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Eye-tracking indices of attention allocation and attention bias variability are differently related to trauma exposure and PTSD

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A R T I C L E I N F O

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A B S T R A C T

Amplified attention allocation to negative information in one's environment has been implicated in post-traumatic stress disorder (PTSD). Attention bias variability (ABV), the magnitude of attention fluctuation between negative and neutral cues, has also been found to be elevated in PTSD. While eye-tracking methodology has been used in research on attention allocation in PTSD, ABV was only explored using manual reaction-time-based indices. Thirty-seven participants with PTSD, 34 trauma-exposed healthy controls (TEHC), and 30 non-exposed healthy controls (HC) completed an eye-tracking free-viewing task in which matrices comprised of neutral and negatively-valenced faces were presented. Threat-related attention allocation was calculated as the proportion of dwell time (DT%) on negatively-valenced faces. Eye-tracking-based ABV was calculated as the standard deviation of DT% across matrices. DT% on negatively-valenced faces was greater in participants with PTSD compared to both TEHC ($p = .036$, $d = 0.50$) and HC ($p < .001$, $d = 1.03$), with TEHCs showing a greater attentional bias compared to HCs ($p = .001$, $d = 0.84$). Controlling for average fixation duration, ABV was higher in both the PTSD and TEHC groups relative to the HC group ($p = .004$, $d = 0.40$), with no difference between the two trauma-exposed groups. Biased attention allocation toward negative social information is related to PTSD pathology, whereas elevated ABV measured with eye-tracking appear to be related to trauma-exposure per-se.

1. Introduction

Exposure to trauma can have a profound effect on one's beliefs about the self, others, and the world (American Psychiatric Association, 2013), and on one's perception of the world as safe and benevolent (Janoff-Bulman, 1992). Trauma exposure has been associated with various perturbations in cognitive processes (Aupperle et al., 2012), including attention allocation to negatively-valenced and threat cues in one's environment (Iacoviello et al., 2014; Shechner & Bar-haim, 2016). In particular, threat-related attention has been implicated in the maintenance of posttraumatic stress disorder (PTSD; e.g., Aupperle et al., 2012; Ehlers & Clark, 2000; Foa et al., 1989). However, the fact that only a small portion of trauma-exposed individuals develop PTSD (Bryant, 2003), raises the question of what attentional processes might distinguish trauma-exposed individuals who become clinically symptomatic from those who remain asymptomatic. Here, we explore this question by utilizing two eye-tracking-based measures of attention: Sustained attention on negatively-valenced faces (calculated as percent dwell time on negatively-valenced faces) and an attention bias variability (ABV) measure, reflecting the magnitude of attentional fluctuations between negative and neutral information (calculated as the standard deviation of a series of scores of dwell time percent on negatively-valenced faces).

Cognitive models for PTSD have suggested several deficient cognitive processes in the disorder, including attentional biases in the processing of threat-related information (Brewin & Holmes, 2003; Ehlers & Clark, 2000; Foa, Steketee, & Rothbaum, 1989), possibly reflecting a more sensitive or vigilant attentional system for threat cues in the environment following exposure to life-threatening events (Shechner & Bar-haim, 2016). Accordingly, early research on attention allocation in PTSD and trauma exposure, applying reaction-time-(RT)-based measures, focused on threat-related attention bias. This line of research indicates that compared to healthy controls with no trauma-exposure,

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trauma-exposed participants' show attention bias toward negatively-valenced over neutral stimuli (Briggs-Gowan et al., 2015; pp. 7, 1239; DePierro et al., 2013; Lakshman et al., 2020), and that this biased-attention pattern is even more pronounced in those with PTSD (Fani et al., 2012). Taken together, results suggest that enhanced attention bias toward negative information is related to trauma-exposure and is further exacerbated in participants with PTSD.

Subsequent RT-based research investigated attention bias variability (ABV) in PTSD, namely, attentional fluctuations between threat vigilance and threat avoidance over time – which are also congruent with PTSD symptomatology (Iacoviello et al., 2014; Naim et al., 2015). This inconsistent attentional pattern is believed to reflect attentional dysregulation (Todd, Coutts-Bain, Wilson, & Clarke, 2023) and has been found to be correlated with poor attentional control (Bardeen, Tull, Daniel, Evenden & Stevens, 2016; Clarke et al., 2020) and emotional dysregulation (Bardeen, Daniel, Hinnant, & Orcutt, 2017; Klanecky Earl et al., 2020). As ABV is theoretically independent of threat-related attention bias (Alon, Naim, Pine, Bliese & Bar-Haim, 2019; Kruijt, Field, & Fox, 2016) it could explicate further variance in PTSD symptom severity. Indeed, research showed that participants with PTSD are characterized by greater ABV relative to non-trauma-exposed healthy controls (Alon et al., 2019; Todd, Wilson, Coutts-Bain & Clarke, 2022) and trauma-exposed healthy controls (Bardeen et al., 2016; Iacoviello et al., 2014; Naim et al., 2015), with the latter two groups showing no difference between them. These findings suggest that high ABV may either be specifically associated with pathological trauma-related processes and not with trauma-exposure per se. Alternatively, ABV might not be sensitive enough to capture existing differences between healthy trauma-exposed individuals and non-exposed controls. Of note, some recent criticisms have been raised regarding the validity of RT-based ABV (Carlson, Fang, & Kassel, 2022; Kruijt et al., 2016).

More recently, attention processes have been also studied using eye-tracking technology, which entails several advantages over RT-based tasks, including, among others, more reliable measurement of sustained attention (Waechter, Nelson, Wright, Hyatt & Oakman, 2014) and continuous tracking of attentional processes over time (Armstrong & Olatunji, 2012; Lazarov et al., 2019). Similar to RT-based studies, eye-tracking studies of attention allocation in PTSD indicate increased dwell time on negatively-valenced relative to neutral information in trauma-exposed healthy participants relative to non-exposed controls, and an even more pronounced bias among participants with PTSD (for a review see Lazarov et al., 2019). However, eye-tracking-based indices of ABV have neither been calculated yet nor investigated in the context of PTSD and trauma exposure. Notably, one eye-tracking study of veterans with and without posttraumatic symptoms (Kuester et al., 2022) separately calculated the variability in dwell time on neutral *or* threat stimuli, reporting a higher general variability in veterans with PTSD symptoms relative to both healthy exposed and non-exposed veterans. Nevertheless, these calculations reflect general variability in eye-movements, rather than specific variability in threat-related attention allocation over time, a conceptualization that does not correspond with the traditional conceptualization of ABV (Iacoviello et al., 2014; Naim et al., 2015).

Here, we introduce an eye-tracking-based ABV index. We compute this index as well as an eye-tracking-based attention allocation index (Lazarov et al., 2017; Shamai-Leshem, Lazarov, Pine & Bar-Haim, 2021; Suarez-Jimenez, Lazarov, Zhu, Pine, Bar-Haim & Neria, 2022), to explore whether and how these two indices relate to trauma-exposure and PTSD. Specifically, we compare ABV and percent dwell time on negative stimuli (DT%) between three groups of participants: PTSD, trauma-exposed healthy controls (TEHC), and non-exposed healthy controls (HC). If attention allocation to negative information or ABV are broadly related to trauma-exposure, rather than specifically to PTSD pathology, then these indices are expected to be elevated in both the PTSD and TEHC groups relative to the HC group. In contrast, if attention allocation to negative information or ABV are uniquely related to the symptomatology of PTSD, then elevation should be expected in the PTSD group relative to both the TEHC and HC groups. Based on previous findings we expected that the PTSD and TEHC groups would show an attention bias toward negative information (Lazarov et al., 2019) while the HC group would show an attentional avoidance from negative information (Lazarov, Suarez-Jimenez, Zhu, Pine, Bar-Haim & Neria, 2021). We also expected that attention allocation to negative information would be increased in the PTSD compared to the TEHC group (Lazarov et al., 2019). In contrast, based on previous RT-based studies, we expected ABV to be uniquely elevated in the PTSD group relative to the TEHC and HC groups, which were not expected to differ between them (Naim et al., 2015).

2. Method

2.1. Participants

Secondary analyses were conducted on 101 participants (M_{age} = 39.20, SD = 13.21; Lazarov et al., 2021): 37 with PTSD (18 women), 34 TEHC participants without present or past diagnosis of PTSD (16 women), and 30 non-exposed HC participants without any present or past psychiatric disorder (18 women). Demographics and clinically relevant characteristics of the current sample are presented in Table 1. Groups were matched on age, sex, and race. Participants in both the PTSD and TEHC groups experienced an interpersonal trauma meeting DSM-5 criterion A (e.g., physical assault, sexual assault, combat). The PTSD and TEHC groups did not significantly differ in trauma types, $\chi^2(5) = 6.49$, $p = .26$. Trauma exposure was established using the Life Events Checklist for DSM-5 (LEC-5; Weathers, Blake, Schnurr, Kaloupek, Marx & Keane, 2013). Diagnosis of PTSD was determined using the Clinician-Administered PTSD Scale-5 (CAPS-5; Weathers et al., 2018). All participants were also assessed for anxiety and depression using the Hamilton rating scales for anxiety (HAM-A; Hamilton, 1959) and depression (HAM-D; Hamilton, 1960; see Table 1), and primary and co-morbid psychiatric diagnoses were determined using the Structured Clinical Interview for DSM-5 (SCID-5; First, Williams, Karg, & Spitzer, 2015). The study was approved by the New York Psychiatric Institute

Table 1
Demographic and clinical characteristics by group.

	PTSD group (n = 37)		TEHC group (n = 34)		HC group (n = 30)	
	M	***S.D.***	***M***	***S.D.***	***M***	***S.D.***
Age	40.94	14.23	38.97	12.80	37.33	12.43
Gender Ratio (Men:Women)	19:18	-	18:16	-	12:18	-
Race (% white)	75.68	-	82.35	-	76.67	-
Ethnicity (Hispanic: Non-Hispanic)	9:28	-	6:28	-	7:23	-
Age at trauma (years)	26.46	12.62	27.79	12.78	-	-
Time since trauma (years)	14.49	11.23	11.18	12.56	-	-
Trauma type						
Combat	n = 8	(21.62%)	n = 3	(8.81%)	-	-
Sexual assault	n = 11	(29.73%)	n = 7	(20.59%)	-	-
Violent assault	n = 5	(13.51%)	n = 5	(14.71%)	-	-
MVA	n = 2	(5.41%)	n = 7	(20.59%)	-	-
Serious injury	n = 3	(8.11%)	n = 5	(14.71%)	-	-
Terror attack	n = 8	(21.62%)	n = 7	(20.59%)	-	-
CAPS severity score	34.19	6.69	2.50	2.78	-	-
HAM-D	14.08	5.39	2.41	3.13	0.50	1.04
HAM-A	21.95	27.69	2.76	4.28	0.40	0.77

Note. TEHC = trauma-exposed healthy control; HC = healthy control; MVA = motor vehicle accident; CAPS = clinician-administered PTSD scale; HAM-D = Hamilton Rating Scale for Depression; HAM-A = Hamilton Anxiety Rating Scale.

(NYPSI) Institutional Review boards and followed the declaration of Helsinki ethical guidelines.

2.2. Clinical measures

2.2.1. Life events checklist for DSM-5 (LEC-5)

The LEC-5 was used to determine trauma exposure (Weathers et al., 2013). It is comprised of 17 self-reported items inquiring about life-time exposure to potentially traumatic events (e.g., physical assault, sexual assault, combat). Participants are requested to indicate for each event whether they experienced it personally, witnessed it, learned about it, experienced it as part of their job, were not certain if they experienced it, or believed the event was irrelevant to them. Then, participants are requested to choose one event that currently is most concerning them and refer to it in the CAPS-5.

2.2.2. Clinician-administered PTSD scale-5 (CAPS-5)

CAPS-5 was utilized to assess PTSD diagnosis as well as PTSD symptom severity (Weathers et al., 2018). The CAPS-5 is a structured interview that screens for all 20 DSM-5 symptoms of PTSD, permitting to determine whether one meets the diagnostic criteria for PTSD (i.e., present/absent). It also produces a continuous PTSD symptom severity score ranging 0 – 80, with higher scores denoting higher symptom severity. Cronbach's α in the current sample was.95.

2.2.3. Hamilton rating scale for depression (HAM-D)

The HAM-D is a clinician-rated questionnaire comprised of 17 items inspecting core symptoms of depression during the past week (Hamilton, 1960; Williams, 1988). Cronbach's α in the current sample was.90.

2.2.4. Hamilton rating scale for anxiety (HAM-A)

The HAM-A is a clinician-rated measure consisting 14 items relating to anxiety symptoms during the past week (Hamilton, 1959; Shear et al., 2001). Cronbach's α in the current sample was.93.

2.3. Measurement of attention allocation patterns

Eye-tracking-based attention indices (DT%, ABV) were calculated using data from an established eye-tracking free-viewing task (Klawohn et al., 2020; Lazarov et al., 2016, 2021; see Fig. 1).

Each trial of the task began with a central fixation cross that disappeared after a fixation of 1000 ms was recorded, verifying participants' gaze was located at the center of the screen before matrix stimuli presentation. Then, a matrix comprised of 8 neutral and 8 negatively-valenced faces (anger, fear, and sad in separate blocks) was presented for 6000 ms, succeeded by an inter-trial-interval of 2000 ms. Participants were requested to freely view the face matrices until they disappeared. Each single face stimulus appeared once per matrix at a random position with the following constraints: (a) each matrix included 8 males and 8 females; (b) half of the faces presented in each matrix were negative and half were neutral; a ratio that was also maintained for the 4 faces adjacent to the fixation cross (2 negative faces and 2 neutral faces).

Participants viewed 3 blocks of 30 matrices, with each block contrasting a specific emotion and neutral faces: neutral-angry, neutral-fear, and neutral-sad. Order of blocks was counterbalanced across participants. The actors and actresses who provided emotional and neutral face stimuli differed between blocks. The stimuli were taken from the validated Karolinska Directed Emotional Faces database (KDEF; Lundqvist, Flykt, & Öhman, 1998) that includes Caucasian actors and actresses, 20–30 years of age. We opted to use faces in which teeth were not exposed, or were barely visible, to decrease the effects of low-level visual factors on gaze patterns (Lazarov, Abend, & Bar-Haim, 2016). Stable fixations of at least 100 ms within 1-degree visual angle were analyzed (Hooge, Niehorster, Nyström, Andersson, & Hessels, 2022; Salvucci & Goldberg, 2000), excluding shorter fixations, saccades, and blinks. Two areas of interest (AOIs) were defined for each matrix: a negative AOI including the 8 negatively-valenced faces and a neutral AOI including the 8 neutral faces of each presented matrix.

Attention allocation to negative faces was calculated per block (angry-neutral, fear-neutral, and sad-neutral) as the proportion of dwell time (DT%) on the negative AOI out of the total of dwell time on the negative and neutral AOIs (Lazarov et al., 2017; Shamai-Leshem et al., 2021). Thus, a value of 50 % reflects equal attention allocation to both AOIs, values greater than 50 % reflect attention bias towards negative faces, and values lower than 50 % reflect attentional avoidance of the negative faces.

Attention bias variability (ABV) scores, representing fluctuations in attention bias to negative information over time, were calculated per block (angry-neutral, fear-neutral, and sad-neutral faces, that is 3 ABV scores in total), as the standard deviation of DT% on negative faces across matrices (see Naim et al., 2015 for a similar approach in RT-based ABV calculations). Higher ABV values denote greater fluctuations in attention allocation over time between the negative and neutral AOIs.

2.4. Data analysis

To explore the reliability of the derived DT% and ABV indices, split-half Pearson bivariate coefficients were computed. To address concerns raised about the reliability of the RT-based ABV index, which tends to drastically diminish when controlling for general RT properties (Carlson et al., 2022), split-half Pearson coefficient was computed for ABV with average fixation duration, reflecting a general gaze characteristic, as a covariate.

To test whether attention allocation differed between the study groups, a two-way ANOVA was conducted with emotion expression (angry, fearful, sad) as a within-subject factor and group (PTSD, TEHC, HC) as a between-subjects factor.[1] Follow-up *t*-tests were performed for significant effects corrected for multiple comparisons using the Holm-Bonferroni method. To test whether DT% in each group significantly differed from 50% (i.e., equal attention allocation per AOI), one-sample *t*-tests were performed.

To examine whether ABV differed between the study groups, a two-way ANCOVA was conducted with emotion expression as a within-subject factor (angry, fearful, sad), group (PTSD, TEHC, HC) as a between-subjects factor, and average fixation duration as a covariate to control for general gaze patterns irrelevant to negatively-valenced attention (Alon et al., 2019).[2] To further explore pairwise group differences, follow-up ANCOVAs were performed corrected for multiple comparisons using the Holm-Bonferroni method.

To gauge the probability of support for the null hypothesis when non-significant group differences emerged in the above-described analyses of DT% and ABV, a post-hoc Bayesian ANCOVA was applied (Rouder, Morey, Verhagen, Swagman & Wagenmakers, 2017) using multivariate Cauchy prior with a fixed effects scale factor of $r = 0.5$ and a random effects scale factor of $r = 1$.

Exploratory multinominal regressions were conducted to examine whether entering DT% as an independent variable improves the prediction of group classification (PTSD, TEHC, HC) compared to a model that merely includes ABV and average dwell time. The regression was repeated twice, each time with a different reference group: PTSD or HC. Average fixation duration and ABV were set as forced entry terms and DT% was entered as a stepwise term. All predictors were *z*-transformed to facilitate interpretation.

All statistical assumptions were checked and were sufficiently met. All reported *p*-values (including for the one sample t-tests mentioned above) are for 2-tailed hypotheses.

[1] This analysis permitted an actual power of.99 (η_p^2 =.22, α = .05)

[2] This analysis permitted an actual power of.82 (η_p^2 =.09, α = .05).

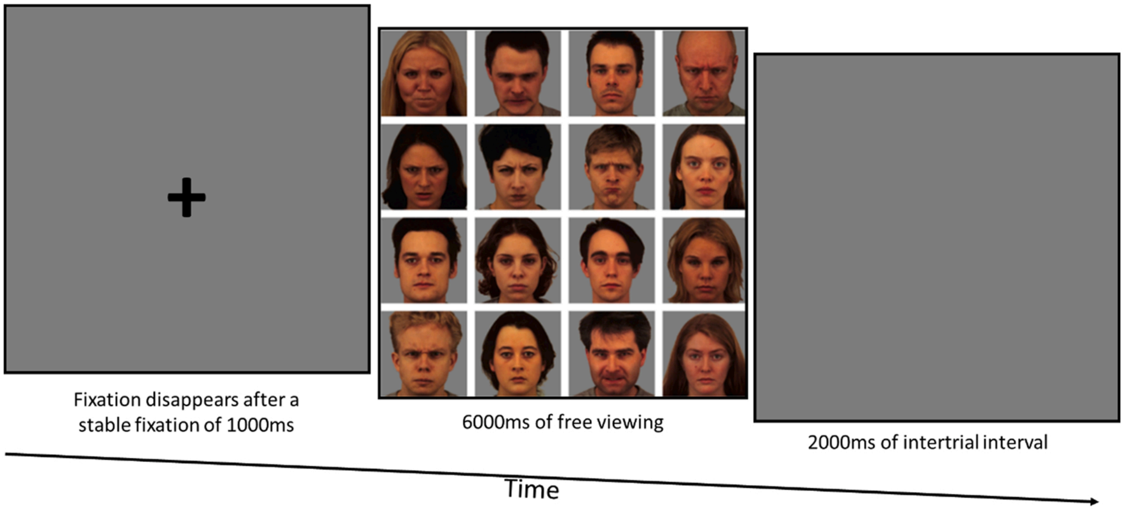

Fig. 1. An example trial of the free-viewing task from the angry-neutral block.

3. Results

Preliminary analyses indicated good internal consistency for the calculated attention measures. Split-half reliability of DT% toward negative over neutral stimuli and the ABV index were .89 and .85, respectively, *ps* $< .001$. When controlling for average dwell time, split-half reliability of ABV was .79, $p < .001$.

3.1. Attention allocation (DT%)

DT% significantly differed between the study groups, $F(2, 98) = 13.41$, $p < .001$, $\eta_p^2 = .22$ (PTSD: $M = 0.55$, $SD = 0.06$; TEHC: $M = 0.53$, $SD = 0.03$; HC: $M = 0.44$, $SD = 0.14$). The group-by-emotion expression interaction, $F(4, 196) = 0.51$, $p = .730$, $\eta_p^2 = .01$, and the main effect of emotion expression, $F(2, 196) = 0.65$, $p = .523$, $\eta_p^2 = .01$, were non-significant. Hence, DT% was collapsed across the three emotion expression blocks in all subsequent analyses (see Fig. 2a for DT % by group). Follow-up analyses revealed that participants with PTSD dwelled longer on negative faces, compared to both the TEHC participants, $t(69) = 2.15$, $p = .036$, $d = 0.50$, and HC participants, $t(65) = 4.18$, $p < .001$, $d = 1.03$, and that TEHCs dwelled longer on negative faces relative to HC participants, $t(62) = 4.18$, $p = .001$, $d = 0.84$.

DT% was significantly above 50% for the PTSD group, $t(36) = 4.90$, $p < .001$, $d = 0.81$, and the TEHC group, $t(33) = 4.72$, $p < .001$, $d = 0.81$, reflecting attention allocation favoring the negative over neutral facial expressions. In contrast, in the HC group DT% was significantly below 50%, $t(29) = 2.24$, $p = .033$, $d = 0.41$, reflecting attention allocation favoring the neutral over negative expressions.

3.2. Attention bias variability (ABV)

ABV significantly differed between the study groups, $F(2, 97) = 4.96$, $p = .009$, $\eta_p^2 = .09$ (PTSD: $M = 0.034$, $SD = 0.03$; TEHC: $M = 0.03$, $SD = 0.023$; HC: $M = 0.023$, $SD = 0.017$). The group-by-emotion expression interaction, $F(4, 194) = 0.81$, $p = .520$, $\eta_p^2 = .02$, and the main effect of emotion expression block, $F(2, 194) = 0.35$, $p = .707$, $\eta_p^2 = .01$, were non-significant. Hence, here too, subsequent analyses collapsed across the three emotion expression blocks (see Fig. 2b for ABV per group). Follow-up analyses indicated that ABV was lower in the HC group, compared to both the PTSD group, $F(1,64) = 6.94$, $p = .011$, $\eta_p^2 = 0.10$, and the TEHC group, $F(1,61) = 6.38$, $p = .014$, $\eta_p^2 = 0.10$, with no difference between them, $F(1,68) = 1.10$, $p = 0.298$, $\eta_p^2 = 0.02$. Collapsing across these two trauma-exposed groups and comparing to the non-exposed HC group showed that ABV was significantly greater among trauma-exposed participants ($M = 0.032$, $SD = 0.027$), relative to non-exposed HC participants ($M = 0.023$, $SD = 0.017$), $t(97) = 2.99$, $p = .004$, $d = 0.40$. Finally, the Bayesian ANCOVA revealed that the absence of group difference between the PTSD and TEHC groups (the null hypothesis) is 5.07 times more likely than the existence of such a group difference (the alternative hypothesis).

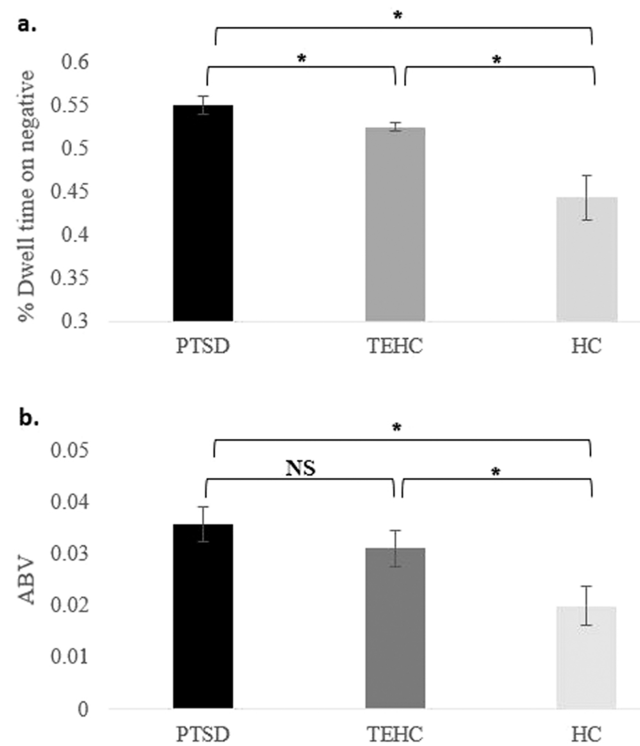

Fig. 2. Study results per group for: (a) percent dwell time (DT%) on negative faces; and (b) attention bias variability (ABV). Asterisks denote a *p*-value smaller than.05, and NS denotes a non-significant group difference. TEHC = trauma-exposed healthy controls; HC = healthy controls. Error bars reflect ± 1 standard error from group's mean.

3.3. The unique contribution of DT% beyond ABV to clinical status

As the main analyses show that ABV distinguishes at the group level between trauma-exposed (PTSD, TEHC) and non-exposed (HC) participants, whereas DT% distinguishes between all three study groups, we explored whether DT% could still distinguish between the three study groups beyond the variance explained by the ABV measure. Table 2 provides details on the parameter estimates of the multinominal logistic regression models with group as the dependent variable and average fixation duration, ABV, and DT% (all averaged across emotion expression blocks and *z*-transformed) as the independent variables. Entering DT% to the model containing average fixation duration and ABV improved the prediction of group compared to a model that contained only average fixation duration and ABV, $\chi^2(2) = 19.79$, $p < .001$, Nagelkerke $R^2 = .31$. Likelihood ratio tests indicated that average dwell time and ABV did not significantly predict group in the final model that contained all three predictors (i.e., average dwell time, ABV, DT%), $\chi^2(2) = 3.27$, $p = .195$, $\chi^2(2) = 5.53$, $p = .063$, respectively.

4. Discussion

This study introduces a reliable eye-tracking-based ABV index, applied along with an established attention allocation index (DT%) to characterize attentional patterns in relation to trauma-exposure and PTSD pathology. Results indicate that DT% is elevated among the PTSD group relative to the TEHC group, and in the TEHC group relative to the HC group. In contrast, ABV was found to be higher in both trauma-exposed groups (PTSD and TEHC), relative to the HC group, with no difference between them. Finally, DT% predicted trauma-exposure/PTSD status beyond ABV and mean fixation duration, whereas ABV and mean fixation duration were non-predictive of trauma-exposure/status when all three predictors were entered into the same model.

The current results are consistent with previous RT- and eye-tracking-based studies showing that trauma-exposure is associated with an attention bias toward negative/threat stimuli (Briggs-Gowan et al., 2015; pp. 7, 1239; DePierro et al., 2013; Lakshman et al., 2020), and that this bias is greater among individuals diagnosed with PTSD (Fani et al., 2012; Lee & Lee, 2014; Lee & Lee, 2012). Thus, attention bias towards negative over neutral stimuli appear to emerge following trauma-exposure, but an even stronger attention bias characterizes pathological PTSD manifestation.

Unlike RT-based ABV studies reporting a unique association between elevated ABV and PTSD pathology (Bardeen et al., 2016; Iacoviello et al., 2014; Naim et al., 2015; Todd et al., 2022), this first investigation using an eye-tracking-based ABV index reveals that elevated ABV is associated with trauma-exposure, irrespective of PTSD status. At least three factors could explain this divergence between the RT-based and eye-tracking-based findings. First, this discrepancy could reflect insufficient statistical power of the current eye-tracking ABV index in differentiating PTSD and TEHC participants. Supporting this stance, the descriptive statistics of the mean ABV per group in the current study were in the same direction as those of the DT% (i.e., PTSD > TEHC > HC). However, the possibility of lack of power is mitigated by a few factors: (1) the current ABV index was sensitive enough to reveal a difference between trauma-exposed and non-exposed participants; (2) post-hoc power analyses indicate that actual power was good (.82); and (3) Bayesian analyses indicate that the null hypothesis according to which there is no group difference is approximately 5 times more likely than the alternative hypothesis. Future replications in larger samples with greater statistical power are warranted to address whether the lack of difference in ABV between the PTSD and TEHC groups represents a true phenomenon or a lack of statistical power.

Second, inherent differences between manual responses and eye-tracking methodology could yield more sensitive ABV indices in one approach relative to the other. The current results may suggest that eye-tracking-based ABV is sensitive to general attentional adaptations following trauma exposure while RT-based ABV indices may be more sensitive to signals of psychopathology. Eye-tracking tasks follow attention allocation patterns continuously as they unfold (Armstrong & Olatunji, 2012; Lazarov et al., 2019) whereas RT-based paradigms gauge the endpoint of unfolding attentional processes, providing a "snapshot" of participants' attention at the endpoint of discreet task trials. Further research directly comparing RT-based and eye-tracking derived ABV indices in the same participants could shed light on these distinctions (Price et al., 2015). In addition, task parameters are markedly different between the current task and tasks applied in previous threat-related attention studies among trauma exposure/PTSD participants (e.g., Alon et al., 2019; Iacoviello et al.; Naim et al., 2015). Specifically, while previous studies, using both RT-based and eye-tracking tasks, generally used 2–4 stimuli per trial, also widely varying in presentation durations (e.g., Lazarov et al., 2019; Todd et al., 2023), the current task used matrices of 16 stimuli presented for an extended time period of 6000 ms. Indeed, prior research has shown these elements to influence emergent gaze patterns (Richards, Benson, Donnelly, & Hadwin, 2014). For example, it has been suggested that increasing stimulus array size might increase cognitive load which may affect, in turn, early processes of attention orientation to threat-related stimuli (Richards et al., 2014). It is possible that any specific difference or a combination of differences between the tasks affected gaze patterns. Further mechanistic research is now needed to clarify the specific contribution of such parameters on emergent results. Future studies could also inspect the relation between the RT-based and eye-tracking-based ABV indices using more similar task parameters.

Finally, another important difference between the two tasks relates to the context in which attention is captured by threat-related and neutral stimuli. Whereas in the RT-based tasks participants are requested to attain a certain goal (e.g., indicating the direction of the

Table 2
Multinomial logistic regression parameter estimates with average fixation duration, ABV, DT% as covariates and group (PTSD/TEHC/HC) as a dependent variable (N = 101).

Variable	TEHC (vs. PTSD)					HC (vs. PTSD)					TEHC (vs. HC)				
	B	*S.E.*	χ2	*OR* [95% *CI*]	*p*	*B*	*S.E.*	χ2	*OR* [95% *CI*]	*p*	*B*	*S.E.*	χ2	*OR* [95% *CI*]	*p*
Average fixation duration	0.51	0.39	1.69	1.66 [0.77 – 3.57]	.194	0.83	0.51	2.66	2.29 [0.85 – 6.17]	.103	-0.32	0.47	0.45	0.73 [0.29 – 1.85]	.502
ABV	-0.43	0.33	1.71	0.65 [0.34 – 1.24]	.191	-1.05	0.53	3.93	0.35 [0.12 – 0.99]	.047	0.62	0.52	1.41	1.86 [1.01 – 5.19]	.235
DT%	-1.14	0.56	4.11	0.32 [0.11 – 0.96]	.043	-2.45	0.74	10.96	0.09 [0.02 – 0.37]	< .001	1.31	0.66	4.00	3.71 [1.03 – 49.17]	.045

Note. ABV = attention bias variability; DT% = dwell time percentage on negatively-valenced faces; PTSD = posttraumatic stress disorder; TEHC = trauma exposed healthy controls; HC = healthy controls; *OR* = odds ratio; *S.E.* = standard error; *CI* = confidence interval. *OR* > 1 indicates that the odds of being in the group relative to the odds of being in the reference group (indicated in parentheses with preceding "vs.") increases as the variable increases. Conversely, *OR* < 1 indicates that the odds of being in the group relative to the odds of being in the reference group decreases as the variable increases.

arrowhead in the dot-probe task) while presented with task-irrelevant emotional stimuli (e.g., Alon et al., 2019), in the current eye-tracking task participants freely observe the facial matrices with no specific goals. The difference between passive viewing in the eye-tracking task and the parallel operation of goal-directed and stimulus-driven attention in the RT-based tasks (Corbetta & Shulman, 2002) could partly account for the noted discrepancy between RT-based and eye-tracking ABV patterns (Basel, Hallel, Dar, & Lazarov, 2023).

Taken together, the current results propose that increased eye-tracking-based ABV and DT% on negatively-valenced stimuli may reflect a universal alteration in threat monitoring patterns following exposure to a traumatic event, while a more pronounced inclination to dwell longer on negatively-valenced stimuli is more specifically related to PTSD symptomatology. One possible explanation of current findings is that a world that is no longer perceived as safe following a traumatic exposure (Janoff-Bulman, 1992) may warrant novel strategies to monitor trauma-related risks. One such adaptive attentional strategy could be heightened attentional threat vigilance, expressed here as heightened DT% on negative stimuli, and an offsetting mechanism that balances attention between threats and neutral stimuli to retain balance of resources, expressed here as elevated ABV. However, when the bias towards the negative stimuli is excessively high (expressed here as heightened DT%), this proposed offsetting mechanism might not be potent enough in balancing threat vigilance and a potentially maladaptive pathway associated with PTSD pathology may emerge. Alternatively, it could also be that the elevated ABV demonstrated among the trauma-exposed groups is the result of general attention or emotional dysregulation expressed as inconsistent attention to negative stimuli following trauma (Bardeen et al., 2017; Klanecky Earl et al., 2020). Focused research is now needed to determine the mechanistic contributions of DT% and ABV to PTSD development.

Even though RT-based ABV seems to be a replicable correlate of PTSD, a recent criticism has been raised against its validity. Specifically, it has been suggested that it may not capture the intended fluctuations in threat-related attention over time, but rather general properties of manual RT distributions such as mean or standard deviation (Kruijt et al., 2016). To overcome this potential obstacle, it has been proposed to control for these artifacts in statistical analyses (Alon et al., 2019). However, a more recent study concluded that when controlling for general RT variability, the reliability and validity of the RT-based index vanishes, rendering this index invalid (Carlson et al., 2022). This discussion of attention bias variability vs. reaction time variability might be mirrored as well in eye-tracking studies in terms of threat-related gaze patterns vs. general eye-movement patterns. For instance, the sole study that has previously attempted to explore ABV using eye-tracking, separately calculated the variability in dwell time on neutral or threat stimuli (Kuester et al., 2022), thus reflecting general variability in eye-movements, rather than specific variability in threat-related attention allocation over time. The current study attempted to control for this possible artifact by calculating variability in DT% scores that represent attentional bias toward negatively-valenced faces while entering average fixation duration as a covariate. Contrary to RT-based ABV findings, the current eye-tracking ABV demonstrated good reliability (.79), even when controlling for general gaze characteristics. In addition, this index was sufficiently potent to predict trauma exposure status when controlling for average dwell time. Hence, it appears that using eye-tracking in the context of ABV research may overcome some of the limitations of RT-based ABV (Carlson et al., 2022). Future replications are warranted to establish eye-tracking ABV as a reliable and valid index. Future studies are also encouraged to control for general gaze characteristics to ascertain that the observed effects indeed represent threat-related attentional processes.

This study should be viewed considering some limitations. First, the applied task presented negative facial expressions, presumably relevant to interpersonal trauma (angry, sad, fearful; see Lazarov et al., 2021). However, it remains open whether the detected group differences are unique to negative trauma-relevant facial expressions, or alternatively, would have also emerged for other emotional expressions (e.g., happy), or for non-social stimuli. Second, facial stimuli were all of Caucasian actors and actresses, aged 20–30 years, limiting the external validity of the current findings. Future studies could utilize a more diverse pool of stimuli. Third, the current cross-sectional design did not allow to uncover the development of threat-related attention allocation and ABV following trauma exposure. Specifically, it remains to be discovered at what point in time following a traumatic exposure ABV in fact elevates, and whether a deviating pattern of increase in ABV is related to a more pathological trajectory of PTSD symptoms. Prospective studies of ABV following traumatic exposure could address these issues. Finally, despite a statistically significant group-level differences in attention allocation between PTSD and TEHC participants, more work is needed to allow usage of this potential marker of pathology at the individual level. Future studies with larger samples could potentially provide DT% and ABV norms that allow cutoff definitions for clinical and research purposes.

4.1. Conclusions

In conclusion, this is the first study to introduce an eye-tracking-based ABV index with improved reliability compared to previous RT-based ABV indices. Additional studies are now needed to validate this measure and incorporate it alongside more traditional attention allocation indices. Together, the current eye-tracking results suggest that whereas biased attention allocation toward negative information is related to PTSD pathology, elevated variability in negatively-valenced attention allocation is related more generally to trauma-exposure. This divergence between the two attentional processes may suggest that some alterations in attention following trauma, such as elevated ABV, may be more adaptive than others. However, if one also presents an enhanced attention allocation toward negative information, this could reflect a more unique marker of PTSD pathology.

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Declaration of Competing Interest

None.

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