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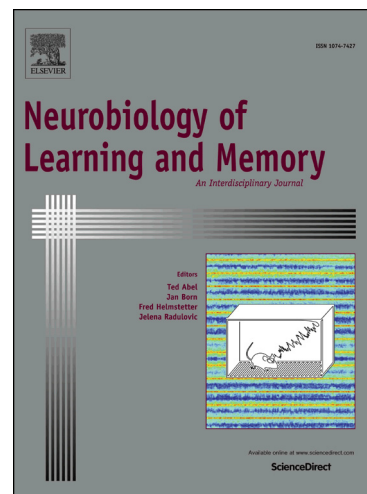
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**Impairment in active navigation from trauma and Post-Traumatic Stress Disorder**

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## ABSTRACT

The study investigated the impact of trauma exposure and of Post-Traumatic Stress Disorder (PTSD) on spatial processing and active navigation in a sample ( $n = 138$ ) comprising civilians ( $n = 91$ ), police officers ( $n = 22$ ) and veterans ( $n = 27$ ). Individuals with previous trauma exposure exhibited significantly poorer hippocampal-dependent (allocentric) navigation performance on active navigation in a virtual environment (the Alternative Route task) regardless of whether or not they had PTSD (scoring above 20 on the PTSD Diagnostic Scale). No performance differences were found in static perspective taking (the Four Mountains task). Moreover, an associative information processing bias in those with PTSD interfered with ability to use hippocampal-dependent processing in active navigation. This study provides new evidence of impaired active navigation in individuals with trauma exposure and highlights the importance of considering the relationship between trauma and spatial processing in clinical and occupational settings.

Keywords: trauma, PTSD, hippocampus, allocentric spatial processing, associative processing, navigation.

## 1 INTRODUCTION

Post-Traumatic Stress Disorder (PTSD) is used to describe stress-related cognitive dysfunction among individuals who have not adequately processed traumatic experiences (Brandes, et al. 2002). Behaviours and phenomena associated with PTSD include intrusion, avoidance, alterations in arousal and negative alterations in mood and cognition (American Psychiatric Association, APA, 2013). Considerable neuropsychological research suggests that hippocampal dysfunction co-occurs with the manifestation of PTSD (Bremner et al., 1995; Brewin et al., 1996; Sapolsky, 2000; Bremner & Elzinga, 2002; Astur et al., 2006; Teicher et al., 2003, 2012; Quereshi et al., 2011; Thomaes et al., 2013). Contemporary neurocognitive accounts of PTSD specify that a particularly spatial component of hippocampal-dependent processing is used to process and contextualise trauma memories (Brewin et al., 2010; Brewin & Burgess, 2014; Smith et al., 2015; Bisby & Burgess, 2016; Kaur et al., 2016). Here, we investigate this spatial component of hippocampal function further and examine the relationships between PTSD, trauma exposure and navigation behaviour.

### 1.1 Trauma processing in the hippocampus

When fully functioning, the hippocampus facilitates the formation and consolidation of memories and this is crucial to processing traumatic experiences (Smith et al., 2015; Bisby & Burgess, 2016). The hippocampal memory system is declarative and provides contextual information for our memories, which enables us to verbalise what has happened to us and to 'put it in context' (Pearson et al., 2012; Frankland et al., 1998; Vermetten et al., 2003; Brewin & Burgess, 2014; Morris in Andersen et al., 2007; Eichenbaum, 1997, 2000; Byrne et al., 2007; Reber et al., 1996; Glazer et al., 2013).

A core component of this hippocampal-dependent contextualisation is spatial (Morris, 1981; Meyer et al., 2012) and is facilitated by allocentric processing (Bisby et al., 2010; Brewin & Burgess, 2014; Smith et al., 2015). Essentially, allocentric processing enables individuals to construct a viewer-independent (non-egocentric) representation or image of a scene. This is useful in navigation and facilitates techniques such as using cardinal or compass direction points, and visualising overhead

map-like representations of buildings, streets and landscapes (Ekstrom et al., 2014; O'Keefe, 1990; Wiener et al., 2009). This hippocampal-dependent spatial processing also has clinical implications, particularly when contextualising past traumatic experiences. An allocentric representation of a traumatic scene can provide context to otherwise sensory and evocative representations of the trauma (Bisby et al., 2010; Brewin & Burgess, 2014; Smith et al., 2015; Bisby & Burgess, 2016; Kaur et al., 2016).

The relationship between traumatic stress and hippocampal-dependent processing is complex. In cases of PTSD, hippocampal integrity is generally considered compromised, either because stress-related atrophy or disruption (Gilbertson et al., 2007; Wang, 2010; Pitman et al., 2012; Vasterling & Brewin, 2005; Sapolsky, 2000; Andersen et al., 2007; Bremner & Elzinga, 2002). Traumatic memories are often extreme in nature and may demand greater processing resources from the hippocampus than 'ordinary normative memories' (Brewin, in Vasterling & Brewin, 2005; Van der Kolk et al., 1989). Furthermore, when impaired, the hippocampus' role in consolidating new memories of safety - memories which could otherwise help to alleviate and minimise a stress or fear response - is weakened (Peters et al., 2010; Scoville & Milner 1957; Anderson et al., 2007; Le Doux, 2000; Notaras, et al., 2015; Maren, 2008, 2011; Rosas-Vidal et al., 2014; Takei et al., 2011). These dynamics culminate in a situation where hippocampal impairment may be both a contributor to, and a consequence of, PTSD (Gilbertson et al., 2007; Smith et al., 2015). More specifically, *hippocampal-dependent 'allocentric' processing* is known to be affected by stress and negative emotions (Eichenbaum, 2000; Tempesta et al., 2011; van Gerven et al., 2016; Bisby & Burgess, 2016).

### **1.2 Recent research into trauma and spatial processing**

This relationship between hippocampal dysfunction and trauma processing has stimulated research into the relationship between PTSD and allocentric processing (Bisby et al., 2010; Smith et al., 2015; Kaur et al., 2016). Smith et al. (2015) investigated allocentric spatial processing performance in trauma exposed individuals with and without clinical levels of PTSD. They found that the PTSD group was significantly more impaired than the non-PTSD group in two tasks involving allocentric processing: a topographical recognition task comprising perceptual and memory components (the Four Mountains task by Hartley et al., 2007); and a test of memory for objects' locations within a virtual environment, within which allocentric and non-allocentric (egocentric) memory was tested (the Town Square task by King et al., 2004).

### **1.3 How does trauma and PTSD affect active navigation?**

Together, the trauma processing literature and cognitive neuroscientific accounts of contemporary research present a coherent and valuable narrative about the implications that PTSD may have for hippocampal-dependent processing (Bisby et al., 2010; Tempesta et al., 2012, 2015; Smith et al., 2015). However, to date these advances in our understanding of trauma processing have only been applied to clinical conditions of PTSD with little known about the implications of trauma exposure for hippocampal-dependent processing in healthy individuals.

Most people are exposed to at least one traumatic event in their lives (Ogle et al., 2013). Trauma exposure prevalence rates range from 40% to 90% (Breslau et al., 2013) and these rates can be even higher in certain professions such as paramedics and some areas of the military (Greenberg et al., 2015). Given that PTSD prevalence rates are estimated to be 3% (Greenberg et al., 2015; KCMHR, 2010; Atwoli, 2015) it is safe to assume that trauma exposure without PTSD is common to a significant proportion of the population. It is therefore important to investigate if trauma exposure in itself has an impact on people's ability to apply hippocampal resources when they are in high demand, such as during navigation.

The existing literature propose that healthy individuals access and utilise sufficient allocentric resources for trauma processing as and when they are required (Brewin et al. 1996; Brewin et al., 2010). However, the studies on which these assertions are based (e.g. Bisby et al, 2010; Gilbertson et al., 2007; Tempesta et al., 2012) did not compare allocentric resource allocation between healthy individuals with and without trauma exposure. Impairment in individuals' navigation-related behaviour have featured in trauma literature, namely travel anxiety, driving behaviour and willingness to explore the environment (e.g. Osofsky et al., 1995; Ehrling et al., 2006; Ehlers et al., 1998; Mayou et al., 2001; Adler et al., 2009; Handley et al., 2009; Butler et al., 1999; Beck & Coffey, 2007). While it is feasible that these impairments may simply result from high levels of anxiety and avoidance symptoms in PTSD, these behavioural problems were not reported in the literature as being unique to clinical cases of PTSD. One could speculate that these impairments could also be an effect of a relationship between trauma exposure and navigation behaviour.

The aims of this study were twofold. Firstly, to assess how clinical levels of PTSD affect allocentric processing in active navigation behaviour (looking at strategy use in activities such as wayfinding and route learning). Secondly, to determine how trauma exposure *itself* impacts on spatial processing and navigation behaviour, by comparing spatial processing and navigation behaviours between healthy individuals either with or without trauma exposure. Allocentric processing was assessed using the memory version of the Four Mountains task (Hartley et al., 2007). We also employed a more active navigation task which assessed strategy use ('navigation style') and route learning (Wiener et al., 2013) to assess the strategies, techniques and skills that individuals might use in everyday navigation. Performance on these tasks was compared between 138 participants who were trauma unexposed or exposed (with and without PTSD).

## 2. METHODS AND MATERIALS

### 2.1 Participants

The study involved 138 participants (62 females) who were grouped according to trauma exposure:

- (i) Those with PTSD; the *PTSD* group ( $n = 47$ )
- (ii) Those who had been exposed to trauma previous but did not have PTSD; the *Trauma Exposed No PTSD* group ( $n = 58$ )
- (iii) Those without previous trauma; the *Trauma Unexposed* group ( $n = 33$ ).

Seventy-eight healthy controls (without PTSD) were recruited through Bournemouth University (BU) and these comprised staff, students, and members of the public (through the Psychology Research

Volunteer Scheme). Nine participants with symptoms of PTSD were recruited through the Intensive Psychotherapy Treatment Service (IPTTS) at Dorset NHS. Twenty-four participants with trauma exposure were recruited from Dorset and Cambridgeshire Police forces. Twenty-five military veterans diagnosed with PTSD were recruited from Combat Stress's rehabilitation programme (Ex Services Mental Welfare Society Registered Charity No. 206002, Surrey). Two healthy combat trauma exposed participants from the UK Armed Forces were recruited through British Military Fitness and Forces Fit military fitness programmes.

No participants met criteria for current substance or alcohol misuse or had suffered a head injury. Demographic and clinical variables pertinent to hippocampal dependent spatial processing were recorded and these included: age (in years), gender (male or female), pain, sleep disturbance, depression and the taking of Selective Serotonin Reuptake Inhibitors (SSRI) anti-depressants, taking benzodiazepines or opiates.

The study was approved by the BU Ethics Board; the Combat Stress Research Ethics Committee; and the NHS South West (Cornwall and Plymouth) National Research Ethics Committee, (reference number 13/SW/0041).

## 2.2 Procedure

Informed consent was obtained from all participants ( $n = 138$ ). Participants were screened for trauma exposure via an online version of the Life Events Checklist (LEC, Blake et al., 1995). Participants who did not self-report trauma exposure using the LEC formed a '*Trauma Unexposed*' control group ( $n = 33$ ). Participants who did self-report trauma exposure using the LEC were then assessed using the PTSD Diagnostic Scale (PDS, Foa et al., 1995) to determine whether or not individuals were living with PTSD. All participants who were recruited with pre-diagnosed clinical levels of PTSD were also given the PDS to determine their current level of trauma impact and symptomology for analysis.

Individuals with scores at or above the threshold of 21 comprised a *PTSD* group ( $n = 47$ ). Those with scores below the threshold of 21 comprised a '*Trauma Exposed*' *No PTSD* group ( $n = 58$ ).

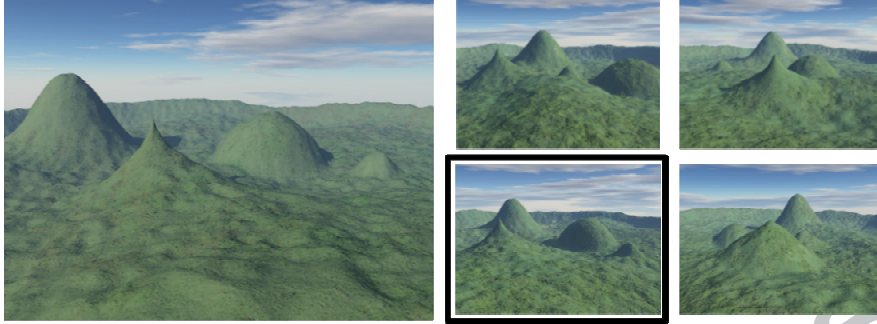
Participants also completed online versions of measures of other clinical factors which were potentially confounding variables for either PTSD or hippocampal function. These included: depression using the Beck Depression Inventory (BDI, Beck et al., 1996), pain, using the standard Numerical Rating Scale (NRS, Jensen et al., 1986) and sleep, using the Pittsburg Sleep Quality Index Addendum for PTSD (PSQI-A, Germain et al., 2005). Participants were also asked if they were taking Selective Serotonin Reuptake Inhibitors (SSRIs), opiates or benzodiazepines.

Participants were administered a practice trial of the Four Mountains task before the main test which took about 10 minutes to complete. Participants were given written instructions for the Alternative Route (AR) paradigm and a demonstration before the main test which took about 24 minutes to complete.

### 2.2.1 Topographic memory (The Four Mountains Task, Hartley et al., 2007)

The Four Mountains memory task (Hartley et al., 2007) is a match-to-sample test of short term memory for the topographical aspects of visual scenes, which is considered to require allocentric processing (Hartley et al., 2002; Hartley & Harlow, 2012; Bird et al., 2010). The memory test comprised an A4 paper booklet of 15 separate computer-generated landscapes (the stimuli), each

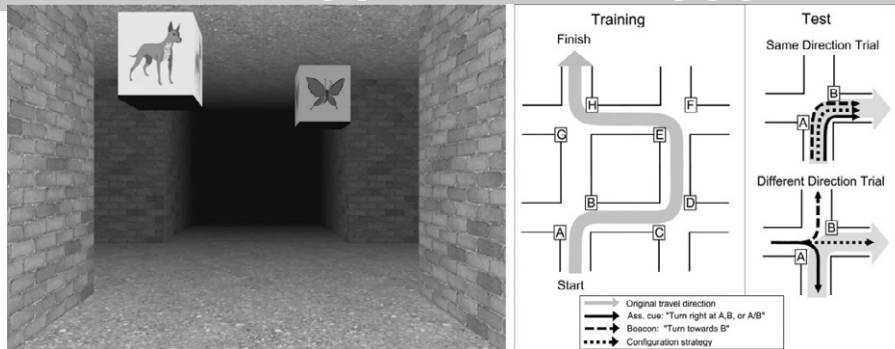
containing 4 mountains. Participants were presented with the original scene for 10s, followed by a blank page for 2s, and then a page with four alternative scenes arranged in a 2 x 2 grid. Three of those images were variations of the original scene, with its spatial and non-spatial features independently varied. A fourth image was the original scene but depicted from a different perspective (this is highlighted in black in Figure 1). The task was for the participant to identify, within 30 seconds, which of the four images was the original scene. This was repeated 15 times, and the total score was the number of trials out of the total fifteen in which the correct image was selected.



**Fig. 1.** Image extracted from the Four Mountain task (Hartley et al., 2007). The highlighted box indicates the correct answer (the original scene but depicted from a different perspective).

### 2.3.2 Active navigation paradigm (The Alternative Route, Wiener et al., 2013)

The Alternative Route (AR) paradigm (Wiener et al., 2013) is a route-learning paradigm designed to test allocentric and egocentric navigation performance and to identify the application of spatial processing strategies. Participants were taken on a route in a virtual environment, which they learned over a period of 24 minutes. During the 24 minutes, participants were regularly 'tested' on the route they were learning. The task was divided into six experimental blocks which consisted of a learning phase and a testing phase. During the learning phase, participants were trained by being transported twice through moving footage of a route which consist of four intersections. In the test phase, participants were asked to re-join the original route 12 times over. They were presented with intersections from the route and are asked to select in which direction they would turn at this test intersection in order to re-join the route. The order in which the trials was presented to each participant was random. As depicted in Figure 2, intersections along the route were characterized by two unique landmarks located in diagonally opposite corners, unambiguously identifying the intersection as well as the direction from which it was approached. A black fog effect was used in the paradigm to ensure that only one intersection was visible to the participant at any one time. Participants received no feedback about the accuracy of their responses to prevent learning from feedback.



**Fig. 2:** Screen shot from the Alternative Route Paradigm (Wiener et al., 2013) with diagrams of the training route and test intersections. The large image on the left is a participants' view of the route. The second image is the training route. The final images on the right are tests (or trials), the upper image being of a same direction trial, and the lower being of a different direction trial.

Egocentric performance was measured by the percentage of trials in which intersections were approached from the *same direction* as during the learning phase (as illustrated in the top right image in Figure 2) which were correct. Allocentric performance was measured by the percentage of *different direction* trials which were correct (i.e., those approached from a different direction that was presented in the learning phase, and as illustrated in the bottom right image in Figure 2). Accuracy on egocentric trials and allocentric trials was calculated by block. A subset of the different direction trials (those which approached an intersection from a different side, but in the same order) allowed us to distinguish between three different navigation strategies: an egocentric 'beacon' strategy, an egocentric 'associative cue' strategy and an allocentric 'configural' strategy (Wiener et al., 2013). Participants used a beacon strategy when they moved towards a landmark to bring them closer to the goal. Participants used an associative cue strategy when they associated a directional turn with a certain landmark. Participants only used a configural strategy when they were able to spatially configure local cues to form a 'cognitive map' of the environment around them. The number of times an individual used each strategy was calculated by block (1 to 6) and as a mean overall score.

## 2.4 Statistical analysis

All statistical analyses were performed using SPSS version 22 (SPSS, IBM Corp. in Armonk, NY). Group comparisons using ANOVA were made between those with no self-reported trauma, those who reported trauma exposure without PTSD, and those with PTSD. Measures of performance comprised the total Four Mountains score and egocentric and allocentric performance and strategy use on the Alternative Route paradigm, by block and as a total overall score. Hierarchical regression analysis was used to assess the contribution of demographic and clinical variables to performance on the Four Mountains task (as was used in the study by Smith et al., 2015). Demographic and clinical factors were included in the analysis as covariates where there had been baseline differences (see below).

## RESULTS

### 3.1 Demographic and clinical data

Table 1 illustrates that there were significant group differences for all demographic and clinical variables, requiring each variable to be controlled for in subsequent analyses. The PTSD group were predominantly male, older, had more pain and sleep disturbance and were more likely to be taking SSRIs, benzodiazepines or opiates.



Table 1. Means (SDs) for demographic and clinical data.

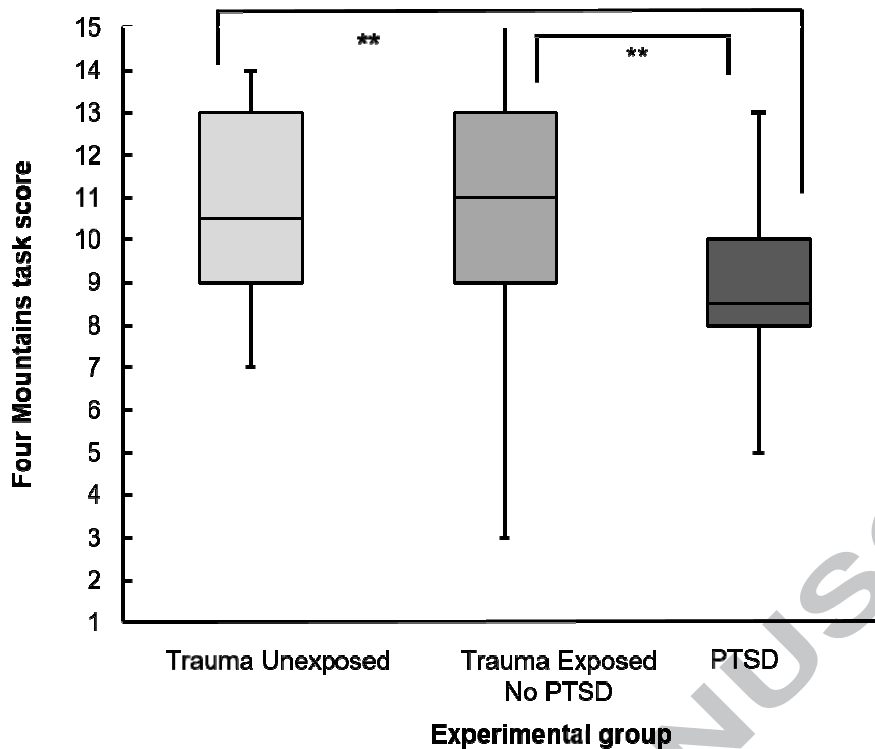
Demographic or clinical factor		Trauma Unexposed (n = 32)	Trauma Exposed No PTSD (n = 58)	PTSD (n = 47)	Group comparison
Mean age in years (± SD)		32.5 SD ± 10.4	38.9 SD ± 10.3	38.2 SD ± 9.6	$F(2, 135) = 4.61, p = 0.01^*$
Gender (%)	Male	36.4%	46.6%	78.7%	$\chi^2 = 17.0, p < .01^{**}$
	Female	63.6%	53.5%	21.3%	
Currently taking SSRIs (%)	No	100%	94.1%	71.1%	$\chi^2 = 17.7, p < .01^{**}$
	Yes	0%	5.9%	28.9%	
Currently taking Benzodiazepines or opiates (%)	No	100%	96.6%	72.3%	$\chi^2 = 20.7, p < .01^{**}$
	Yes	0%	3.5%	27.7%	
Sleep Disturbance: Mean PSQI score (± SD)		0.41 SD ± 1.5	1.02 SD ± 2.43	8.11 SD ± 6.17	$F(2, 135) = 50.3, p < .01^{**}$
Pain: Mean Numerical Rating Scale score (± SD)		0.42 SD ± 1.37	0.86 SD ± 1.94	3.15 SD ± 3.70	$F(2, 130) = 14.2, p < .01^{**}$
PTSD: Mean PTSD Diagnostic Scale score (± SD)		-	7.06 SD ± 6.62	35.3 SD ± 9.46	$F(1, 94) = 290, p < .01^{**}$

Note: one participant did not provide full demographic data, n = 137

### 3.2 Topographic memory (Four Mountains task)

A univariate ANOVA showed a significant main effect of group (*Trauma Unexposed*, *Trauma Exposed No PTSD* and *PTSD*) on topographical memory performance,  $F(2, 136) = 7.49, p < 0.01, \eta^2 = 15.0$ .

The mean Four Mountains score was 11.3 for the *Trauma Unexposed* group ( $n = 33, SD \pm 2.31$ ), 10.8 for the *Trauma Exposed No PTSD* Group ( $n = 58, SD \pm 2.47$ ) and 9.3 for the *PTSD* group ( $n = 47, SD \pm 2.25$ ). Post hoc tests (using Bonferroni) revealed a significant difference in performance between the *PTSD* group and both the *Trauma Exposed No PTSD* group, mean difference (MD) = -1.42,  $SD \pm 0.46, p < 0.01$ , and the *Trauma Unexposed* group, MD = -1.91,  $SD \pm 0.54, p < 0.01$ . There was no significant difference in performance between the *Trauma Exposed No PTSD* and the *Trauma Unexposed* group, MD = .491,  $SD \pm 0.52, p = 0.35$ . This suggests that PTSD had a significant impact on static topographical spatial processing but that trauma exposure alone did not.



**Fig. 3.** Box plot presenting the analysis of variance in the Four Mountains task scores by experimental group (*Trauma Unexposed*, *Trauma Exposed No PTSD* and *PTSD*) ( $n = 138$ ).

### 3.2.1 Clinical and demographic factors involved in topographic memory

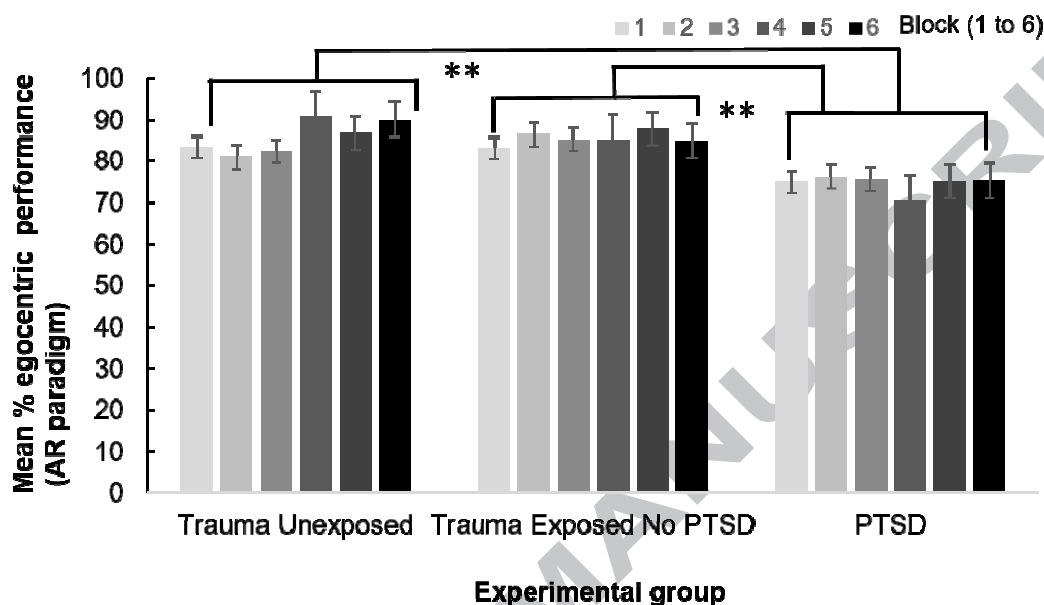
Age, gender, the taking of SSRIs, benzodiazepines and opiates, sleep disturbance score and pain score were entered into a hierarchical regression at step 1. Group (*Trauma Unexposed*, *Trauma Exposed No PTSD* and *PTSD*) was entered at step 2, with the Four Mountains score as the dependent variable. At step 1, the clinical and demographic variables did not explain a significant amount of variance,  $F(6, 130) = 0.66$ ,  $p = 0.68$ ,  $r^2 = 0.03$ , Adjusted  $r^2 = -0.15$ . At the second step, group accounted for a significant proportion of the variance,  $F(7, 129) = 2.87$ ,  $p < 0.01$ ,  $r^2 = 0.14$ , adjusted  $r^2 = 0.09$ , suggesting that PTSD differed from other variables in its impact on performance. In the final equation, only group provided a unique contribution,  $b(-1.36) = -4.06$ ,  $p < 0.01$ , confirming the impact of PTSD on topographical memory in the static spatial processing task.

## 3.3 Active navigation

### 3.3.1 Egocentric navigation performance

Egocentric navigation performance (mean percentage of *same direction* trial correctness) was compared between the groups (*Trauma Unexposed*, *Trauma Exposed No PTSD*, *PTSD*) over each of the six experimental sessions (blocks) of the task. A repeated measures 3 x 6 ANOVA with the between factor *group* (*Trauma Unexposed*, *Trauma Exposed No PTSD*, *PTSD*) and the within factor *Block* revealed a significant main effect of *group*,  $F(2, 135) = 7.50$ ,  $p < 0.01$ ,  $\eta^2 = 0.94$ . Post hoc tests (using Bonferroni) demonstrated that the *PTSD* group performed significantly worse ( $M = 0.75$ ,  $SD \pm 0.02$ ) than both the *Trauma Unexposed* group ( $M = 0.86$ ,  $SD \pm 0.03$ , *PTSD* vs *Trauma Unexposed* group  $p < 0.01$ ) and the *Trauma Exposed No PTSD* group ( $M = 0.86$ ,  $SD \pm 0.02$ , *PTSD* vs *Trauma Exposed No PTSD* group,  $p < 0.01$ ). There was no significant difference between the *Trauma*

Exposed No PTSD group and the *Trauma Unexposed* group ( $p > 0.05$ ). There was no significant main effect of block,  $F(4.51, 135) = 0.53$ ,  $p = 0.74$ ,  $\eta^2 = 0.01$ . Overall percentage correct for block 1 was 81% ( $SD \pm 2.1\%$ ) which only increased to 83% at block 6 ( $SD \pm 2.1\%$ ). There was no significant interaction between block and group,  $F(9.03, 135) = 0.14$ ,  $p = 0.10$ ,  $\eta^2 = 0.41$ . This suggested that PTSD had a significant impact on egocentric navigation performance, but that trauma exposure alone did not.



**Fig. 4.** Mean (%) egocentric performance (mean percentage of *same direction* trial correctedness) in the AR paradigm by experimental group (*Trauma Unexposed*, *Trauma Exposed No PTSD*, *PTSD*) for different direction trials by block (1 to 6) ( $n = 138$ ) with error bars, \*\*  $p < 0.01$ .

### 3.3.2 Clinical and demographic factors involved in egocentric performance

Clinical and demographic factors were each entered as covariates in to the repeated measures  $3 \times 6$  ANOVA with a between factor of group (*Trauma Unexposed*, *Trauma Exposed No PTSD*, *PTSD*) and a within factor *Block*. There were no significant effects for: age,  $F(1,134) = 0.41$ ,  $p = 0.52$ ; gender,  $F(1,134) = 2.15$ ,  $p = 0.14$ ; the taking of anti-depressant SSRIs,  $F(1,134) = 0.30$ ,  $p = 0.59$  or of benzodiazepines or opiates,  $F(1,134) = 0.42$ ,  $p = 0.52$ ; pain,  $F(1,134) = 1.42$ ,  $p = 0.21$ ; or sleep disturbance,  $F(1,134) = 0.33$ ,  $p = 0.57$ . This suggested that the impact of PTSD on egocentric navigation performance is independent of other clinical or demographic factors.

### 3.3.3 Allocentric navigation performance

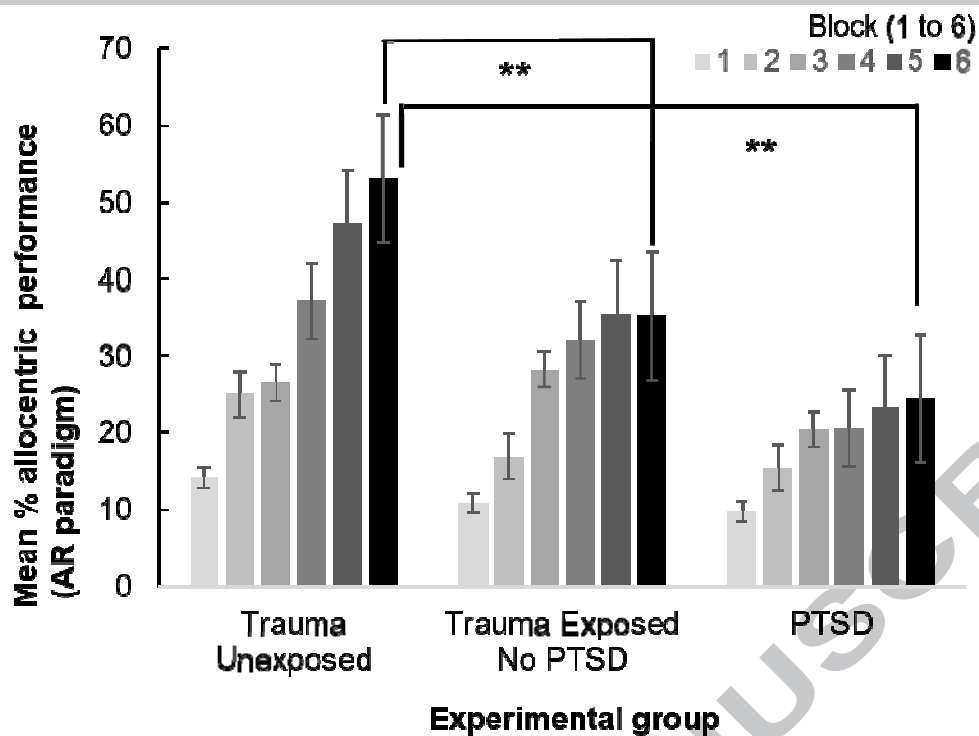
Allocentric navigation performance (mean % *different direction* trial accuracy) was compared between the experimental groups (*Trauma Unexposed*, *Trauma Exposed No PTSD*, *PTSD*) over each of the six experimental blocks. A repeated measures  $3 \times 6$  ANOVA with the between factor *group* (*Trauma Unexposed*, *Trauma Exposed No PTSD*, *PTSD*) and the within factor *Block* revealed a significant main effect of block,  $F(4.14, 135) = 32.5$ ,  $p < .01$ ,  $\eta^2 = 0.19$ . Performance increased over the experimental sessions (block 1 to 6), demonstrating an effect of learning in the task. Mean performance increased from 11.6% ( $SD \pm 1.9\%$ ) in block 1 to 37.6% ( $SD \pm 2.8\%$ ) in block 6. This

suggested that allocentric (hippocampal dependent) performance changed over the duration of the task.

There was a significant main effect of group,  $F(2, 135) = 4.23, p = 0.02, \eta^2 = 0.06$ . Pairwise comparisons (with Bonferroni correction) showed that the *PTSD* group performed significantly differently ( $M = 0.19, SD \pm 0.03$ ) to the *Trauma Unexposed* group ( $M = 0.34, SD \pm 0.04$ ) (*PTSD* vs *Trauma Unexposed*,  $p = 0.01$ ) but not to the *Trauma Exposed No PTSD* group. This suggested that PTSD had an impact on allocentric performance, and that performance was comparable to that of others with trauma exposure (without PTSD), but not to those with no experience of trauma exposure.

There was a significant group x block interaction,  $F(8.29, 135) = 2.84, p = 0.01, \eta^2 = 0.04$ , suggesting that group significantly affected allocentric learning in the navigation task. To explore the nature of this interaction between group and allocentric performance on route learning, post hoc t-tests were conducted. In Figure 5 allocentric performance (%mean correct on different direction trials) is presented as a function of group and block. The differences between the groups were not significant for all blocks, but for the final block.

In the first experimental block (Block 1), the *Trauma Exposed No PTSD* group did not perform significantly differently from the *Trauma Unexposed* group ( $p = 0.47$ ). There were no significant performance differences in Block 1 between the *PTSD* group and the *Trauma Exposed No PTSD* group ( $p = 0.8$ ), nor between the *PTSD* group and the *Trauma Unexposed* group ( $p = 0.37$ ). However, in the last experimental block (Block 6), the *Trauma Exposed No PTSD* group ( $M = 0.35, SD \pm 0.30$ ) performed significantly worse than the *Trauma Unexposed* group ( $M = 0.53, SD \pm 0.33$ ) with a mean difference of  $-0.18, p = 0.01$ , as did *PTSD* group ( $M = 0.24, SD \pm 0.31$ ) to the *Trauma Unexposed* group ( $M = 0.53, SD \pm 0.34$ , mean difference  $-0.29, p < 0.01$ ). This suggests that when it came to allocentric performance outcomes in active navigation, the negative impact of trauma exposure was comparable to that of PTSD.



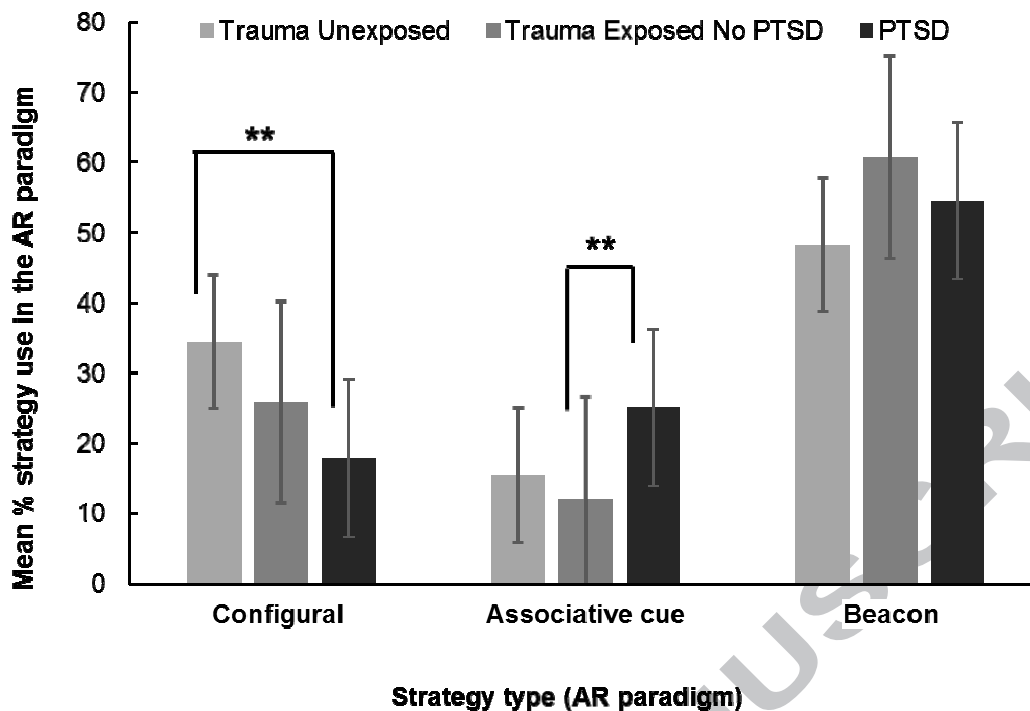
**Fig. 5.** Mean (%) allocentric performance in the AR paradigm by experimental group (Trauma Unexposed, Trauma Exposed No PTSD, PTSD) for different direction trials by block (1 to 6) ( $n = 138$ ) with error bars,  $**p < 0.01$ .

### 3.3.3 Clinical and demographic factors involved in allocentric performance

Clinical and demographic factors each entered as covariates in to the repeated measures 3 x 6 ANOVA between trauma groups as before, but with the within factor *Block*. Only pain (measured using the Numeric Rating Scale) had a significant main effect,  $F(1, 135) = 8.36$ ,  $p < 0.01$ ,  $\eta^2 = 0.06$ , contributing 2.7% to the variance in allocentric processing:  $b(-.027) = -2.07$ ,  $p = 0.04$ . This suggests that aside from pain, the impact of PTSD and trauma exposure on allocentric performance is unique.

### 3.4 Strategy use in active navigation

To assess group differences (*Trauma Unexposed*, *Trauma Exposed No PTSD*, *PTSD*) in strategy use, participants' responses were analysed at the intersections which were approached from a different side but in the same order as the route learned. The responses participants gave at these particular junctions predicted which strategy they were using to navigate the route, i.e. the associative, beacon or configural strategy. Mean percentage associative, beacon and configural strategy use of over the six blocks was then calculated and is presented at Figure 6.



**Fig.6.** Mean strategy use (configural, associative cue and beacon) overall in the AR paradigm between experimental group (*Trauma Unexposed*, *Trauma Exposed No PTSD*, *PTSD*) ( $n = 138$ ).

In the Alternative Route paradigm (Wiener et al., 2013), use of configural strategy is inextricably linked to allocentric performance. This is because trials approached from a different side but in the same order to the route which was learned can *only* be solved correctly by using an allocentric, configural strategy. The significant differences in configural strategy use overall between the *PTSD* group and the *Trauma Unexposed* group are likely due to the performance differences between these groups. Independent t-tests confirmed that overall configural strategy use was significantly higher in the *Trauma Unexposed* group ( $M = 0.34$ ,  $SD \pm 0.23$ ) than the *PTSD* group ( $M = 0.18$ ,  $SD \pm 0.22$ ),  $t(78) = 3.24$ ,  $p < 0.01$ . What is worthy of note is that there are no significant differences in configural strategy use between the *PTSD* group and the *Trauma Exposed No PTSD* group; pairwise comparisons showed a mean difference of  $-0.08$ ,  $SD \pm 0.05$ ,  $p = 0.24$ . This indicates that the impact of trauma exposure on configural strategy use here is independent of a probable or clinical diagnosis of PTSD.

Overall associative cue strategy use was significantly higher in the *PTSD* group ( $M = 0.25$ ,  $SD \pm 0.25$ ) than the *Trauma Exposed No PTSD* group ( $M = 0.12$ ,  $SD \pm 0.15$ ),  $t(103) = 3.23$ ,  $p < 0.01$ . This suggested that the contribution of an associative bias to navigation behaviour comes from clinical levels of PTSD and not trauma exposure alone.

### 3.5 Summary of findings

Those with PTSD performed significantly worse than healthy trauma exposed (*Trauma Exposed No PTSD*) in the topographical memory test (The Four Mountains) and this was independent of any clinical or demographic variables. This is consistent with findings by Smith et al. (2015) who demonstrated that PTSD influenced the combined perception and memory score of the Four

Mountains task, along with age. Our study introduced a sample of healthy participants who were unexposed to trauma (the *Trauma Unexposed Group*). We found that participants with PTSD were significantly impaired in the topographical memory test compared to this trauma unexposed group, and again, this was independent of any clinical or demographic variables. Performance on the topographical memory test did not differ between participants without PTSD but reporting trauma exposure and those reporting no trauma exposure (i.e. the *Trauma exposed No PTSD* and the *Trauma Unexposed* group).

Participants with PTSD performed significantly worse than the healthy unexposed (*Trauma Unexposed*) and healthy trauma exposed (*Trauma Exposed No PTSD*) groups in terms of both egocentric and allocentric performance on the Alternative Route paradigm. Impairment in active allocentric navigation in cases of PTSD was accompanied by an associative bias in the PTSD group. That is, participants with PTSD applied an associative cue strategy significantly more in active navigation than those who were trauma exposed without PTSD (*Trauma Exposed No PTSD*). The performance of the *Trauma Unexposed* and *Trauma Exposed No PTSD* groups did not differ in overall egocentric and allocentric performance on the Alternative Route task, but the *Trauma Exposed No PTSD* group exhibited significantly worse allocentric route learning performance than the those in the *Trauma Unexposed* group.

## 4 DISCUSSION

### 4.1 PTSD, navigation impairment and associative bias

This study showed for the first time that PTSD impairs actual active egocentric and allocentric navigation and this extends findings by Smith et al. (2015) which showed that PTSD impaired allocentric performance in object location. In this study, we also determined that the contribution of PTSD to allocentric and egocentric performance deficits in active navigation was unique.

The results of this study also demonstrate for the first time an associative information processing bias being applied to navigation in cases of PTSD; a bias which is well-recognised in clinical trauma literature (Lang, 1977; Erwin, 2003; Maren, 2008, Steel et al., 2005). The associative bias in PTSD in this study interferes with individuals' capacity to apply allocentric spatial processing to hippocampal dependent navigation tasks. This relationship between unprocessed trauma and impairment in allocentric spatial processing substantiates an increasing evidence base that hippocampal dependent trauma and spatial processing are related (Bisby et al., 2010; Brewin & Burgess, 2014; Smith et al., 2015; Tempesta et al., 2012; Ferrara et al., 2016; Kaur et al., 2016). What is more, these findings raise questions as to what other areas of cognition and everyday behaviour may be affected by this associative bias.

### 4.2 Trauma exposure in healthy individuals

In the current study healthy trauma exposed participants exhibited poor allocentric performance on a virtual active navigation task. Their performance was significantly worse than those of trauma unexposed individuals and yet was comparable to those with PTSD. Their use of the allocentric strategy was also comparable to those with clinical levels of PTSD.

Given that performance in more simple static spatial processing task did not differ between trauma exposed and unexposed participants, this raises the question of whether performance on simple static

spatial assessments may mask more serious performance deficits in active hippocampal-dependent navigation.

Findings from this research highlight the importance of differentiating between healthy trauma unexposed individuals, healthy trauma exposed individuals, and individuals with PTSD when considering navigation performance and assessment. This will be particularly relevant to navigation tasks considered to be hippocampal-dependent, such as mentally constructing and then using 'cognitive maps' of an environment (including floor plans, road layouts or larger terrains). These navigation activities may be significantly compromised by trauma exposure alone, not just PTSD. When trauma impact is at probable or clinical levels, navigation impairments are likely to be more profound, accompanied by an associative bias, and can extend to non-hippocampal dependent (egocentric) navigation, such as using landmarks, and learning routes using sets of directions.

#### **4.3 Theoretical considerations**

Somewhat contrary to recent studies in -and theories of- PTSD (e.g. Brewin et al., 1996; Bisby et al., 2010, etc.) this study suggests that healthy individuals (without PTSD) who have had previous trauma exposure may *not* always be able to apply allocentric processing sufficiently in hippocampal dependent navigation. To understand this better, one could return to earlier theory which made reference to memory representations 'competing' with other demands on the hippocampus to access resources in the hippocampus which are needed to retrieve and encode them (Brewin, 2006). Dual Representation Theory (DRT) has since been developed (Bisby et al., 2010) and DRT identified these resources as being hippocampal (and allocentric) in nature. So, to apply these concepts to our study, a reasonable explanation for hippocampal dependent processing deficits after trauma exposure may be that individuals have simply 'used up' (or are still using up) some hippocampal resources to contextualise their experiences.

This explanation is consistent with findings from other non-PTSD studies that have investigated the relationship between modulation of hippocampal resources and stress (Schwabe et al., 2008; Conrad et al., 2006), down-regulation of the hippocampus in response to negative emotions (Bisby & Burgess, 2016) and hippocampal impairment and intrusive imagery (Bisby et al., 2010; Meyer et al., 2012). These studies demonstrated impairments in aspects of hippocampal functionality in the absence of current clinical levels of PTSD. Recent *in vivo* physiological research with rodents (Tomar et al., 2015) has shown that repeated stress has a dynamic impact on hippocampal dependent spatial processing in that while hippocampal neuronal excitability may subside over time, the capacity to contextualise spatial information (using the hippocampus) may continue to be compromised.

#### **4.4 Spatial processing in trauma assessment and trauma interventions**

This study has shown that hippocampal-dependent active navigation assessments (such as the Alternative Route paradigm) are sensitive to trauma-related performance impairments in healthy individuals. Such assessment tools may be particularly valuable to occupations which demand competence in 'situational awareness' under stressful conditions, such as emergency response and the military (MOD, 2014, 2016).



The finding in this study that trauma exposure may impair hippocampal dependent spatial processing may have relevance beyond navigation. Trauma literature advocates improving individuals' hippocampal-dependent (allocentric) spatial processing to assist the contextualisation of trauma memories in therapy (Smith et al., 2015; Bisby et al. 2010; Steel, 2005; Neuner, 2008; Mclsaac & Eich, 2004; Miller & Wiener, 2014). This has been tested with a small clinical case study in which two combat veterans who were trained to apply allocentric spatial processing techniques in PTSD therapy demonstrated decreased PTSD symptomology as a result (Kaur et al., 2016).

Our study now presents a case for supporting healthy individuals (i.e. those without probable or clinical levels of PTSD) in the active processing of their experiences to minimise the negative impact that trauma may have on their cognition and behaviour. Applying hippocampal dependent (allocentric) spatial processing techniques may well complement existing trauma intervention occupational practices well, such as Trauma Risk Management (TRiM, Greenberg et al., 2015). What is more, recent findings of this study and others (e.g. Smith et al., 2015; Kaur et al., 2016, etc) suggest that applying these techniques might not only help to maximise hippocampal functionality in navigation in healthy individuals but may also increase their resilience to the longer term impact of unprocessed trauma.

## 5 Limitations

It is important to acknowledge that the sampling strategy of this study may have introduced bias. When recruiting individuals who self-report trauma exposure or PTSD the range of potential environmental conditions of that trauma are not controlled for- and they may be extensive, including the timing, nature and duration of exposure and previous access to treatment (e.g. Breslau et al., 2012; Brewin et al., 2000). A further consideration is the demographic profile of the veteran PTSD population, about whom much research has revealed influential environmental factors including childhood adversity, the specific nature of combat exposure, and more restricted access to trauma processing interventions during active service (Bremner et al., 1993; Mac Manus et al., 2014). The homogeneity or diversity of military and civilian populations has been shown to be of critical value to PTSD research (Zhang et al., 2014) and is something which should not be overlooked.

## CONCLUSION

The findings from this highlight the importance of detecting potentially dynamic trauma-related impairment in healthy individuals and reveals that PTSD-related associative bias may affect other areas of cognition and behaviour. A final suggestion is that future neuropsychological research considers *other* influences over hippocampal integrity which may influence how resources are accessed for spatial processing under traumatic conditions, such as genetically determined activity-dependent plasticity (see: Miller & Wiener, 2014; Zhang et al., 2014; Lovden et al., 2012; Banner et al., 2012). Further research to better understand the complex nature of trauma resilience remains valuable in a modern world which faces increasingly new challenges and threats to our sense of safety and of our right to protect it.

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ACCEPTED MANUSCRIPT

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## Highlights

- PTSD brings an 'associative bias' to active navigation behaviour
- PTSD impairs spatial processing and both egocentric and allocentric navigation

- Trauma exposure in healthy participants without PTSD impairs active allocentric navigation
- Findings have clear implications for trauma processing interventions
- Findings have clear implications for navigation performance assessment

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