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Eye-tracking exploration of inhibitory control in post-traumatic stress disorder: an emotional antisaccade paradigm

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ABSTRACT

Background: Cognitive-behavioural studies among individuals suffering from post-traumatic stress disorder (PTSD) have highlighted attentional biases towards threats as a key factor in the maintenance of the disorder. Anxiety-related studies have hypothesized that attentional biases were due to attentional control difficulties in inhibition and flexibility of threatening information.

Objective: Because it remains unclear how this theory could be applied to PTSD, this study aims to evaluate the inhibitory control and flexibility abilities of negative and threatening information in this population, using eye-tracking technology.

Method: Fifteen adults with a history of physical assault and a current diagnosis of PTSD, and 15 healthy control participants, completed an original mixed antisaccade task.

Results: We found enhanced overt attentional allocation towards every item of emotional information among PTSD participants, such as indexed by the latencies of the first saccade in prosaccade trials, followed by disengagement difficulties, such as indexed by increased reaction time to identify the target.

Conclusion: Our results could represent empirical evidence of the general enhancement of attentional vigilance in people with PTSD in comparison with healthy controls, as well as specific inhibitory deficits. The results are interpreted through a fear-generalization hypothesis.

Exploración de seguimiento-ocular del control inhibitorio en el Trastorno de Estrés Postraumático: un paradigma emocional de antisacada

Antecedentes: Los estudios cognitivo-conductuales entre personas que padecen Trastorno de Estrés Postraumático (TEPT) han destacado los sesgos atencionales (AB, por su sigla en inglés) por amenaza como factor clave para el mantenimiento del trastorno. La literatura relacionada con ansiedad ha planteado la hipótesis de que los AB se debían a la dificultad del control atencional en la inhibición y flexibilidad de la información amenazante (Eysenck, 2008).

Objetivo: Debido a que no está claro cómo se podría aplicar esta teoría al TEPT, este estudio tiene como objetivo evaluar el control inhibitorio y las capacidades de flexibilidad de la información negativa y amenazante en esta población, utilizando tecnología de seguimiento-ocular.

Método: 15 adultos agredidos físicamente con un diagnóstico actual de TEPT y 15 participantes de Controles Sanos (CS) completaron una tarea original de antisacada mixta.

Resultados: Encontramos una asignación atencional directa-abierta aumentada hacia información emocional entre los participantes con TEPT, tales como las latencias indexadas de la primera sacada en los ensayos de prosacada, seguida por las dificultades de desenganche, indexada por un tiempo de reacción mayor para identificar el objetivo diana.

Conclusión: Nuestros resultados podrían representar una evidencia empírica de un aumento general de la vigilancia atencional en el TEPT en comparación con los CS, así como de déficits inhibitorios específicos. Los resultados se interpretan a través de una hipótesis de generalización del miedo.

创伤后应激障碍抑制控制的眼动追踪探索:一种情绪反向眼跳范式

背景: 在创伤后应激障碍 (PTSD) 患者中进行的认知行为研究强调了对威胁的注意偏向 (AB) 是维持该疾病的关键因素。焦虑相关文献假设AB是由于对威胁性信息的注意控制在抑制能力和灵活性上有困难。

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PALABRAS CLAVE

seguimiento-ocular; tarea antisacada; procesos ejecutivos; hipervigilancia; TEPT

关键词

眼动追踪; 反向眼跳任务; 执行加工; 高警觉; PTSD

HIGHLIGHTS

- The ability to detect a relevant information in our environment and disengage from it is an important process in our daily life.
- PTSD patients presented a general hyper vigilant behavior followed by disengagement difficulties.
- We did not highlight impairments in flexibility among PTSD participants.

目的: 由于尚不清楚此理论应用于创伤后应激障碍效果如何, 本研究旨在使用眼动追踪技术评估此人群中负性和威胁性信息的抑制控制和灵活性能力。

方法: 15名遭受躯体袭击, 当前诊断患PTSD的成年人 (和15名健康对照参与者完成了原始的混合反向眼跳任务。

结果: 我们发现, PTSD参与者对每种情绪信息的外显注意力分配增加, 例如在朝向眼跳试验中首次眼跳潜伏期为指标, 其次是脱离困难, 例如以识别目标增加的反应时为指标。

结论: 我们的结果可能代表了PTSD组相较于HC组注意警觉普遍增强以及特定抑制减弱的实证证据。结果可由恐惧泛化假设解释。

1. Introduction

Post-traumatic stress disorder (PTSD) is a psychiatric condition characterized by a prolonged maladaptive response to a traumatic event, which highly impacts a person's quality of life (Ehlers & Clark, 2000). This disorder is known to be resistant to therapy in more than one-third of patients, and results in only short-term improvements in about 50% of them after treatment (Bradley, Greene, Russ, & Dutra, 2005; Difede, Olden, & Cukor, 2014). Therefore, a more precise comprehension of the processes underlying the symptomatology of this pathology is needed. While most research has focused on the memory processes of PTSD, attentional biases towards threatening information have been proposed to be a new target of study and intervention (Bardeen, Daniel, Hinnant, & Orcutt, 2017).

Attentional biases have been conceptualized in anxiety as a deficit in attentional control. They are known to result from an excessive attentional allocation towards threat (heightened bottom-up attentional system). This increased attentional allocation leaves insufficient resources for executive control processes (reduced top-down attentional system) to inhibit such information and relocate attentional resources towards pertinent stimuli (Eysenck, Derakshan, Santos, & Calvo, 2007). However, although research conducted on anxiety-related disorders has highlighted homogeneous results regarding the presence of heightened bottom-up activation (Bar-Haim, Lamy, Pergamin, Bakermans-Kranenburg, & van Ijzendoorn, 2007), this has not been the case for PTSD (Blekic, Wauthia, Kandana Arachchige, Lefebvre, & Rossignol, 2020; Cisler et al., 2011; Torrence & Troup, 2017). Therefore, studies have recently turned to the identification of a possible top-down dysfunction that could help us to understand the clinical hyperarousal observed in the daily clinical aspects of this pathology. Towards this aim, Falconer et al. (2007) performed functional magnetic resonance imaging during a Go/No-Go inhibition task among PTSD patients. They found that PTSD patients showed an increased activation of brain regions associated with sensory processing along with a greater demand on inhibitory control. The hypervigilance clinically observed among the

PTSD patients may therefore reflect an enhanced stimulus processing in PTSD, leading to inhibition difficulties. The authors proposed evaluating other components of executive control, such as behavioural flexibility, to further understand the impact of post-traumatic symptomatology on top-down processes.

The antisaccade task (Hallett, 1978) could answer this need (Eysenck & Derakshan, 2011). This task relies on the study of voluntary saccadic eye movements and requires participants to inhibit the visual processing of a stimulus located on one side of the screen by making a saccade and overtly directing their attention towards a target located on the other side of the screen. In the prosaccade condition, participants are instructed to direct their attention towards the stimulus location on the screen by making an appropriate saccade (Hallett, 1978). This condition is thought to reflect the prepotent or automatic response to a salient peripheral cue (Hutton & Ettinger, 2006). In the antisaccade condition, participants are required to override the automatic response to look towards the target, and start a voluntary motor command to look away from the target (Coe & Munoz, 2017). Consequently, antisaccade trials recruit attentional control to inhibit the reflexive saccade towards the salient peripheral cue acting as a distracting stimulus. Hallett and Adams (1980) added a mixed condition that requires participants to switch between antisaccade and prosaccade tasks, which allows researchers to assess cognitive flexibility (Cherkasova, Manoach, Intriligator, & Barton, 2002). In healthy controls, a beneficial effect of switch trials was observed, as indexed by shorter latencies in the antisaccade in the switch trials in comparison with the repeat trials. It was suggested that more attentional resources were allocated in such mixed conditions (Cornwell, Mueller, Kaplan, Grillon, & Ernst, 2012; Hodgson, Golding, Molyva, Rosenthal, & Kennard, 2004), which could explain this paradoxical improvement. Conversely, anxiety seems to impair this process because anxious individuals are less able to exercise top-down attentional control owing to their attentional control impairments (Eysenck et al., 2007). Therefore, the cognitive load induced by the mixed condition may be too high regarding the restricted top-down resources induced by anxious

symptomatology among this population (Ansari, Derakshan, & Richards, 2008). While this paradigm offers a sensitive observation of flexibility and inhibitory mechanisms, it suffers from the flaws inherent in reaction-time based experiments. The behavioural response (key press) has a temporal delay from the cognitive processes that are targeted by the experiment (Lazarov et al., 2019). We can only make inferences on the cognitive processes that occurred at the end of the task, based on the behavioural output. Eye-tracking methodology can be implemented to address such reaction-time based paradigms. This technology is based on the assumption that the gaze pattern (overt attention) represents a person's visual attention allocation (covert attention) (Gaspelin, Leonard, & Luck, 2017).

To our knowledge, only Reinhard, Allen, Wong, and Schwartz (2017) have performed this task with an eye-tracking device, in a study on war veterans with and without PTSD. They compared gaze patterns from a standard and an emotional antisaccade task. They found that veterans with PTSD presented increased saccade latencies in the antisaccade condition, in both the emotional and standard tasks. The authors concluded that there was reduced inhibitory control linked with post-traumatic symptomatology (Reinhard et al., 2017). However, the reaction times were not analysed, which could have brought to light compensatory processes implemented by the participants. In our study, we developed a mixed emotional antisaccade task to test the two executive processes that are interrelated in attention control mechanisms (Eysenck & Derakshan, 2011): inhibitory control and cognitive flexibility. While the mixed condition allows us to evaluate cognitive flexibility, the single condition is centred on the evaluation of inhibitory control (antisaccade trials) and overt allocation of attention (prosaccade trials). We hypothesized that PTSD will be associated with (1) inhibition deficits, as shown by increased directional gaze errors in the antisaccade task; (2) an enhanced overt attentional allocation towards threat, indexed by shorter prosaccade latencies; (3) deficits in flexibility, as shown by a lack of switching benefit in the mixed condition; and (4) general executive dysfunction, as indexed by a higher intraindividual coefficient of variation.

2. Method

2.1. Population

Fifteen PTSD patients (4 males, 26 females, mean age 46.8, range 18–72 years) were recruited from the Victim Support Service of Charleroi (Belgium). They were all victims of physical aggression more than 4 months before the tests (range 7 months to 30 years). The total score on the PTSD Checklist for

DSM-5 (PCL-5) (Weathers, Litz, et al., 2013) was used to estimate symptom severity over the past month, secondary to the physical aggression identified by the Life Events Checklist (LEC) for DSM-5 (Weathers, Blake, et al., 2013). All participants assigned to the PTSD group were following a course of therapy with a master's level psychologist for 2–6 weeks. They were matched in age, gender and socio-economic status with 15 healthy controls (HC) reporting no previous trauma exposure. Control subjects did not meet criteria for any mental health disorder. Exclusion criteria for both groups included substance abuse in the past year; use of psychotropic medications within 4 weeks, history of psychosis, general anxiety disorder, attention deficit disorder or learning disability; neurological illness; and head trauma. These were evaluated through an anamnestic questionnaire. This study was approved by the ethics committee of the University of Mons and the executive committee of the Victim Support Service of Charleroi.

2.2. Questionnaires

2.2.1. Life Events Checklist (LEC)

The LEC is a self-report measure that assesses lifetime exposure to potentially traumatic events (Blake et al., 1995; Gray, Litz, Hsu, & Lombardo, 2004). A list of 17 potentially traumatic events is presented and subjects are asked to indicate whether the event happened to them, they witnessed it, or they learned about it. The French translation of this scale (Weathers, Blake, et al., 2013) was used.

2.2.2. PTSD Checklist for DSM-5 (PCL-5)

The PCL (Weathers, Litz, Herman, Huska, & Keane, 1993) is a self-report measure commonly used to assess PTSD symptoms, which has been adapted to the DSM-5 symptom criteria for PTSD (Weathers, Litz, et al., 2013). Patients have to rate the frequency and/or severity of 20 symptoms experienced in the past month (0 = not at all to 3 = 5 or more times per week/very much) in relation to the traumatic event identified as the most distressing on the LEC. Items 1–5 correspond to cluster B (intrusion criteria – PCL-B), items 6 and 7 correspond to cluster C (avoidance criteria, PCL-C), items 8–14 correspond to cluster D (negative thoughts and feelings criteria, PCL-D) and items 15–20 correspond to cluster E (arousal criteria, PCL-E). A cut-off for the suspicion of PTSD is determined at 33 points.

2.2.3. Attentional Control Scale (ACS)

The ACS (Derryberry & Reed, 2002) is a self-report questionnaire designed to assess the control of attentional resources. Twenty items are rated from 1 to 4 (1 = almost not true to 4 = always true). Participants have to judge how often or how much each statement

applies to them. The French version of this scale was used (Blekic et al., 2018, 2019).

2.2.4. Beck Depression Inventory – 13 items (BDI-13)

The BDI-13 is a short version of the Beck Depression Inventory (Collet & Cottiaux, 1986). It is a self-reported questionnaire designed to assess depression indices on a scale of 0–4. The subject is asked to choose which one of four sentences applies the most to his or her state.

2.2.5. State-Trait Anxiety Inventory (STAI)

The STAI (Gauthier & Bouchard, 1993; Spielberger, Gorsuch, Lushene, Vagg, & Jacobs, 1983) is a self-reported questionnaire designed to assess two different components of anxiety, namely anxious traits of personality and actual emotional state.

2.2.6. Peritraumatic Distress Inventory (PDI)

The PDI is a self-reported scale of 13 items rated on a Likert scale of 0–4 (0 = not at all, 4 = extremely true) designed to assess peritraumatic distress. The set point for each item scores the patient's response based on 'what you felt during and immediately after the critical event' (Brunet et al., 2001).

2.2.7. Peritraumatic Dissociation Experience Questionnaire (PDEQ)

The PDEQ assesses dissociative experiences that occurred during a traumatic event and in the minutes and hours that followed (Birmes et al., 2005; Marmar, Metzler, & Otte, 2004).

2.3. Experimental task

Participants completed an emotional mixed antisaccade task in which they were required to direct their gaze either 'away from' a picture without looking at it (antisaccade) or 'towards' it (prosaccade). An example of those trials is depicted in Figure 1. The task was divided into two conditions: single (in which participants completed either antisaccade or prosaccade trials consecutively) and mixed (in which participants were required to switch between the two instructions, as depicted in Figure 2). We proposed an emotional version of this task, replacing the neutral stimuli with emotional pictures (Blekic et al., 2021). A full description of this task is available in the Supplementary material.

2.4. Stimuli and equipment

An HP computer with EPRIME 2.0 as the presentation program was used to generate stimuli and present them on a 34 × 19 cm LCD screen running at a frame rate of 60 Hz. Stimuli were presented against

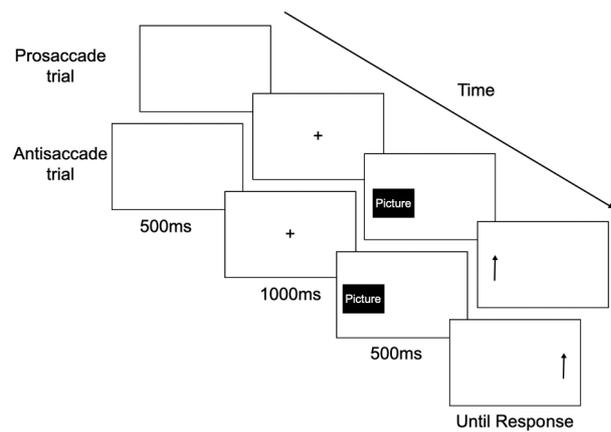


Figure 1. Example of anti- and prosaccade in the single condition.

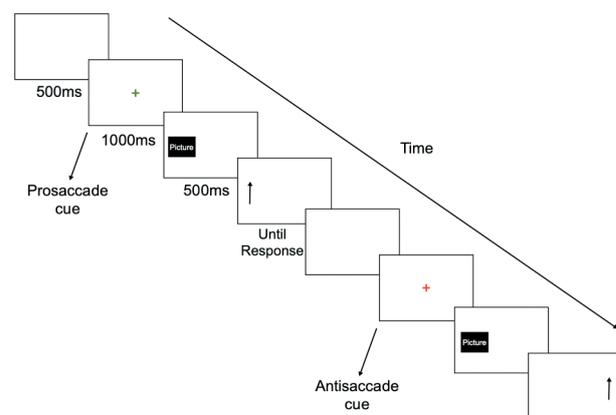


Figure 2. Example of a switch trial in the mixed condition.

a blank background. An SMI RED eye tracker was used to binocularly record eye movements at a sampling rate of 60 Hz. The average viewing distance was 54 cm, which approximates the distance at which the eye-tracker receives the best signal. This position was adjusted for each participant until the best possible eye-tracking signal was acquired. Stimulus sizes specified in visual angle are based on this distance. Before each task condition, eye location was calibrated using a nine-point system.

2.5. Analyses

Before conducting statistical analyses, a data reduction, as described in the Supplementary material, was performed. All analyses were performed using SPSS 21 with a probability (p) value of <0.05 being considered statistically significant. Trials in which the behavioral response was incorrect were counted and removed from further analyses. Four dependent measures were then examined; the first was inhibition deficits were investigated through the total fixation count recorded on wrong side of the screen in antisaccade trials (see supplementary material for further

development). The second was deficits in flexibility were explored using data from the mixed condition. We compared (1) reaction times (RT, in milliseconds) for the identification of the target and (2) fixation count recorded on the wrong side of the screen between repeated and switch trials. Thirdly, the stability of executive processes was investigated by the computation of reaction time variability. This intra-individual coefficient of variation (ICV), was obtained by the calculation “SD/mean RT” (Stuss, 2003). Finally, the presence of an attentional bias toward threat was assessed using the latency of the first saccade in the prosaccade trials.

First, we compared single versus mixed tasks using a General Linear Model (GLM) analysis with 2-Group (PTSD versus. HC) as the between-subjects factor and 2-Condition (single versus. mixed) \times 2-Saccade (prosaccade versus. antisaccade) \times 3-Emotion (positive – negative – violent) as within-subject’s factors. Then, mixed conditions were specifically analyzed using a GLM with 2-Group (PTSD versus. HC) as the between-subjects factor and \times 2-Trial Type (switch versus. repeat) \times 2-Saccade (prosaccade versus. antisaccade) \times 3-Emotion (positive – negative – violent) as within-subject’s factors. Finally, using hierarchical multiple linear regression we tested if some variables of interest could predict PTSD symptoms. To minimize type I errors, the Greenhouse-Geisser correction was applied in all GLMs and Bonferroni Adjustment were computed for the regressions (Mundfrom et al., 2006).

3. Results

3.1. Sample characteristics

Demographic information for the total sample is shown in Table 1. The PTSD group was composed of patients who self-reported at least 33 points on this

Table 1. Sample demographics and characteristics.

	PTSD group (n = 15)		Control group (n = 15)		t	p
	M	SD	M	SD		
Education (years)	11.60	2.50	12.40	1.92	-0.983	0.334
Age (years)	46.80	15.69	46.47	16.17	0.057	0.95
ACS Total	41.60	10.32	53.73	3.37	-4.33	0.00
STAI – S	41.60	13.03	26.27	3.65	4.39	0.00
STAI – T	54.33	11.38	33.87	4.29	6.52	0.00
BDI	14.53	8.48	0.53	0.91	6.36	0.00
PCL-5 Total	48.60	17.75	0.40	0.91	10.50	0.00
PCL-5 B	14.40	4.45	0.00	0.00	12.52	0.00
PCL-5 C	5.40	2.16	0.00	0.00	9.66	0.00
PCL-5 D	14.33	8.29	0.07	0.26	6.66	0.00
PCL-5 E	14.47	5.23	0.33	0.90	10.30	0.00
PDEQ	28.27	11.84	0.00	0.00	9.25	0.00
PDI	34.00	9.65	0.00	0.00	13.64	0.00

PTSD, post-traumatic stress disorder; ACS Total, global score of the Attentional Control Scale; STAI – S, State-Trait Anxiety Inventory – State questionnaire; STAI – T, State-Trait Anxiety Inventory – Trait questionnaire; BDI, Beck Depression Inventory; PCL-5, PTSD Checklist for DSM-5; PDEQ, Peritraumatic Dissociation Experience Questionnaire; PDI, Peritraumatic Distress Inventory.

scale. Groups did not differ in age ($p < 0.001$), but the PTSD group exhibited higher levels of state anxiety, trait anxiety, depression and post-traumatic symptoms. Finally, the PTSD group presented lower attentional control.

3.2. Behavioural data

3.2.1. Error rate

RT data were subjected to GLM analyses. No significant differences were found between prosaccade and antisaccade, single and mixed condition, or PTSD and HC participants.

3.2.2. Mean reaction times

3.2.2.1. Single condition versus mixed condition.

First, a significant main effect of Emotion [$F(2,56) = 7.18, p = 0.011$] was found, with targets following positive pictures being answered more quickly than those following negative or violent pictures. Secondly, a main effect of Group [$F(1,28) = 24.95, p < 0.001$] was highlighted, with PTSD patients being slower to identify all targets than HC. Finally, a Group * Emotion effect [$F(2,56) = 6.06, p = 0.019$] was found, with the PTSD group being slower to identify targets following violent pictures compared to targets following both positive [$t(14) = -2.64; p = 0.019$] and negative [$t(14) = -2.35; p = 0.034$] pictures. Mean RTs are shown in Figure 3.

3.2.2.2. Switch versus repeat trials in the mixed condition.

A main effect of Emotion was highlighted [$F(2,56) = 9.86, p = 0.015$], with targets following violent pictures being identified more slowly than targets following positive pictures. A main effect of Group was also identified [$F(1,28) = 24.49, p < 0.001$], with PTSD participants being slower than HC. Figure 4 depicts this observation.

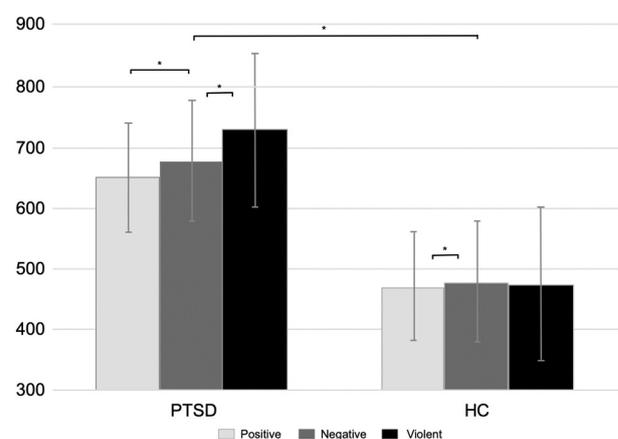


Figure 3. Mean reaction time (with standard errors) for PTSD Group and Healthy Controls on each picture valence (positive, negative and violent).

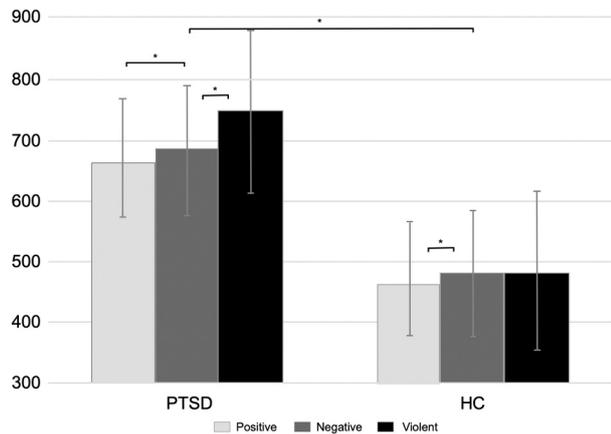


Figure 4. Mean reaction time within the mixed-task block (with standard errors) for PTSD Group and Healthy Controls on each picture valence (positive, negative and violent).

3.2.3. Reaction time variability

3.2.3.1. Single condition versus mixed condition.

GLM examining RT variability (ICV) revealed a main effect of Saccade [$F(1,28) = 5.82, p = 0.023$], with participants showing significantly smaller ICV in the prosaccade than in the antisaccade. Furthermore, PTSD patients showed significantly greater response variability than HC [$F(1,28) = 29.88, p < 0.001$].

3.2.3.2. Switch versus repeat trials in the mixed condition.

In the mixed condition, the main effect of Group was replicated [$F(1,28) = 26.11, p < 0.001$], showing that PTSD patients presented an increase in ICV compared to HC. No differences were observed between switch and repeat trials.

3.3. Eye-movement data

3.3.1. Error rate

3.3.1.1. Single condition versus mixed condition.

GLM examining fixation counts on the wrong side of the screen (on the white side for the prosaccade and the picture for the antisaccade) highlighted a significant main effect of Condition [$F(1,28) = 171.05, p < 0.001$], with individuals making more mistakes in the mixed conditions than in the single conditions. A significant main effect of saccade was also highlighted [$F(1,28) = 29.59, p < 0.001$], with participants making more errors in antisaccade than in prosaccade. Emotion also had a significant effect [$F(1,27) = 284.43, p < 0.001$], with errors increasing significantly between targets following positive and negative and between negative and violent pictures, under all conditions. Finally, a main effect of Group was found [$F(1,28) = 10.85, p = 0.003$], with PTSD participants making more errors than HC.

3.3.1.2. Switch versus repeat trials in the mixed condition.

In the mixed condition, a main effect of Trial Type was found [$F(1,28) = 5.39, p = 0.028$], with

participants committing more errors in the switch trials than in the repeat trials. A main effect of Saccade was also highlighted [$F(1,28) = 81.70, p < 0.001$], with participants committing more errors in antisaccade than in prosaccade. Emotion also had a significant effect [$F(2,56) = 3.90, p = 0.026$], with participants making more mistakes for targets following negative pictures than for targets following positive pictures. Finally, PTSD participants made more errors than HC [$F(1,28) = 7, p = 0.013$].

3.3.2. First saccade latency

3.3.2.1. Single condition versus mixed condition.

A main effect of Condition was found [$F(1,27) = 39.19, p < 0.001$], with participants being faster in the single condition in comparison with the mixed condition. We also highlighted a main effect of Saccade [$F(1,27) = 95.34, p < 0.001$], with participants being slower to perform an antisaccade than a prosaccade. Regarding interactions, we were able to highlight as significant the Condition * Emotion effect [$F(2,54) = 4.79, p = 0.017$]: we observed a decrease in first saccade latency in the single condition [$t(1,29) = 2.02, p = 0.053, d = 0.751$] for targets following a violent picture in comparison with a positive one. In the mixed condition, participants had significantly shorter saccade latencies for violent pictures than both positive pictures [$t(1,28) = -2.48, p = 0.019$] and negative pictures [$t(1,28) = -2.33, p = 0.027$]. Finally, even though Group did not have a significant main effect, we found that PTSD patients were faster in orienting their gaze towards each picture (prosaccade) in the single condition [$t(1,28) = -3.103, p = 0.004, d = 1.153$]. Figure 5 shows the mean saccade latencies.

3.3.2.2. Switch versus repeat trials in the mixed condition.

A main effect of Saccade was found [$F(1,28) = 114.20, p < 0.001$], with participants being slower in the antisaccade than in the prosaccade task.

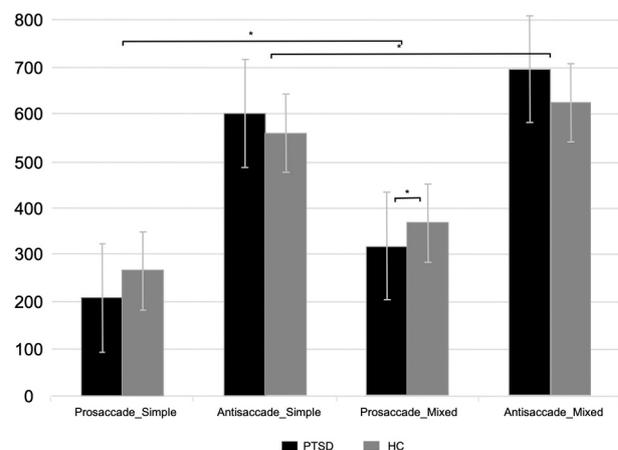


Figure 5. Mean saccade latency toward (prosaccade) or away (antisaccade) the emotional picture within the simple-task block and mixed-task block (with standard deviation) and between PTSD group and HC (Healthy Controls).

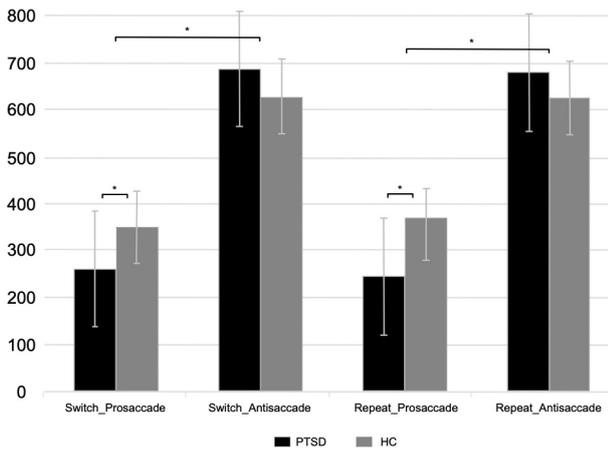


Figure 6. Mean saccade latency toward (prosaccade) or away (antisaccade) the emotional picture on repeat or switch trials, between PTSD group and HC (Healthy Controls).

We also highlighted a Saccade * Group interaction effect [$F(1,28) = 5.24, p = 0.030$]. A one-way analysis of variance (ANOVA) showed that PTSD patients were faster [$F(1,29) = 7.38, p = 0.011$] in orienting their gaze towards the picture in the prosaccade task in comparison to HC. Finally, a Trial Type * Emotion effect was found [$F(1,28) = 5.82, p = 0.005$], with gaze being correctly oriented more slowly in the switch trials than in the repeat trials when violent pictures were involved. Figure 6 shows the mean saccade latencies between repeat and switch trials.

3.4. Regressions

We performed three hierarchical regression analyses on three variables of interest that resulted from the previous analyses: latency of the first saccade in the prosaccade task, ICV for the prosaccade and ICV for the antisaccade. In the prediction of the first saccade latency for the prosaccade, only the peritraumatic dissociation made a significant contribution to the model [$F(1,28) = 13.67, p = 0.001, R^2 = 0.336$]. In the prediction of ICV for the prosaccade, only the depression score made a significant contribution ($\Delta R^2 = 0.692, t = 5.075, \beta = -0.692, p < 0.001$). Finally, in the prediction of ICV for the antisaccade, both the peritraumatic dissociation [$F(1,29) = 38.85, p < 0.001, R^2 = 0.566$] and the attentional control score [$F(2,29) = 27.72, p < 0.001, R^2 = 0.648$] made significant contributions.

4. Discussion

This study aimed to investigate the attentional control processes of inhibitory control and cognitive flexibility in PTSD. We hypothesized that PTSD participants would present difficulties in both executive processes, as well as an enhanced overt attentional allocation towards threat. To this end, 15 patients suffering from PTSD due to physical aggression and 15 healthy

participants performed a mixed antisaccade task in which they needed to orient their gaze either towards or away from emotional pictures in order to identify a target appearing in the selected visual field. Both eye-tracking data and behavioural responses were recorded.

The main result of our research is the presence of an enhanced overt attentional allocation towards every item of emotional information by the PTSD participants, in comparison with HC subjects. Indeed, PTSD patients presented a shorter latency of first saccades towards violent pictures, as expected, but also towards negative and positive pictures in comparison with HC. Furthermore, the saccade latency progressively decreased from positive to negative and violent pictures, in that PTSD participants moved their attention more rapidly towards emotional content than HC. This could represent empirical evidence of the general enhancement of attentional vigilance in PTSD in comparison with HC, as well as a reinforced hypervigilance from negative to violent pictures. Furthermore, our results show that only peritraumatic dissociation predicts this hypervigilant pattern. Even though increased vigilant behaviour is a diagnostic criterion of PTSD according to the DSM-5, as well as a strong clinical observation (American Psychiatric Association, 2013), there are no empirical observations of this phenomenon (Lazarov et al., 2019). While previous research has performed free-viewing tasks, in which either the latency of first fixation or pupillometry-based data were recorded to investigate vigilance behaviours, our paradigm demands an intentional orientation of attention from the participant. Lazarov et al. (2019) highlighted that as free viewing does not imply specific demands from participants, it constitutes a limitation for detecting attentional patterns that appear in the context of task performance such as vigilant behaviour. Our design addressed this need by asking participants to orient their gaze in a given direction, resulting in an allocation of attentional resources that could be modulated by emotional content. Considering our paradigm, we decided to focus on the first saccade latency. Saccades are known to represent a change in the focus of attention, whereas fixations tend to reflect maintenance on some information of interest (Duchowski, 2007). Considering that the prosaccade condition of our paradigm allowed us to investigate attentional movements towards one single piece of information in the visual field, the saccade was better suited to represent attentional vigilance.

The second main result of our study is the presence of longer RTs for the identification of the targets in the PTSD group. This can be understood as difficulties in disengaging from emotional content. This is consistent with previous research, which found associations between PTSD and difficulty in disengaging attention from one stimulus to focus on more task-relevant

stimuli (Pineles, Shipherd, Mostoufi, Abramovitz, & Yovel, 2009). This ability represents a core mechanism in daily life; determining whether a selected stimulus is relevant to one's current goal and disengaging attention from it to prioritize more relevant stimuli is an important aspect of everyday life (Aupperle, Melrose, Stein, & Paulus, 2012). In this study, we observed that PTSD participants needed a longer time-delay to move their attentional focus from every emotional picture towards task-relevant information, which allows us to suggest a potential generalization of fear. Fear generalization is a complex process that requires individuals to learn to classify stimuli as safe or threatening depending on their similarity to learned danger and safety cues (Lis et al., 2020). Only a few studies have focused on the underlying processes involved in performing such judgements of safety or danger. As taking a longer time to judge the safety or dangerousness of information has been understood as a cue for fear generalization, our research could represent empirical evidence of such a phenomenon. Indeed, our PTSD sample presented a longer time-delay in disengaging from every item of emotional information to correctly perform a neutral task.

This study also highlighted a higher error rate in the PTSD participants, as indexed by wrong fixations in the antisaccade task. This typically represents a deficit in the inhibitory control abilities, with PTSD participants being less able than HC to prevent themselves looking at the emotional picture when they are told not to. However, the higher error rate among PTSD participants is only seen by the chosen eye-tracking index, and not in the behavioural response that followed. We suggest that even though PTSD patients had difficulties in inhibiting emotional information, they used compensatory mechanisms to behaviourally perform as well as HC participants, as indexed by the longer RT presented by the clinical group. This is corroborated by the higher RT variability found in the PTSD group, this index having previously been interpreted as a general marker of executive dysfunction and mental noise (Swick, Honzel, Larsen, & Ashley, 2013). Indeed, while the RT variability of the prosaccade was predicted by depression score, suggesting that ruminations can interfere with the completion of the task, the variability observed in the antisaccade task was due to high peritraumatic dissociation and low attentional control scores.

Finally, contrary to our hypothesis, we did not find group differences regarding the switch and repeat trials in the mixed conditions, on either RT or eye-tracking measures. It is important to note that the

increase in RTs, saccade latencies, error rates (behavioural and saccadic) and variability of responses indicate that the cognitive load of the mixed condition is indeed higher than in the single condition. However, participants did not exhibit the beneficial effect of switch trials as reported by previous research (Ansari et al., 2008; Cornwell et al., 2012; Hodgson et al., 2004), and PTSD individuals reported longer saccade latencies and more saccadic errors than HC in both trial types. This lack of beneficial switch effect has already been observed by Derakshan, Ansari, Hansard, Shoker, and Eysenck (2009): when switch trials were announced by external cues, the switch effect was not observed. Those authors suggested that the individuals relied on external cue to facilitate attentional control. Furthermore, the significant interaction between Condition and Emotion might suggest that when the cognitive load increases (in the mixed condition), the arousal of the picture begins to be a greater distractor and interferes with the normal functioning highlighted in previous research. Indeed, the mixed antisaccade task has only been used with neutral cues and targets, which did not allow us to evaluate the effect of emotion on flexibility processes. We could interpret our result as a hypervigilance towards emotional cues in healthy and pathological individuals that may become a distractor when cognitive load is increased.

This study needs to be considered with respect to some limitations. Future studies on larger samples are warranted, notably to investigate the same ocular responses on both neutral and emotional cues in order to reach conclusions on the possible impairment in flexibility, which could be masked in the present study by the emotional context induced by our experimental design. Furthermore, the recording of electrophysiological components such as event-related potentials would provide a better understanding of the compensatory processes used by PTSD patients.

In summary, we demonstrated that the PTSD participants presented a general hypervigilant behaviour, followed by difficulties in disengaging their attentional focus from the emotional picture towards task-relevant information. The recording of both behavioural and ocular measures provided complementary information that allowed us to conclude that PTSD is associated with attentional control impairments and, specifically, inhibitory control deficits. Finally, peritraumatic dissociations seem to be a core factor in this attentional control functioning in PTSD, by interfering with top-down processes.

Data availability statement

The data that support the findings of this study are available on request from the corresponding author, W.B. The data

are not publicly available owing to privacy and ethical restrictions.

Disclosure statement

No potential conflict of interest was reported by the authors.

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