Avoidance Behavior Generalizes to Eye Processing in Posttraumatic Stress Disorder

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Highlights

Avoidance is a key symptom of posttraumatic stress disorder (PTSD). Avoidance is often viewed as limited to reminders linked to the trauma. Results show that attention to the eyes of sad faces is also affected by PTSD. This effect is correlated with avoidance symptoms in PTSD.

Abstract

Background: *Avoidance* describes any action designed to prevent an uncomfortable situation or emotion from occurring. Although it is a common reaction to trauma, avoidance becomes problematic when it is the primary coping strategy, and plays a major role in the development and maintenance of posttraumatic stress disorder (PTSD). Avoidance in PTSD may generalize to non-harmful environmental cues that are perceived to be unsafe.

Objective: We tested whether avoidance extends to social cues (i.e., emotional gazes) that are unrelated to trauma.

Method: A total of 159 participants (103 who had been exposed to the 2015 Paris terrorist attacks and 56 who had not) performed a gaze-cueing task featuring sad, happy and neutral faces. Attention to the eye area was recorded using an eyetracker. Of the exposed participants, 52 had been diagnosed with PTSD (PTSD+) and 51 had not developed PTSD (PTSD-). As a result of the preprocessing stages, 52 PTSD+ (29 women), 50 PTSD- (20 women) and 53 nonexposed (31 women) participants were included in the final analyses.

Results: PTSD+ participants looked at sad eyes for significantly less time than PTSD- and nonexposed individuals. This effect was negatively correlated with the intensity of avoidance symptoms. No difference was found for neutral and happy faces.

Conclusions: These findings suggest that maladaptive avoidance in PTSD extends to social processing, in terms of eye contact and others' emotions that are unrelated to trauma. New therapeutic directions could include targeting sociocognitive deficits. Our findings open up new and indirect avenues for overcoming maladaptive avoidance behaviors by remediating eye processing.

Keywords: PTSD, eye-tracking, social cognition, eye avoidance, emotions

1. Introduction

Posttraumatic stress disorder (PTSD) refers to a set of symptoms that emerge following exposure to one or more traumatic events. One of these symptoms is *avoidance*, which involves the engagement of thoughts or behaviors to limit exposure to reminders of the stressful experience (Sautter et al., 2009). Although it is a momentarily helpful reaction to trauma, avoidance becomes problematic as a long-term strategy (Boden et al., 2013), and is central to PTSD (Salters-Pedneault et al., 2004). Attempts to avoid distressing situations may either precipitate or worsen PTSD symptoms (Badour et al., 2012). Most current PTSD treatments attempt to overcome avoidance of trauma-related elements that do not represent danger, and restore normal processing of these elements (Brewin, 2018).

In addition to thoughts or external reminders, avoidance has also been shown to prevent uncomfortable trauma-related emotions (*emotional avoidance*), including subjective, physiological and expressive components of emotional responses (Salters-Pedneault et al., 2004). Social cues conveying emotions, such as faces and gazes, may also trigger emotional experiences in the observer, causing discomfort (Samson, 2009). The computation of others' emotions is fast and automatic, thereby facilitating the understanding and sharing of emotional states (De Vignemont & Singer, 2006). The eyes play a critical role in social interactions and emotional contagion (Land & Tatler, 2009). In PTSD, gaze processing leads to sustained activation of the brain's innate alarm (Lanius et al., 2017). Avoiding eye contact may therefore reflect a coping mechanism for minimizing the emotional impact of others and reducing perceived threat (e.g., Moukheiber et al., 2010). Eye avoidance may also explain the impaired recognition of fear and sadness observed in PTSD (Poljac et al., 2011). While several studies have demonstrated an avoidance of threatening stimuli in PTSD (e.g., Schoorl et al., 2014), other conclude to an increase hypervigilance towards these stimuli (e.g., Bardeen & Orcutt, 2011). Various tracks are proposed by scientists to explain these discrepancies in the literature, such as the measures, tasks or timing investigated (see for example Armstrong & Olatunji, 2012 or Lazarov et al., 2019 for a review). According to Mogg et al. (1997), these inconsistencies are mainly explained by the sequential nature of attentional effects in the face of threat. Thus, the presence of a negative stimulus automatically attracts the attention of anxious individuals. This hypervigilance phase is followed by an avoidance phase, when attention is shifted away from the stimulus. Interestingly, this model developed for trait and generalized anxiety is still debated for PTSD and more controlled studies are needed (Felmingham et al., 2011).

The quality of the social environment and its relation to avoidance symptoms has been extensively investigated in PTSD (Stevens & Jovanovic, 2019). However, studies interested in the perception and understanding of social information (i.e., social cognition) conveyed by others in PTSD are scarce (Stevens & Jovanovic, 2019). Patients with PTSD have a social cognition deficit characterized by emotion recognition and mentalizing difficulties (e.g., Plana et al., 2014). Inference of a person's emotional state based solely on the eye area is also disrupted in PTSD (e.g., Schmidt & Zachariae, 2009). However, the relationship between this social cognition deficit and avoidance behaviors remains poorly understood.

Moreover, although avoidance contributes to failure to recover from trauma, little is known about the extent to which the processing of unpleasant social cues contributes to adaptive behaviors and resilience in the aftermath of a trauma. *Resilience* is an adaptive process that is engaged to maintain mental health following a stressful event (Kalisch et al., 2017). Facing an unpleasant stimulation may contrast with the goal of avoiding negative emotion, but it may also serve a longer-term purpose of maximizing wellbeing (Tamir & Ford, 2012).

In the present study, we investigated whether individuals with and without PTSD, but who had all been exposed to the same degree of traumatic exposure, behaved differently when processing eye cues during an attentional task specifically designed to require the visual processing of the eye area in face stimuli. In order to better understand how the processing of non-trauma-related social cues (eyes of faces expressing either an emotion or no emotion) may be related to distinct clinical trajectories in response to trauma, we designed a *gaze cueing* paradigm (see Fig. 1). The gaze cueing task is a well-established paradigm that is ideal for revealing any difficulty associated with eye processing and social skills (Frischen et al., 2007). It was recently adapted to emotional faces, to show how emotions, particularly fearful expressions, enhance joint attention (Lachat et al., 2012). In our adaptation of the task, we used sadness instead of fear, to avoid destabilizing traumatized individuals and prevent emotional overload from compromising task success. Using sad faces also allowed us to assess the hypothesis of a general reluctance of emotions associated with the same dysfunctional behavior as avoidance, independently of fear, which has a special resonance in PTSD. In this sense, sadness also represents a neater negative counterpart of happiness, allowing for cleaner comparisons between the two. Task performances were monitored in terms of both reaction times and response accuracy, even though these behavioral measures are often biased (for a review, see Armstrong & Olatunji, 2012) and lack sensitivity, especially when gaze direction is uninformative. Critically, fixations on the eye area were recorded throughout the task, using an eyetracker. This investigation technique is an ecological measure of attention selection performed via eye movements, i.e. *overt attention*. In between eye movements, attention selection can also be accomplished with *covert attention*, i.e. without reorienting the gaze. However, although the eye-tracking methodology cannot capture covert attention, it has been shown that overt attention is the primary means of attentional selection in natural viewing situation and that it is a central mediator of covert visual biases in anxiety (Armstrong & Olatunji, 2012). The eye-tracking methodology has recently been adopted to capture threat-related hypervigilance in PTSD (see Felmingham, 2015), but so far, no visual scanpath studies have focused on eye processing and avoidance in PTSD. Here, we looked at the percentage of fixations made during gaze cueing (see Fig. 1) and whether PTSD avoidance symptoms generalized to the processing of the eyes of our stimuli, particularly those expressing negative emotions. We expected that being affected by a PTSD would be characterized by a significantly lower percentage of fixations on the eyes of sad faces. Finally, we investigated whether eye avoidance was negatively related to the severity of avoidance symptoms in individuals with PTSD, as measured with Cluster C from the PTSD Checklist for DSM-5 (PCL-5; Blevins et al., 2015).

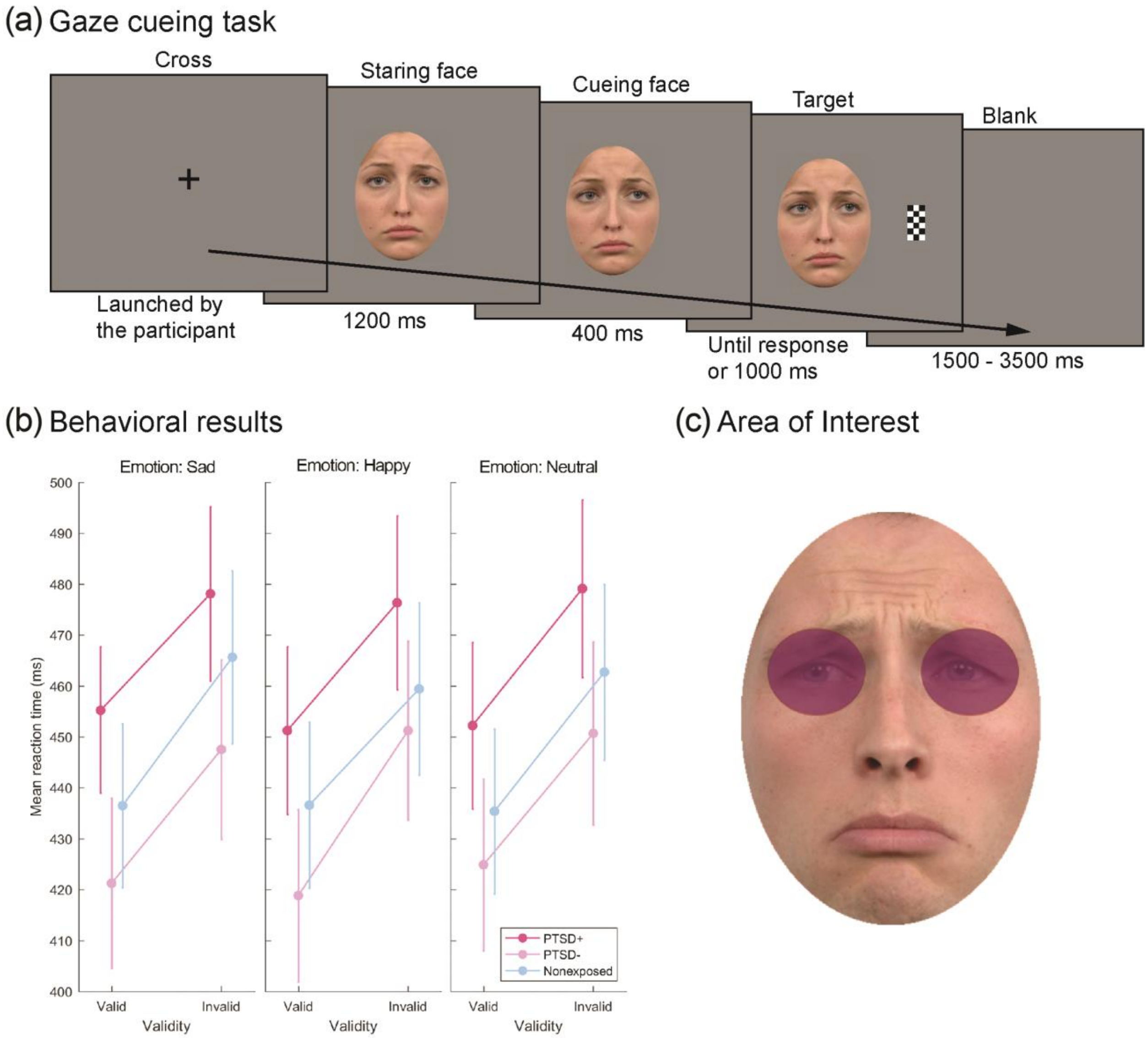

Figure 1. Experimental design and behavioral results. (a) Overview of the displays and timing of events in the gaze cueing task. A fixation cross appeared in the center of the screen, followed by a staring face displaying a happy, sad or neutral expression. This staring face was then replaced by a cueing face looking right or left, but expressing the same emotion. Participants were instructed to look at these two stimuli. Finally, a target face was shown, looking either in the cued direction (valid trials) or in another direction (invalid trials). Participants had to press one of two response

buttons on a keypad to indicate whether the target was displayed on the right or left side of the screen. (b) Interaction plots representing the mean reaction time (ms) for each group in each emotion and validity condition. (c) Illustration of a sad stimulus with the eye-tracking area of interest drawn around the eyes.

2. Methods

2.1. Participants

We recruited 159 participants. Of these, 52 had been exposed to the terrorist attacks and had developed PTSD (PTSD+; 26 women; M_{age} = 36.33 years, *SD* = 7.60), 51 had been exposed to the same event but did not develop PTSD (PTSD-; 20 women; M_{age} = 36.27 years, *SD* = 7.07), and 56 were nonexposed controls who did not live in Paris recruited from a local panel of volunteers living in the vicinity of Caen, Normandy (32 women; M_{age} = 34.43 years, *SD* = 10.85). Exposed participants had experienced the traumatic event either as direct victims or witnesses, or as grieving relatives or first responders (in line with DSM-5 definition of exposure). They were recruited through the French *13-November* transdisciplinary and longitudinal research program (http://www.memoire13novembre.fr/), a nationwide government-funded program supported by victim organizations. More demographic and clinical information about our participants can be found in Appendix F of the Supplemental material section and in Mary et al. (2020), a study involving the same clinical research trial. No statistical methods were used to predetermine the sample size, given the novelty of the question and the effect tested, but the sample size used in this study (*N* = 159) was higher than in previous PTSD studies using eye-tracking methodology (for a review, see Felmingham, 2015). Participants were financially compensated for their participation in the study.

The study was approved by the regional research ethics committee (Comité de Protection des Personnes Nord-Ouest III, sponsor ID: C16-13, RCB ID: 2016-A00661-50, clinicaltrials.gov registration number: NCT02810197). All participants gave written informed consent before participation, in agreement with French ethical guidelines. Participants were asked not to consume psychostimulants, drugs, or alcohol before or during the experimental period.

2.2. PTSD diagnosis

Exposed participants were diagnosed using the semistructured clinical interview for DSM-5 (First et al., 2015), conducted by a trained psychologist and supervised by a psychiatrist. PTSD symptom intensity was measured using the PCL-5 (Blevins et al., 2015). The PCL-5 is a self-report measure that assesses the 20 symptoms of PTSD identified in the DSM-5. DSM-5 symptom cluster severity scores can be obtained by summing the scores for PCL-5 items within each cluster. Items 1-5 assess intrusion symptoms (Cluster B of the DSM-V), Items 6 and 7 avoidance symptoms (Cluster C), Items 8-14 negative changes in cognition and mood (Cluster D), and Items 15-20 changes in arousal and reactivity (Cluster E). In the present study, we used the PCL-5 to gauge the level of our participants' avoidance symptoms (Cluster C) and correlate it with our results for emotional gaze fixations. More information about participants' diagnosis can be found in Mary et al. (2020).

2.3. Materials and stimuli

Participants were comfortably installed at a distance of 65 cm from a Dell P2213 22″ monitor with 1680 x 1050 px resolution, connected to an HP Elite Intel Inside Core i3 computer. The task was designed and executed using the innate Experiment Center 3.6 software provided by SMI (SensoMotoric Instruments GmbH, Teltow, Germany). All the task items were randomized and then evenly divided into two blocks, to allow participants to take a break midway through. The stimuli were taken from the validated Radboud Faces Database (Langner et al., 2010). They consisted of color photographs of the faces of seven men and eight women wearing sad, happy and neutral expressions with a direct, left-oriented, or right-oriented gaze. A mask was added so that the faces were visible, but not the background, hair, ears, or neck. Faces (450 x 580 px) were displayed against a gray background in the center of the screen. The target was a checkerboard (450 x 540 px) displayed on the left or right side of the screen. It was vertically centered, at a horizontal distance of 390 px from the face.

2.4. Procedure

An overview of the task is provided in Figure 1. First, a fixation cross was displayed in the middle of the screen. In order to proceed to the next step, participants had to look at it for at least 400 ms. The cross was then replaced by the first face (staring face), which remained on the screen for 1200 ms. This staring face could be that of a man or woman, expressing either a sad or happy emotion, or no emotion at all (i.e., neutral), and it looked directly at the participant. It was replaced by a second face (cueing face), which was displayed alone for 400 ms. This face depicted the same person, expressing the same emotion, but its eyes looked to the left or right, in order to direct participants' attention to the left or right part of the screen. Participants were told that the direction of the cueing face's gaze did not necessarily correspond to the location of the ensuing target, in line with Lachat et al. (2012)'s paradigm. The cueing face's eyes indicated the correct location of the target in only 50% of the trials. This way, participants were allowed to use gaze information, but attentional bias and reorientation processes were limited. In 91% of the trials, a target appeared on the left or right side of the cueing face until the participant gave a response concerning its location, but for no longer than 1000 ms. Participants responded by pressing the 1 or 0 key on a keypad, using their left or right index finger. We created two experimental conditions. In one condition, the target appeared in the location cued by the cueing face's gaze (valid trials), and in the other, the target appeared on the opposite side (invalid trials). To discourage anticipatory responses, 9% of the trials were catch trials, in which no target was presented. Participants were instructed not to respond to them. Finally, a blank screen was displayed for 1500-3500 ms until the next trial.

The 144 trials of the gaze cueing task were a combination of 12 ID photographs (6 women), 3 emotions (sad vs. happy vs. neutral), 2 gaze directions (left vs. right) and 2 target locations (left vs. right). For the reason outlined above, we added 14 catch trials featuring 3 new ID photos (1 man) expressing the same 3 emotions as the other trials, and with the same 2 gaze directions as for the cueing face. These catch trials were excluded from the analyses.

2.5. Eye tracking

Eye movements were measured using the SMI RED 250 screen-based eyetracker. Movements were detected using corneal reflection with a detection algorithm standard in the SMI® system. Data were sampled at 250 Hz. BeGaze 3.6 SMI's software was used to overlay fixations (minimum fixation duration set at 100 ms) on the stimuli for subsequent offline analyses.

Each part of the gaze cueing task started with a calibration/validation sequence in which participants had to follow a dot presented randomly at 13 different locations on the screen. The system was calibrated on a per participant basis at the beginning of the task to a mean spatial accuracy of 0.61° (*SD* = 0.41). The calibration procedure was repeated up to three times if necessary, and the best of the three trials was retained. Once the calibration was completed, participants began the first trial.

To analyze how participants processed the eye area, we defined one area of interest (AOI) by contouring the eyes of our stimuli with the AOI editor function of SMI's BeGaze 3.6 software (Fig. 1). We were particularly interested in fixations on this AOI for sad and happy versus neutral stimuli. For information purposes, results for fixations on the mouth and nose areas can be found in Appendix E of the Supplemental Material Section. It should, however, be noted that the number of fixations on the mouth in particular, all participants and conditions taken together, was much lower than that of fixations on the eyes, making it difficult to compare the two areas (3444 vs. 16227 fixations). Moreover, about ten participants did not fixate the mouth at all in our task. To analyze fixations on the eye AOI, we binarized the fixation timecourses (1 during a fixation on the AOI of a given stimulus, and 0s outside the fixation period). A Gaussian-weighted moving average filter was then applied to this binary vector, using the smoothdata function and specifying the Gaussian method in MATLAB R2018b (Mathworks, Natick, MA, USA) in order to normalize it. The smoothed timecourses were averaged across items in a given condition, producing a fixation timecourse percentage per participant and condition.

2.6. Preprocessing

Although almost all participants performed very well on the gaze cueing task (99.23% of correct responses), two participants (1 PTSD- and 1 nonexposed) only correctly responded to 45% (*SD* = 49.93%) and 46.85% (*SD* = 50.08%) of trials. Their data were therefore excluded from the analyses. Data from one nonexposed participant also had to be excluded, owing to extensive use of the wrong response keys during the task, generating missing data. Preprocessing of reaction times during the behavioral task involved excluding trials with incorrect (0.77% of total trials), late (> 2 *SD*s above the mean; 4.68% of total trials) or anticipatory (< 2 *SD*s below the mean; 0.18% of total trials) responses. This preprocessing was performed separately for each group and each experimental condition.

Concerning eye-tracking recordings, we ran a data quality check before the analyses. We projected all the fixations of participants who had an X and/or Y deviation of the right and/or left eye of more than 1° at the end of the calibration procedure (10% of the participants) to visually check whether the exploration patterns revealed systematic deviations from the fixation crosses and faces. Data from two PTSD+ participants, one PTSD- participant, and three nonexposed controls were excluded from the analyses as a result. Moreover, data from three PTSD+ participants and one PTSD- participant were not available, as their experiment had to be interrupted for schedule reasons. Following the data quality control, preprocessing of eye-tracking recordings also included the exclusion of outliers from the analyses. This preprocessing was performed on the fixation timecourse percentages (see above). First, participants with an unusual number of fixations regardless of the emotion (2 *SD*s above or below their group mean) were excluded. Second, unusual swings between the minimum and maximum fixation percentages, indicative of attentional lapses, were screened separately for each group and each emotion. In total, after these preprocessing steps, the data of five PTSD+, four PTSD- and six nonexposed participants were excluded from the final analyses. As a result of the preprocessing stages, 52 PTSD+ (23 men), 50 PTSD- (30 men) and 53 nonexposed (22 men) participants were included in the final analyses.

2.7. Behavioral analysis

We first sought to ensure that groups performed equally on the gaze cueing task, to check that eye-tracking differences were not driven by behavioral differences. As accuracy of target direction detection revealed a ceiling effect; all participants made on average 99.23% correct responses (SD = 8.71%; PTSD+: M = 99.51%, SD = 6.98%; PTSD-: M = 98.56%, SD = 11.93%; nonexposed: M = 99.61%, SD = 6.24%); we particularly focused our behavioral analyses on the reaction times for target detection. A mixed analysis of variance was chosen, with group (PTSD+ vs. PTSD- vs. nonexposed), emotion (sad vs. happy vs. neutral) and validity (valid vs. invalid) as factors.

2.8. Eye-tracking analysis

Binary raw fixations were smoothed and weighted using a Gaussian-weighted moving average window before statistical analysis, producing fixation timecourse percentages (see Method and Fig. 2). Based on the literature (see Introduction) showing a reduction in the percentage of fixations on the eyes of faces expressing negative emotions in PTSD, and in agreement with our a priori hypothesis that individuals with PTSD make fewer fixations on the eye area of emotional faces, we ran statistical analyses of eye fixations using one-tailed t statistics, comparing sad and happy faces with neutral ones. In addition, we directly compared sad and happy faces. These analyses were performed for each timepoint in the cueing face window and using the mean percentage of fixations on the eye AOI (1200-1600 ms; see Section 2, "Methods"). Our primary focus was on cueing faces because attention was maximally directed toward the eye AOI during this time period. For the sake of completeness, we also report findings for the staring face in Appendix B in the Supplemental Material section. However, processing of this face was biased by the initial central fixation cross, which automatically focused the gaze on the eye AOI, potentially masking intergroup differences, especially at early timepoints. Descriptive results concerning fixations on the eye AOIs of the staring and cueing faces can be found in Appendices C and D of the Supplemental Material section. The problem of correcting for multiple comparisons across the cueing face (1200-1600 ms) and staring face (800-1200 ms) timepoints to correct for initial bias was solved by using random field theory (Brett et al., 2003), which controls for the familywise error rate using a general expression that accounts for spatial dependences between datapoints. For the sake of completeness, we also calculated group-level inferences, using nonparametric random effects statistics, by bootstrapping the participant set with 2000 iterations and computing 90% confidence intervals on the means of the staring face and cueing face windows (and thus indicating significance when they did not overlap with zero). To account for confounding variables, namely age, sex, education level, type of exposure to the traumatic event, and level of depressive symptoms, as measured with the Beck Depression Inventory (Beck et al., 1961), we included them as nuisance covariates in our analyses (results without covariates can be found in Appendix G of the Supplemental material section).

In order to correlate the eye-tracking results of the PTSD+ and PTSD- groups to the avoidance symptoms of PTSD, we performed r-skipped correlations (Pernet et al., 2013) while scaling avoidance symptoms by total symptom severity, to ensure that this relationship was not confounded with PTSD intensity and other symptoms. Robust correlations were preferred over more classical association analyses, because they allow to take into account bivariate outliers in their calculations (Pernet et al., 2013).

3. Results

3.1. Behavior

Behavioral results are summarized in Figure 1 and Appendix A in the Supplemental Materials. There were two significant outcomes. First, we observed a main effect of validity, $F(1, 151) = 263.02$, $p < .001$, $\eta_p^2 = .635$. Participants were significantly faster in the valid condition than in the invalid one. Second, validity did not interact with group, $F(2, 151) = 0.32$, $p = .729$, showing that each group benefited equally from the gaze of the cueing face and processed the face efficiently. It should, however, be noted that we observed a main effect of group, $F(1, 151) = 3.18$, $p = .044$, $\eta_p^2 = .040$, characterized by reaction times that were significantly longer overall (irrespective of conditions) for PTSD+ participants than for PTSD- participants, $t(152) = 2.52$, $p = .013$, but not for the nonexposed group, $t(152) = 1.39$, $p = .168$. PTSD- participants were not significantly different than the nonexposed group, $t(152) = 1.16$, $p = .246$.

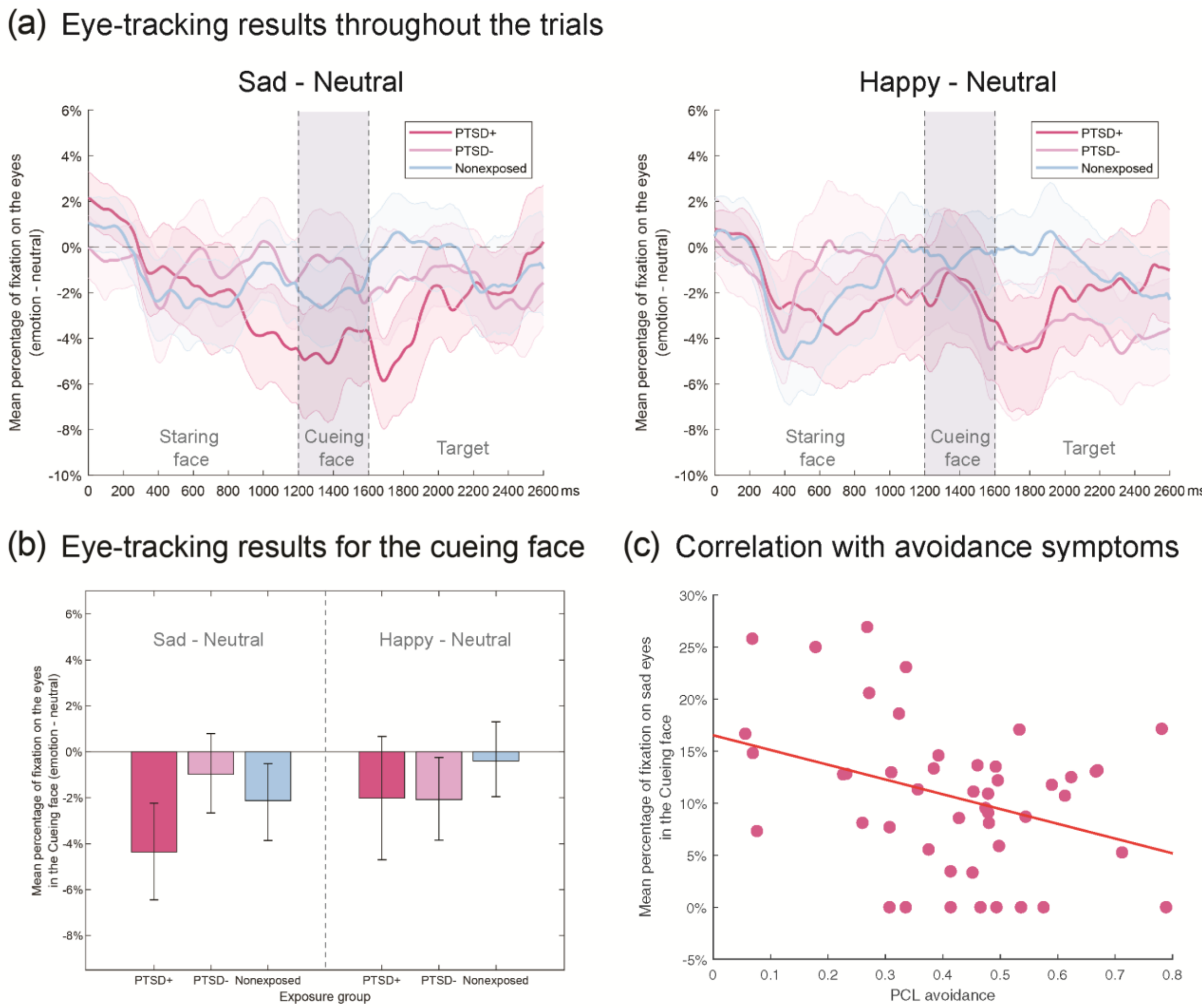

Figure 2. Eye-tracking results. (a) Mean percentage of fixations throughout the trials on the eye AOI of sad and happy stimuli for each group. The analysis time window (1200-1600 ms), corresponding to the presentation of the cueing face, is highlighted in light gray. (b) Mean percentage of fixations on the eye AOI of the cueing face for each group in each emotion condition. Vertical bars represent 90% bootstrapped confidence intervals (and thus indicate significance when they do not overlap with zero). It should be noted that this plot displays the confidence intervals before adjustment for multiple comparisons (see Section 3 “Results”). (c) Plot of the correlation between the mean percentage of fixations on sad eyes for the cueing face in PTSD+

participants and their avoidance symptoms, as assessed with PCL-5 Cluster C items. The regression line is shown in red.

3.2. Eyetracking

Eye-tracking results are summarized in Figure 2, as well as Tables 1 and 2.

Table 1. Eye-tracking results summarizing contrasts between the experimental conditions for PTSD+, PTSD- and nonexposed participants.

PTSD+						
contrast	t_{-peak}**(df)**	p_{FWER}	**peak-max**	t_{-mean}**(df)**	p_{-mean}	**bootstrapped 90% CI**
Sad *versus* Neutral	-3.59(48)	.002	24	-3.36(48)	< .001	[-0.06; -0.02]
Happy *versus* Neutral	-1.95(48)	.092	400	-1.17(48)	.123	[-0.04; 0.007]
Sad *versus* Happy	-2.38(48)	.038	164	-1.75(48)	.043	[-0.05; -0.012]
PTSD-						
contrast	t_{-peak}**(df)**	p_{FWER}	**peak-max**	t_{-mean}**(df)**	p_{-mean}	**bootstrapped 90% CI**
Sad *versus* Neutral	-2.22(45)	.069	384	-0.90(45)	.185	[-0.03; 0.008]
Happy *versus* Neutral	-3.45(45)	.004	372	-1.86(45)	.035	[-0.04; -0.002]
Sad *versus* Happy	0.30(45)	.681	4	1.08(45)	.143	[-0.006; 0.03]
Nonexposed						
contrast	t_{-peak}**(df)**	p_{FWER}	**peak-max**	t_{-mean}**(df)**	p_{-mean}	**bootstrapped 90% CI**
Sad *versus* Neutral	-2.57(47)	.029	124	-2.10(47)	.021	[-0.038; -0.005]
Happy *versus* Neutral	-0.56(47)	.521	156	-0.07(47)	.474	[-0.018; 0.016]
Sad *versus* Happy	-2.18(47)	.072	316	-2.17(47)	.018	[-0.04; -0.005]

Note. FWER = familywise error rate.

Table 2. Eye-tracking results summarizing group contrasts for sad versus neutral, happy versus neutral, and sad versus happy. It should be noted that these results take into account five nuisance covariates: age, sex, education level, type of exposure to the traumatic event, and level of depressive symptoms.

Sad *versus* Neutral contrast	***t**-peak*(df)	***p**FWER*	**peak-max**	***t**-mean*(df)	***p**-mean*	**bootstrapped 90% CI**
PTSD+ *versus* PTSD-	2.77(93)	.016	36	2.73(86)	.004	[0.006; 0.06]
Nonexposed *versus* PTSD+	2.29(95)	.047	152	1.89(88)	.031	[-0.005; 0.05]
Nonexposed *versus* PTSD-	1.65(92)	.172	60	1.22(85)	.113	[-0.04; 0.01]
Happy *versus* Neutral contrast	***t**-peak*(df)	***p**FWER*	**peak-max**	***t**-mean*(df)	***p**-mean*	**bootstrapped 90% CI**
PTSD+ *versus* PTSD-	0.97(93)	.361	44	0.73(86)	.235	[-0.03; 0.03]
Nonexposed *versus* PTSD+	1.73(95)	.138	400	1.45(88)	.075	[-0.01; 0.05]
Nonexposed *versus* PTSD-	2.20(92)	.064	392	1.28(85)	.102	[-0.006; 0.04]
Sad *versus* Happy contrast	***t**-peak*(df)	***p**FWER*	**peak-max**	***t**-mean*(df)	***p**-mean*	**bootstrapped 90% CI**
PTSD+ *versus* PTSD-	1.87(93)	.110	188	1.79(86)	.038	[0.008; 0.06]
Nonexposed *versus* PTSD+	1.02(95)	.343	160	0.24(88)	.406	[-0.02; 0.03]
Nonexposed *versus* PTSD-	-0.78(92)	.461	72	-0.17(85)	.432	[-0.05; -0.008]

Note. FWER = familywise error rate.

PTSD+ participants made significantly fewer fixations on sad faces than on neutral or happy faces. Regarding the sad versus neutral contrast, we observed a greater difference in the number of fixations in the PTSD+ group than in the PTSD- or nonexposed groups. There were no significant group differences for the sad versus happy contrast. Moreover, there was no significant difference in fixations on happy versus neutral faces in the PTSD+ group. In the PTSD- group, a late marginal difference was observed between fixations on sad versus neutral faces, but no significant difference was observed between fixations on sad versus happy faces. Despite the absence of a significant difference between fixations on sad versus happy faces in the PTSD- group, there were significantly fewer fixations on happy versus neutral faces. This difference occurred at a late point in the 400-ms cueing face window, and was not obtained when we compared the PTSD+ and nonexposed groups. Finally, nonexposed individuals exhibited an intermediate pattern of findings. They made significantly fewer fixations on sad faces than on neutral faces, and marginally fewer fixations on sad faces than on happy faces. Critically, however, no differences were observed between the nonexposed and PTSD- groups for the sad versus neutral and sad versus happy contrasts. Moreover, we found no differences between fixations on happy versus neutral faces in the nonexposed group.

Interestingly, the smaller number of fixations on sad faces made by PTSD+ participants was specifically related to avoidance symptoms (r-skipped = -0.35, $t(46) = -2.58$, $p = .007$, bootstrapped 90% CI [-0.56, -0.12], 2 bivariate outliers detected; Fig. 2). This relationship was specific to sad faces, and was not observed for happy ones (r-skipped = -0.13, $t(47) = -0.89$, $p = .190$, bootstrapped 90% CI [-0.37, 0.14]; 1 bivariate outlier detected). Moreover, we did not observe it among PTSD- participants for either sad (r-skipped = -0.02, $t(41) = -0.89$, $p = .440$; bootstrapped 90% CI [-0.26, 0.22], 4 bivariate outliers detected) or happy (r-skipped = 0.08, $t(41) = 0.54$, $p = .290$; bootstrapped 90% CI [-0.19, 0.32], 4 bivariate outliers detected) faces.

4. Discussion

According to models of PTSD, avoidance behavior increases the severity of PTSD symptoms. Avoidance becomes problematic when it affects the processing of elements that do not represent any danger. Using an eyetracker, we found that resilient individuals (i.e., PTSD-) did not display the normal tendency to avoid sad eyes, compared with those expressing happiness or no emotion, whereas this tendency was accentuated in PTSD+, in parallel with their avoidance symptoms. These findings link eye avoidance to variations in responses following trauma, and cannot be attributed to poor behavioral performances of individuals with PTSD.

Our results suggest that PTSD is accompanied by difficulties in processing non-trauma-related social cues, such as the eyes, and that these difficulties relate to the same avoidance mechanism that targets trauma-related material (e.g., Salters-Pedneault et al., 2004). Although extensive research has emphasized the relationship between a healthy social environment and resilience and recovery from PTSD (Sharp et al., 2012), the potential role of social cognition remains poorly understood (Stevens & Jovanovic, 2019). Previous studies among individuals with PTSD have highlighted difficulty recognizing emotional facial expressions (e.g., Mazza et al., 2012). In the present study, we extended this framework, and our results suggest that emotional difficulties may also result from the effort to avoid negative social information, such as the eyes.

Gaze is an important component of social interactions (Land & Tatler, 2009). A link between gaze avoidance and poor social functioning has been found in typically developing persons (Hayward & Ristic, 2017), and individuals with autism (Pelphrey et al., 2005) or social phobia (Moukheiber et al., 2010). No studies, however, have previously investigated social functioning in PTSD through the lens of attention paid to gaze. Contrary to what is observed in other pathologies, our results indicate that PTSD is not accompanied by a general avoidance of the eyes, but by an avoidance of the eyes of negative faces (e.g., expressing sadness). Eye-tracking studies show that sadness recognition is mainly related to the eyes area, which receives more initial fixations and attention (Eisenbarth & Alpers, 2011). This suggests that individuals with PTSD avoid sad eyes because they perceive them to be aversive (Emery, 2000). This idea was corroborated by the significant correlation between avoidance symptoms and the percentage of fixations on sad eyes. Eye contact triggers affective processing through the activation of subcortical routes or higher mentalizing processes (Hietanen, 2018). Activation of affective systems may be perceived as a threat in PTSD, triggering avoidance behaviors. However, it is worth mentioning that only sad faces were presented to participants in the present study and evidences are missing in order to fully generalize our results to other negative emotions.

Does eye avoidance reflect a preexisting factor or an acquired behavior exacerbated by chronic stress? We noticed that the percentage of eye fixations clearly differentiated PTSD+ from PTSD- participants, while results for the nonexposed participants were in between these two exposed groups. This suggests that PTSD+ and PTSD- participants lay at the two ends of a continuum. Interestingly, our observations are in line with PTSD studies about social cognition, which found the largest effect size when participants with PTSD were compared with trauma control participants, that is, the equivalent of our PTSD+ and PTSD- groups (Stevens & Jovanovic, 2019). A recent functional imaging study among the same participants as in the present study found a similar pattern of intergroup differences with respect to memory control processes (Mary et al., 2020). Taken together, our findings suggest that a fundamental personality trait of resilient individuals is the ability to optimize the cognitive processing of trauma by facing up to unpleasant content (Iacoviello & Charney, 2014). The sociocognitive model of PTSD also suggests that preexisting vulnerability factors in attachment schemas, which form the basis of representations of the self and others, can explain differences in responses to trauma across individuals (Sharp et al., 2012), and may predict resilience to or recovery from PTSD. One specificity of the sample of unexposed participants must be considered when comparing this group to exposed participants in our study. We choose to include people geographically distant from the place and the repercussions of the attacks that occurred in Paris and Saint-Denis as non-exposed participants. There are, however, socio-demographic differences between the people living in Caen and those exposed to the attacks living in Paris and its suburbs. Some studies highlighted the impact of socio-demographic factors in the variations of the response to trauma (e.g., Afana et al., 2002; Gaviria et al., 2016; Zambaldi et al., 2011). Among the factors retained age, gender, ethnicity and immigration status are often highlighted. Groups of our study did not differ in gender, age, education level. However, inhabitants of Caen which is a medium-sized provincial city have a different lifestyle from that of the Parisians. Such environmental aspects may have played a role in the differences observed with the non-exposed group compared to the others. Further studies should investigate the importance of these factors, in particular the social support variables, for the functional status of individuals.

Although pre-existing factors may explain the largest difference in behaviors between the groups in response to social stimuli, this pattern may also reflect an acquired deficit associated with PTSD. Avoidance is a maladaptive coping mechanism that is closely linked to learning abnormalities, and leads to the heightening of the anxiety response to environmental cues (Lissek & van Meurs, 2015). This in turn cascades into overgeneralization of fear to non-harmful stimuli (Dunsmoor & Paz, 2015). Further studies will be required to assess whether this overgeneralization extends to other anxiety-provoking situations, resulting in more defensive behaviors. Moreover, the exposed participants of our study developed or not a PTSD after a terrorist attack, which is a fairly particular event, which has a unique (not repeated) and sudden (unlike those of a military for example who may be concerned about the occurrence of an event) character, and it might thus impact the generalizability of our results to PTSD from other causes. Another particularity of our study is that we integrated participants with different levels of exposure to the traumatic events. We were careful to control for this variable in our analyses and the majority of our participants are direct victims, but it might be interesting in a future study to better characterize the effect of the type of exposure on the differences we have highlighted by trying to get a significant equivalent number of participants for each level of exposure.

The cross-sectional nature of our study meant that it could not shed any light on the origin of the eye processing distinction between the exposed subgroups. However, our findings suggest that gaze processing could help us to understand resilience to trauma and treat PTSD. In the presence of negative social stimuli, understanding others' emotions, and benefitting from a healthy social environment, may be the keys to resilience and prevention. To the best of our knowledge, none of the current therapies for PTSD focus on the attention paid to social stimuli, such as the information conveyed by eye contact, whereas sociocognitive behavioral therapies deal with dysfunctions in social support (Tarrier & Humphreys, 2004). In recent years, current PTSD therapies have come in for criticism, mainly because of their failure to fully address trauma-related concerns, and more particularly social indicators (Yehuda et al., 2016). As a result, clinicians have suggested developing more integrative therapies as a way of considering all aspects of PTSD (Yehuda et al., 2016). The present study therefore opens up a new avenue for research that goes beyond reducing social discomfort, and aims to target social cues (i.e., eyes) to reduce avoidance symptoms. Effective treatments for PTSD often involve overcoming avoidance to improve the processing of distressing trauma-related material (e.g., Brewin, 2018). If avoidance spreads to other, non-trauma-related contexts, such as eye contact, it may be possible to treat it by administering tasks that stimulate and remediate eye processing. Treatment that does not reawaken trauma could be an important complement to existing therapies, whose success in overcoming trauma avoidance does, to some degree, required fresh exposure to problematic content.

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The authors report no potential conflict of interest.

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Data availability statement

Data presented in the manuscript are available for download at https://unicloud.unicaen.fr/index.php/s/B8QkyeifYt2WdZm.

Author contributions statement

F.E., D.P., P.G. and M.L. conceived and designed the study. M.L. programmed the study. F.F. recruited, informed the participants and organized the recording sessions. J.D. was in charge of the clinical assessment of the participants. S.Y.C. and F.D. preprocessed the eye-tracking data. S.Y.C. organized and performed data analysis supervised by F.E., P.G. and M.L. S.Y.C., P.G. and M.L. wrote the main manuscript text. S.Y.C. designed the figures. All authors were involved in the discussions about the interpretation of the results.

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Supplemental Material

Appendix A

Summary of reaction time results

Effect	***F***	***p***	η_p^2
Exposure group (1)	3.180	.044	.040
Emotion (2)	1.680	.188	.011
Validity (3)	263.02	< .001	.635
1 x 2	1.1	.357	.014
1 x 3	0.32	.729	.004
2 x 3	0.04	.963	< .001
1 x 2 x 3	1.35	.252	.020

Appendix B

Eye-tracking results for the staring face time window (800-1200 ms)

In agreement with the results of the cueing face, PTSD+ participants showed a significant reduction in eye fixation of sad faces compared with neutral faces ($t_{-peak}(48) = -3.46$, $p_{FWER} = .003$, peak-max = 400 ms; $t_{-mean}(48) = -3.19$, $p = .001$, [-0.05; -0.02] bootstrapped 90% CI). This sustained reduction increased significantly compared with PTSD- individuals ($t_{-peak}(93) = 2.76$, $p_{FWER} = .016$, peak-max = 212 ms; $t_{-mean}(86) = 2.54$, $p = .006$, [0.003; 0.05] bootstrapped 90% CI), but unlike the cueing face, not significantly with Nonexposed participants ($t_{-peak}(95) = 1.72$, $p_{FWER} = .150$, peak-max = 152 ms; $t_{-mean}(88) = 1.19$, $p = .118$, [-0.002; 0.04] bootstrapped 90% CI). Furthermore, although PTSD+ individuals appeared to marginally decrease their fixations on sad faces compared with happy faces before correcting for multiple comparisons, it was not significantly the case after this adjustment ($t_{-peak}(48) = -1.83$, $p_{FWER} = .106$, peak-max = 376 ms; $t_{-mean}(48) = -1.42$, $p = .082$, [-0.04; 0.003] bootstrapped 90% CI). In accordance with previous results in the cueing face, the Happy *versus* Neutral contrast was not significant in PTSD+ participants ($t_{-peak}(48) = -1.31$, $p_{FWER} = .217$, peak-max = 4 ms; $t_{-mean}(48) = -1.04$, $p = .152$, [-0.04; 0.009] bootstrapped 90% CI). Following the results at the level of the cueing face, PTSD- participants did not reveal any significant reductions in eye fixation when comparing sad and neutral faces ($t_{-peak}(45) = -1.31$, $p_{FWER} = .252$, peak-max = 376 ms; $t_{-mean}(45) = -0.57$, $p = .285$, [-0.02; 0.01] bootstrapped 90% CI), nor sad and happy faces ($t_{-peak}(45) = 0.73$, $p_{FWER} = .452$, peak-max = 4 ms; $t_{-mean}(45) = 0.53$, $p = .299$, [-0.01; 0.03] bootstrapped 90% CI). The Happy *versus* Neutral contrast was also not significant ($t_{-peak}(45) = -1.97$, $p_{FWER} = .094$, peak-max = 304 ms; $t_{-mean}(45) = -1.11$, $p = .136$, [-0.03; 0.006] bootstrapped 90% CI). Finally, Nonexposed participants, in line with what was observed in the cueing face, showed an intermediate pattern of results. They exhibited a marginal decrease in eye fixation of sad faces compared with neutral faces ($t_{-peak}(47) = -2.31$, $p_{FWER} = .056$, peak-max = 4 ms; $t_{-mean}(47) = -1.61$, $p = .057$, [-0.03; -0.0001] bootstrapped 90% CI), but the Sad *versus* Happy ($t_{-peak}(47) = -$

1.85, p_{FWER} = .130, peak-max = 400 ms; t_{-mean}(47) = -0.40, *p* = .346, [-0.02; 0.01] bootstrapped 90% CI), nor the Happy *versus* Neutral contrast (t_{-peak}(47) = -1.73, p_{FWER} = .142, peak-max = 112 ms; t_{-mean}(47) = -0.96, *p* = .170, [-0.03; 0.007] bootstrapped 90% CI) were not significant.

As expected, the results of the staring face appear to be consistent with what was obtained in the cueing face, but probably for the reasons described above, the differences are less pronounced. The correlation between the mean percentage of fixation on sad eyes in the staring face in PTSD+ and their PTSD avoidance symptoms followed the same pattern. Indeed, although the reduced eye fixation over sad faces observed in PTSD+ participants was significantly related to avoidance symptoms in the cueing face, this result was only marginal in the staring face (r-skipped = -0.23, *t*(45) = -1.59, *p* = .06; [-0.50; 0.08] bootstrapped 90% CI; 3 bivariate outliers detected). Once again, this relationship was not significantly observed for happy faces (r-skipped = -0.03, *t*(47) = -0.18, *p* = .430; [-0.28; 0.20] bootstrapped 90% CI; 1 bivariate outlier detected) and was not found in PTSD- for both sad (r-skipped = -0.01, *t*(41) = -0.05, *p* = .480; [-0.29; 0.32] bootstrapped 90% CI; 1 bivariate outlier detected) or happy (r-skipped = 0.01, *t*(41) = 0.08, *p* = .469; [-0.28; 0.31] bootstrapped 90% CI; 1 bivariate outlier detected) faces.

Appendix C

Descriptive results concerning the fixations in the eyes of the staring face (0 – 1200 ms) for each exposure group and emotion condition. Mean fixation duration, number of fixation and latency of the first fixation. The number in brackets corresponds to the standard deviation

		Sad	
	PTSD+	PTSD-	Non-exposed
Fixation duration	251.1 (152.39)	281.24 (181.06)	262.16 (173.83)
Number of fixation	49.038 (33.97)	52.14 (29.23)	52.73 (29.44)
Latency of the first fixation	404.24 (226.92)	381.2 (213.63)	376.05 (228.71)
		Happy	
	PTSD+	PTSD-	Non-exposed
Fixation duration	241.59 (146.34)	279.93 (178.03)	262.36 (168.88)
Number of fixation	49.48 (34.86)	52.08 (29.52)	51.11 (27.36)
Latency of the first fixation	419.47 (215.60)	378.94 (210.97)	401.65 (232.56)
		Neutral	
	PTSD+	PTSD-	Non-exposed
Fixation duration	244.91 (148.44)	289.25 (188.63)	260.99 (174.18)
Number of fixation	52.5 (35.33)	53.08 (30.4)	54.79 (30.17)
Latency of the first fixation	407.82 (210.79)	360.26 (190.40)	377.69 (208.55)

Appendix D

Descriptive results concerning the fixations in the eyes of the cueing face (1200 - 1600 ms) for each exposure group and emotion condition. Mean fixation duration, number of fixation and latency of the first fixation. The number in brackets corresponds to the standard deviation

		Sad	
	PTSD+	PTSD-	Non-exposed
Fixation duration	223.62 (123.54)	244.4 (128.18)	219.79 (129.09)
Number of fixation	15.02 (9.62)	15.94 (10.03)	16.35 (9.40)
Latency of the first fixation	29.67 (56.36)	21.28 (43.26)	27.61 (50.76)
		Happy	
	PTSD+	PTSD-	Non-exposed
Fixation duration	223 (126.06)	243.21 (129.46)	226.14 (129.33)
Number of fixation	16.1 (9.84)	15.78 (9.80)	16.31 (9.08)
Latency of the first fixation	34.76 (65.11)	25.56 (51.67)	36 (68.91)
		Neutral	
	PTSD+	PTSD-	Non-exposed
Fixation duration	224.29 (123.88)	236.48 (128.26)	222.73 (127.82)
Number of fixation	16.22 (10.17)	16.98 (10.86)	16.65 (10.63)
Latency of the first fixation	22.56 (46.45)	25.1 (52.81)	22.69 (45.86)

Appendix E

Summary of eye-tracking results in the nose and mouth area

	t(df)	*p*	bootstrapped 95% CI
Nose			
Emotion difference			
[*]PTSD+: [†]S vs. [‡]H	1.75(94)	.084	[-0.003; 0.06]
[§]PTSD- S vs. H	0.92(89)	.360	[-0.01; 0.04]
Non-exposed: S vs. H	1.35(93)	.179	[-0.008; 0.05]
Group difference			
S: PTSD+ vs. PTSD-	0.11(91)	.913	[-0.03; 0.03]
S: PTSD+ vs. Non-exposed	-0.15(93)	.881	[-0.03; 0.03]
S: PTSD- vs. Non-exposed	-0.30(90)	.769	[-0.03; 0.02]
H: PTSD+ vs. PTSD-	-1.09(92)	.280	[-0.04; 0.01]
H: PTSD+ vs. Non-exposed	-0.88(94)	.379	[-0.04; 0.01]
H: PTSD- vs. Non-exposed	0.19(92)	.851	[-0.02; 0.03]
Mouth			
Emotion difference			
PTSD+: S vs. H	0.28(85)	.781	[-0.08; 0.11]
PTSD- S vs. H	-1.79(84)	.078	[-0.16; -0.0003]
Non-exposed: S vs. H	0.60(88)	.552	[-0.05; 0.10]
Group difference			
S: PTSD+ vs. PTSD-	2.20(86)	.031	[0.01; 0.20]
S: PTSD+ vs. Non-exposed	0.55(88)	.580	[-0.07; 0.11]
S: PTSD- vs. Non-exposed	-1.83(88)	.071	[-0.17; 0.0005]
H: PTSD+ vs. PTSD-	0.56(83)	.579	[-0.06; 0.10]
H: PTSD+ vs. Non-exposed	0.85(85)	.400	[-0.05; 0.11]
H: PTSD- vs. Non-exposed	0.39(84)	.694	[-0.05; 0.07]

[*] Participants exposed with a post-traumatic stress disorder (PTSD)
[†] Sad
[‡] Happy
[§] Participants exposed without a PTSD

Appendix F

Demographic and clinical characteristics

	PTSD+ (n = 52)	**PTSD-** (n = 51)	**Nonexposed** (n = 56)
Age	36.33 (7.60)	36.27 (7.07)	34.43 (10.85)
Sex	Men: 26	Men: 31	Men: 24
	Women: 26	Women: 20	Women: 32
Education level	University: 41	University: 41	University: 45
	High school: 11	High school: 10	High school: 10
	Compulsory school: 0	Compulsory school: 0	Compulsory school: 1
Exposure type	Direct victim: 37	Direct victim: 19	NA
	Witness: 8	Witness: 9	
	Grieving relative: 4	Grieving relative: 3	
	First responder: 3	First responder: 20	
PCL-5	37.60 (13.04)	13.67 (11.19)	4.59 (6.08)
BDI	8.56 (5.38)	4.04 (4.49)	2.02 (2.87)
STAI state	36.27 (10.10)	29.63 (8.07)	26.98 (5.42)
STAI trait	47.87 (9.97)	38.90 (11.32)	34.70 (8.46)

Note. Mean scores (standard deviation in parentheses) for age, Posttraumatic Stress Disorder Checklist for DSM-5 (PCL-5), Beck Depression Inventory (BDI), State-Trait Anxiety Inventory (STAI state and STAI trait). Number of participants for sex, education level and exposure type. Exposure type is not applicable (NA) in the nonexposed group.

Appendix G

Eye-tracking results without covariates summarizing group contrasts for sad versus neutral, happy versus neutral, and sad versus happy.

Sad *versus* Neutral						
contrast	$t_{\text{-peak}}$**(df)**	p_{FWER}	**peak-max**	$t_{\text{-mean}}$**(df)**	$p_{\text{-mean}}$	**bootstrapped 90% CI**
PTSD+ *versus* PTSD-	2.26(93)	.054	156	2(93)	.024	[0.007;0.06]
Nonexposed *versus* PTSD+	1.66(95)	.153	16	1.35(95)	.089	[-0.004; 0.05]
Nonexposed *versus* PTSD-	0.66(92)	.049	400	0.79(92)	.217	[-0.03; 0.01]
Happy *versus* Neutral						
contrast	$t_{\text{-peak}}$**(df)**	p_{FWER}	**peak-max**	$t_{\text{-mean}}$**(df)**	$p_{\text{-mean}}$	**bootstrapped 90% CI**
PTSD+ *versus* PTSD-	0.46(93)	.513	56	0.11(93)	.456	[-0.03; 0.03]
Nonexposed *versus* PTSD+	1.67(95)	.152	388	0.94(95)	.174	[-0.01; 0.05]
Nonexposed *versus* PTSD-	2.80(92)	.015	388	1.32(92)	.094	[-0.004; 0.04]
Sad *versus* Happy						
contrast	$t_{\text{-peak}}$**(df)**	p_{FWER}	**peak-max**	$t_{\text{-mean}}$**(df)**	$p_{\text{-mean}}$	**bootstrapped 90% CI**
PTSD+ *versus* PTSD-	2.13(93)	.067	200	2.03(93)	.023	[0.006; 0.06]
Nonexposed *versus* PTSD+	1.02(95)	.344	164	0.26(95)	.399	[-0.02; 0.03]
Nonexposed *versus* PTSD-	1.39(92)	.676	160	2.27(92)	.013	[-0.05; -0.008]

Note. FWER = familywise error rate.