a combat-related or neutral word. The difference in accuracy for combat-related versus neutral words was used as a measure of attentional bias.

RESULTS: All soldiers showed a bias for combat-related words. This bias was enhanced in the PTSD group, and behavioral differences were associated with distinct patterns of brain activity. At early latencies, non-PTSD soldiers showed activation of midline frontal regions associated with fear regulation (90–340 msec after the second target presentation), whereas those with PTSD showed greater visual cortex activation linked to enhanced visual processing of trauma stimuli (200–300 msec).

CONCLUSIONS: These findings suggest that attentional biases in PTSD are linked to deficits in very rapid regulatory activation observed in healthy control subjects. Thus, sufferers with PTSD may literally see a world more populated by traumatic cues, contributing to a positive feedback loop that perpetuates the effects of trauma.

Keywords: Affect-biased attention, Attentional bias, Attentional blink, Beamforming, Magnetoencephalography (MEG), Posttraumatic stress disorder (PTSD), Soldiers

Posttraumatic stress disorder (PTSD) is a trauma-related mental disorder with anxious and depressive features, resulting from exposure to one or more events involving actual or threatened death or serious injury. Although the clinical presentation varies, individuals suffering from this condition experience symptoms that include re-experiencing the traumatic event, avoidance of associated situations or stimuli, negative mood and appraisals, and elevated levels of arousal and reactivity (1). It is well documented that a traumatic experience can influence a wide range of cognitive processes [e.g., (2)]. Yet, it is still not known whether a history of traumatic experience is associated with specific patterns of selective attention that may influence how an individual literally sees the world and whether neural and behavioral indices of selective attention characterize PTSD. Here, we examined these questions by investigating patterns of perceptual awareness for combat-related stimuli in Canadian soldiers with and without diagnoses of PTSD, as well as in civilians, and used magnetoencephalography (MEG) to measure the temporal-spatial patterns of associated brain activation in the soldiers.

A body of evidence indicates there is preferential allocation of attention to trauma-related stimuli following a traumatic experience. Studies of trauma-related attentional biases indicate difficulty disengaging both spatial [for review, see (3)] and temporal (4) attentional resources from trauma-related stimuli. Other studies have found enhanced perception of trauma-related stimuli as measured by an increased signal-to-noise ratio in perception for both visual (5) and auditory (6) information. However, some studies have failed to find such attentional biases (7). The specificity of attentional biases for trauma-related stimuli or threat in general has also been questioned (8,9).

The attentional blink (AB) (10) is an experimental manipulation that effectively measures biases in rapid perceptual encoding and resulting awareness. The blink itself is a phenomenon where participants are typically unable to report...
a target stimulus when it is presented within ~500 milliseconds of a previous target in a rapid stream of stimuli. There are a number of competing interpretations of the AB phenomenon, but one interpretation that has garnered empirical support is that it reflects a failure of attentional filters to consolidate the second target into working memory when it appears too quickly after the first, resulting in impaired perceptual awareness (11). When the second target (T2) is emotionally salient (e.g., RAPE vs. ROPE), there is a reduced blink or an emotional sparing (12–14). This emotional sparing can be seen as reflecting the relative robustness of selective attention for affective stimuli (15). Fear conditioning can also elicit AB sparing for conditioned stimuli, suggesting a link between emotional learning and enhanced perceptual awareness (16), and functional magnetic resonance imaging (fMRI) research has found sparing for conditioned stimuli in healthy control subjects to be mediated by coactivation between the amygdala and visual cortices (16). Further, in healthy adults, an MEG investigation of the temporal-spatial patterns of sparing for emotionally salient words found emotional sparing to be characterized by early activation in regions of the extended amygdala followed by later activation in key frontal regions (17).

Individual differences in the degree of AB emotional sparing have been observed and may be influenced by temperament, genotype, and experience. Greater emotional sparing for threatening faces has been linked to higher levels of trait anxiety (18). Moreover, carrying a deletion variant of the ADRA2B gene influencing norepinephrine levels has been linked to higher levels of overall emotional enhancement of memory, including intrusive memory following trauma (19). Notably, the ADRA2B deletion variant is also associated with greater sparing for negatively valenced words (20). Such links between common genetic variations associated with intrusive traumatic memory, enhanced limbic activation linked to emotional sparing, and AB emotional sparing linked to threat provide convergent evidence suggesting PTSD may be associated with enhanced AB sparing for trauma-related cues.

Such enhanced AB sparing should also be related to distinct patterns of brain activity in PTSD. Although neuroimaging studies using different experimental tasks show mixed results, meta-analyses of fMRI data indicate that overall symptom provocation elicits greater activation in bilateral amygdalae, mid-cingulate cortex, and precuneus and reduced activation in ventromedial prefrontal cortex and frontoparietal control networks in participants with PTSD relative to control subjects (21,22). PTSD has also been linked to patterns of altered functional connectivity (23). Yet, rapidly occurring patterns of brain activity coupled with sorting salient from mundane stimuli in the AB, which may be crucially altered in PTSD, may not be captured by the slow time courses of positron emission tomography and fMRI.

The present study addressed the question of whether PTSD is linked to altered tuning of attentional filters to the visual environment under conditions of high visual competition. Here, we used MEG to examine the connection between PTSD, behavioral indices of AB emotional sparing for trauma-specific stimuli, and patterns of brain activation at a high temporal resolution. Combat veterans currently in the Canadian Armed Forces performed an AB task in the MEG scanner using combat-related and neutral words as the T2 stimuli. We predicted that AB performance would differentiate soldiers with and without PTSD, such that soldiers with PTSD would show greater AB sparing than soldiers without PTSD. For participants with no combat exposure, the AB for combat-related words should not differ from that for neutral words. Based on evidence of altered structure and function of regulatory processes in PTSD, we predicted that control soldiers would show greater activation in regulatory regions of anterior cingulate cortex (ACC) in the presence of combat-related stimuli. Based on convergent evidence of the role of valuation networks in AB sparing and greater excitability of valuation networks in PTSD, we predicted that those with PTSD would show enhanced activation in nodes of valuation networks (amygdalae, orbitofrontal cortex), higher levels of visual cortex activity associated with emotional sparing, or both.

**METHODS AND MATERIALS**

Participants for the MEG study were active-duty service members from the Canadian Armed Forces. The initial sample included 24 soldiers diagnosed with PTSD (all male subjects; mean age = 37.7 years ± 6.8 SD; range 26–48 years) and 24 control soldiers (all male subjects; mean age = 32.9 years ± 4.6 SD; range 27–42 years). All participants were veterans of combat who had served in Afghanistan. At the time of MEG testing, 4 soldiers were excluded because of scanner incompatibility or unusable MEG data, leaving a final number of 22 soldiers with PTSD (mean age = 37.6 years; range 26–48 years) and 22 soldiers without PTSD (mean age = 32.4 years; range 27–40 years). We also collected behavioral data from an additional group of 18 age- and education-matched participants with no combat experience (all male participants; mean age = 28.05 years ± 5.84 SD; range 20–39 years) to serve as nonmilitary control subjects. These civilians were actively recruited from the hospital and university community for a separate study on traumatic brain injury and agreed to complete the behavioral version of the AB task.

Individuals with PTSD were diagnosed using a semistructured clinical interview for DSM-IV Axis I Disorders (American Psychiatric Publishing Inc., Arlington, Virginia), performed by a military psychiatrist according to Canadian Forces protocol. The diagnosis also included psychometric testing by a psychiatrist or psychologist at a Canadian Armed Forces Operational Trauma and Stress Support Centre and identified through clinicians at one of the Canadian Armed Forces Operational Trauma and Stress Support Centres (for details, see Supplement 1, and for demographic information, see Table 1). All testing was conducted in the MEG Lab at the Hospital for Sick Children and received institutional ethics approvals from both the Hospital for Sick Children and Defense Research and Development Canada. All participants gave informed written consent.

**Neuropsychological and Clinical Assessments**

All participants completed a short battery of neuropsychological tests as well as brief clinical assessments (Supplement 1). The tests, their means, and standard deviations for each group are contained in Table 1.
Enhanced Tuning to Combat-Related Cues in PTSD

### Experimental Tasks

Before entering the MEG scanner, participants performed a practice version of the AB task using only neutral T2 words. Following the practice task, participants entered the MEG scanner and MEG data were collected while participants performed the experimental version of the AB task. Both the practice and the experimental versions of the AB task were rapid serial visual presentation tasks with the following parameters. In each trial, following a fixation cross, 15 stimuli were presented sequentially for 100 milliseconds each in a rapid stream (Figure 1). For each trial, participants were required to report two targets that were presented among the series of distractors: the first (T1) was a string of numbers and the second (T2) was always a word, both presented in green font. Distractor words were neutral, presented in black font, and selected to be longer than target words to optimize masking effects. Following each trial, participants were asked to report both targets.

### Practice Task.

The practice task was used for two purposes: to familiarize participants with the experimental task and to determine the lag at which each participant had approximately 60% accuracy for T2 words (see Supplement 1 for details). All T2 words were emotionally neutral.

### Experimental Task: MEG.

In the MEG version of the task, T2 words were either combat-related words, selected to be emotionally arousing for soldiers, or neutral words (a separate set of neutral words from those employed in the practice task). Combat-related words and neutral words were balanced for length, written frequency, and neighborhood frequency (the frequency of words of the same length that could be created by changing a single letter). Stimuli were presented foveally and subtended a visual angle of 6°. After each trial, there was a variable interstimulus interval between the final word in the stream and the fixation cross that marked the beginning of the next trial. During this interval, participants observed a black screen and reported both targets verbally into a microphone. Responses were scored as hits (accurately reported numbers and words) or misses (either T1 or T2 inaccurately reported) by an experimenter during data acquisition (for trial counts, see Table S1 in Supplement 1). In total, participants completed 172 trials, 86 in which T2 was combat-related and 86 in which it was neutral.

### MEG Data Acquisition and Preprocessing

MEG data were recorded continuously (600 Hz sampling rate, 100 Hz low-pass filter, third-order spatial gradient noise cancellation) on a 151 channel whole-head CTF system (MISL Ltd., Coquitlam, British Columbia, Canada) in a magnetically shielded room (for details and calculation of global field power, see Supplement 1).

As we were interested in measures related to accuracy for T2, all reported activations were time-locked to T2 onset. T2 trials were sorted by combat-related and neutral words. A vector beamformer source localization algorithm (24,25) integrated over 50-millisecond nonoverlapping time windows from 90 to 590 milliseconds was applied with a spatial resolution of 5 mm over the whole brain. This resulted in images for 10 time windows (i.e., 90–140, 140–190, 190–240, 240–290, 290–340, 340–390, 390–440, 440–490, 490–540, 540–590 msec). The beamforming algorithm was applied to each condition separately, so that the covariance matrix was appropriately computed for the number of trials and variability in the data.

### RESULTS

#### Behavioral Results

**Word Ratings.** After completing the AB task, participants rated all T2 words for both subjective levels of arousal and...
word familiarity. Full results are reported in Supplement 1, and arousal ratings for each group are illustrated in Figure 2.

Accuracy. Accuracy was calculated as the proportion of correctly reported words for T2 trials that followed correct T1 trials in the combat-related and neutral conditions (Table S1 in Supplement 1). A repeated measures analysis of variance was performed on accuracy with T2 category (combat-related vs. neutral) as the within-subject factor and PTSD group as the between-subject factor. All reported contrasts were Bonferroni corrected to control for multiple comparisons. There was no main effect of group, $F_{1,42} = 1.56, p > .20$, indicating that the groups did not differ in overall accuracy. There was a main effect of T2 category, $F_{1,42} = 113.24, p < .001, \eta_p^2 = .73$, with higher accuracy signifying a reduced attentional blink, or AB sparing, for combat-related words. Contrasts showed this effect to be significant in both groups separately, $p < .001$. This was qualified by a PTSD group by T2 accuracy interaction, $F_{1,42} = 6.34, p = .01, \eta_p^2 = .13$, indicating a greater difference in accuracy between combat-related and neutral words for the soldiers with PTSD. Thus, whereas all soldiers showed an advantage in perceptual encoding of combat-related relative to neutral words, those with PTSD had a greater advantage than those without PTSD (Figure 2B).

To ensure that the overall AB sparing for combat-related words was due to combat experience and not such factors as greater semantic relatedness, we examined behavioral data from control participants with no combat experience. Analysis of accuracy results indicated no combat-related sparing for civilian control subjects. Familiarity and arousal ratings as well as AB accuracy results for all groups are reported in Supplement 1 and arousal ratings are illustrated in Supplementary Figure S3.

Because attentional biases are symptomatic of anxiety and depression (26,27,28), we further examined the relation between combat-word sparing and Generalized Anxiety Disorder 7-item (GAD-7) score as a measure of anxiety in the PTSD group and military control subjects (left); Patient Health Questionnaire 9-item (PHQ-9) score as a measure of depression in the PTSD group and military control subjects (middle); and PTSD Checklist (PCL) score in the PTSD group as a measure of PTSD symptoms (right). AB, attentional blink.

Figure 2. Behavioral results. (A) Arousal rating and (B) second target accuracy for combat-related and neutral words for soldiers with posttraumatic stress disorder (PTSD), soldiers without PTSD, and combat-naïve control subjects. (C) Correlations between second target combat-word sparing (accuracy for combat words > neutral words) and Generalized Anxiety Disorder 7-item (GAD-7) score as a measure of anxiety in the PTSD group and military control subjects (left); Patient Health Questionnaire 9-item (PHQ-9) score as a measure of depression in the PTSD group and military control subjects (middle); and PTSD Checklist (PCL) score in the PTSD group as a measure of PTSD symptoms (right). AB, attentional blink.
combat-word sparing was related to both anxiety and depression, and this difference was driven by the soldiers with PTSD. They also revealed a continuous relationship between PTSD symptoms and combat-word sparing.

**MEG Results**

**Global Field Power Results.** MEG analyses were conducted only on the two groups of soldiers. Whole-head global field power (GFP) plots for the soldiers with and without PTSD for each category of stimuli were used to identify beamformer window widths that would encompass prominent peaks. GFPs for each subject were visually inspected before inclusion in source analysis to ensure adequate data quality. Three soldiers in the PTSD group and three in the non-PTSD group were excluded from MEG source analysis due to excessively high-amplitude signals and poor signal-to-noise ratios, leaving 19 participants in each group. GFP plots of the frontal sensors, between groups, showed that both groups revealed the typically observed differences between hits and misses (collapsed across word category) at the time of the P3 (around 400 msec) (Figure 3).

**Source Analyses.** To assess activation across time in specific source regions, we focused on brain activity underlying the emotional sparing effect (the difference between correct combat-related and neutral words) in 50-millisecond time windows using the following contrasts. In one analysis, [(combat hits – neutral hits) – (combat misses – neutral misses)] in the PTSD group were subtracted from [(combat hits – neutral hits) – (combat misses – neutral misses)] in the military control subjects. In the other analysis, the same contrasts in military control subjects were subtracted from those in the PTSD group. To control for multiple comparisons, data were permuted (2946 permutations) across conditions to be compared, and the largest differences for any voxel in this surrogate data were used to obtain a threshold for each voxel. Locations with significant activations between groups (p < .05, corrected) are listed in Table 2 and all significant results are plotted on three-dimensional brains for visualization (for three-dimensional depictions of all regions showing contrasts related to differences in AB sparing between groups, see Figure S1 in Supplement 1).

Here, we focus on the most robust results related to group differences in neural substrates of emotional sparing in hypothesized regions. First, there was greater activation associated with combat-word sparing for the control group over the PTSD group at an early latency (90–140 msec) with a peak in the caudate nucleus and activation extending along the subgenual ACC. This early ventral midline activity was followed directly by activation in the dorsal ACC at 140 to 190 milliseconds and by dorsal ACC again 100 milliseconds later at 290 to 340 milliseconds (Figure 4). Thus, soldiers without PTSD showed more rapid activation than the PTSD group in regions known to modulate amygdalae and autonomic activation. At a longer latency (540–590 msec), military control subjects showed greater activation in the right inferior orbital gyrus, a prefrontal region previously found to discriminate between emotional and neutral T2 hits in healthy control subjects (17). In the opposite direction, there was a robust mid-latency activation (290–340 msec) that was greater for the PTSD group than the non-PTSD group in occipital visual cortex with peaks in the left posterior precuneus and left lingual gyrus (Figure 4).

**DISCUSSION**

In this study, we employed a novel experimental paradigm in PTSD research—an attentional blink task—to index selective awareness of trauma-related cues. We compared task performance and temporal-spatial patterns of brain activation in Canadian combat veterans with and without diagnoses of PTSD. Results showed that whereas all combat veterans showed emotional sparing of the attentional blink with greater accuracy for combat-related over neutral words, this sparing was enhanced in the PTSD group.
Crucially, soldiers with PTSD also rated combat-related words as significantly more arousing relative to neutral words than soldiers without PTSD, indicating a greater subjective emotional response to the words. As Figure 2A and 2B illustrate, these higher arousal patterns show a similar pattern to the AB accuracy results showing greater combat-word sparing for the PTSD group. This finding is consistent with a body of research in healthy adults finding that words rated as higher in arousal are subject to emotional sparing of the attentional blink (12,14,20). Thus, it is likely that the PTSD group showed higher levels of combat-word sparing because they found the combat-related words to be more arousing, consistent with patterns of elevated arousal and reactivity to trauma-related stimuli associated with PTSD (29,30).

It should be noted that whereas there was greater sparing for combat words, there was overall poorer performance for neutral words in the PTSD group relative to the military control subjects and the difference in performance was reduced by the combat-word sparing for combat-related words. This reduced performance for neutral words in the PTSD group may reflect a number of factors related to being in the scanner, including heightened stress/anxiety triggered by combat-related words, suppression of selective attention to neutral words in the presence of combat words, or greater deterioration of sustained attention to the task in the PTSD group.

Our MEG results revealed that the distinct patterns of brain activity for combat-related versus neutral words further distinguished the two groups. In soldiers without PTSD, Table 2. Brain Regions Associated with Between-Group Differences in Combat-Word Sparing in 50-Millisecond Windows for Soldiers With and Without PTSD

<table>
<thead>
<tr>
<th>Time (msec)</th>
<th>Anatomical Location</th>
<th>BA x, y, z</th>
<th>PseudoZ</th>
<th>Anatomical Location</th>
<th>BA x, y, z</th>
<th>PseudoZ</th>
</tr>
</thead>
<tbody>
<tr>
<td>PTSD &gt; Military Control Subjects</td>
<td></td>
<td></td>
<td></td>
<td>Military Control Subjects &gt; PTSD</td>
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<tr>
<td>90–140</td>
<td>Culmen</td>
<td>−3 −3 37</td>
<td>1.51</td>
<td></td>
<td></td>
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</tr>
<tr>
<td></td>
<td>Caudate</td>
<td>25 −3 15 0</td>
<td>1.39</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Mid temporal gyrus</td>
<td>21 −53 23</td>
<td>1.16</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>140–190</td>
<td>Anterior cingulate</td>
<td>24 3 24</td>
<td>1.48</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>Precentral gyrus</td>
<td>6 27 14 70</td>
<td>1.59</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>290–340</td>
<td>Precuneus</td>
<td>31 −10 −52</td>
<td>27 1.44</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Lingual gyrus</td>
<td>18 −11 −73</td>
<td>4 1.34</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>340–390</td>
<td>Insula</td>
<td>13 40 15 18</td>
<td>1.54</td>
<td></td>
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<tr>
<td></td>
<td>Anterior cingulate</td>
<td>9 −1 44 15</td>
<td>1.22</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>390–440</td>
<td>Fusiform gyrus</td>
<td>19 −36 −67</td>
<td>13 1.83</td>
<td></td>
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<tr>
<td></td>
<td>Mid occipital gyrus</td>
<td>19 −37 −75</td>
<td>7 1.12</td>
<td></td>
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<tr>
<td>440–490</td>
<td>Mid temporal gyrus</td>
<td>13 −13 41</td>
<td>48 0.36</td>
<td></td>
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<tr>
<td></td>
<td>Superior parietal lobule</td>
<td>7 −36 −70</td>
<td>50 0.35</td>
<td></td>
<td></td>
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<tr>
<td>490–540</td>
<td>Precuneus</td>
<td>4 −31 −14 47</td>
<td>1.14</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>Precentral gyrus</td>
<td>31 18 −70</td>
<td>22 1.1</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>540–590</td>
<td>Precuneus</td>
<td>30 9 −47 22</td>
<td>1.65</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Inferior frontal orbital gyrus</td>
<td>47 51 26</td>
<td>14 1.58</td>
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</table>

BA, Brodmann area; L, left; PTSD, posttraumatic stress disorder; R, right.

Crucially, soldiers with PTSD also rated combat-related words as significantly more arousing relative to neutral words than soldiers without PTSD, indicating a greater subjective emotional response to the words. As Figure 2A and 2B illustrate, these higher arousal patterns show a similar pattern to the AB accuracy results showing greater combat-word sparing for the PTSD group. This finding is consistent with a body of research in healthy adults finding that words rated as higher in arousal are subject to emotional sparing of the attentional blink (12,14,20). Thus, it is likely that the PTSD group showed higher levels of combat-word sparing because they found the combat-related words to be more arousing, consistent with patterns of elevated arousal and reactivity to trauma-related stimuli associated with PTSD (29,30).

It should be noted that whereas there was greater sparing for combat words, there was overall poorer performance for neutral words in the PTSD group relative to the military control subjects and the difference in performance was reduced by the combat-word sparing for combat-related words. This reduced performance for neutral words in the PTSD group may reflect a number of factors related to being in the scanner, including heightened stress/anxiety triggered by combat-related words, suppression of selective attention to neutral words in the presence of combat words, or greater deterioration of sustained attention to the task in the PTSD group.

Our MEG results revealed that the distinct patterns of brain activity for combat-related versus neutral words further distinguished the two groups. In soldiers without PTSD, com-

![Figure 4](https://example.com/figure4.png)Locations where significantly greater activations were observed for emotional sparing of combat-related words in the posttraumatic stress disorder (PTSD) compared with non-PTSD soldiers (red/orange) and when greater activations were observed for non-PTSD soldiers compared with those with PTSD (blue).
pared with those with PTSD, combat-word sparing was characterized by early and strong activation of midline frontal regions associated with fear regulation and extinction (22,31,32). In contrast, at mid latencies, PTSD soldiers showed extensive activation of visual cortex. These findings suggest that the differences in combat-word sparing observed in the two groups may be linked to reductions in rapid regulatory activity leading to enhanced processing of emotionally salient targets in the PTSD group.

**Early-Mid Latency Activation Patterns**

One influential model of PTSD proposes that symptoms reflect a failure of fear extinction processes following a traumatic event (33,34). Consistent with this model, source localization results indicated that very early activation in prefrontal midline regions associated with amygdala/autonomic regulation differentiated control soldiers from those with PTSD. Between 90 and 140 milliseconds after T2 presentation, soldiers without PTSD showed greater activation in the caudate nucleus/subgenual ACC, regions consistently implicated in PTSD in both structural imaging and challenge studies (21,29,35,36). It has been proposed that reduced caudate activity is linked to anhedonia characteristic of both depression and PTSD (35). Activity in subgenual ACC is implicated in modulation of amygdala activity in humans (37), and a large body of human and animal literature shows its key role in fear extinction (for review, see [29,38]). Our pattern of activation suggests that for control soldiers without PTSD, very rapid extinction-related processes were recruited immediately after encountering trauma-related stimuli. For control subjects, such processes were associated with greater successful perceptual encoding of combat-related stimuli.

The pattern of greater ventral midline activation associated with combat-word sparing for military control subjects was followed by greater dorsal ACC activation for control subjects in two subsequent early- to mid-latency time windows between 140 and 340 milliseconds. Interestingly, PTSD challenge studies using fMRI have typically revealed the opposite pattern, with enhanced relative activation in PTSD compared with control subjects (39,40). Yet, dorsal ACC activation has been consistently linked to both fear acquisition/expression and its regulation/extinction (41), including modulation of amygdala activity via reappraisal (42), suggesting it may play a flexible role in these processes. Inconsistency with fMRI results may further reflect differences in measures (e.g., transient neuronal activity captured by MEG may not be detectable in the slower blood oxygen level-dependent response) or differences in the AB task and emotional challenge paradigms typically used for PTSD. Overall, our data are consistent with a greater role for the dorsal ACC in regulation and appraisal for control participants. Here, such regulatory activity occurred at latencies just before and during the time window when stimuli that reach awareness are discriminated from those that are subject to the attentional blink (17,43).

Subsequently, we observed a period of greater activation in early visual cortex in the PTSD group than in military control subjects. AB sparing for fear-conditioned stimuli has been linked to greater connectivity between the amygdalae and visual cortex (16). PTSD challenge studies have also reported greater influence of the amygdalae and reduced influence of prefrontal regions on the visual cortex in PTSD (23), indicating that PTSD is associated with altered functional connectivity patterns that enhance visual processing of threat. Here, the PTSD group showed visual cortex intensified activation patterns associated with enhanced emotional processing in the absence of regulatory activation observed in control subjects. Thus, our data suggest that whereas combat-related cues are highly salient for all soldiers, at earlier latencies those without PTSD are able to rapidly downregulate affective responses to stay on task. In contrast, PTSD is linked to intensified processing of emotional salience reflected in visual cortical processing.

**Late Activation Patterns**

At longer latencies, the beamforming results revealed that control subjects showed greater emotional sparing-related activation than the PTSD group in right inferior orbital gyrus. This is consistent with a activity previously observed in prefrontal region found to characterize emotional sparing at later latencies in healthy control subjects (17). The orbitofrontal cortex plays a key role in the flexible evaluation of stimulus salience in relation to context and has been implicated in learning and decision-making processes related to emotional or motivational salience (44–46). Here, the non-PTSD group showed an activation pattern similar to that found to be associated with emotional sparing in civilian control subjects, with greater activation linked to context-sensitive valuation processes that appeared just before making a response. This finding is consistent with a pattern of reduced prefrontal activation in PTSD (29).

Although our analysis approach with the beamformer data did not permit examination of patterns correlated with individual differences in depression and anxiety, our behavioral findings suggest that the group differences in neural activation we observed reflect high-frequency rates of comorbid depression and/or anxiety found in PTSD in an estimated 21% to 94% of PTSD sufferers [e.g., (47)]. Future research examining connectivity patterns could employ graph theory to correlate activation with individual behavioral scores. Another goal of future research is to examine patterns of phase synchrony at specific frequency bands to examine whether attentional tuning to trauma-related stimuli is characterized by altered patterns of functional connectivity between the amygdalae, anterior cingulate regions, and visual cortices. Other areas for future research include examining the relation between effects of medication and MEG activation to disembed potential medication effects. They can also include investigation of the relation between PTSD symptoms and neural and behavioral measures of combat-word sparing to ascertain whether the pattern of results we observed is independent of clinical levels of PTSD.

**Conclusion**

Heightened attentional tuning to combat-related words was observed for combat veterans with and without a diagnosis of PTSD; however, those soldiers with PTSD showed higher levels of tuning to threat. Our results suggest that behavioral patterns that differ between groups only in degree reflect distinct patterns of neural activation. These differences are
particularly distinct at early latencies, when emotionally signi-
ficant stimuli may be preattentively sorted from the mun-
dane. Because of deficits in rapid regulatory activation,
soldiers who suffer from PTSD may literally see a world more
populated with reminders of trauma than those without PTSD.

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