Alteration of early attentional processing after analogue trauma exposure: Evidence from event-related potentials

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Abstract

The present study aimed to determine whether exposure to an analogue traumatic event affects attentional processing of emotional information. Two groups of non-clinical participants matched on anxiety level, depression symptoms and stressful life events viewed either a trauma or a neutral film. They then performed an emotional Stroop task during which both continuous electroencephalographic activity was recorded and intrusive memories were measured. Results revealed that the valence effect (measured by the difference between emotional and neutral conditions) for the P1 amplitude was significantly greater in participants who viewed the trauma film than in participants who viewed the neutral film. This interaction was specific to words semantically related to the analogue trauma event and did not extend to all negative words. Further analyses revealed a relationship between intrusions frequency, P1 amplitude and emotional Stroop interference, indicating a link between attention and intrusive memories. Our findings suggest that exposure to potentially traumatic events has an important impact on neurocognitive function, even in the absence of psychopathology, and that this impact occurs at an early, possibly automatic stage of processing.

Keywords: Event-related potentials; Trauma film; Emotional Stroop; Selective attention; Intrusive memories.

Introduction

Exposure to a traumatic situation can persistently affect cognitive processing (see e.g., Tapia et al. 2007; Weber 2008, for reviews), especially selective attention (Block and Liberzon 2016). Although selective attention biases have mainly been observed in patients suffering from post-traumatic stress disorder (PTSD; e.g., Fani, Jovanovic et al. 2012; Fani, Tone et al. 2012; McNally et al. 1990; Powers et al. 2019), similar effects have been reported in trauma-exposed individuals without PTSD (e.g., Caparos and Blanchette 2014; Cassiday et al. 1992), suggesting that trauma exposure itself is a critical factor that can change information processing. This is noteworthy given that individuals who experience a traumatic event predominantly do *not* develop PTSD. The lifetime prevalence of PTSD after trauma exposure is estimated to be approximately 5.6% (Koenen et al. 2017), while up to 90% of the population will be exposed to at least one potentially traumatic situation (the lifetime prevalence of experiencing a traumatic event is 89.7%; Kilpatrick et al. 2013). However, given that these studies are necessarily correlational, it is difficult to know whether exposure to trauma is causally responsible for these changes in attention. In this paper, we use an experimental paradigm to investigate whether exposure to an analogue traumatic event causes alterations of attentional processing, outside PTSD.

Impaired selective attention after trauma exposure has been demonstrated with the emotional Stroop task (see Cisler et al. 2011; Williams et al. 1996, for reviews), in which participants have to identify the ink color of emotional or neutral words. The emotional Stroop effect (i.e., the longer response times for emotional compared to neutral words) is typically greater in trauma-exposed participants, relative to non-exposed controls, when the emotional words are trauma-related. The common interpretation is that traumatic event exposure, regardless of PTSD, impairs attentional control and enhances processing of trauma-related information. As a consequence, attention is biased toward trauma-related words, even when these stimuli are not task-relevant, in trauma-exposed individuals (Cisler et al. 2011).

While the emotional Stroop task has established that trauma exposure alters selective attention to trauma-related stimuli, it is not clear what neurocognitive processes this results from. In particular, behavioral results obtained with this paradigm do not permit to determine the time course of processes involved in the emotional Stroop effect. Examining the neurophysiological processing of emotional information should reveal the level at which processing differences occur (e.g., early or late) between trauma-exposed and controls participants. This is important both to understand the nature of the impact of trauma on cognition, and the possibilities for altering these effects, when they are negative. Event-related potentials (ERPs) provide precise temporal data about distinct neural responses that take place during the processing of emotional and neutral information, and can be used to identify the temporal locus of this difference (Luck, 2005).

In a recent electroencephalographic study using the Stroop paradigm, early processing of trauma-related emotional words was altered in sexual abuse victims without PTSD (Grégoire et al. 2018). Specifically, the P1 (an early component related to selective attention) amplitude difference between trauma-associated and neutral words was higher in sexual abuse victims than in non-exposed controls. This result suggests that exposure to potentially traumatic events can have an important impact on neurocognitive function even in the absence of psychopathology (see also Zhang et al. 2014).

However, studies designed to evaluate the repercussions of trauma exposure on cognition typically compare existing groups (exposed and non-exposed) and therefore encounter two common methodological limitations: 1) the possibility of preexisting group differences in cognitive function (Gilbertson et al. 2006), and 2) the presence of potential confounding variables, which can be a consequence of trauma exposure, such as depression (Shalev et al. 1998), anxiety (Marshall et al. 2000; Tapia et al. 2012), maladaptive behaviors (e.g., substance abuse; Barrett et al. 1996), or a greater number of stressful life events (Grégoire et al. 2020). Thus, it cannot be asserted with confidence that differences in attention towards trauma-related stimuli are necessarily caused by trauma exposure.

One way to circumvent this problem is to use the trauma film paradigm (see Holmes and Bourne 2008; James et al. 2016, for reviews). This approach consists in presenting short films containing scenes of stressful or traumatic situations to non-clinical participants. Watching a trauma films is not traumatic per se but permits to experimentally (and transiently) induce some of the reactions typically associated with PTSD, such as negative emotional reactions (e.g., fear, distress), intrusive memories (also called *intrusions*), and even dissociation (Brewin and Saunders 2001; Holmes and Bourne 2008; Holmes et al. 2010). Because it enables the use of an experimental design, comparing one group exposed to a trauma film to one exposed to a neutral film, this paradigm allows researchers to examine the causal effects of analogue trauma exposure on cognitive processes while controlling for potential confounding factors usually present in trauma-exposed populations.

The main goal of the present study was to confirm and extend findings from Grégoire et al. (2018) by determining whether analogue trauma exposure produces an alteration of selective attention in non-clinical participants. The experiment consisted in performing an emotional Stroop task (during which continuous electroencephalographic activity was recorded) after viewing either a trauma or a neutral film. We employed electrophysiological measures to examine in more detail the specific mechanisms that were affected by analogue trauma exposure. Evoked potentials can allow to determine whether analogue trauma exposure alter early or late stages of information processing. A modulation of early processing is thought to be associated with perceptual, more automatic processing (Näätänen et al. 1982), while later components are generally associated with more strategic, controlled cognitive processes (Mangun and Hillyard 1995). We focused on two ERP components, one early (P1) and one late (P3b), known to be modulated by the attentional processing of emotional information (e.g., Li et al. 2007; Sass et al. 2010; Thomas et al. 2007). The P1 component is a positive-going voltage fluctuation peaking approximately between 100 and 130 ms after stimulus onset, originating from extrastriate areas of visual cortex and maximal over lateral occipital regions (Luck 2005). The P1 is related to sensory and perceptual processing of visual stimuli (Woodman 2010). Previous studies have shown a modulation of P1 by the emotional value of the contents, specifically in emotional Stroop tasks, with non-clinical populations. A greater amplitude of P1 was observed for emotional, particularly negative and threat-related words, compared to neutral words (Li et al. 2007; Sass et al. 2010; van Hooff et al. 2008). These results suggest an effect of emotion on attention allocation which may occur at an early stage of processing, outside the participants' control. The P3b component (which is part of the P300 complex; Polich 2007) has a predominantly parietal distribution, peaking approximately between 300 and 600 ms after stimulus onset. The P3b is related to increased attentional resource deployment (Yee and Miller 1994) and can be used as an index of updating or consolidation in short-term memory (see e.g., Bourassa et al. 2015; Brisson 2015; but see Verleger 1988). P3b amplitude is often larger for emotional than neutral stimuli (e.g., Herbert et al. 2008; Schupp et al. 2004), reflecting prioritization of emotional information. A differential valence effect between the two groups on the P1 component would indicate that analogue trauma exposure affects automatic processing of emotional words. A similar effect for the P3b would reveal that analogue trauma exposure alters later, strategic processing of emotional words.

A secondary objective of this study was to assess whether alterations in selective attention are specific to emotional words related to the analogue trauma content, or whether they affect all emotional words. Grégoire et al. (2018) could not ascertain whether the early attentional effect resulted from trauma-related or (non-traumatic) generally-emotional words because they only used trauma-related emotional words. A recent paper reported attentional biases to emotional stimuli in trauma-exposed participants but only when these stimuli were trauma-related (Grégoire et al. 2020), suggesting that trauma exposure would not affect attentional processing of generally-emotional information. Four types of words were employed in the Stroop task of the current study: emotional words related to the trauma film, emotional words unrelated to the trauma film, neutral words related to the neutral film and neutral words unrelated to the neutral film. We hypothesized that the P1 amplitude difference between emotional words related to the trauma film and neutral words unrelated to the neutral film would be higher in participants who watched the trauma film, relative to participants who watched the neutral film. The same effect should be smaller or absent with emotional words unrelated to the trauma film.

Finally, we exploited the capacity of the trauma film paradigm to induce intrusive memories to examine the link between selective attention and intrusions. Intrusions can be defined as distressing memories of the traumatic event that occur involuntarily into consciousness (Holmes et al. 2004; Rattel et al. 2019), taking the form of thoughts or sensory-perceptual impressions (James et al. 2016). While the attentional and memory-related effects of trauma exposure, in clinical and non-clinical populations, have often been investigated, they have rarely been inspected together in the same study, at least not using an experimental setting. Theoretical models of PTSD suggest that intrusions are related to increased perceptual (as opposed to conceptual) processing of trauma-related stimuli (Ehlers and Clark 2000). In this trauma-analogue study, we expected that 1) the trauma film would generate more intrusions than the neutral film and we explored whether 2) the number of intrusions related to the trauma film was linked to perceptual processing (indexed by the P1 component) of stimuli associated with the trauma film.

Method

Participants

Twenty-seven undergraduate students at the University of Quebec at Trois-Rivières participated in the experiment after having responded to emails or poster advertisements on campus. The study was announced as exploring the interaction between emotion and attention. Each participant first had to fill out a set of questionnaires and return them to the experimenter. All participants were White, native French speakers, and reported normal or corrected-to-normal visual acuity and normal color vision. According to self-report, none had neurological or psychiatric antecedents or were taking medication known to affect the central nervous system. In addition, no participant had severe depression, as measured by the *Beck Depression Inventory-II* (BDI-II; Beck et al. 1996), or reported any history of trauma. Moreover, participants having been involved in a moderate or severe car accident were not invited to participate because the trauma film concerned car accidents. Thus, the trauma video was not related to a potentially traumatic event which might have affected the cognitive dispositions of our participants. Three participants were excluded from analyses because more than 50% of their trials were removed (see artefact criteria rejection criteria below; Grégoire et al. 2018), leaving a sample of 24 participants. We provide details of participant characteristics in Table 1.

The sample size was chosen to achieve 0.95 power at α = 0.05, based on the effect size (η_p^2 = .151) observed in Grégoire et al. (2018) for the interaction effect between Valence (emotional, neutral) and Group (trauma, control) in a mixed analysis of variance (ANOVA). Specifically, the power analysis indicated that a sample size of 22 (11 participants per group) would be sufficient to detect the interaction effect. The study was approved by the local ethics committee of the University of Quebec at Trois-Rivières and all participants provided written informed consent prior to testing, being fully aware of the nature of the stimuli to be presented and having seen examples of the questions that would be asked. They received a financial compensation of 20$CA for their participation.

Table 1. *Participant characteristics for trauma and control groups.*

	Trauma group	Control group	*t*-tests
N	12	12	-
Women/Men	7/5	7/5	-
Age (years)	22.50 (3.48)	23.92 (6.80)	$t(22) = 0.64$, $p = .527$ ($p_{rand} = .620$), $d = 0.26$
BDI-II	7.33 (6.41)	6.17 (7.91)	$t(22) = 0.40$, $p = .695$ ($p_{rand} = .716$), $d = 0.16$
STAI-S	36.25 (10.61)	31.33 (9.21)	$t(22) = 1.21$, $p = .238$ ($p_{rand} = .248$), $d = 0.50$
STAI-T	34.92 (8.60)	35.42 (9.27)	$t(22) = 0.14$, $p = .892$ ($p_{rand} = .911$), $d = 0.06$
LEI	14.17 (8.03)	15.67 (6.43)	$t(22) = 0.51$, $p = .619$ ($p_{rand} = .635$), $d = 0.21$

Note. Standard deviations are in parentheses. BDI-II = Beck Depression Inventory; STAI-S = State-Trait Anxiety Inventory-State; STAI-T = State-Trait Anxiety Inventory-Trait; LEI = Life Events Inventory.

Experimental Setup

Testing took place in a dark room. The experimental protocol included the administration of several questionnaires, the presentation of a video and an emotional Stroop task during which continuous electroencephalographic activity was recorded from 64 active scalp electrodes (actiCap). The video, questions and stimuli were presented on a CRT 17-in monitor, operating at a resolution of 1,024 × 768 pixels. Viewing distance was about 60 cm. The stimuli were generated and the experiment was run using EPrime (Schneider et al. 2002). Participants came to the laboratory for a single 90-min session.

Stimuli and procedure

Participants first completed and returned by e-mail several questionnaires concerning demographic information (age, mother tongue, education level, color blindness, visual impairment, neurological or psychiatric antecedents, medications altering cognition and prior potentially traumatic experiences including car accidents), depression (BDI-II), anxiety (STAI) and stressful life events (LEI). If they met all the inclusion criteria (see *Participants* section), they were invited to participate in the experiment. Note that STAI and LEI tests were not used to exclude participants but to verify that the two groups did not differ on anxiety and stressful life events measures.

The first part of the experiment consisted in watching a short video (traumatic or neutral), which was preceded and followed by a subjective self-evaluation targeting five emotions (anger, powerlessness, horror, sadness and fear). Participants were then asked to report, during a period of five minutes, intrusions related to the video. Finally, participants performed an emotional Stroop task during which both continuous electroencephalographic activity was recorded and intrusions were measured.

*Questionnaires***.** The BDI-II (Beck et al. 1996) was used to evaluate the severity of depressive symptoms. It consists of 21 questions, each with a score between 0 and 3. The minimum score is

0 and the maximum score is 63. Scores above 28 are considered consistent with “severe” depression. Internal consistency (measured by Cronbach's α) of BDI-II varies between .83 and .96. Test-retest reliability (measured by Pearson's r) varies between .73 and .96 (Wang and Gorenstein 2013). In our experimental sample (N = 24), internal consistency of BDI-II is .90.

The *State-Trait Anxiety Inventory* (STAI; Gauthier and Bouchard 1993) was filled in by participants to evaluate their state (STAI-S) and trait (STAI-T) anxiety levels. Each scale has 20 items. Participants had to choose, for each item (e.g., “I am worried”), an answer ranging from “1: Not at all” to “4: Very much so”. This questionnaire provides a score from 20 to 80 with higher scores indicating greater levels of anxiety. Internal consistency varies between .86 and .95 for STAI-S and between .89 and .96 for STAI-T. Test-retest reliability varies between .16 and .62 for STAI-S and between .65 and .86 for STAI-T (Spielberger et al. 1983). In our experimental sample, internal consistency is .90 for STAI-S and .88 for STAI-T.

The *Life Events Inventory* (LEI; Cochrane and Robertson 1973) was administered to evaluate the occurrence of stressful life events experienced by participants throughout their lifetime (pleasant, unpleasant or neutral; for example, moving to a new house, pregnancy, divorce). Participants simply read the 52 events and answered if each one had happened to them or not. ‘No’ answers were coded as zero and ‘yes’ answers as one; each participant was thus given a score from zero to fifty-two with higher scores indicating a greater number of stressful life events.

Trauma and neutral videos. The trauma video consisted of an 8-minute compilation of five scenes (from public television programs) all related to real and serious traffic accidents. In three scenes, emergency services intervened at the site of the accident to treat injured people. Another scene was related to a fatal collision between a motorcycle and a car, and the last one concerned consequences of a traffic accident for a victim (i.e., permanent handicap). The trauma film was used in a previous study (manuscript in preparation) in which we observed a significant effect on the five self-reported emotions (i.e., anger, powerlessness, horror, sadness and fear) measured before and after the viewing of the video ($N = 22$, all ps < .05). We choose scenes from real situations in order to produce vivid emotional reactions. The neutral video consisted of an 8-minute film depicting the daily life of an accountant in a bookkeeping firm. As for the trauma film, the neutral video was composed of five scenes and extracted from a public television program. For the sake of simplicity, we refer to the group of participants who watched the trauma film the *trauma group* (though the trauma film is not a real traumatic situation, as mentioned in Introduction) and the group of participants who watched the neutral film the *control group*. Note that we employed *control* group instead of *neutral* group to avoid that two of the factors used in the analyses (i.e., valence and group) have a modality with the same label. Participants were randomly assigned to one of the two groups (trauma or control) using a random number generator (with integers from 1 to 100). Participants with an odd number were assigned to the trauma group; participants with an even number were assigned to the control group.

Self-reported emotion. Before and after viewing the video, participants evaluated on a 10-point scale ranging from “0: Not at all” to “10: Extremely” their current affective state for each of the five following emotions: anger, powerlessness, horror, sadness and fear.

Immediate intrusions. After the second subjective rating, immediate intrusive memories were measured for a 5-minute period. Participants were asked to close their eyes keeping their dominant hand above the space bar of the keyboard. They were required to press the space bar when an intrusive memory about the film occurred, and to release the space bar when it had gone. An intrusive memory was defined as a mental image or a thought that appears spontaneously in consciousness. Intrusions do not include deliberate recollections or verbal ruminations about the film. Participants were carefully instructed to only report memories that met these criteria. This procedure, based on a method employed by Nixon et al. (2009), mainly aimed to verify that the trauma film induced intrusive memories, and so that our manipulation was effective. An audio signal informed participants that the 5-minute period was finished. We measured the frequency and duration (in seconds) of intrusions.

Emotional Stroop task. Thirty-two words (substantives) were used in the Stroop task. We manipulated the valence (emotional, neutral) and the semantic relatedness (related, unrelated) of words such that eight emotional words were related to the trauma film (emotional-related words; e.g., accident, blood), eight emotional words were not related to the trauma film (emotional-unrelated words; e.g., cancer, divorce), eight neutral words were related to the neutral film (neutral-related words; e.g., office, file) and eight neutral words were not related to the neutral film (neutral-unrelated words; e.g., plate, boot). The four types of words (i.e., emotional-related, emotional-unrelated, neutral-related and neutral-unrelated) were matched for frequency, number of orthographic neighbors, number of letters and number of syllables as derived from the online database Lexique 3.80 (http://www.lexique.org; New, 2006). None of the two-by-two comparisons were significant (all *p*s > .10).

We also tested valence and arousal dimensions of words using the same method as Gilet et al. (2012). Twenty-six participants (11 males, native French speakers, mean age: 22.19 years, SD = 3.27), who did not participate in the main study evaluated the 32 words on line, using a 7-point scale ranging from “1 = very unpleasant, unpleasant, negative connotation” to “7 = very pleasant, pleasant, positive connotation” for the valence dimension and from “1 = very calming, soothing, relief feeling” to “7 = very arousing, exciting, stressful” for the arousal dimension. As expected, results revealed significantly lower valence ratings for related and unrelated emotional words than for related and unrelated neutral words (all *p*s < .001), and significantly greater arousal ratings for related and unrelated emotional words than for related and unrelated neutral words (all *p*s < .001). No significant differences were observed between emotional-related words and emotional-unrelated words for valence and arousal (all *p*s > .10). Similarly, no significant differences were observed between neutral-related words and neutral-unrelated words for the same dimensions (all *p*s > .05). The complete list of words and their characteristics are presented in the Appendix. Details of the statistical analyses performed on the characteristics of words are reported in the Supplemental Material 1.

Each type of word (i.e., emotional-related, emotional-unrelated, neutral-related and neutral-unrelated) was presented in a blocked fashion, with a random order of presentation within each block, because this method is known to potentiate the emotional Stroop effect (e.g., Kaspi et al. 1995; see also, Algom et al. 2004, Experiment 6; Holle et al. 1997). The blocked presentation was also more convenient to measure intrusions relative to each type of words. The order of block presentation was counterbalanced across participants, with the restriction that a block of emotional words always alternated with a block of neutral words and vice versa (leading to eight possible presentation orders). Each of the four blocks comprised 128 trials with a self-paced break every eight trials, to allow participants to rest, move, or blink. Before the start of the emotional Stroop task, participants performed twelve practice trials (with neutral words different from the experimental words).

The frequency of appearance of colors was manipulated in order to measure the P3b component, which is evoked by infrequent stimuli (Polich and Kok 1995). In each block, the blue and green colors appeared 48 times each (75% of trials), while the red and yellow colors appeared only 16 times each (25% of trials). Thus, each word was presented six times in blue, six times in green, two times in red and two times in yellow. The order of presentation of colors was randomized. The amplitude of the P3b is larger to less frequent stimuli, in this case the colors red and yellow. Therefore, subtracting frequent trials (i.e., with blue or green colors) from infrequent trials (i.e., with red or yellow colors) isolates the P3b from overlapping activity that is not sensitive to our category-defined frequency manipulation.

At the beginning of each trial, a black fixation cross appeared at the center of the screen for a random duration between 400 ms and 800 ms. Then, a colored word was presented at the center of the screen and stayed displayed until participants gave their response via the computer keyboard. Participants had to press the “C” key when the word was presented in green or red, and they had to press the “M” key when the word was presented in blue or yellow. They were instructed to keep the middle finger of the left hand above the “C” key and the middle finger of the right hand above the “M” key throughout the Stroop task. Participants were encouraged to respond as fast and as accurately as possible while ignoring the word’s meaning. After they had responded, there was a 1000 ms delay before the next trial started (Figure 1). Words appeared in lowercase bold, font “Courrier New 18”. The background of the screen was grey during the entire task.

Throughout the emotional Stroop task, participants were also required to press the space bar each time they had an intrusion (they were instructed to keep their forefingers above the space bar throughout the task) while prioritizing the Stroop task. More precisely, we specified that intrusions had to be reported after determining the word color and before the beginning of the next trial (i.e., before the presentation of the fixation cross). Note that pressing space bar during the presentation of a Stroop stimulus terminated the trial. Finally, participants were encouraged to avoid eye movements or blinks during trials. If they needed to blink, they were instructed to do so after pressing the response key.

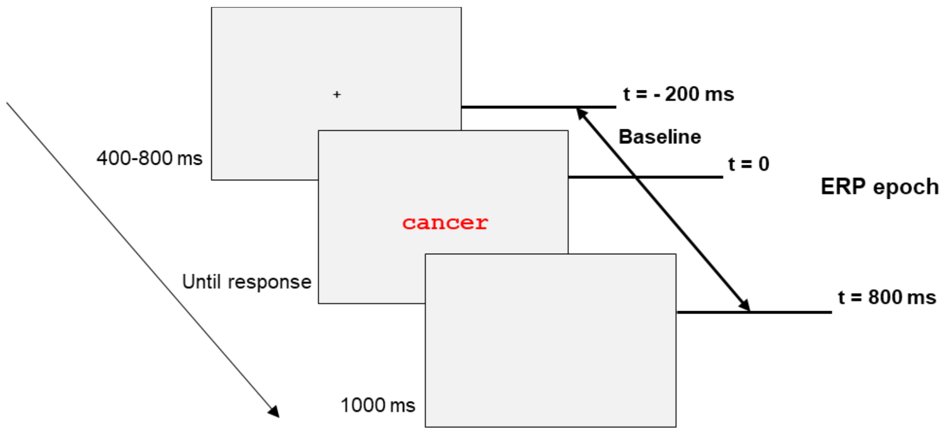

Figure 1. Sequence of events in the emotional Stroop task. Each trial began with a fixation cross of a random duration between 400 ms and 800 ms, followed by the presentation of a colored word. The stimulus stayed on the screen until the participant's response. Then, a 1000-ms interval preceded the start of the next trial.

Electrophysiological Data Acquisition

The electroencephalography (EEG) was recorded from 64 active Ag/AgCl electrodes (ActiCHamp system with ActiCAP, Brain Products) positioned according to the standard 10–10 system, with the exception that the TP9 and TP10 electrode sites were not used; they were replaced by electrodes placed at the mastoids. Activity at all electrodes was recorded with a left-mastoid reference, and the data were re-referenced offline to the algebraic average of the left and right mastoids (Luck 2005). Additional cutaneous electrodes were used to monitor electrooculographic activity; two placed on external canthi to record the horizontal electrooculogram (HEOG) and two placed on infra/supraorbital regions of the right eye to record the vertical electrooculogram (VEOG). All electrode impedances were kept below 15 kΩ. The EEG was sampled and digitized at 500 Hz.

Event-Related Potentials Analysis

Using the software Brain Vision Analyser 2.0 (Brain Products, Germany), signals were high-pass filtered at 0.01 Hz and lowpassed at 20 Hz offline. Trials with eye blinks (VEOG > 50 μV), large horizontal eye movements (HEOG > 50 μV), and/or other artifacts at electrodes of interest (> 80 μV at PO7, PO8, POz, Pz or CPz) were excluded from further analyses using an automated screening procedure. The EEG was segmented relative to the onset of the presentation of each word in the emotional Stroop task to create stimulus-locked epochs of 1000 ms that included a 200 ms pre-stimulus period, which served as the epoch baseline (Figure 1). For each ERP component, epochs were averaged after removing error trials and trials with response times (RTs) beyond 1500 ms and below 200 ms.

The mean amplitude of the P1 (time window: 80-140 ms post-stimulus) was computed separately for each type of words at the PO7 and PO8 electrode sites, where the deflection is typically maximal (Luck 2005).

The mean amplitude of the P3b (time window: 400-750 ms post-stimulus) was computed separately for each type of word at the POz, Pz and Cpz electrode sites, where the component is typically maximal. To isolate the P3b component, we subtracted the average signals of trials with frequent colors (blue and green) from the average of trials with infrequent color (red and yellow).

Statistical Data Analysis

In the emotional Stroop task, trials with errors (5.38%) and correct trials with RTs under 200 ms or over 1500 ms (2.15%) were discarded from RT as well as ERP analyses. A mixed factorial ANOVA with Valence (emotional, neutral) and Relatedness (related, unrelated) as within-subject variables and Group (trauma, control) as a between-subject variable was run on each of the following dependent variables: P1 amplitude, P3b amplitude, RTs and intrusions during the Stroop task. Subsequent paired-sample *t*-tests were used when appropriate. For each paired-sample *t*-test, data were checked for normality of distribution with the Kolmogorov-Smirnov test. Note that we calculated Cohen's *d* using the formula $d_z = t/\text{sqrt}(n)$ for all paired-sample *t*-tests (Lakens, 2013; Rosenthal, 1991). We also performed independent-samples *t*-tests, mainly to compare the two groups of participants for frequency and duration of immediate intrusions, subjective ratings of emotions, and pre-tests. For each independent-samples *t*-test, we additionally reported p_{rand}, which reflects the probability of the observed effect when comparing to an empirically-derived sampling distribution in which the assignment to the group (e.g., trauma or control) is randomly determined for each participant over 10,000 iterations; such a randomization test does not make assumptions about normality of the data distribution or homoscedasticity and is relatively robust to small sample sizes (Craig & Fisher, 2019; Ludbrook, 1994). Finally, correlational analyses were performed, particularly to examine the relationship between intrusions measured during the Stroop task and the P1 amplitude. None of the correlations reported in this paper includes outliers (i.e., data above 2.5 standard deviations from their corresponding mean). Intrusions measured during the Stroop task were normalized using a natural logarithm transformation (i.e., we applied the transformation $\ln(x + 1)$ for the number of intrusions (x) obtained with each type of words for each participant). Raw data concerning subjective ratings of emotions and intrusions as well as histograms of distributions for normalized data (after log-transformation) are reported in the Supplemental Material 2.

Results

Questionnaires

Pre-tests scores are presented in Table 1. No significant differences between the two groups were observed for the BDI-II, STAI-S, STAI-T and LEI scores (all *p*s > .10).

Self-reported emotion

Before the presentation of the video, there were no significant differences between the two groups for self-reported levels of anger, powerlessness, horror, sadness and fear (all *p*s > .10). After the viewing of the video, self-reported levels of powerlessness, horror, sadness and fear were significantly greater for the trauma group than for the control group (all *p*s < .01). Levels of anger were not significantly greater for the trauma group than for the control group, $t(22) = 1.81$, $p = .083$ ($p_{rand} = .102$), $d = 0.74$ (Table 2). Altogether, these results confirm that the trauma film induced negative emotional reactions.

Table 2. *Subjective ratings of emotions before and after the viewing of the video for trauma and control groups.*

		Trauma group	Control group	*t*-tests
Anger	Before	0.42 (0.79)	0.58 (2.02)	$t(22) = 0.27$, $p = .793$ ($p_{rand} > .999$), $d = 0.10$
	After	1.83 (2.62)	0.33 (1.15)	$t(22) = 1.81$, $p = .083$ ($p_{rand} = .102$), $d = 0.74$
Powerlessness	Before	2.08 (2.11)	0.75 (2.30)	$t(22) = 1.48$, $p = .153$ ($p_{rand} = .185$), $d = 0.60$
	After	5.50 (3.32)	0.42 (1.44)	$t(22) = 4.87$, $p < .001$ ($p_{rand} < .001$), $d = 1.99$
Horror	Before	0.17 (0.39)	0.25 (0.87)	$t(22) = 0.30$, $p = .764$ ($p_{rand} > .999$), $d = 0.12$
	After	4.75 (2.18)	0.00 (0.00)	$t(22) = 7.55$, $p < .001$ ($p_{rand} < .001$), $d = 3.08$
Sadness	Before	1.33 (1.92)	0.75 (2.30)	$t(22) = 0.67$, $p = .507$ ($p_{rand} = .588$), $d = 0.27$
	After	6.08 (2.15)	0.50 (1.73)	$t(22) = 7.00$, $p < .001$ ($p_{rand} < .001$), $d = 2.86$
Fear	Before	1.25 (2.18)	0.50 (0.90)	$t(22) = 1.01$, $p = .283$ ($p_{rand} = .381$), $d = 0.45$
	After	2.50 (2.65)	0.08 (0.29)	$t(22) = 3.15$, $p = .005$ ($p_{rand} = .003$), $d = 1.28$

Note. Standard deviations are in parentheses.

Immediate intrusions

Intrusions frequency and duration measured in the 5-minute period after viewing the video did not significantly differ between the trauma and the control group, neither for frequency

(*M* = 12.25, *SD* = 8.26 and *M* = 14.67, *SD* = 12.15, respectively), $t(22) = 0.57$, $p = .574$ ($p_{rand} = .581$), $d = 0.23$, nor duration (*M* = 233.97, *SD* = 47.23 and *M* = 235.68, *SD* = 97.25, respectively), $t(22) = 0.06$, $p = .957$ ($p_{rand} > .999$), $d = 0.02$.

Emotional Stroop task - Behavioral results

Intrusions during the Stroop task. Analyses performed on intrusions measured during the Stroop task revealed a significant main effect of Relatedness, $F(1, 22) = 16.84$, $p < .001$, $\eta_p^2 = .434$, with more intrusions in the block of related words (*M* = 1.45, *SD* = 1.30) than in the block of unrelated words (*M* = 0.93, *SD* = 0.92). We also observed a significant Valence x Group interaction, $F(1, 22) = 38.99$, $p < .001$, $\eta_p^2 = .639$. In the trauma group, participants reported a significantly greater number of intrusions in the block of emotional words than in the block of neutral words, $t(11) = 4.96$, $p < .001$, $d_z = 1.43$. A reverse effect was evidenced in the control group, where participants reported more intrusions in the block of neutral words than in the block of emotional words, $t(11) = 4.36$, $p = .001$, $d_z = 1.26$. These last two effects were driven by words related to the film viewed by participants, as reflected by the significant three-way Valence x Group x Relatedness interaction, $F(1, 22) = 10.04$, $p = .004$, $\eta_p^2 = .313$ (Table 3). In the trauma group, the number of intrusions was significantly greater in the block of emotional-related words than in the blocks of emotional-unrelated, neutral-related and neutral-unrelated words, $t(11) = 4.42$, $p = .001$, $d_z = 1.28$, $t(11) = 4.16$, $p = .002$, $d_z = 1.20$, and $t(11) = 5.22$, $p < .001$, $d_z = 1.51$, respectively. No significant difference was observed between the block of emotional-unrelated words and the blocks of neutral-related and neutral-unrelated words, $t(11) = 0.33$, $p = .749$, $d_z = 0.09$, and $t(11) = 0.71$, $p = .491$, $d_z = 0.21$, respectively. Similarly, the number of intrusions in the block of neutral-related words did not differ significantly from the number of intrusions in the block of neutral-unrelated words, $t(11) = 0.28$, $p = .782$, $d_z = 0.08$. In the control group, the number of intrusions was significantly greater in the block of neutral-related words than in the blocks of emotional-related, emotional-unrelated and neutral-unrelated words, $t(11) = 3.84$, $p = .003$, $d_z = 1.11$, $t(11) = 4.60$, $p = .001$, $d_z = 1.33$, and $t(11) = 3.45$, $p = .005$, $d_z = 1.00$, respectively. No significant difference was observed between the block of neutral-unrelated words and the blocks of emotional-related and emotional-unrelated words, $t(11) = 1.23$, $p = .243$, $d_z = 0.36$, and $t(11) = 0.31$, $p = .760$, $d_z = 0.09$, respectively. Similarly, the number of intrusions in the block of emotional-related words did not differ significantly from the number of intrusions in the block of emotional-unrelated words, $t(11) = 0.59$, $p = .568$, $d_z = 0.17$. In sum, participants reported more intrusions when stimuli were related to the video they had watched. All remaining effects were not significant. Specifically, we observed no main effect of Valence, $F(1, 22) = 2.55$, $p = .125$, $\eta_p^2 = .104$ (with $M = 1.10$, $SD = 1.09$, and $M = 1.28$, $SD = 1.21$, for emotional and neutral words, respectively), no main effect of Group, $F(1, 22) = 0.66$, $p = .427$, $\eta_p^2 = .029$ (with $M = 1.33$, $SD = 1.10$, and $M = 1.05$, $SD = 1.19$, for trauma and control group, respectively), no Valence x Relatedness interaction, $F(1, 22) = 1.15$, $p = .295$, $\eta_p^2 = .050$, and no Relatedness x Group interaction, $F(1, 22) = 0.17$, $p = .684$, $\eta_p^2 = .008$ (with significantly more intrusions for related words than for unrelated words in the trauma group, $t(11) = 3.99$, $p = .002$, $d_z = 1.15$, and the control group, $t(11) = 3.31$, $p = .007$, $d_z = 0.96$).

Table 3. *Number of intrusions (normalized data) and percentage of trials retained after rejecting artifacts (for EEG measures) in the emotional Stroop task as a function of Valence (emotional, neutral) and Relatedness (related, unrelated) for trauma and control groups.*

		Emotional-related	Emotional-unrelated	Neutral-related	Neutral-unrelated
Trauma group	Number of intrusions	2.02 (1.10)	1.17 (0.96)	1.11 (1.19)	1.03 (0.98)
Control group		0.51 (0.67)	0.72 (1.03)	2.17 (1.45)	0.82 (0.74)
Trauma group	Percentage of trials (EEG)				
	Mean	78.71 (9.92)	78.45 (12.12)	76.43 (11.44)	79.10 (11.65)
	Minimum	57.03	57.03	53.91	55.47
	Maximum	94.53	93.75	89.06	95.31
Control group	Percentage of trials (EEG)				
	Mean	81.97 (9.29)	79.95 (9.99)	79.75 (8.97)	77.99 (10.09)
	Minimum	64.06	58.59	66.41	59.38
	Maximum	98.44	95.31	97.66	89.84

Note. Standard deviations are in parentheses.

RTs. Analyses performed on RTs indicated a significant Valence x Group interaction, $F(1, 22) = 8.14$, $p = .009$, $\eta_p^2 = .270$. RTs were marginally (but not significantly) greater for emotional words than for neutral words in the trauma group, $t(11) = 1.80$, $p = .099$, $d_z = 0.52$, while the emotional Stroop effect was reversed in the control group, with RTs significantly greater for neutral words than for emotional words, $t(11) = 2.21$, $p = .049$, $d_z = 0.64$. This last effect was driven by increased RTs with neutral-related words, just as the (marginal) emotional Stroop effect observed in the trauma group was driven by increased RTs with emotional-related words, as reflected by the significant three-way Valence x Group x Relatedness interaction, $F(1, 22) = 10.98$, $p = .003$, $\eta_p^2 = .333$ (Figure 2). All remaining effects were not significant. Specifically, we observed no main effect of Valence, $F(1, 22) = 0.36$, $p = .555$, $\eta_p^2 = .016$ (with $M = 557.88$ ms, $SD = 89.46$, and $M = 563.32$ ms, $SD = 87.08$, for emotional and neutral words, respectively), no main effect of Relatedness, $F(1, 22) = 1.69$, $p = .207$, $\eta_p^2 = .071$ (with $M = 567.30$ ms, $SD = 90.84$, and $M = 553.91$ ms, $SD = 85.19$, for related and unrelated words, respectively), no main effect of Group, $F(1, 22) = 0.62$, $p = .439$, $\eta_p^2 = .027$ (with $M = 547.74$ ms, $SD = 92.52$, and $M =$

573.47 ms, *SD* = 81.88, for trauma and control group, respectively), no Valence x Relatedness interaction, $F(1, 22) = 2.79$, $p = .109$, $\eta_p^2 = .112$, and no Relatedness x Group interaction, $F(1, 22) = 0.01$, $p = .934$, $\eta_p^2 < .001$ (with no significant difference between related and unrelated words in the trauma group, $t(11) = 0.95$, $p = .362$, $d_z = 0.27$, and the control group, $t(11) = 0.90$, $p = .388$, $d_z = 0.26$).

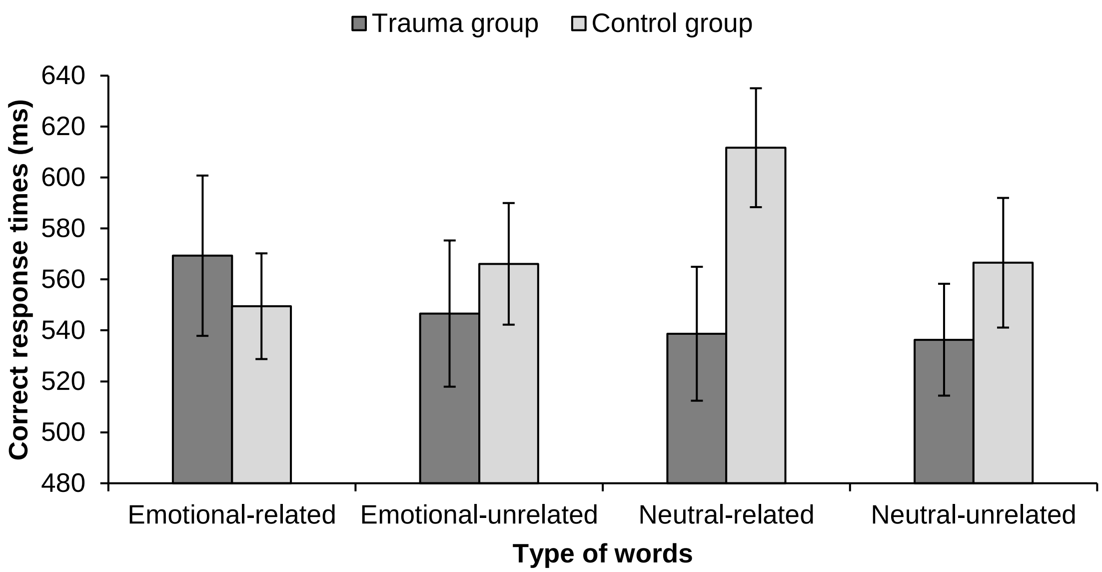

Figure 2. Correct response times as a function of Valence (emotional, neutral) and Relatedness (related, unrelated) for trauma and control groups. Error bars indicate standard errors.

Emotional Stroop task - Electrophysiological results

Mean and range percentages of trials retained after rejecting artifacts (for EEG measures) in the emotional Stroop task are reported in Table 3.

P1 (80-140 ms). The analysis of P1 amplitude revealed a significant Valence x Group interaction, $F(1, 22) = 5.46$, $p = .029$, $\eta_p^2 = .199$, reflecting a valence effect (measured by the amplitude difference between emotional and neutral words) significantly greater in the trauma group than in the control group (Figure 3 and Figure 4A). Consistent with our hypothesis, this interaction was still significant when analyses were performed only with emotional-related and neutral-unrelated words, $F(1, 22) = 4.47$, $p = .046$, $\eta_p^2 = .169$ (Figure 4B). No significant Valence x Group interaction was observed when analyses were performed with emotional-unrelated and neutral-unrelated words, $F(1, 22) = 0.16$, $p = .691$, $\eta_p^2 = .007$. All remaining effects were not significant. Specifically, we observed no main effect of Valence, $F(1, 22) = 0.09$, $p = .766$, $\eta_p^2 = .004$ (with *M* = 2.43 µV, *SD* = 2.81, and *M* = 2.41 µV, *SD* = 2.80, for emotional and neutral words, respectively), no main effect of Relatedness, $F(1, 22) = 0.65$, $p = .430$, $\eta_p^2 = .029$ (with *M* = 2.36 µV, *SD* = 2.72, and *M* = 2.48 µV, *SD* = 2.89, for related and unrelated words, respectively), no main effect of Group, $F(1, 22) = 0.42$, $p = .523$, $\eta_p^2 = .019$ (with *M* = 2.05 µV, *SD* = 2.55, and *M* = 2.79 µV, *SD* = 2.99, for trauma and control group, respectively), no Valence x Relatedness interaction, $F(1, 22) = 1.46$, $p = .240$, $\eta_p^2 = .062$, no Relatedness x Group interaction, $F(1, 22) = 0.43$, $p = .518$, $\eta_p^2 = .019$ (with no significant difference between related and unrelated words in the trauma group, $t(11) = 0.11$, $p = .915$, $d_z = 0.03$, and the control group, $t(11) = 0.99$, $p = .342$, $d_z = 0.29$), and no Valence x Group x Relatedness interaction, $F(1, 22) = 1.16$, $p = .293$, $\eta_p^2 = .050$.

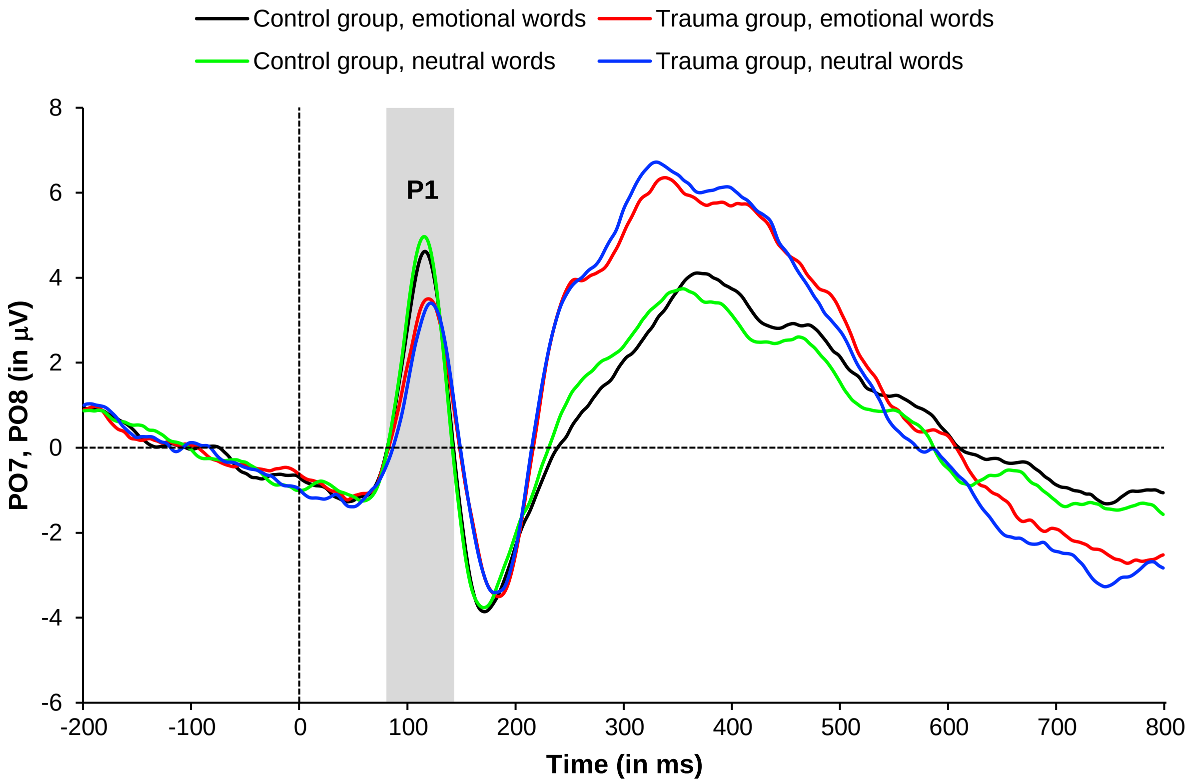

Figure 3. Grand average event-related potential (ERP) waveforms representing the P1 component (80-140 ms) for trauma and control groups with emotional and neutral words. Artifact-free trials with a correct response were included in the grand-average ERPs (see text for details). Note that lines of this figure were smoothed for display purposes.

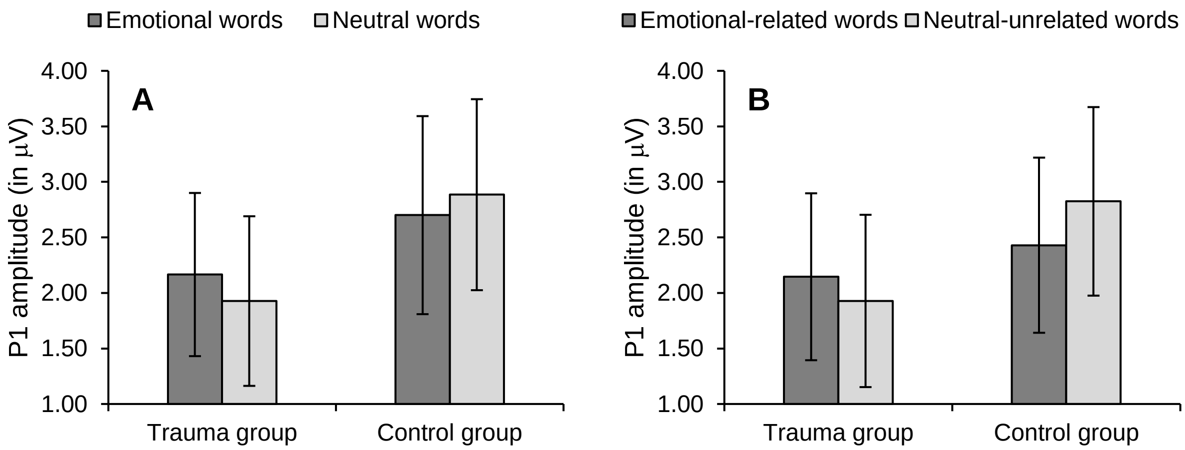

Figure 4. P1 amplitude (80-140 ms) as a function of valence and group. The valence condition comprises (A) emotional and neutral words, and (B) emotional-related and neutral-unrelated words. Error bars indicate standard errors.

P3b (400-750 ms). The analysis of P3b amplitude revealed no significant Valence x Group interaction, $F(1, 22) = 0.06$, $p = .815$, $\eta_p^2 = .003$, but a significant Relatedness x Group interaction, $F(1, 22) = 4.43$, $p = .047$, $\eta_p^2 = .168$. P3b amplitude was numerically larger for related words than for unrelated words in the trauma group (*M* = 1.54 µV, *SD* = 2.42 and *M* = 0.69 µV, *SD* = 1.99, respectively), but the difference was not significant, $t(11) = 1.26$, $p = .233$, $d_z = 0.36$, while in the control group, P3b amplitude was descriptively (but not significantly) larger for unrelated words than for related words (*M* = 1.64 µV, *SD* = 2.69 and *M* = 0.56 µV, *SD* = 3.07, respectively), $t(11) = 1.74$, $p = .110$, $d_z = 0.50$. All remaining effects were not significant. Specifically, we observed no main effect of Valence, $F(1, 22) = 0.10$, $p = .751$, $\eta_p^2 = .005$ (with *M* = 1.04 µV, *SD* = 2.46, and *M* = 1.18 µV, *SD* = 3.25, for emotional and neutral words, respectively), no main effect of Relatedness, $F(1, 22) = 0.06$, $p = .809$, $\eta_p^2 = .003$ (with *M* = 1.05 µV, *SD* = 3.07, and *M* = 1.17 µV, *SD* = 2.68, for related and unrelated words, respectively), no main effect of Group, $F(1, 22) < 0.01$, $p = .987$, $\eta_p^2 < .001$ (with *M* = 1.12 µV, *SD* = 2.48, and *M* = 1.10 µV, *SD* = 3.23, for trauma and control group, respectively), no Valence x Relatedness interaction, $F(1, 22) = 0.31$, $p = .585$, $\eta_p^2 = .014$, and no Valence x Group x Relatedness interaction, $F(1, 22) = 1.03$, $p = .322$, $\eta_p^2 = .045$.

Correlational Analyses

We used correlational analyses to examine the potential links between attentional processing and intrusive memories. ANOVAs performed on the number of intrusions, RTs and the P1 amplitude during the emotional Stroop task revealed a similar interaction pattern in all three cases between Valence and Group, with higher scores in the emotional condition than in the neutral condition for the trauma group, and conversely, higher scores in the neutral condition than in the emotional condition for the control group. In order to evaluate relationships between intrusions, RTs and the P1 amplitude, we computed a score for each of these three measures (for each participant): called *intrusions Stroop*, *RT Stroop* and *P1 Stroop*. For each, we subtracted the mean score obtained in the neutral condition (for related and unrelated words) from the mean score obtained in the emotional condition (for related and unrelated words). Thus, the scores represent the number of additional intrusions, time and errors related to processing emotional words.

We observed a significant positive relationship between P1 Stroop and RT Stroop, $r(22) = .429$, $p = .037$ (Figure 5A), and a significant positive relationship between P1 Stroop and intrusions Stroop, $r(22) = .418$, $p = .042$ (Figure 5B). The correlation between RT Stroop and intrusions Stroop was also positive and significant, $r(22) = .688$, $p < .001$ (Figure 5C). To better understand the origin of these relationships, we performed the same analyses separately for related words and unrelated words.

Related words. We observed a positive relationship between P1 Stroop and RT Stroop which was close to significance, $r(22) = .403$, $p = .051$ (Figure 5D). We also observed a significant positive relationship between P1 Stroop and intrusions Stroop, $r(22) = .460$, $p = .024$ (Figure 5E), and a strong positive correlation between RT Stroop and intrusions Stroop, $r(22) = .726$, $p < .001$ (Figure 5F).

Unrelated words. The same analyses with unrelated words revealed low and non-significant correlations between P1 Stroop and RT Stroop, $r(22) = .118$, $p = .582$ (Figure 5G), P1 Stroop and intrusions Stroop, $r(22) = -.137$, $p = .522$ (Figure 5H), and RT Stroop and intrusions Stroop, $r(22) = -.265$, $p = .211$ (Figure 5I).

No relationship was observed between the amplitude of the P3b component and both RTs and the number of intrusions measured during the Stroop task. Specifically, there was no significant correlation between P3 Stroop and RT Stroop, $r(22) = .212$, $p = .320$, as well as between P3 Stroop and intrusions Stroop, $r(22) = .091$, $p = .671$. Note that Stroop effects were calculated, as previously, by subtracting the mean score obtained in the neutral condition (for related and unrelated words) from the mean score obtained in the emotional condition (for related and unrelated words). These correlations were also not significant when analyses were performed separately for related and unrelated words (all *p*s > .10).

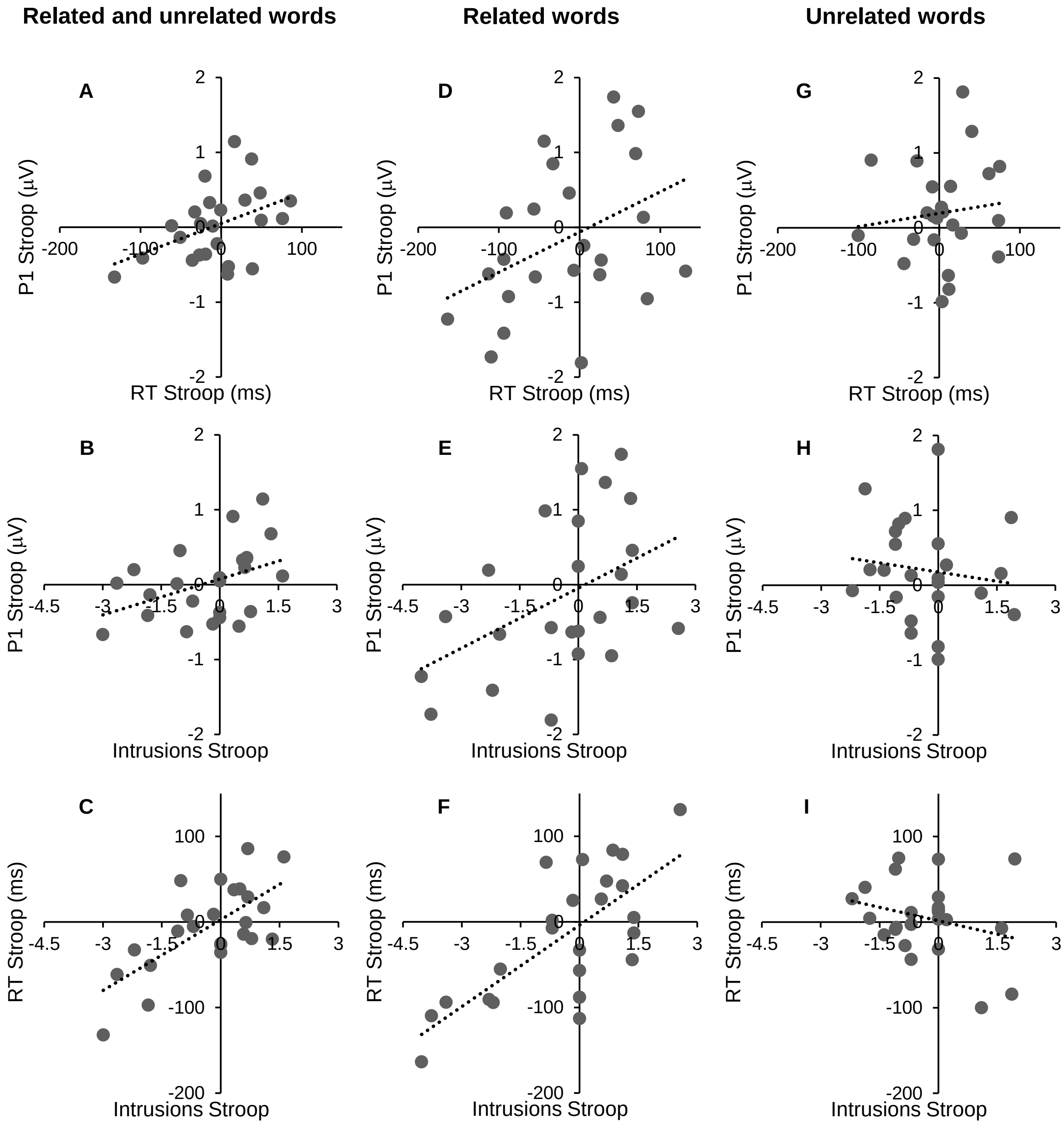

Figure 5. Relationship between P1 Stroop (mean P1 amplitude difference between emotional and neutral conditions) and RT Stroop (mean RT difference between emotional and neutral conditions) for (A) related and unrelated words, (D) related words and (G) unrelated words. Relationship between P1 Stroop and intrusions Stroop (intrusion number difference between emotional and neutral conditions) for (B) related and unrelated words, (E) related words and (H) unrelated words. Relationship between RT Stroop and intrusions Stroop for (C) related and unrelated words, (F) related words and (I) unrelated words.

Discussion

The present study aimed to determine whether attentional processing of emotional information is altered by exposure to an analogue traumatic event. Two groups of non-clinical participants matched on anxiety level, depression symptoms and stressful life events viewed either a trauma or a neutral film. They then performed an emotional Stroop task during which both continuous electroencephalographic activity and intrusive memories were recorded. Results observed for the P1 component revealed that the valence effect, measured by the amplitude difference between emotional and neutral words, was significantly greater in the trauma group than in the control group. This interaction was still significant when analyses were performed only with emotional-related and neutral-unrelated words (which corresponds to the conditions used by Grégoire et al. 2018), but not when analyses were performed with emotional-unrelated and neutral-unrelated words, suggesting that exposure to the emotional video altered early attentional processing of trauma-related stimuli specifically, with probably preferential attention to these stimuli (Sass et al. 2010; van Hooff et al. 2008). This finding, using an experimental design, suggests that alterations of selective attention observed with participants exposed to potentially traumatic events in the real world may result from trauma exposure itself in the absence of comorbidity.

Our data also show that this outcome does not ensue from an emotional induction effect (i.e., the simple exposure to an emotional situation) because the interaction between valence and group was specific to words semantically related to the emotional event and did not extend to all negative information. However, one could assume that the greater valence effect (emotional-related minus neutral-unrelated) observed in the trauma group, relative to the control group, stems from relatedness and not from valence. Thus, in the trauma group, the P1 amplitude would be affected by relatedness (i.e., emotional-related words) independently of valence. Following this line of reasoning, the P1 amplitude measured in the control group should also be affected by relatedness (i.e., neutral-related words), but the partial interaction between neutral words (related, unrelated) and group (trauma, control) was not significant ($F < 1$). This result argues against the hypothesis that the partial interaction observed between valence (emotional-related, neutral-unrelated) and group (trauma, control) for the P1 amplitude was due to the semantic association (or the relatedness) between emotional-related words and the trauma film, independently of the emotional nature of the trauma film; otherwise, neutral-related words would have produced a similar effect in the control group, relative to the trauma group, when compared to neutral-unrelated words.[1] Note that we decomposed the Valence x Relatedness x Group interaction for the P1 amplitude though it was not significant (possibly due to a lack of statistical power) because the partial interactions allowed to directly test our a priori hypotheses.

While we observed effects of analogue trauma exposure on early attentional processing, we did not observe an effect on later, strategic processing of emotional words. Indeed, no main effect of valence or interactions between valence and group was significant for the P3b component. The only EEG studies which, to our knowledge, investigated effects of trauma exposure on attention using an emotional Stroop task reported a similar outcome (Grégoire et al. 2018; Metzger et al. 1997). Though it is difficult to draw strong conclusions based on null findings, we can at least conclude that effects related to valence, in our study, were stronger for

[1] An alternative explanation is that the P1 component may be more sensitive to semantic preactivation effects for emotional-related words (in the trauma group) than for neutral-related words (in the control group). However, this hypothesis could be tested by assuming that the emotional semantic priming effect in the trauma group corresponds to the amplitude difference between emotional-related and neutral-unrelated words while the (neutral) semantic priming effect in the control group corresponds to the amplitude difference between neutral-related and neutral-unrelated words. A comparison between data obtained in each group revealed no significant effect ($t < 1$), which seems to exclude the assumption that the partial interaction observed between valence (emotional-related, neutral-unrelated) and group (trauma, control) for the P1 amplitude resulted from an emotional semantic priming effect.

early than for late components. Note however that we observed an interaction between relatedness and group for the P3b amplitude, with a higher relatedness effect (measured by the amplitude difference between related and unrelated words) in the trauma group than in the control group. This outcome could reflect, at least partially, increased attentional resources toward trauma-related information to update or consolidate memories of recent emotional events. The P3b is indeed related to increased attentional resource deployment (Yee and Miller 1994) and can be used as an index of updating or consolidation in short-term memory (Bourassa et al. 2015; Brisson 2015).

We observed a similar three-way interaction between valence, relatedness and group for RTs and intrusions measured in the Stroop task. These effects were driven by emotional-related words in the trauma group and neutral-related words in the control group. Recall that emotional-related words were semantically associated to the trauma film (for the trauma group) and neutral-related words were semantically associated to the neutral film (for the control group). Thus, intrusions in the trauma group seemed to be triggered by emotional-related words whereas intrusions in the control group seemed to be triggered by neutral-related words. In other words, specific memories of the film (independent of its nature, trauma or neutral) might be induced (i.e., spontaneously appear in consciousness) by semantically related information. Intrusive memories are often experienced as occurring spontaneously, but they may also be evoked by a wide range of triggers perceptually or semantically related to the traumatic event (Ehlers and Clark 2000; Ehlers et al. 2004; Lyttle et al. 2010). RTs in the Stroop task followed the same pattern of results as the number of intrusions, probably because intrusive memories tended to distract participants' attention and so increase RTs to identify the color of the Stroop stimuli. An alternative (and possibly complementary) explanation is that intrusions could have loaded working memory and attenuated attentional resources available to perform the Stroop task.

These interpretations are consistent with the results of the correlational analyses we conducted. The valence effect (emotional minus neutral) measured on RTs (i.e., RT Stroop) was positively correlated with the valence effect measured on intrusions (i.e., intrusions Stroop). However, this relationship was specific to related words and resulted from the combined effect of positive valence effects (for RTs and intrusions) in the trauma group and negative valence effects (for RTs and intrusions) in the control group. A positive valence effect in the trauma group corresponds to a greater number of intrusions and larger RTs for emotional-related words than for neutral-related words. A negative valence effect in the control group corresponds to a greater number of intrusions and larger RTs for neutral-related words than for emotional-related words. Overall, the positive correlation between RT Stroop and intrusions Stroop indicates that the more participants experienced intrusions during the Stroop task (independently of the valence of words), the more the RT Stroop was high. Put differently, the extent to which related words produced interference in the Stroop task was positively correlated with the extent of intrusions for these stimuli. Despite the abundant literature on the emotional Stroop effect after trauma exposure, to our knowledge, this is the first demonstration of a relationship between intrusions and Stroop interference.

Our data also reveal that the valence effect measured on the P1 amplitude (i.e., P1 Stroop) was positively correlated with the valence effect measured on intrusions and RTs (i.e., intrusions Stroop and RT Stroop, respectively). Again, these correlations were specific to related-words and resulted from the combined effect of positive valence effects in the trauma group and negative valence effects in the control group. These results therefore suggest an important link between early perceptual processing of stimuli and later attentional and memory effects.

The current study, however, has one important limitation. The sample sizes are too small to perform correlations in each specific group (i.e., trauma and control). David (1938) recommends the use of bivariate correlations only for a sample size equal or superior to 25 (see also Bonett and Wright 2000). Thus, we cannot determine whether two-by-two correlations between Stroop effects computed for each of the three measures (intrusions, RTs and the P1 amplitude) are significant in each group, separately. Future investigations should include a greater number of participants. It is worth adding that this study was not primarily devised to perform correlational analyses, but results provide promising outcomes to explain the relationship between attention and intrusions after trauma exposure.

We obtained unexpected results about intrusions frequency. No difference was observed between the trauma and the control group for both immediate intrusions and intrusions measured during the Stroop task (when averaged across conditions). Studies using a trauma and a neutral film usually show that intrusions related to the trauma film are more frequent, but they generally report the total number of intrusions recorded for a certain period (e.g., 7 days; Gvozdanovic et al. 2017; Hagenaars et al. 2010; Sachschal et al. 2019). It is therefore possible that the difference between the number of intrusions induced by the trauma and the neutral film does not appear shortly after the presentation of the film but only after a certain time. Experiencing intrusions is not pathological per se. Non-exposed, healthy individuals may have intrusive memories in everyday life (Brewin et al 1996; Mace 2005) which represent no concern for the experiencer (Holmes and Bourne 2008). However, intrusions could be more persistent when related to stressful rather than neutral events (Hamann 2001; LaBar and Cabeza 2006).

Conclusion

To summarize, the present study shows that exposure to an analogue trauma event can affect the attentional processing of emotional information related to this event, with neurocognitive alterations occurring at an early stage of processing, which is presumably automatic and not amenable to strategic control.

Declarations

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Conflict of interest. None of the authors have any conflict of interest to disclose.

Availability of data and material. Data and material are available from the corresponding author upon request.

References

Algom D, Chajut E, Lev S (2004) A rational look at the emotional Stroop phenomenon: A generic slowdown, not a Stroop effect. J Exp Psychol Gen 133(3):323-338. https://doi.org/10.1037/0096-3445.133.3.323

Barrett DH, Green ML, Morris R, Giles WH, Croft JB (1996) Cognitive functioning and posttraumatic stress disorder. Am J Psychiatry 153(11):1492-1494. https://doi.org/10.1176/ajp.153.11.1492

Beck AT, Steer RA, Brown G (1996) Manual for the Beck Depression Inventory-II. Psychological Corporation, San Antonio

Block SR, Liberzon I (2016) Attentional processes in posttraumatic stress disorder and the associated changes in neural functioning. Exp Neurol 284:153-167. https://doi.org/10.1016/j.expneurol.2016.05.009

Bonett DG, Wright TA (2000) Sample size requirements for estimating Pearson, Kendall and Sprearman correlations. Psychometrika 65(1):23-28. https://doi.org/10.1007/BF02294183

Bourassa ME, Vachon F, Brisson B (2015) Failure of temporal selectivity: Electrophysiological evidence for (mis)selection of distractors during the attentional blink. Psychophysiology 52(7):933-941. https://doi.org/10.1111/psyp.12426

Brewin CR, Christodoulides J, Hutchinson G (1996) Intrusive thoughts and intrusive memories in a nonclinical sample. Cogn Emot 10(1):107-112. https://doi.org/10.1080/026999396380411

Brewin CR, Saunders J (2001) The effect of dissociation at encoding on intrusive memories for a stressful film. Br J Clin Psychol 74:467-472. https://doi.org/10.1348/000711201161118

Brisson B (2015) Task switching mediates direct interference of intertarget distractors in the attentional blink: An event-related potential study. Psychophysiology 52(7):919-932. https://doi.org/10.1111/psyp.12416

Caparos S, Blanchette I (2014) Emotional Stroop interference in trauma-exposed individuals: A contrast between two accounts. Conscious Cogn 28:104-112. https://doi.org/10.1016/j.concog.2014.06.009

Cassiday KL, McNally RJ, Zeitlin SB (1992) Cognitive processing of trauma cues in rape victims with posttraumatic-stress disorder. Cognit Ther Res 16(3):283-295. https://doi.org/10.1007/bf01183282

Cisler JM, Wolitzky-Taylor KB, Adams TG, Babson KA, Badour CL, Willems JL (2011) The emotional Stroop task and posttraumatic stress disorder: A meta-analysis. Clin Psychol Rev 31(5):817-828. https://doi.org/10.1016/j.cpr.2011.03.007

Cochrane R, Robertson A (1973) The life events inventory: A measure of the relative severity of psycho-social stressors. J Psychosom Res 17(2):135-139. https://doi.org/10.1016/0022-3999(73)90014-7

Cohen J (1988) Statistical power analysis for the behavioral sciences (2nd ed.). Lawrence Erlbaum Associates, Hillsdale

Craig AR, Fisher WW (2019) Randomization tests as alternative analysis methods for behavior-analytic data. J Exp Anal Behav 111(2):309-328. https://doi.org/10.1002/jeab.500

David FN (1938) Tables of the ordinates and probability integral of the distribution of the correlation coefficient in small samples. University Press, Cambridge

Ehlers A, Clark DM (2000) A cognitive model of posttraumatic stress disorder. Behav Res Ther 38(4):319-345. https://doi.org/10.1016/s0005-7967(99)00123-0

Ehlers A, Hackmann A, Michael T (2004) Intrusive re-experiencing in post-traumatic stress disorder: Phenomenology, theory, and therapy. Memory 12(4):403-415. https://doi.org/10.1080/09658210444000025

Fani N, Jovanovic T, Ely TD, Bradley B, Gutman D, Tone EB, Ressler KJ (2012) Neural correlates of attention bias to threat in post-traumatic stress disorder. Biol Psychol 90(2):134-142. https://doi.org/10.1016/j.biopsycho.2012.03.001

Fani N, Tone EB, Phifer J, Norrholm SD, Bradley B, Ressler KJ, Kamkwalala A, Jovanovic T (2012) Attention bias toward threat is associated with exaggerated fear expression and impaired extinction in PTSD. Psychol Med 42(3):533-543. https://doi.org/10.1017/s0033291711001565

Fu S, Fedota JR, Greenwood PM, Parasuraman R (2010) Dissociation of visual C1 and P1 components as a function of attentional load: an event-related potential study. Biol Psychol 85(1):171-178. https://doi.org/10.1016/j.biopsycho.2010.06.008

Gauthier J, Bouchard S (1993) A French-Canadian adaptation of the revised version of Spielberger's State-Trait Anxiety Inventory. Can J Behav Sci 25(4):559-578. https://doi.org/10.1037/h0078881

Gilbertson MW, Paulus LA, Williston SK, Gurvits TV, Lasko NB, Pitman RK, Orr SP (2006) Neurocognitive function in monozygotic twins discordant for combat exposure: Relationship to posttraumatic stress disorder. J Abnorm Psychol 115(3):484-495. https://doi.org/10.1037/0021-843x.115.3.484

Gilet AL, Gruhn D, Studer J, Labouvie-Vief G (2012) Valence, arousal, and imagery ratings for 835 French attributes by young, middle-aged, and older adults: The French Emotional

Evaluation List (FEEL). Eur Rev Appl Psychol 62(3):173-181. https://doi.org/10.1016/j.erap.2012.03.003

Grégoire L, Caparos S, Leblanc CA, Brisson B, Blanchette I (2018) Sexual Abuse Exposure Alters Early Processing of Emotional Words: Evidence from Event-Related Potentials. Front Hum Neurosci 11:1-15. https://doi.org/10.3389/fnhum.2017.00655

Grégoire L, Gosselin I, Blanchette I (2020) The impact of trauma exposure on explicit and implicit memory. Anxiety Stress Coping 33(1):1-18. https://doi.org/10.1080/10615806.2019.1664477

Gvozdanovic GA, Stämpfli P, Seifritz E, Rasch B (2017) Neural correlates of experimental trauma memory retrieval. Hum Brain Mapp 38(7):3592-3602. https://doi.org/10.1002/hbm.23613

Hagenaars MA, Brewin CR, van Minnen A, Holmes EA, Hoogduin KAL (2010) Intrusive images and intrusive thoughts as different phenomena: Two experimental studies. Memory 18(1):76-84. https://doi.org/10.1080/09658210903476522

Hamann S (2001) Cognitive and neural mechanisms of emotional memory. Trends Cogn Sci 5(9):394-400. https://doi-org.acces.bibl.ulaval.ca/10.1016/S1364-6613(00)01707-1

Herbert C, Junghofer M, Kissler J (2008) Event related potentials to emotional adjectives during reading. Psychophysiology 45(3):487-498. https://doi.org/10.1111/j.1469-8986.2007.00638.x

Holle C, Neely JH, Heimberg RG (1997) The effects of blocked versus random presentation and semantic relatedness of stimulus words on response to a modified Stroop task among social phobics. Cognit Ther Res 21(6):681-697. https://doi.org/10.1023/a:1021860324879

Holmes EA, Bourne C (2008) Inducing and modulating intrusive emotional memories: A review of the trauma film paradigm. Acta Psychol 127(3):553-566. https://doi.org/10.1016/j.actpsy.2007.11.002

Holmes EA, Brewin CR, Hennessy RG (2004) Trauma films, information processing, and intrusive memory development. J Exp Psychol Gen 133(1):3-22. https://doi.org/10.1037/0096-3445.133.1.3

Holmes EA, James EL, Kilford EJ, Deeprose C (2010) Key Steps in Developing a Cognitive Vaccine against Traumatic Flashbacks: Visuospatial Tetris versus Verbal Pub Quiz. PLoS One 5(11):1-9. https://doi.org/10.1371/journal.pone.0013706

James EL, Lau-Zhu A, Clark IA, Visser RM, Hagenaars MA, Holmes EA (2016) The trauma film paradigm as an experimental psychopathology model of psychological trauma: intrusive memories and beyond. Clin Psychol Rev 47:106-142. https://doi.org/10.1016/j.cpr.2016.04.010

Kaspi SP, McNally RJ, Amir N (1995) Cognitive processing of emotional information in posttraumatic stress disorder. Cognit Ther Res 19(4):433-444. https://doi.org/10.1007/bf02230410

Kilpatrick DG, Resnick HS, Milanak ME, Miller MW, Keyes KM, Friedman MJ (2013) National Estimates of Exposure to Traumatic Events and PTSD Prevalence Using DSM-IV and DSM-5 Criteria. J Trauma Stress 26(5):537-547. https://doi.org/10.1002/jts.21848

Koenen KC, Ratanatharathorn A, Ng L, McLaughlin KA, Bromet EJ, Stein DJ, Karam EG, Meron Ruscio A, Benjet C, Scott K, Atwoli L, Petukhova M, Lim CCW, Aguilar-Gaxiola S, Al-Hamzawi A, Alonso J, Bunting B, Ciutan M, de Girolamo G, Degenhardt L, Gureje O, Haro JM, Huang Y, Kawakami N, Lee S, Navarro-Mateu F, Pennell BE, Piazza M, Sampson N, ten Have M, Torres Y, Viana MC, Williams D, Xavier M, Kessler RC (2017) Posttraumatic stress disorder in the World Mental Health Surveys. Psychol Med 47(13):2260-2274. https://doi.org/10.1017/s0033291717000708

LaBar KS, Cabeza R (2006) Cognitive neuroscience of emotional memory. Nat Rev Neurosci 7(1):54–64. https://doi-org.acces.bibl.ulaval.ca/10.1038/nrn1825

Lakens D (2013) Calculating and reporting effect sizes to facilitate cumulative science: A practical primer for t-tests and ANOVAs. Front Psychol 4:1-12. https://doi.org/10.3389/fpsyg.2013.00863

Li W, Zinbarg RE, Paller KA (2007) Trait anxiety modulates supraliminal and subliminal threat: Brain potential evidence for early and late processing influences. Cogn Affect Behav Neurosci 7(1):25-36. https://doi.org/10.3758/cabn.7.1.25

Luck SJ (2005) An introduction to the event-related potential technique. The MIT Press, Cambridge

Ludbrook J (1994) Advantages of permutation (randomization) tests in clinical and experimental pharmacology and physiology. Clin Exp Pharmacol Physiol 21(9):673-686. https://doi.org/10.1111/j.1440-1681.1994.tb02570.x

Lyttle N, Dorahy MJ, Hanna D, Huntjens RJC (2010) Conceptual and perceptual priming and dissociation in chronic posttraumatic stress disorder. J Abnorm Psychol 119(4):777-790. https://doi.org/10.1037/a0020894

Mace JH (2005) Priming involuntary autobiographical memories. Memory 13(8):874-884. https://doi.org/10.1080/09658210444000485

Mangun GR, Hillyard SA (1995) Mechanisms and models of selective attention. In: Rugg MD, Coles MGJ (Eds.), Electrophysiology of mind: Event-related brain potentials and cognition. Oxford University Press, Oxford, pp 40–85

Marshall RD, Schneier FR, Lin S, Simpson HB, Vermes D, Liebowitz M (2000) Childhood trauma and dissociative symptoms in panic disorder. Am J Psychiatry 157(3):451-453. https://doi.org/10.1176/appi.ajp.157.3.451

McNally RJ, Kaspi SP, Riemann BC, Zeitlin SB (1990) Selective processing of threat cues in posttraumatic stress disorder. J Abnorm Psychol 99(4):398-402. https://doi.org/10.1037/0021-843x.99.4.398

Metzger LJ, Orr SP, Lasko NB, McNally RJ, Pitman RK (1997) Seeking the source of emotional stroop interference effects in PTSD: A study of P3s to traumatic words. Integr Physiol Behav Sci 32(1):43-51. https://doi.org/10.1007/bf02688612

Näätänen R, Simpson M, Loveless NE (1982) Stimulus deviance and evoked-potentials. Biol Psychol 14(1-2):53-98. https://doi.org/10.1016/0301-0511(82)90017-5

New B (2006) "Lexique 3: Une nouvelle base de données lexicales", in Actes de la Conférence Traitement Automatique des Langues Naturelles (TALN 2006), avril 2006, Louvain, Belgique.

Nixon RDV, Cain N, Nehmy T, Seymour M (2009) Does post-event cognitive load undermine thought suppression and increase intrusive memories after exposure to an analogue stressor? Memory 17(3):245-255. https://doi.org/10.1080/09658210802592353

Polich J (2007) Updating p300: An integrative theory of P3a and P3b. Clin Neurophysiol 118(10):2128-2148. https://doi.org/10.1016/j.clinph.2007.04.019

Polich J, Kok A (1995) Cognitive and biological determinants of P300 - An integrative review. Biol Psychol 41(2):103-146. https://doi.org/10.1016/0301-0511(95)05130-9

Powers A, Fani N, Murphy L, Briscione M, Bradley B, Tone EB, Norrholm SD, Jovanovic T (2019) Attention bias toward threatening faces in women with PTSD: eye tracking correlates by symptom cluster. Eur J Psychotraumatol 10:1-9. https://doi.org/10.1080/20008198.2019.1568133

Rattel JA, Grunberger LM, Reichenberger J, Liedlgruber M, Miedl SF, Blechert J, Wilhelm FH (2019) Frequency of Intrusions and Appraisal of Related Distress After Analogue Trauma: A Comparative Ecological Momentary Assessment Methods Study. Cognit Ther Res 43(1):174-184. https://doi.org/10.1007/s10608-018-9941-6

Rosenthal R (1991) Meta-analytic procedures for social research (2nd ed.). Newbury Park, CA: Sage

Sachschal J, Woodward E, Wichelmann JM, Haag K, Ehlers A (2019) Differential effects of poor recall and memory disjointedness on trauma symptoms. Clin Psychol Sci 7(5):1032-1041. https://doi.org/10.1177/2167702619847195

Sass SM, Heller W, Stewart JL, Silton RL, Edgar JC, Fisher JE, Miller GA (2010) Time course of attentional bias in anxiety: Emotion and gender specificity. Psychophysiology 47(2):247-259. https://doi.org/10.1111/j.1469-8986.2009.00926.x

Schneider W, Eschman A, Zuccolotto A (2002) E-prime user’s guide. Psychology Software Tools, Pittsburgh

Schupp HT, Junghofer M, Weike AI, Hamm AO (2004) The selective processing of briefly presented affective pictures: An ERP analysis. Psychophysiology 41(3):441-449. https://doi.org/10.1111/j.1469-8986.2004.00174.x

Shalev AY, Freedman SA, Peri T, Brandes D, Sahar T, Orr SP, Pitman RK (1998) Prospective study of post-traumatic stress disorder and depression following trauma. Am J Psychiatry 155(5):630-637. https://doi.org/10.1176/ajp.155.5.630

Spielberger CD, Gorsuch RL, Lushene R, Vagg PR, Jacobs GA (1983) Manual for the State-Trait Anxiety Inventory. Consulting Psychologists Press, Palo Alto

Tapia G, Clarys D, Bugaiska A, El-Hage W (2012) Recollection of negative information in posttraumatic stress disorder. J Trauma Stress 25(1):120-123. https://doi.org/10.1002/jts.21659

Tapia G, Clarys D, El-Hage W, Isingrini M (2007) Cognitive deficits in post-traumatic stress disorder: A review. Annee Psychol 107(3):489-523. https://doi.org/10.4074/S0003503307003065

Thomas SJ, Johnstone SJ, Gonsalvez CJ (2007) Event-related potentials during an emotional Stroop task. Int J Psychophysiol 63(3):221-231. https://doi.org/10.1016/j.ijpsycho.2006.10.002

van Hooff JC, Dietz KC, Sharma D, Bowman H (2008) Neural correlates of intrusion of emotion words in a modified Stroop task. Int J Psychophysiol 67(1):23-34. https://doi.org/10.1016/j.ijpsycho.2007.09.002

Verleger R (1988) Event-related potentials and cognition: A critique of the context updating hypothesis and an alternative interpretation of P3. Behav Brain Sci 11(3):343-356. https://doi.org/10.1017/S0140525X00058015

Wang Y-P, Gorenstein C (2013) Psychometric properties of the Beck Depression Inventory-II: A comprehensive review. Braz J Psychiatry 35(4):416-431. https://doi.org/10.1590/1516-4446-2012-1048

Weber DL (2008) Information Processing Bias in Post-traumatic Stress Disorder. Open Neuroimaging J 2:29-51. https://doi.org/10.2174/1874440000802010029

Williams JMG, Mathews A, MacLeod C (1996) The emotional stroop task and psychopathology. Psychol Bull 120(1):3-24. https://doi.org/10.1037/0033-2909.120.1.3

Woodman GF (2010) A Brief Introduction to the Use of Event-Related Potentials (ERPs) in Studies of Perception and Attention. Atten Percept Psychophys 72(8):2031-2046. https://doi.org/10.3758/APP.72.8.2031

Yee CM, Miller GA (1994) A dual-task analysis of ressource-allocation in dysthymia and anhedonia. J Abnorm Psychol 103(4):625-636. https://doi.org/10.1037//0021-843x.103.4.625

Zhang Y, Kong F, Han L, ul Hasan AN, Chen H (2014) Attention bias in earthquake-exposed survivors: An event-related potential study. Int J Psychophysiol 94(3):358-364. https://doi.org/10.1016/j.ijpsycho.2014.09.004