Psychological Medicine

cambridge.org/psm

Review Article

Cite this article: Lazarov A, Suarez-Jimenez B, Tamman A, Falzon L, Zhu X, Edmondson DE, Neria Y (2019). Attention to threat in posttraumatic stress disorder as indexed by eye-tracking indices: a systematic review. *Psychological Medicine* **49**, 705–726. https://doi.org/10.1017/S0033291718002313

Received: 31 May 2018
Revised: 26 July 2018
Accepted: 7 August 2018
First published online: 4 September 2018

Key words:
Attention bias; eye-tracking; posttraumatic stress disorder; systematic review; trauma exposure

Author for correspondence:
Amit Lazarov, E-mail: al3676@cumc.columbia.edu

Attention to threat in posttraumatic stress disorder as indexed by eye-tracking indices: a systematic review

Amit Lazarov[1,2], Benjamin Suarez-Jimenez[1], Amanda Tamman[3], Louise Falzon[4], Xi Zhu[1], Donald E. Edmondson[4] and Yuval Neria[1]

[1]Department of Psychiatry, Columbia University Medical Center, New York Psychiatric Institute, New York, NY, USA; [2]School of Psychological Sciences, Tel Aviv University, Tel-Aviv, Israel; [3]New York Psychiatric Institute, New York, NY, USA and [4]Department of Medicine, Columbia University Medical Center, New York, NY, USA

Abstract

Background. Cognitive models of posttraumatic stress disorder (PTSD) implicate threat-related attentional biases in the etiology and phenomenology of the disorder. However, extant attentional research using reaction time (RT)-based paradigms and measures has yielded mixed results. Eye-tracking methodology has emerged in recent years to overcome several inherent drawbacks of RT-based tasks, striving to better delineate attentional processes.
Methods. A systematic review of experimental studies examining threat-related attention biases in PTSD, using eye-tracking methodology and group-comparison designs, was conducted conforming to Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) guidelines. Studies were selected following a systematic search for publications between 1980 and December 2017 in PsycINFO, MEDLINE and the National Center for PTSD Research's Published International Literature on Traumatic Stress (PILOTS) database. Additional records were identified by employing the Similar Articles feature in PubMed, and the Cited Reference Search in ISI Web of Science. Reference sections of review articles, book chapters and studies selected for inclusion were searched for further studies. Ongoing studies were also sought through Clinicaltrials.gov.
Results. A total of 11 studies ($n = 456$ participants in total) were included in the final review. Results indicated little support for enhanced threat detection, hypervigilance and attentional avoidance. However, consistent evidence emerged for sustained attention on threat (i.e. attention maintenance) in PTSD.
Conclusions. This review is the first to systematically evaluate extant findings in PTSD emanating from eye-tracking studies employing group-comparison designs. Results suggest that sustained attention on threat might serve as a potential target for therapeutic intervention.

Posttraumatic stress disorder (PTSD) is a debilitating disorder manifesting in a prolonged maladaptive response to traumatic events. While several psychotherapies and pharmacotherapies have been developed for PTSD, research has consistently shown that more than one-third of patients never fully remit, even if treated (Difede *et al*., 2014). A multidimensional meta-analysis of psychotherapies for PTSD has found only short-term improvements in about 50% of patients following treatment, with most patients continuing to show substantial residual symptoms post-treatment (Bradley *et al*., 2005). A critical lack of advancement was noted also for pharmacotherapy, with only 20–30% of patients achieving complete remission (Krystal *et al*., 2017). Thus, an acute need to identify new targets for therapeutic interventions arise, hoping that these might serve as the basis for developing alternative or augmenting treatments for PTSD (Difede *et al*., 2014). Threat-related attentional biases, defined as the heightened tendency to allocate attentional resources to threatening stimuli in the environment (Bar-Haim *et al*., 2007), have been proposed as one such potential target in PTSD (Armstrong and Olatunji, 2012). Indeed, cognitive models for PTSD have implicated several faulty cognitive processes in the disorder (Buckley *et al*., 2000; Brewin and Holmes, 2003), including biased attentional processes of trauma-related information (Chemtob *et al*., 1988; Foa *et al*., 1989; Litz and Keane, 1989; Ehlers and Clark, 2000; Aupperle *et al*., 2012).

To date, research examining threat-related attentional biases in PTSD has relied mostly on reaction time (RT)-based tasks and measures (In-Albon and Schneider, 2010), in which attention bias to threat is inferred from facilitated or interfered performance (i.e. changes in RT) due to the presence of threatening stimuli. For example, in the emotional Stroop task (Williams *et al*., 1996), threatening and non-threatening words are paired along with a color (the word or its background), and participants are asked to name that color while ignoring its semantic meaning. Threat-related attention bias is inferred when participants are slower in naming the color of threatening words compared with non-threatening words. In the dot-probe task (MacLeod *et al*., 1986), threatening stimuli, usually words or facial expressions, are presented simultaneously alongside neutral stimuli, and their removal is followed by a small probe appearing at the location just occupied by one of these stimuli. Participants must determine as fast as possible between two variants of the probe (e.g. 'E' or 'F') which appear with equal probability at the location previously occupied by the threat or neutral stimuli. Threat-related attention bias is revealed when participants are faster to respond to probes replacing threat rather than neutral stimuli. Several advantages of these tasks have contributed to their wide dissemination and extensive usage over the years. They require simple hardware (usually a laptop or a desktop computer) and software, making them cost-effective and accessible for researchers, and easily understood and operated by participants. These advantages are further heightened when considering treatment protocols designed to modify attention biases (i.e. attention bias modification (ABM) procedures), as these can be easily delivered to a wide range of patients. In addition, as ABM procedures can be also delivered remotely, via web-based protocols, they minimize the need for in-person contact, thus enabling treating potential patients that have no access to other forms of mental health services (Bar-Haim, 2010).

While advancing our knowledge in the field, extant studies using RT-based tasks have yielded mixed results in PTSD. For the emotional Stroop task, some studies have shown biased attention towards threat (McNally *et al.*, 1990; Foa *et al.*, 1991; Cassiday *et al.*, 1992; Kaspi *et al.*, 1995; Harvey *et al.*, 1996; Beck *et al.*, 2001; Ashley *et al.*, 2013; Martinson *et al.*, 2013), while others revealed attention bias away from threat or lack of differences between trauma-exposed healthy participants (TEHC) and patients with PTSD (McNally *et al.*, 1996; Freeman and Beck, 2000; Shin *et al.*, 2001; Bremner *et al.*, 2004; Constans *et al.*, 2004; Devineni *et al.*, 2004; Reid *et al.*, 2011). One meta-analysis concluded that the Stroop effect in PTSD is extremely weak or subtle, if exists at all (Kimble *et al.*, 2009), while a second more recent one concluded that while PTSD patients do differ from healthy controls on the task, they do not differ from TEHC participants (Cisler *et al.*, 2011). Similar equivocal conclusions also emerge for the dot-probe task, with some evidence suggesting biased attention toward threat (Dalgleish *et al.*, 2001; Bardeen and Orcutt, 2011; Fani *et al.*, 2012*b*), some suggesting an association between PTSD and bias away from threat (Bar-Haim *et al.*, 2010; Fani *et al.*, 2011; Sipos *et al.*, 2014), some finding no attention bias in PTSD (Fani *et al.*, 2012*a*; Schoorl *et al.*, 2013; Iacoviello *et al.*, 2014), and some implicating an enhanced tendency for attention to fluctuate between threat vigilance and threat avoidance (Iacoviello *et al.*, 2014; Naim *et al.*, 2015). Thus, while theoretical thinking and laboratory research assert that threat-related attentional biases are important in PTSD, these mixed findings have slowed progress in converting the understandings of attention biases into novel intervention targets for PTSD.

Below we argue that several inherent weaknesses of RT-based tasks and measures might contribute to this state of affairs, and offer eye-tracking as an alternative strategy for assessing attention processes, potentially offering more precise targets for intervention. We then discuss the results of a systematic review of the literature on threat-related attentional biases in PTSD using eye-tracking methodology, and offer suggestions for best practices and next steps for researchers in the field.

The first disadvantage of RT-based tasks is their limited ability to capture the complexity of attention processes and to easily distinguish between the different aspects of attention (Weierich *et al.*, 2008; Felmingham *et al.*, 2011; Armstrong *et al.*, 2013), such as facilitated threat detection, difficulty disengaging attention from threat, and attentional threat avoidance (Weierich *et al.*, 2008; Cisler and Koster, 2010). *Facilitated threat detection,* or *threat vigilance*, is defined as the ease or speed in which threat is detected, as attention is preferentially drawn to threatening stimuli in the environment. *Difficulty disengaging attention from threat* refers to the degree to which attention is held by a threatening stimulus, once detected, due to difficulty in diverting attention away from it. Finally, *attentional threat avoidance* is the tendency to preferentially allocate attention away from threatening stimuli, as if to intentionally avoid threatening information altogether (Cisler and Koster, 2010). While seemingly different, these aspects of attention are not mutually exclusive, and might operate at different stages of information processing (Weierich *et al.*, 2008). For example, individuals with PTSD may display facilitated threat detection at early stages of visual processing, followed by difficulty disengaging attention once threat has been detected, and finally, exhibit avoidance at later, more strategic stages of processing (Mogg *et al.*, 1997; Cisler and Koster, 2010). However, as RT-based measures of attention are derived from keypresses occurring at the end of the information processing course they inevitably involve an inherent temporal distance between the behavioral output (i.e. key presses) and the examined attentional components taking place earlier in the process. Thus, attentional processes are only measured indirectly, inferred from facilitated or interfered performance measured at the end of the process (Kimble *et al.*, 2010; Lee and Lee, 2012; Thomas *et al.*, 2013), providing no information about the course of attention deployment before or after the moment of measurement (Hermans *et al.*, 1999; Bar-Haim *et al.*, 2007; Bar-Haim, 2010; In-Albon and Schneider, 2010; Yiend, 2010; Felmingham *et al.*, 2011; Armstrong and Olatunji, 2012; Shechner *et al.*, 2013; Thomas *et al.*, 2013; Lazarov *et al.*, 2016; Price *et al.*, 2016; Lazarov *et al.*, 2017*b*). In addition, due to their 'snapshot' nature, RT-based tasks are limited in their ability to differentiate the different aspects of attention, especially within single trials, and to accurately describe the dynamic and ongoing process of attention as it unfolds and changes over time (Lee and Lee, 2012; Thomas *et al.*, 2013). Indeed, it has been suggested that the Stroop effect may index difficulty in threat-disengagement, or even avoidance of processing aversive information, rather than vigilance or attention toward threat (De Ruiter and Brosschot, 1994; Fox, 1994; 2004; Hermans *et al.*, 1999; Tolin *et al.*, 1999; Mogg and Bradley, 2004; In-Albon and Schneider, 2010; Thomas *et al.*, 2013), with similar claims raised also for the dot-probe task (Fox *et al.*, 2001; Bar-Haim *et al.*, 2007; Weierich *et al.*, 2008; Felmingham *et al.*, 2011). Consequently, it remains less clear which attentional mechanisms are driving observed results on these tasks, which is crucial in providing valuable insights into the maintenance of symptoms and in clarifying novel specific targets for therapeutic intervention (Armstrong *et al.*, 2013).

Two additional disadvantages of RT-based tasks further highlight the need to find new and improved paradigms capable of assessing, and subsequently modifying threat-related attentional biases. First, RT-based tasks suffer from poor psychometric properties including low internal consistency and test-retest reliability, as well as poor convergent and ecological validity (In-Albon and Schneider, 2010; Rodebaugh *et al.*, 2016). Low test-retest reliability and minimal convergent validity were found for the Stroop (Eide *et al.*, 2002; Strauss *et al.*, 2005) and for the dot-probe tasks (Schmukle, 2005; Staugaard, 2009; Waechter *et al.*, 2014;

https://doi.org/10.1017/S0033291718002313 Published online by Cambridge University Press

Waechter and Stolz, 2015). Importantly, the observed low reliability of RT-based tasks is an inevitable consequence of deriving attention bias scores from differences in the RTs of two highly correlated conditions (e.g. response time to probes that replace threat and neutral stimuli in the dot-probe task). Subtracting highly-correlated components inescapably leads to a low-reliability composite, even when each separate component, in itself, demonstrates high reliability (Sipos *et al.*, 2014; McNally, 2018). Indeed, while RT components of the dot-probe task are usually found to be highly reliable (Waechter *et al.*, 2014) they are also highly correlated (Sipos *et al.*, 2014), rendering it extremely difficult for the RT-based attentional indices to achieve even modest reliability (McNally, 2018). Second, as RT-based tasks rely on keypresses as indices of attention, they give rise to potential confounding elements related to the execution of the motor responses (i.e. key-presses), possibly obscuring the interpretation of obtained results (In-Albon and Schneider, 2010; Kimble *et al.*, 2010; Armstrong and Olatunji, 2012; Thomas *et al.*, 2013; Price *et al.*, 2016).

An alternative approach for assessing attentional biases, eye-tracking methodology, has emerged in attention research to overcome the above-mentioned shortcomings of RT-based tasks. Eye-tracking is a non-invasive method that continuously samples gaze data at different rates (ranging from 60 to 2000 Hz). Using eye-tracking measures to indicate attentional processes is based on the assumption that the individual's overt eye movements and direction of gaze highly correspond with the visual attention allocation deployed over time (Just and Carpenter, 1976; Wright and Ward, 2008; In-Albon and Schneider, 2010). While deployment of visual attention allocation can also occur via covert attention, with no overt gaze shifting, in naturalistic viewing overt eye-movements are considered to be a primary source for attention selection, to follow closely covert attention and to be directed by it, and are regarded as a necessary mediator for the effects of covert attention (Kowler *et al.*, 1995; Hayhoe and Ballard, 2005; Armstrong and Olatunji, 2012). Furthermore, research has shown that the eye movement system plays a vital role in covert attention, with common mechanisms underlying both overt and covert attention orienting (Smith *et al.*, 2004). Finally, the relation between covert attention and overt eye movements is considered much closer than the one between covert attention and manual responses, such as those used in RT-based tasks (Armstrong and Olatunji, 2012).

In eye-tracking research, all facets of eye-data (e.g. saccades, fixations, and pupillometry) are recorded, analyzed, and later interpreted to characterize attentional patterns. *Fixations*, defined as the time periods between eye-movements when the eye stops at a certain position and visual information is encoded, reflects maintenance of gaze on an object of interest. *Saccades*, defined as fast movements of the eye, are considered manifestations of changing the focus of attention. *Scan-path* usually refers to the resulting series of saccades reflecting stimulus scanning (Duchowski, 2007), and is typically measured in terms of saccade/fixation count, saccade duration or overall scan-path length (Stewart, 2012; Kimble *et al.*, 2014). *Pupillometry*, the measurement of pupil size and reactivity, allows continuous measurements of involuntary physiological reactions and autonomic activity (i.e. arousal) that is intimately related to emotional states (Cascardi *et al.*, 2015). These various measures are then used to describe differences in gaze-related behavior reflecting different attentional processes and biases.

Free-viewing, one of the most widely used eye-tracking paradigms in visual attention research, can help illustrate this process. In free-viewing tasks, participants are requested to freely view arrays of stimuli without any specific requirements or demands. Attentional measures and processes are then deduced from the recorded eye-data (see Fig. 1 for a schematic timeline of stimulus presentation and the inferred attentional measures). *Facilitated/biased threat detection* can be determined by examining the location and the latency of initial eye movements occurring immediately after stimulus onset, namely, first fixations. A greater proportion of first fixations on threat compared with neutral stimuli, or shorter latencies to first fixate on threat compared with neutral stimuli, are considered evidence of facilitated threat detection (Felmingham *et al.*, 2011; Armstrong *et al.*, 2013). Likewise, while less common, scan-path variables are sometimes used to reflect *hypervigilance behavior* occurring when scanning different stimuli, which might enhance threat detection (Stewart, 2012; Kimble *et al.*, 2014). These include saccades/fixations count, saccade duration/length or number of revisits to predefined areas of the displayed stimulus, usually measured throughout stimuli presentation duration. Pupillometry measures can be also used to examine hypervigilance (Cascardi *et al.*, 2015). *Difficulty disengaging attention from threat* is usually indicated by measuring fixation duration (i.e. dwell time). When computed for initial fixations, increased dwell time on threat compared with neutral stimuli signals difficulty in *initial attention disengagement*. When accumulating the durations of all fixations made on threat compared with neutral stimuli during stimulus presentation (i.e. total dwell time), increased dwell time usually reflects *sustained attention* or *maintenance of attention* on threat (Armstrong and Olatunji, 2012; Armstrong *et al.*, 2013). Alternatively, though less common, total fixation count may be also used to indicate sustained attention, although total fixation count and dwell time are usually highly correlated (Waechter *et al.*, 2014). Importantly, sustained attention on threat usually refers to threats that have already been detected and are known to exist in the environment (i.e. an initial fixation on threat has already occurred; Armstrong *et al.*, 2013), and as such provide vital information that is not accessible by RT-based tasks. Lastly, total dwell time can also be computed separately for consecutive time intervals to reflect changes in attention deployment over time (i.e. time course analysis). Reduction in total dwell time on threatening stimuli across time intervals is used to indicate *attentional threat avoidance*. For example, for a presentation duration of 6 s (second), dwell time can be computed separately for three 2-s intervals, with a reduction in total dwell time on threat across intervals indicating avoidance. A second less common measure of attentional avoidance is the location or dwell time of second fixations that follow an initial fixation on threat (Kimble *et al.*, 2010; Felmingham *et al.*, 2011).

Another example of a widely-used eye-tracking-based paradigm in attentional research is that of visual search (Armstrong and Olatunji, 2012). In this paradigm, eye-movements are recorded while participants are engaged in an active search for a target embedded among an array of distractors. *Facilitated/biased threat detection* is usually examined in trials in which the target is a threatening stimulus with non-threatening stimuli used as distractors. Latency to fixating on the threat target (Miltner *et al.*, 2004; Rinck *et al.*, 2005; Huijding *et al.*, 2011), as well as number of fixations 'needed' to detect it (Ohman *et al.*, 2001), can be used to reflect facilitated threat detection. Conversely, *difficulty disengaging attention from threat* is usually examined using a neutral target situated within an array of threatening stimuli or an array of neutral stimuli with one threat

https://doi.org/10.1017/S0033291718002313 Published online by Cambridge University Press

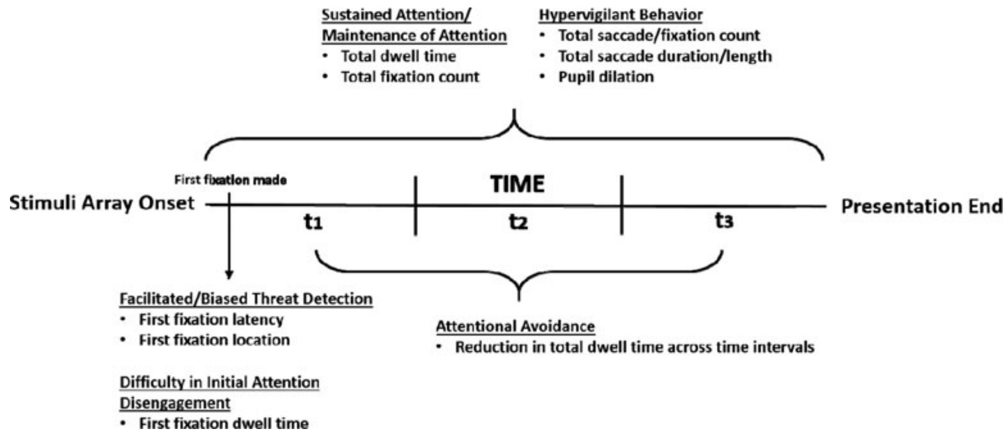

Fig. 1. Schematic timeline of stimulus presentation and the inferred attentional measures.

stimulus (Armstrong and Olatunji, 2012). Attention bias is reflected by the detrimental effects of threat distractors on eye-movement in searching for the neutral target (Rinck *et al.*, 2005; Gerdes *et al.*, 2008; Derakshan and Koster, 2010). However, as we will shortly describe, no eye-tracking attentional study to date has used the visual search paradigm in patients with PTSD.

Importantly, the extracted eye-tracking-based indices of attention described above can be then used to reflect different aspects of PTSD phenomenology. For example, facilitated threat detection and hypervigilant scanning of stimuli could be used to reflect hypervigilance (Kimble *et al.*, 2010), a widely-reported symptom of PTSD defined as 'a state of heightened alertness or watchfulness' (American Psychiatric Association, 2013). Sustained attention could be related to the ruminative quality of PTSD, shown to predict and maintain PTSD (Michael *et al.*, 2007), and to the 'persistent negative emotional state' symptom recently introduced in the fifth edition of the Diagnostic and Statistical Manual of Mental Disorders (DSM-5; American Psychiatric Association, 2013). Finally, indices of attentional avoidance could be used to reflect symptoms of Cluster C, namely, persistent avoidance of stimuli associated with the traumatic event.

Several significant features of eye-tracking methodology make it less inherently constrained by the limitations of RT-based tasks and hence potentially better suited for assessing attentional processes and biases (In-Albon and Schneider, 2010; Armstrong and Olatunji, 2012). First, eye tracking provides a more direct measure of attention. Eye movements are recorded continuously over time, allowing for an improved delineation of the time course and the different components of the attentional processes (Armstrong and Olatunji, 2012; Lazarov *et al.*, 2016). Second, continuous recording can increase the efficacy of research as some attentional components can be assessed within a single trial (e.g. enhanced threat detection, sustained attention and later threat avoidance) while also providing different parameters for each element (e.g. first fixation latency and location as measures of threat vigilance), thus reducing the need for multiple repetitive trials/conditions to examine single attentional components (Armstrong and Olatunji, 2012). Third, eye-tracking can eliminate confounding elements due to motor responses, as none are required, especially in free-viewing paradigms (Kimble *et al.*, 2010; Armstrong and Olatunji, 2012). Fourth, eye-tracking psychometrics, including test-retest reliability and internal consistency are more established (In-Albon and Schneider, 2010; Skinner *et al.*, 2017), albeit, recent research has indicated that high reliability is more characteristic of eye-tracking indices computed over long presentation duration (i.e. sustained attention measures) and less for early stage-indices of attentional biases such as first fixation measures reflecting threat vigilance (Waechter *et al.*, 2014; Lazarov *et al.*, 2016; Skinner *et al.*, 2017; Wermes *et al.*, 2017; Lazarov *et al.*, 2018). High ecological validity is also achieved as people typically look at the stimuli they attend to, especially in free-viewing tasks in which no specific requirements exist (Kimble *et al.*, 2010; Lazarov *et al.*, 2016). Finally, eye-tracking-based procedures designed to modify threat-related attentional biases have been found to be perceived as more pleasant and acceptable by participants, resulting in lower dropped-out rates during training (Lazarov *et al.*, 2017*b*).

Despite these advantages, eye-tracking methodology also has some limitations that need to be acknowledged (In-Albon and Schneider, 2010; Armstrong and Olatunji, 2012). First, as mentioned earlier, eye-tracking cannot track covert movement of visual attention, which can be dissociated from direction of gaze. Put differently, attention can shift covertly even when gaze is fixed at a certain location (Posner, 1980; Egeth and Yantis, 1997). This has been specifically emphasized regarding sustained attention, which might occur covertly prior to overt first fixations (Armstrong and Olatunji, 2012). Second, eye-tracking technology is still relatively expansive, less accessible, and cannot be readily used remotely. Finally, while the psychometric properties of eye-tracking are more established compared with RT-based tasks, psychometric research of eye-tracking methodology in attentional research is still in its early stages, and as such necessitates additional research, using different paradigms and different populations, to reach a more definitive conclusion (In-Albon and Schneider, 2010; Skinner *et al.*, 2017). Still, research explicitly examining the psychometric properties of RT- and eye-tracking-based attentional tasks and indices has clearly demonstrated the superiority of the latter (Waechter *et al.*, 2014; Price *et al.*, 2015; Skinner *et al.*, 2017). In sum, while eye-tracking does entail some limitations, we believe that the advantages of using eye-tracking methodology in attentional research outweigh its shortcomings, a premise that motivated the current review.

Here, we systematically reviewed all experimental studies of threat-related attentional biases in PTSD that used eye-tracking methodology. Our goal was to determine whether individuals with high levels of PTSD symptoms (i.e. sub-clinical and clinically diagnosed PTSD patients) demonstrate increased threat-related attentional biases compared with individuals low in PTSD symptoms (trauma-exposed as well as non-TEHC) to clarify mixed results of extant RT-based paradigms. Threat-related attention biases included: (a) facilitated threat detection, including hypervigilance; (b) difficulty disengaging attention from threat (initial disengagement) and sustained attention; and (c) attentional avoidance of threat. We also documented the effects of comparison group (i.e. subclinical *v.* diagnosed PTSD group and trauma exposed *v.* non-trauma-exposed healthy controls) and stimuli used to elicit attentional processes (i.e. stimuli type, valence, and threat-specificity).

Method

The systematic review protocol was registered in Prospero before undertaking the review (Lazarov *et al.*, 2017*a*), and this report conforms to PRISMA guidelines (Moher *et al.*, 2009).

Search strategy

Studies were selected following a systematic search for publications between 1980, when PTSD was first introduced in the DSM (American Psychiatric Association, 2013) and December 2017 in PsycINFO, MEDLINE and the National Center for PTSD Research's Published International Literature on Traumatic Stress (PILOTS) database. All relevant subject headings and free-text terms were used to represent PTSD and eye tracking in search strategies (see Supplemental material for copies of all search strategies). Additional records were identified by employing the Similar Articles feature in PubMed, and the Cited Reference Search in ISI Web of Science. Reference sections of review articles, book chapters and studies selected for inclusion were searched for further studies. Ongoing studies were also sought through Clinicaltrials.gov.

Search selection process

Titles and abstracts were independently screened by two reviewers (LF and AT) using the inclusion and exclusion criteria outlined below. Discrepancies were resolved by discussion between the two reviewers. Full articles were then independently screened by two reviewers (AL and AT). Inter-rater reliability was calculated, and where disagreements occurred, a consensus meeting was held to decide on study inclusion. Study selection process and reasons for exclusions are described in Fig. 2.

Study inclusion criteria were: (1) used eye-tracking methodology; (2) investigated post-traumatic symptoms using an accepted measure of PTSD or Acute Stress Disorder (ASD) or clinician diagnosis; (3) compared performance of at least two groups that differed on PTSD symptoms or diagnosis; (4) assessed attention to different emotional (i.e. negative, threatening, positive) and/or neutral stimuli – as standalone stimuli or in comparison with each other; and (5) the primary outcome measure was an attentional measure operationally defined using eye-data. Studies were excluded on the following grounds: (1) review article, case study, or book chapter; (2) clinically-relevant symptoms of PTSD were not used in defining study groups; (3) the PTSD group was not specifically identified; (4) lack of a non-PTSD control group; (5) the index trauma was a psychotic episode or participants had comorbid traumatic brain injury (TBI); (6) studies were not designed to examine threat-related attentional biases in PTSD; and (7) attention was not assessed using eye-tracking methodology.

Data extraction and assessment of study quality

Data extraction and quality assessment were undertaken by two reviewers (AT and AL) and checked by a third (BSJ) for errors. Study characteristics extracted from reviewed studies included: (1) clinical status of the PTSD group (clinical *v.* subclinical) and PTSD/ASD measures used to define PTSD; (2) comparison group (trauma-exposed healthy controls *v.* healthy controls); (3) trauma type ; (4) stimulus type used (faces, pictures, words), pictures refers to images of scenes or objects; (5) threat stimulus specificity (trauma-related, general negative/threat); (6) stimulus valence; (7) stimuli array size; (8) presentation duration; and (7) type of attentional variable examined.

Quality assessment was conducted independently by two reviewers (AL and AT) following a method recently employed in a systematic review of attention to threat in generalized anxiety disorder (GAD) involving similar experimental designs (Goodwin *et al.*, 2017). Accordingly, the following six quality domains were addressed based on the Q-Coh I and II (Jarde *et al.*, 2013) and the Effective Public Health Practice Project Quality Assessment Tool (Thomas *et al.*, 2004): selection bias, information bias, performance bias, attrition bias, representativeness, and statistical analysis. S*election bias* examined the inclusion criteria used, accounting for the confounding factors. *Information bias* measured whether studies used validated and reliable methods of assessment. Assessing information bias was done for the assessment of participants at recruitment (i.e. the measures that were used to assess PTSD symptomology and create the experimental groups) and for outcome measurement (i.e. the quality and characteristics of the eye-tracking apparatus used to record eye-data). *Performance bias* assessed whether the experimental procedure used in the study to examine attentional processes was appropriate. Finally, *attrition bias* assessed whether studies reported or accounted for dropouts/data loss. In *representativeness,* we considered whether the sample was selected from a group that is indeed representative of the population aimed by the study, and in the *statistical analysis,* we determined whether the statistics and conclusions were appropriate and checked whether null results were reported as well. As was done in by Goodwin *et al.* (2017), we emphasized the attention devoted to the study's design to control for relevant confounding variables in deciding studies' quality. Age as a confounding variable was considered key in quality assessment as research has clearly shown age-related changes in attention processes using RT-based tasks (Mather and Carstensen, 2005; Spaniol *et al.*, 2008) and eye-tracking methodology (Knight *et al.*, 2007; Nikitin and Freund, 2011; Isaacowitz and Choi, 2012). We also emphasized the clinical status of the PTSD group and sample size in deciding the study's quality. Finally, we considered the control group/s used (i.e. trauma-exposed, non-trauma-exposed) and the threat-specificity and emotion-valence of the stimuli employed in the study.

Results

Search results

Our initial search yielded 3475 potential records after removing one duplication (see Fig. 2 for the PRISMA flowchart of paper

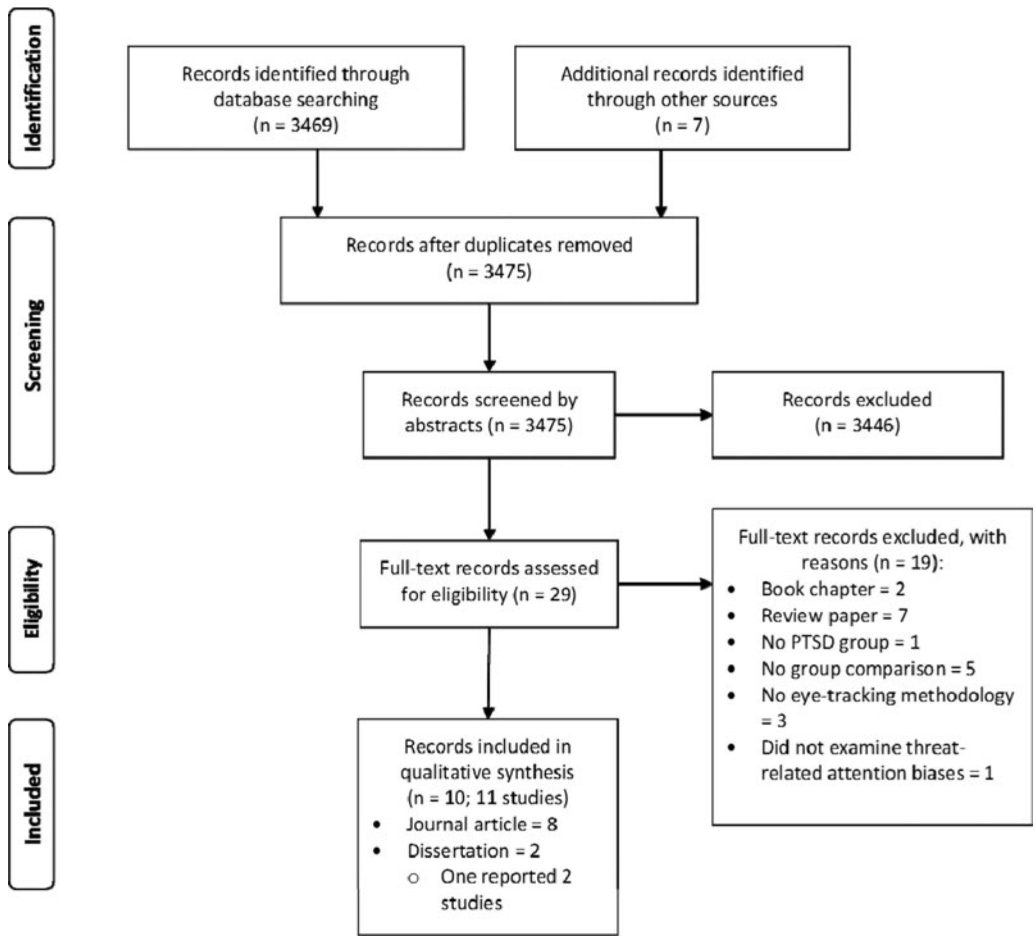

Fig. 2. PRISMA flowchart of paper selection.

selection). Records were then screened using titles and abstracts and those deemed irrelevant (e.g. not examining PTSD, not using eye-tracking methodology) were excluded ($n = 3446$), resulting in 29 records that underwent full-text assessment. Records were then removed per inclusion/exclusion criteria (for specific reasons see Fig. 2). After full-text review, eight journal articles (Bryant *et al.*, 1995; Kimble *et al.*, 2010; Felmingham *et al.*, 2011; Lee and Lee, 2012, 2014, Armstrong *et al.*, 2013; Thomas *et al.*, 2013; Cascardi *et al.*, 2015) and two doctorate dissertations (Stewart, 2012; Matlow, 2013), with one dissertation reporting two separate studies (Stewart, 2012), for a total of 11 studies, were included in the final review. Specific studies descriptions are presented in Table 1, their relevant results are summarized in Table 2, and effect sizes of significant findings are reported in Table 3.

Participant characteristics

See Table 1 for a full description of participant characteristics. The reviewed studies included a total $n = 195$ participants with PTSD ($M_{age} = 30.7$), $n = 141$ trauma-exposed healthy controls (TEHC; $M_{age} = 29.5$), and $n = 120$ healthy controls (HC; $M_{age} = 24.1$) with no trauma exposure. One study reported only the overall mean age of the sample (Cascardi *et al.*, 2015). Group size ranged $n = 9–52$ in the PTSD group, $n = 10–24$ in the TEHC group, and $n = 10–33$ in the HC group. The PTSD group comprised 31.3% male participants, ranging from 0% to 100%, the TEHC group 8%, ranging from 0% to 100%, and the HC group 31%, ranging from 0% to 90%. Two studies only reported the gender distribution of their entire sample (Kimble *et al.*, 2010; Thomas *et al.*, 2013). Four studies provided information about ethnicity (Kimble *et al.*, 2010; Armstrong *et al.*, 2013; Matlow, 2013; Cascardi *et al.*, 2015), with only two providing within-group distributions (Armstrong *et al.*, 2013; Matlow, 2013).

Participants with a clinical diagnosis of PTSD were examined in seven studies (Bryant *et al.*, 1995; Felmingham *et al.*, 2011; Stewart, 2012; Armstrong *et al.*, 2013; Thomas *et al.*, 2013; Cascardi *et al.*, 2015), with four using a clinical interview such as the Structured Clinical Interview for DSM (SCID; Spitzer *et al.*, 1996), the Mini-International Neuropsychiatric Interview (MINI; Sheehan *et al.*, 1998), and the Clinician-Administered PTSD Scale (CAPS; Blake *et al.*, 1995) in determining PTSD diagnosis, while the other three relying only on self-reported measures. Thomas *et al.* (2013) used the 17-item PTSD Checklist-Civilian (PCL-C; Weathers *et al.*, 1991) to allocate trauma-exposed participants to the PTSD group contingent on: (a) a PCL-C total score ⩾44, and (b) a score of at least 3 ('moderately so') on one intrusion symptom, three avoidance symptoms, and two arousal symptoms, as required per DSM-IV (American Psychiatric Association, 2000). Trauma-exposed participants who met only partial criteria were assigned to the TEHC group. In Stewart (2012; Study 1 and 2) group allocation was

https://doi.org/10.1017/S0033291718002313 Published online by Cambridge University Press

Table 1. Systematic review summary of study characteristics

Study (manuscript type)	PTSD group (sample size)	Control group	PTSD diagnosis measures (general measure)	M:F ration	Age mean (S.D.)	Trauma type/ Population	Ethnicity	Comorbidity
Armstrong *et al.* (2013) *Journal article*	Clinical (*n* = 21)	TEHC (*n* = 16) HC (*n* = 21)	MINI, PCL-C	PTSD = 19:2 TEHC = 15:1 HC = 19:2	PTSD = 32.65 (not reported) TEHC = 34.69 (not reported) HC = 32.81(not reported)	War veterans	PTSD = 81% White, 9.5% Black, 9.5% Hispanic TEHC = 87.5% White, 6.2% Black, 6.2% Hispanic HC = 76.2% White, 19% Black, 4.8% Hispanic	PTSD = 43% alcohol abuse disorder, 48% anxiety disorders (GAD, panic disorder, agoraphobia), 24% mood disorders (MDD, dysthymia).
Bryant *et al.* (1995) *Journal article*	Clinical (n = 10)	HC (n = 10)	DSM-IV Clinical interview, PTSD-I, IES (STAI)	PTSD = 7:3 HC = 7:3	PTSD = 34.3 (11.0) HC = 36.4 (11.3)	MVA survivors	Not reported	Not reported
Cascardi *et al.* (2015) *Journal article*	Clinical (*n* = 16)	TEHC (*n* = 24)	CAPS, TSQ, THS (STAI)	PTSD = 1:15 TEHC = 5:24	Entire sample = 35.5 (11.63)	Heterogeneous sample	Entire sample = 67.5% Black, 22.5% White, 5.0% Latino	Not reported
Felmingham *et al.* (2011) *Journal article*	Clinical (*n* = 11)	TEHC (*n* = 10)	SCID-IV, CAPS, IES (STAI, AUDIT, BDI-I)	PTSD = 6:5 TEHC = 5:5	PTSD = 34.2 (9.6) TEHC = 37.8 (15.1)	Non-sexual physical assault victims	Not reported	PTSD = 45% depression, 9% panic disorder TEHC = 10% depression
Kimble *et al.* (2010) *Journal article*	Sub-clinical (*n* = 9; 2 with PTSD)	TEHC (*n* = 10)	SCID-IV, CAPS, CES, PSS	Entire sample = 17:2	PTSD = 26.56 (6.75) TEHC = 31.7 (9.41)	War veterans (Iraq war)	Entire sample = 89.5% White, 10.5% Hispanic	Entire sample = 16% major depression, 5% GAD, 10.5% panic disorder
Lee and Lee (2012) *Journal article*	Sub-clinical (*n* = 14)	TEHC (*n* = 14) HC (*n* = 15)	PDS, CTS-R (STAI, BDI-I)	PTSD = 14:0 TEHC = 14:0 HC = 15:0	PTSD = 22.5 (1.91) TEHC = 22.71 (1.38) HC = 22.2 (1.21)	Dating violence (DV) survivors	Not reported	Not reported
Lee and Lee (2014) *Journal article*	Sub-clinical (*n* = 20)	TEHC (*n* = 22) HC (*n* = 21)	PDS, CTS-R (STAI, BDI-I)	PTSD = 20:0 TEHC = 22:0 HC = 21:0	PTSD = 20.85 (2.11) TEHC = 20.82 (2.22) HC = 21.1 (2.05)	Dating violence (DV) survivors	Not reported	Not reported
Matlow (2013) *Ph..D thesis*	Sub-clinical (*n* = 52)	HC (*n* = 33)	PDS, CTS-2 – only in PTSD group, THQ – only in HC group (BDI-II, BAI, DES)	PTSD = 0:52 HC = 9:24	PTSD = 36 (11.63) HC = 19.14 (1.12)	Inter-personal violence (IPV) survivors	PTSD = 46% Hispanic, 42% Caucasian, 26% African-American, 16% Native-American/Alaska Native, 7% other HC = 90% Caucasian, 14% Hispanic, 7% Asian, 5% Native-American/Alaska Native, 3% African-American, 3% other	Not reported

(*Continued*)

Table 1. (*Continued.*)

Study (manuscript type)	PTSD group (sample size)	Control group	PTSD diagnosis measures (general measure)	M:F ration	Age mean (S.D.)	Trauma type/ Population	Ethnicity	Comorbidity
Stewart (2012) – Study 1 *Ph.D. thesis*	Clinical (n = 12)	TEHC (n = 16)	PDS, CAPS – hypervigilance score only, DRRI	PTSD = 12:0 TEHC = 16:0	PTSD = 39.5 (5.1) TEHC = 42.6 (5.6)	War veterans	Not reported	Not reported
Stewart (2012) – Study 2 *Ph.D. thesis*	Clinical (n = 12)	TEHC (n = 16)	PDS, CAPS – hypervigilance score only, DRRI	PTSD = 12:0 TEHC = 16:0	PTSD = 39.5 (5.1) TEHC = 42.6 (5.6)	War veterans	Not reported	Not reported
Thomas *et al.* (2013) *Journal article*	Clinical (n = 18)	TEHC (n = 13) HC (n = 20)	PCL-C, LSC-R (BDI-II)	Entire sample = 8:47	PTSD = 21.2 (5.1) TEHC = 20.8 (1.5) HC = 22.4 (6.5)	Heterogeneous sample	Not reported	Not reported

PTSD, posttraumatic stress disorder; M:F, Male:Female; TEHC, trauma-exposed healthy control; HC, healthy control; MINI, Mini International Neuropsychiatric Interview; PCL-C, PTSD checklist-civilian version; GAD, generalized anxiety disorder; PD, panic disorder; MDD, major depressive disorder; DSM, Diagnostic and Statistical Manual of Mental Disorders; IES, Impact of Event Scale; STAI, State-Trait Anxiety Inventory; MVA, motor vehicle accident; CAPS, Clinician Administered PTSD Scale; TSQ, Trauma Screening Questionnaire; THS, Trauma History Screen; SCID, structured clinical interview for DSM Disorders; IES, Impact of event scale; AUDIT, Alcohol use disorders inventory; BDI, Beck depression inventory; CES, Combat Exposure Scale; PSS, PTSD Symptom Scale; PDS, Post-traumatic Diagnostic Scale; CTS-R or CTS-2, Revised Conflict Tactic Scale; THQ, Trauma History Questionnaire; BAI, Beck Anxiety Inventory; DES, Dissociative Experiences Scale; DRRI, Deployment Risk and Resilience Inventory; LSC-R, Life Stressor Checklist-Revised.

dependent upon whether participants reported sufficient PTSD symptoms at the required level in each symptom cluster (i.e. '2–4 times a week/half the time') to meet PTSD diagnostic criteria using the Posttraumatic Stress Diagnostic Scale (PDS; Foa *et al.*, 1997). The remaining four studies examined participants with high levels of PTSD symptoms (i.e. analogue sample) as their study group of interest. Kimble *et al.* (2010) used a median split of the CAPS, indicating an approximate index of PTSD severity, to create PTSD-High and PTSD-Low groups. Lee and Lee (2012, 2014) used the PDS to create study groups, with those scoring above 15 forming the PTSD group, and those scoring below forming the trauma-control group. Finally, Matlow (2013) also used the PDS to assess women exposed to interpersonal violence (IPV) compared with non-exposed women. A score above 11 was used as an exclusion criterion for the non-exposed group.

Trauma type varied across studies with nine targeting a homogeneous sample of participants, including survivors of a motor vehicle accident (MVA), army veterans, survivors of dating violence (DV), victims of IPV, and survivors of non-sexual physical assault. The remaining two studies examined heterogeneous groups. Thomas *et al.* (2013) screened 1086 undergraduate students using the Life Stressor Checklist-Revised (LSC-R; Wolfe *et al.*, 1996) while Cascardi *et al.* (2015) screened potential participants using the Trauma Screen Questionnaire (TSQ; Brewin *et al.*, 2002). In both studies, those that endorsed trauma exposure and were likely to meet criteria for PTSD were invited for an additional clinical assessment.

Comorbidity was reported in three studies, with an additional study assessing but not reporting the results in the paper. Of the remaining seven studies, five used self-report measures of anxiety and depression, such as the Beck Depression Inventory-I or II (BDI; Beck *et al.*, 1961, Beck *et al.*, 1988) and the State-Trait Anxiety Inventory (Spielberger *et al.*, 1983). Finally, Stewart (2012, Study 1 and 2) did not report any additional measures.

Studies also diverged in the control group compared with the PTSD group. Two studies used only healthy participants with no prior trauma exposure (Bryant *et al.*, 1995; Matlow, 2013), five used only TEHCs (Kimble *et al.*, 2010; Felmingham *et al.*, 2011; Stewart, 2012; Cascardi *et al.*, 2015), and four used both HC and TEHC participants (Lee and Lee, 2012, 2014; Armstrong *et al.*, 2013).

Study characteristics

See Table 2 for a full description of study characteristics. Two studies used words as stimuli, while the remaining nine used image-based stimuli (i.e. pictures/faces) such as faces ($n = 2$) or images/pictures ($n = 7$), with three of those using International Affective Picture System (IAPS; Lang *et al.*, 2008) images. Array size and presentation time also varied across studies. Five studies used a 4-stimuli array size, four used pairs of stimuli, and two studies used a single stimulus. Presentation time ranged from 1 to 30 s.

The trauma-specific material was used as threat stimuli in eight of the reviewed studies. Bryant *et al.* (1995) used words relating to MVA (e.g. blood, ambulance) in examining MVA survivors and Felmingham *et al.* (2011) used words relating to physical assault (e.g. blood, attack, agony, terror and dead) when examining survivors of non-sexual physical assault. Kimble *et al.* (2010) used Iraq war slides for Iraq war veterans, Lee and Lee (2012, 2014) used violent IAPS images and angry faces for DV survivors, Matlow (2013) showed images depicting negative

https://doi.org/10.1017/S0033291718002313 Published online by Cambridge University Press

Table 2. Systematic review summary of study findings

Study	Stimuli type	Trauma specificity of threat stimuli?	Additional stimuli (GNS, PS)?	Array size	Display time	Sampling rate (Hz)	Outcome measures	Results – Attention bias to threat?
Armstrong *et al.* (2013) *Journal article*	Faces (disgust, fear, happy, neutral)	Yes (disgust and fear faces)	GNS = N PS = Y (happy faces)	2 faces (disgust-neutral, fear-neutral, happy-neutral)	3 s	60 Hz	1. First fixation location 2. Total dwell time (3 sec.) 3. Dwell time per 500 ms time intervals (6 intervals)	1. N 2. Y (fear and disgust faces) 3. N
Bryant *et al.* (1995) *Journal article*	Words (threat, neutral)	Yes (MVA related words – based on a pilot study)	GNS = N PS = N	4 words (threat trials = 1 threat word + 3 neutral words, neutral trials = 4 neutral words)	10 s	50 Hz	1. First fixation location 2. First fixation latency	1. Y (threat words) 2. N
Cascardi *et al.* (2015) *Journal article*	Images (threat, neutral)	No (general threat images)	GNS = N PS = N	2 images (neutral-threat). Single images were presented sequentially	30 s	1000 Hz	1. Overall pupil dilation 2. Pupil dilation for within image threat elements	1. N 2. Y (within image threat elements)
Felmingham *et al.* (2011) *Journal article*	Words (threat, neutral)	Yes (related to physical assault – based on a pilot study)	GNS = N PS = N	4 words (threat trials = 1 threat word + 3 neutral words, neutral trials = 4 neutral words)	1 s	50 Hz	1. First fixation location 2. First fixation latency 3. First fixation pupil dilation 4. Subsequent (2nd) fixation location	1. Y (for threat words) 2. N 3. N 4. N
Kimble *et al.* (2010) *Journal article*	Images (threat, neutral)	Yes (Iraq war images)	GNS = Y (MVA images) PS = N	2 images (trauma-related threat trials = Iraq-neutral, general negative trials = MVA-neutral)	10 s	1000 Hz	1. First fixation location 2. First fixation latency 3. Total dwell time (10 sec.) 4. Max pupil sizes during stimuli presentation 5. Subsequent (2nd) fixation dwell time	1. N 2. N 3. Y (Iraq and MVA images pooled together) 4. Y (Iraq and MVA images pooled together) 5. N
Lee and Lee (2012) *Journal article*	Images (violent, dysphoric, positive, neutral)	Yes (violent scenes of women being abused by men)	GNS = Y (dysphoric images) PS = Y (positive images)	4 images (all image types presented in each trial)	10 s	30 Hz.	1. First fixation location 2. Total dwell time (10 sec.) 3. Dwell time per 2000 ms time intervals (5 intervals)	1. N 2. Y (increase for violent and dysphoric images, decrease for happy imaged) 3. N

(*Continued*)

Table 2. (*Continued.*)

Study	Stimuli type	Trauma specificity of threat stimuli?	Additional stimuli (GNS, PS)?	Array size	Display time	Sampling rate (Hz)	Outcome measures	Results – Attention bias to threat?
Lee and Lee (2014) *Journal article*	Faces (anger, fear, happy, neutral)	Yes (angry faces)	GNS = Y (fear faces) PS = Y (happy faces)	2 faces (angry-neutral, fearful-neutral, happy-neutral, angry-happy, fearful-happy)	10 s	50 Hz	1. First fixation location 2. Total dwell time (10 sec.) 3. Dwell time per 2000 ms time intervals (5 intervals)	1. N 2. Y (angry and fear faces) 3. N
Matlow (2013) *Ph.D. thesis*	Images (threat, positive, and neutral relationship images)	Yes (negative male-female interaction)	GNS = N PS = Y (positive male-female interaction)	4 images (1 threat + 1 positive + 2 neutral)	15 s	60 Hz	1. First fixation location 2. First fixation latency 3. Total dwell time (15 sec.) 4. Dwell time per 5000 ms time intervals (3 intervals) 5. Dwell time per 1000 ms time intervals (15 intervals)	1. N 2. N 3. Y (different dwell time patterns) 4. N 5. N
Stewart (2012) – Study 1 *Ph.D. thesis*	Image (street scenes)	N/A	GNS = N PS = N	1 image (neutral)	7 s	250 Hz	1. Saccade/ fixation count 2. Saccade duration 3. scan-path length	1. N 2. N 3. N
Stewart (2012) – Study 2 *Ph.D. thesis*	Real streets (viewed while walking)	N/A	GNS = N PS = N	1 image (neutral)	230 m (~2.5 min.)	30 frames per second	1. Saccade/ fixation count 2. Saccade duration 3. scan-path length	1. N 2. N 3. N
Thomas *et al.* (2013) *Journal article*	Images (negative, positive, neutral, general threat/ trauma-relevant threat image	Yes (content specific according to participants self-identified trauma on the LSC-R	GNS = Y (negative and general threat images) PS = Y (positive images)	4 images (general threat trials = negative, positive, neutral + general threat. Trauma-relevant threat = negative, positive, neutral + specific trauma-relevant threat)	6 s	250 Hz	1. First fixation location 2. Total dwell time (6 sec.) 3. Dwell time per 2000 ms time intervals (3 intervals)	1. N 2. Y (specific trauma-relevant threat) 3. N

GNS, general negative stimuli; PS, positive stimuli; Y, yes; N, no; s, seconds; MVA, motor vehicle accident; min., minutes; LSC-R, Life Stressor Checklist-Revised.

Table 3. Systematic review summary of effect sizes for reported significant findings

Study (manuscript type)	Reported findings	Effect size (Cohen's d)	Comments
Armstrong *et al.* (2013) *Journal article*	1. PTSD > HC – dwell time on disgusted faces 2. PTSD > HC – dwell time on fearful faces 3. PTSD > TEHC – dwell time on disgusted faces 4. PTSD > TEHC – dwell time on disgusted faces 5. PTSD group: disgusted faces > happy faces – dwell time 6. PTSD group: fearful faces > happy faces – dwell time	0.74 0.80 0.59 0.63 0.56 0.50	Effect sizes were calculated based on reported means and standard deviations of the groups
Bryant *et al.* (1995) *Journal article*	1. PTSD group: threat words > neutral words – number of initial fixations	1.39	Effect size was calculated based on reported means and standard deviations of the groups
Cascardi *et al.* (2015) *Journal article*	1. PTSD > TEHC – pupil dilation to the threat element in the threat images 2. PTSD group: threat element > neutral element – pupil dilation	0.75 0.76	Effect sizes were reported in the paper
Felmingham *et al.* (2011) *Journal article*	1. PTSD > TEHC – number of initial fixations on trauma-related words		Effect size could not be calculated – groups' standard deviations were not reported
Kimble *et al.* (2010) *Journal article*	1. PTSD > TEHC – maximum pupil size on negative valenced pictures (MVA and Iraq war stimuli pooled together) 2. PTSD > TEHC – dwell time on negative valenced pictures (MVA and Iraq war stimuli pooled together)		Effect size could not be calculated – groups' standard deviations for the pooled negative valenced pictures were not reported
Lee and Lee (2012) *Journal article*	1. PTSD > TEHC – dwell time on violent images 2. PTSD > HC – dwell time on violent images 3. TEHC > HC – dwell time on violent images 4. PTSD > HC – dwell time on dysphoric images 5. TEHC > HC – dwell time on dysphoric images 6. PTSD < HC – dwell time on positive images 7. TEHC < HC –dwell time on positive images	3.69 6.44 2.68 3.59 3.27 5.90 3.90	Effect sizes were calculated based on reported means and standard deviations of the groups
Lee and Lee (2014) *Journal article*	1. PTSD > TEHC – dwell time on angry faces 2. PTSD > HC – dwell time om angry faces 3. TEHC > HC – dwell time on angry faces 4. PTSD > HC – dwell time on fearful faces		Effect sizes could not be calculated – groups' standard deviations were not reported
Matlow (2013) *Ph.D. thesis*	1. IPV group: negative images > neutral images – proportion of fixation time	0.67	Effect size was calculated based on reported means and standard deviations of the groups
Stewart (2012) – Study 1 *Ph.D. thesis*	No significant results	N/A	
Stewart (2012) – Study 2 *Ph.D. thesis*	No significant results	N/A	
Thomas *et al.* (2013) *Journal article*	1. PTSD > HC – dwell time on trauma-relevant images 2. TEHC > HC – dwell time on trauma-relevant images	0.68 1.35	Effect sizes were calculated based on reported means and standard deviations of the groups

PTSD, posttraumatic stress disorder; HC, healthy control; TEHC, trauma-exposed healthy control; MVA, motor vehicle accident.

interaction for IPV-exposed women, and Armstrong *et al.* (2013) used fearful and disgusted expressions for war veterans, as these emotions reflect the primary peritraumatic emotions in combat-related PTSD (i.e. fear and horror). The only study to present exclusively general threat stimuli (i.e. not trauma-specific) was that of Cascardi *et al.* (2015) that used general fear-provoking IAPS images, possibly due to the heterogeneous sample used in this study. Conversely, Thomas *et al.* (2013), also examining a heterogeneous sample, opted to utilize trauma-relevant threat images specifically matched to each participant's self-identified trauma event on the LSC-R (Wolfe *et al.*, 1996). Finally, two studies used a single neutral stimulus (Stewart, 2012, Study 1 and 2), as these studies were designed to examine hypervigilance/scanning behavior of neutral scenes occurring prior to threat detection.

Four studies also incorporated general threat/negative stimuli in addition to trauma-specific stimuli to explore the level of threat specificity needed to elicit threat-related attention biases, which might reflect the generalization of these biases. Kimble *et al.* (2010) used MVA pictures for Iraq war images, Thomas *et al.* (2013) used general negative and general threat images in addition to the specific personal identified trauma images, Lee and Lee (2012) used dysphoric images in addition to the violent ones for DV victims, and Lee and Lee (2014) included fearful faces in addition to the angry faces, as only angry faces were considered

https://doi.org/10.1017/S0033291718002313 Published online by Cambridge University Press

trauma-relevant stimuli for DV survivors. Five studies included also positive-valence stimuli aiming to examine the emotionality hypothesis, namely, determine whether attention bias is manifested exclusively for threatening/negative information, or whether it may also be manifested when different valenced information is presented, such as positive stimuli.

Quality of studies

The quality assessment found most studies to be of acceptable quality ($n = 8$), with one rated as having good quality (Armstrong *et al.*, 2013) and two considered as having low quality (Kimble *et al.*, 2010; Matlow, 2013). The 'good quality' study was rated as such due to two primary considerations. First, it employed a clinical PTSD sample, using both a PTSD-specific measure (i.e. CAPS, PCL) and a general clinical interview to support the PTSD diagnosis (i.e. MINI, SCID), and it assessed co-morbid conditions (*representativeness*). Second, this study controlled for age as a possible confound, as well as for other elements such as gender and ethnicity (*selection bias*). While two additional studies (Bryant *et al.*, 1995; Felmingham *et al.*, 2011) also met these two primary considerations, their small sample size reduced their quality from 'good' to 'acceptable' (*statistical analysis criterion*). Studies that did not support PTSD clinical status by an additional general clinical interview (Cascardi *et al.*, 2015), that employed only self-report measures to deduce a clinical PTSD diagnosis (Stewart, 2012; Thomas *et al.*, 2013), or that included sub-clinical analogue samples (Lee and Lee, 2012, 2014) were considered of acceptable quality, unless other indications hindered this rating. Accordingly, two studies were considered of low quality. While having several strong features, such as the diagnostic tools used in the procedure, the study of Kimble *et al.* (2010) did not control for age or report statistics regarding age differences between groups. In addition, no information was provided regarding within group gender distribution. Finally, the study recruited a small number of participants per group. Matlow (2013) received a low-quality rating due to an absence of a matched control group of women without IPV exposure on gender, age and ethnicity (see Table 1). Most importantly, analyses were performed separately for each sample, not enabling direct group comparisons, deterring the ability to draw definite conclusions from obtained results (*statistical analysis*).

Overall findings – Is there threat-related attentional bias in PTSD?

Facilitated threat detection and hypervigilance

Facilitated threat detection was examined in eight studies, all using *first fixation location* as their primary measure (Bryant *et al.*, 1995; Kimble *et al.*, 2010; Felmingham *et al.*, 2011; Lee and Lee, 2012, 2014, Armstrong *et al.*, 2013; Matlow, 2013; Thomas *et al.*, 2013). Only two found evidence for facilitated threat detection using this measure. Bryant *et al.* (1995) presented participants one threat or one neutral word alongside three filler words and found that MVA survivors with PTSD initially fixated more on threat words than on neutral words. In contrast, HCs displayed a similar number of initial fixations on both word types. Using a similar design, Felmingham *et al.* (2011) found comparable results showing that PTSD patients made more initial fixations on trauma words compared with TEHC participants, with no difference between groups on initial fixations on neutral words. Interestingly, these two studies were also the only studies to use words as stimuli. *Latency to first fixation* as indicating vigilance was examined in four of the above-cited studies (Bryant *et al.*, 1995; Kimble *et al.*, 2010; Felmingham *et al.*, 2011; Matlow, 2013), but none found evidence for group differences on this measure.

Hypervigilance was examined in five studies, with three using *pupillometry-based* measures (Kimble *et al.*, 2010; Felmingham *et al.*, 2011; Cascardi *et al.*, 2015) and two using *scan-path* indices (Stewart, 2012, Study 1, Study 2). Unlike first fixation measures, pupillometry-based measures utilized across studies were highly heterogeneous. Kimble *et al.* (2010) used *maximum pupil size* detected during the entire 10-s stimuli presentation period as reflecting hypervigilance. Results indicated that veterans with high PTSD symptoms demonstrated a larger maximum pupil size to negatively valence pictures (Iraq and MVA pictures pooled together) compared with TEHC participants, with no specificity effect for the combat-related pictures. Felmingham *et al.* (2011) examined *changes in mean pupil dilation from baseline to initial fixations* on threat and neutral words, with baseline mean pupil area computed for a 1-s time interval that preceded stimulus onset. Results indicated only a main effect of group, with the PTSD group displaying increased pupil dilation overall to both threat and neutral words compared with TEHC participants. No evidence emerged for an increase in pupil dilation to traumatic compared with neutral words in the PTSD group. Finally, Cascardi *et al.* (2015) examined pupillometry while PTSD and TEHC participants scanned pairs of neutral and threatening images presented for 30 s. *Pupil dilation* was computed using a ratio-based measure by dividing the pupil area registered when fixating on threat-evoking elements within the image (i.e. areas of interest, AOIs) by the pupil area registered during the entire 30-s viewing period of each image. This ratio-based measure was computed separately for threat and neutral images. Results indicated no group differences in pupil dilation for neutral and threatening images as a whole. However, compared with TEHC participants, PTSD patients showed significantly larger pupil dilation to the threat element within the threat images, with no group difference in pupil dilation for similarly shaped elements within the neutral ones. Within-group analyses showed that patients with PTSD had significantly larger pupil dilation to the threat element than to the neutral element, whereas those without PTSD did not. In sum, pupillometry-based evidence for hypervigilance in PTSD is ambiguous, with one study finding no group differences in overall pupil dilation to threat and neutral stimuli (Cascardi *et al.*, 2015), another reporting larger pupil area to both trauma and neutral initial fixations in PTSD (Felmingham *et al.*, 2011), and a third demonstrating group differences in maximum pupil size to negatively valenced stimuli compared with neutral stimuli in general, not unique to trauma-related stimuli (Kimble *et al.*, 2010).

The two studies using scan-path measures to assess hypervigilance do not clarify this ambiguity (Stewart, 2012, Study 1, Study 2). In Study 1, war veterans with PTSD and TEHC veterans freely viewed street scenes presented one at a time for 7 s each, with attention indices computed for the entire presentation time. Results indicated that while subjective threat ratings of these scenes were higher in the PTSD group compared with the TEHC group, PTSD patients did not differ from controls in the number of saccades/fixations made per trial, in saccade duration or in scan-path length. Study 2 utilized a more naturalistic task analogous to the task used in Study 1, with participants wearing

https://doi.org/10.1017/S0033291718002313 Published online by Cambridge University Press

a portable eye-tracking device while walking along unknown pre-chosen streets in London. Attention indices were computed for the entire walking route of 230 m, lasting approximately 2.5 minutes. Results revealed a group difference in saccade/fixation count, but in the opposite direction to what was hypothesized. Veterans with PTSD made significantly less frequent saccades than did TEHC veterans. Groups also did not differ on the duration of saccades or on scan-path length. Overall, these two scan-path studies do not lend support for a hypervigilance bias in PTSD patients when viewing neutral images that are subjectively perceived as more threatening. Taken together, the evidence for facilitated threat detection and hypervigilance in PTSD is relatively weak, with most studies failing to find evidence supporting these biases.

Sustained attention and difficulty in initial disengagement from threat

None of the reviewed studies examined difficulties in initial disengagement from threat (i.e. dwell time of the first fixation). Sustained attention (i.e. maintenance of attention), as indicated by total dwell time, was examined in six studies (Kimble *et al*., 2010; Lee and Lee, 2012, 2014, Armstrong *et al*., 2013; Matlow, 2013; Thomas *et al*., 2013), with all finding supporting evidence. Kimble *et al*. (2010) presented participants with slides containing either a trauma-relevant threat picture (i.e. Iraq war slides), or a general threatening negative-valenced picture (MVA pictures), paired with a neutral picture for 10 s. Results showed that veterans with high PTSD scores dwelled longer on threatening pictures compared with those with low-PTSD scores. However, this finding was not further qualified by type of threat stimulus (i.e. Iraq and MVA images pooled together). In Lee and Lee (2012), HC participants and DV survivors, categorized as high or low on PTSD symptomology, viewed slides with four images per slide (violent, dysphoric, positive, and neutral) for 10 s. Violent images were considered trauma-relevant, dysphoric images were used to indicate a general 'negative effect,' and positive stimuli were included to examine the emotionality hypothesis. Results showed that for violent images high-PTSD participants dwelled significantly longer compared with the two control groups, with Low-PTSD participants dwelling longer than HCs but only at trend level. The high and low PTSD groups also dwelled significantly longer on dysphoric stimuli and significantly shorter on positive stimuli compared with the HC group. In a subsequent study, similar participant groups were shown an emotional face (angry, fearful or happy) paired with a neutral face, as well as pairs of negative (angry or fearful) and happy faces for 10 s (Lee and Lee, 2014). Angry faces served as trauma-related stimuli, fearful faces were included to examine the generalizability of biases to general threat/negative stimuli, and happy faces were once again used to examine the emotionality hypothesis. Results showed that the high-PTSD group dwelled significantly longer on angry faces compared with the two control groups, with the low-PTSD group dwelling longer compared with the HC group. For fearful faces, the high-PTSD group showed significantly longer dwell time compared with the HC group, but not compared with the low-PTSD group. No group differences were found for happy faces. Armstrong *et al*. (2013) showed veterans with PTSD, trauma-exposed non-PTSD veterans and HC participants pairs of faces containing one emotional (fearful, disgusted, or happy) and one neutral face for 3 s. Fearful and disgusted faces were considered trauma-relevant and happy faces were included to examine the emotionality hypothesis. Veterans with PTSD dwelled significantly longer on disgusted and fearful expressions compared with non-veteran HCs, and dwelled marginally longer compared with veterans without PTSD. The three groups did not differ on dwell time on happy faces. Finally, the two control groups did not differ in dwell time on any of the emotional expressions. Additional analyses within the PTSD group showed that participants dwelled longer on both the disgusted and the fearful expression relative to the happy expression. Thomas *et al*. (2013) examined attention bias toward general and trauma-relevant threat stimuli in individuals with clinical PTSD, TEHCs, and HCs. Participants viewed sets of four images containing one negative, one positive, one neutral, and either a general negative threat image or a trauma-relevant threat image, for 6 s. Analyzing trials containing the general threat image revealed no group differences in dwell time on any of the different images. For trauma-relevant threat trials, a significant difference in dwell time emerged between the PTSD and TEHC groups compared with the HC group, with no differences between the two trauma-exposed groups. No differences were found for positive or general negative stimuli. Finally, Matlow (2013) presented participants with sets of four images containing one negative, one positive, and two neutral relationship images for 15 s. This task was delivered once to a sample of IPV-exposed participants and once to a sample of HC participants with no history of IPV. Analyses were performed separately for each sample. For IPV-exposed participants, the proportion of fixation time was significantly greater for negative images compared with the neutral images. Conversely, for non-IPV exposed participants no such difference was found.

Taken together, the evidence supports an attentional bias in PTSD manifesting in sustained attention on threat stimuli, especially when comparing PTSD participants with HC participants using trauma-relevant stimuli. All five studies using these groups found evidence for increased dwell time on trauma-related threat stimuli, including violent images and angry faces for DV survivors, fear and disgust faces for army veterans, specific trauma-related images for a heterogeneous sample, and negative relationship images for IPV-exposed participants. When using more general negative stimuli, not specifically related to trauma, results were somewhat less consistent, with two studies finding evidence for a similar bias, while one did not. Finally, the emotionality hypothesis received no support.

When comparing PTSD with TEHC participants, a similar pattern of results emerged, with four out of five studies showing performance differences in dwell time on threat. Three studies found group differences for specific trauma-related stimuli only (Lee and Lee, 2012, 2014; Armstrong *et al*., 2013), one study only for general threat stimuli pooled together with trauma-relevant stimuli (Kimble *et al*., 2010), with one study failing to find evidence with either (Thomas *et al*., 2013). Again, all studies incorporating positive stimuli showed no group differences.

Four studies also compared TEHC and HC participants, aiming to elucidate the effect of mere trauma exposure on attention. For trauma-specific stimuli, three studies found evidence for group differences in total dwell time on threat (Lee and Lee, 2012, 2014, Thomas *et al*., 2013), with one failing to do so (Armstrong *et al*., 2013). Conversely, when using general threat/negative stimuli, only one study showed group differences in dwell time on threat (Lee and Lee, 2012) while the other studies did not. Finally, there were no group differences in dwell time on positive stimuli in any of these studies.

https://doi.org/10.1017/S0033291718002313 Published online by Cambridge University Press

Attentional threat avoidance

Attentional threat avoidance was examined by seven studies, with five using a time course analysis in which dwell time was computed per time interval to examine reduction in dwell time across intervals (Lee and Lee, 2012, 2014, Armstrong *et al*., 2013; Matlow, 2013; Thomas *et al*., 2013), and two examining second fixation measures (Kimble *et al*., 2010; Felmingham *et al*., 2011). None of these seven studies found evidence for attentional avoidance.

Armstrong *et al*. (2013) divided a total presentation time of three seconds to six 500 ms (milliseconds) intervals. No evidence was found for time-interval effects, suggesting that the observed group differences in dwell time on threat stimuli (disgust and fearful faces) were relatively sustained over the 3-s trials. Lee and Lee (2012, 2014) divided a 10-s presentation time into five 2-s time intervals in both their studies. In Lee and Lee (2012) results indicated that increased dwell time on violent images in the high-PTSD group was relatively maintained throughout the 10-s trials (or the five 2-s intervals). In Lee and Lee (2014), similar results emerged with significant group differences in dwell time on angry and fearful faces maintained across time intervals. Thomas *et al*. (2013) divided an overall presentation time of six seconds to three 2-s time intervals. While no significant group-by-image type-by-time interval emerged for general threat trials, a significant interaction was found for trauma-relevant threat trials. However, further analyses of these trials revealed that the PTSD group dwelled longer on threat, compared with the HC group, during the 0–2 and 4–6 s time intervals, with no difference in the 2–4 interval, indicating increased dwell time also in the latest stage of stimulus presentation. Thus, no evidence emerged for avoidance at this juncture, which is hypothesized under the vigilance-avoidance hypothesis (Cisler and Koster, 2010). Finally, Matlow (2013) conducted two separate time-course analyses by dividing his 15-s time interval to three 5-s intervals (Analysis 1) and 15 1-s intervals (Analysis 2). However, the two analyses revealed similar patterns of attention allocation across time intervals in IPV-exposed and non-IPV-exposed participants.

Two studies explored avoidance using characteristics of the fixation made following an initial fixation on threat, that is, the second fixation. Kimble *et al*. (2010) inspected whether veterans higher in PTSD symptoms would dwell less on threat stimuli after spending more time when initially fixating on it. No evidence was found supporting avoidance of traumatic visual stimuli. Felmingham *et al*. (2011), examining the location of subsequent fixations following a first threat fixation, hypothesized that the PTSD group would make fewer subsequent fixations on threat words following an initial traumatic fixation, compared with the TEHC group. Results indicated no significant group differences on this measure.

Discussion

The current systematic review examined the eye-tracking-based-empirical evidence for threat-related attention biases in PTSD. It included 11 studies ($n = 456$) employing group-comparison designs examining basic attentional processes. Evidence for facilitated threat detection using first fixation location was found only in two studies using words as stimuli, with no studies demonstrating such evidence using latency to first fixations. None of the reviewed studies found evidence for attentional threat avoidance, whether using time course analysis or second fixation variables. Finally, evidence for increased total dwell time on threat, reflecting sustained attention, was found in all studies examining this process. Importantly, this consistency in findings, or lack of, across studies is striking in comparison with the RT-based research of attentional biases in PTSD, which have yielded mixed results.

Facilitated threat detection and hypervigilance

The lack of evidence for enhanced threat detection in PTSD using image-based stimuli is in line with previous image-based eye-tracking studies in other anxiety disorders, such as social anxiety disorder (Lazarov *et al*., 2016) and GAD (Macatee *et al*., 2017). It is further consistent with image-based dot-probe studies that found no evidence for threat-related attention bias in PTSD (Fani *et al*., 2011; Fani *et al*., 2012*a*; Schoorl *et al*., 2013). Interestingly, the only two eye-tracking studies that did find evidence for enhanced threat detection using first fixation location were also the only ones to use trauma-relevant words as stimuli (Bryant *et al*., 1995; Felmingham *et al*., 2011). This positive finding is in line with a recent meta-analysis of the emotional Stroop task in PTSD, a task inherently using words as stimuli, which found performance differences between PTSD patients and healthy control participants (Cisler *et al*., 2011). In addition, some word-based dot-probe studies have also found evidence for enhanced threat detection in PTSD (Bryant and Harvey, 1997; Dalgleish *et al*., 2001). Still, other word-based RT studies using dot-probe (Iacoviello *et al*., 2014), Stroop (for another meta-analysis, see Kimble *et al*., 2009), or visual search tasks (Pineles *et al*. 2007; Pineles *et al*. 2009) failed to find evidence for enhanced threat detection.

The fact that eye-tracking studies using words as stimuli produced results reflecting enhanced threat detection, whereas image-based studies did not, might be related to the complexity of the stimuli used. As words are considered easier to process they enable rapid appraisal of stimulus content in parafoveal vision, allowing the manifestation of enhanced threat detection (Armstrong *et al*., 2013). However, studies using facial expressions, whose effective value can be easily and rapidly processed even under subprime viewing conditions (Armony *et al*., 2005), have not yielded significant results, undermining this proposition. Armstrong *et al*. (2013) further suggested that faces lack the specificity needed to activate the trauma memory from parafoveal vision, and hence cannot elicit enhanced threat detection in PTSD. A second possible explanation is that the greater visual saliency and complexity of images increase the likelihood of automatic attention capture regardless of the threatening nature of the image, thus obstructing the ability to detect potential existing differences in threat detection (Thomas *et al*., 2013). In a related vein, as lexical stimuli are considered to produce lesser levels of arousal relative to image-based stimuli (Felmingham *et al*., 2003), it is possible that only lexical stimuli enable the manifestation of biased threat detection, while the higher arousal produced by image-based stimuli hinders the detection or manifestation of this bias. Thus, and although examined only by two studies with relatively small sample sizes, it seems that for detecting biased threat detection word-based stimuli might be preferable.

Alternatively, the observed lack of evidence for enhanced threat detection in eye-tracking studies using image-based stimuli might be related to the nature of the task used to assess attention, namely, the free-viewing paradigm, which was the only one

https://doi.org/10.1017/S0033291718002313 Published online by Cambridge University Press

employed in the reviewed studies. As in free-viewing, there are no specific demands from participants in wake of an explicit task, it might be less suited for detecting attentional aspects that are better manifested in the context of task performance. Put differently, if enhanced threat detection is a phenomenon mainly occurring in the context of task performance then free-viewing tasks are less able to detect it. This possibility is line with studies using rapid serial visual presentation (RSVP) paradigms (Most *et al.*, 2005), in which participants are instructed to detect a target image presented within a series of rapidly presented visual stimuli. Importantly, emotional threatening stimuli are presented as part of the stimuli series, preceding the target stimulus by different time intervals. Target awareness (i.e. failing to detect target appearance) is then used to reflect attentional capture by the preceding threatening distractor (Olatunji *et al.*, 2013). Indeed, studies using RSVP tasks have found evidence for attentional capture by threatening distractors in both analogue/experimentally induced trauma samples (Verwoerd *et al.*, 2009; Verwoerd *et al.*, 2010) and clinical populations (Olatunji *et al.*, 2013). Thus, future research should try and combine task requirements with an assessment of eye-movements when exploring enhanced threat detection in PTSD.

Hypervigilance studies were relatively heterogeneous in measures used and thus were more difficult to interpret, with three using differently-computed pupillometry indices (Kimble *et al.*, 2010; Felmingham *et al.*, 2011; Cascardi *et al.*, 2015) and two using saccade-based scan-path indices (Stewart, 2012). Pupillometry indices were further different with regard to the timing of measured pupil responses, with some using pupil dilation during first fixations (Felmingham *et al.*, 2011) while others examined pupil dilation throughout presentation duration (Kimble *et al.*, 2010; Cascardi *et al.*, 2015). Moreover, comparing pupil diameter response with different stimuli within single trials should be interpreted with caution as the pupil diameter response is delayed by approximately 2 s following stimuli onset (Bradley *et al.*, 2008). Considering additional relevant studies and measures may prove useful in attempting to resolve this ambiguity and reach clearer conclusions. One such study, exploring the causal impact of hypervigilance on gaze behavior, was conducted by Kimble *et al.* (2014). In this study, 71 non-selected participants were randomly allocated to one of three conditions, namely, hypervigilant, pleasant, or control condition. Participants were then asked to view a series of single neutral scenes presented sequentially, each for 10 s. Scenes were neutral, yet relevant to PTSD, depicting potentially threatening cues (e.g. an empty street). Hypervigilance was experimentally manipulated by telling participants in the hypervigilance condition that they need to find a threat embedded within each scene to avoid an aversive consequence. Participants in the pleasant condition were instructed to search for a pleasant target and told that a loud noise would be heard if they fail, and control participants were asked to view each image freely and to ignore the loud white noise in the background. Results indicated that hypervigilant participants performed more fixations/saccades compared with the other groups, with fixations covering a greater percentage of the presented scene. Hypervigilant participants also displayed a larger pupil size relative to controls. The authors concluded that these results provide some support for the role of hypervigilance in increased visual scanning and arousal, occurring before the actual threat is detected (Kimble *et al.*, 2014).

Psychophysiological responses, reflecting increased sympathetic arousal, can be also used to indicate hypervigilance, since increased sympathetic activity has been associated with threat-related attention bias (Lang *et al.*, 1998; Kimble *et al.*, 2010; Fani *et al.*, 2011; Felmingham *et al.*, 2011). Psychophysiology was used in two of the reviewed studies, both of which primarily examined enhanced threat detection using first fixations (Bryant *et al.*, 1995; Felmingham *et al.*, 2011). Results indicated higher skin conductance response (SCR) during all first fixations, regardless of stimulus type (i.e. threat and neutral words), when comparing PTSD patients with HC participants (Bryant *et al.*, 1995). Comparing PTSD patients with TEHC participants revealed a more specific effect, indicating group differences on first fixation SCR for threat words but not for neutral words (Felmingham *et al.*, 2011). These additional studies do lend some support for the hypervigilance hypothesis in PTSD, but further eye-tracking research is clearly needed to better elucidate this process.

Attentional threat avoidance

The present review did not find evidence for attentional avoidance examined through second fixation measures or time-course analysis, using a variety of stimuli (i.e. words, facial, and image-based), array sizes, presentation times, or group types (i.e. clinical and sub-clinical PTSD *v.* TEHC, HC or both). Importantly, while the different studies employing time-course analysis used the different timing of measures taken (i.e. different overall presentation times divided differently to sub-intervals) none of them found evidence for attentional avoidance. Two studies demonstrated a tendency for threat avoidance in intermediate time-intervals, but not in early or later stages of stimulus presentation, suggesting a pattern of attentional fluctuations (Matlow, 2013; Thomas *et al.*, 2013). This proposition is in line with some RT-based studies demonstrating increased attention bias variability, defined as the enhanced tendency for attention fluctuating between threat vigilance and threat avoidance, among PTSD patients (Naim *et al.*, 2015). However, variability-based indices have been recently questioned in their current form due to the inability of these indices to de-couple measurement error from bias variability, leading to the emergence of group differences even when no actual bias exists (Kruijt *et al.*, 2016).

Other studies have suggested attentional avoidance as a possible risk factor for PTSD, reflecting vulnerability for developing the disorder *following* exposure to traumatic events. Indeed, previous studies utilizing dot-probe paradigms among war-zone civilians and pre-deployed military personnel have shown attentional avoidance to be a possible risk factor for PTSD (Wald *et al.*, 2011; Wald *et al.*, 2013). Furthermore, attention training toward threat delivered prior to combat deployment was found to mitigate risk for PTSD following combat exposure (Wald *et al.*, 2016). Only one eye-tracking study to date has followed a similar rationale in examining attentional processes in PTSD (Beevers *et al.*, 2011). In this study, eye data of 139 soldiers were assessed before deployment to Iraq with PTSD symptoms being reported periodically by soldiers once deployed. During the assessment, participants freely viewed 2-by-2 matrices depicting one fearful, one sad, one happy and one neutral face for 30 s. Fearful faces were considered PTSD-related stimuli while sad faces were considered depression-relevant. Results indicated that PTSD symptoms were predicted by shorter mean fixation time for fearful faces. The authors concluded that such an eye-gaze measure may serve as a potential vulnerability marker for PTSD. Taken together, findings suggest that attentional avoidance of threat may better reflect a risk factor for PTSD rather than a PTSD characteristic. Future

https://doi.org/10.1017/S0033291718002313 Published online by Cambridge University Press

eye-tracking research could use longitudinal designs to assess change in gaze allocation among at-risk populations prior to- and following trauma exposure.

Sustained attention on threat

The most consistent finding pertains to sustained attention on threat, once detected, in PTSD. Results were consistently demonstrated across studies regardless of stimulus type, array size, presentation time, and PTSD group status, with medium-to-large effect sizes emerging for between-group differences across studies. Findings were most robust when PTSD subjects were compared with HC participants, with all studies using this comparison finding significant results. Comparing PTSD with TEHC participants still yielded consistent results with only one study failing to find group differences. This conclusion is in accordance with visual search studies (Pineles *et al*., 2007; Pineles *et al*., 2009) as well as with dot-probe tasks using an extended presentation times (Bardeen and Orcutt, 2011), both suggesting PTSD to be better related to difficulty disengaging threat than to facilitate threat detection. Eye-tracking studies in other psychopathologies have also shown increased dwell time on threat in anxious and depressed populations (Sanchez *et al*., 2013; Lazarov *et al*., 2016).

Several explanations were proposed for sustained attention on threat in PTSD. First, increased dwell time on threat might be related to the ruminative quality of PTSD (Kimble *et al*., 2010; Lee and Lee, 2012). Accumulative evidence has shown rumination to play a significant role in predicting and maintaining PTSD symptoms, and their severity, as well as in treatment efficacy (Michael *et al*., 2007; Ehring *et al*., 2008; Echiverri *et al*., 2011). Specifically, it has been suggested that repetitive and perseverative thinking about trauma-related issues, such as its causes, consequences, and implications, is significantly associated with PTSD (Michael *et al*., 2007; Ehring *et al*., 2008). Thus, one could conceptualize increased dwell time on threat stimuli as reflecting an attentional component of trauma-related rumination. A second possible explanation relates increased dwell time on threat to the acute emotional reaction induced by threat stimuli serving as trauma-reminders (Lee and Lee, 2014), which may lead to increased attention allocation to threat by activating brain regions involved in fear processing such as the amygdala (Sergerie *et al*., 2008; Hayes *et al*., 2012) and/or by altering activity of brain structures involved in attentional control (Fani *et al*., 2012*a*; Hayes *et al*., 2012). Third, sustained attention in PTSD might be also related to the nature of threats encountered in this disorder compared with other disorders in which attentional avoidance is mainly observed (Mulkens *et al*., 1996; Tolin *et al*., 1999). Specifically, threats represent more urgency and danger for individuals with PTSD, necessitating hyper-monitoring of these threats to prevent harm, and resulting in sustained attention (Armstrong and Olatunji, 2012). Finally, sustained attention on threat in PTSD might be related to diminished attention control, defined as the capacity to execute voluntary and effortful goal-directed attention deployment (i.e. top-down) while ignoring conflicting attentional demands (i.e. Bottom-up; Derryberry and Rothbart, 1997, Sarapas *et al*., 2017). Importantly, research has shown attention control to moderate the association between posttraumatic symptoms and attention bias. Specifically, among participants with relatively higher levels of PTSD symptoms, attention control was found to be positively related to the ability to disengage and shift attention at will away from threat stimuli (Bardeen and Orcutt, 2011; Bardeen *et al*., 2016).

Generalizability, emotionality, and the role of trauma-exposure – preliminary conclusions

While most studies examined threat-related attention biases using specific trauma-relevant stimuli, four studies (Kimble *et al*., 2010; Lee and Lee, 2012, 2014, Thomas *et al*., 2013) also addressed the possible generalization of attentional bias beyond trauma-specific cues by including also more general negative/threat stimuli, such as MVA stimuli for veterans, dysphoric images and fearful faces for DV survivors, and non-personalized general threat and negative stimuli. As evidence for enhanced threat detection and attentional avoidance was not found in any of these studies, for either type of stimuli, we will focus our discussion on sustained attention. When comparing PTSD with HC participants, two studies found evidence for increased dwell time beyond trauma-specific (Lee and Lee, 2012, 2014) while one did not (Thomas *et al*., 2013). When comparing PTSD with TEHC participants, generalizability effects were found in only one study (Kimble *et al*., 2010) with three finding no effect of general threat stimuli (Lee and Lee, 2012, 2014, Thomas *et al*., 2013). While research examining the generalization of attentional bias is relatively scarce, preliminary evidence implies that generalization might be more evident when comparing PTSD with healthy participants than to trauma-exposed individuals. This tentative conclusion is in line with the meta-analysis of Cisler *et al*. (2011) examining the Stroop task in PTSD. Comparing PTSD patients with HC participants revealed a significant Stroop interference effect for PTSD-relevant and general threatening words. However, comparing the PTSD and TEHC groups showed an interference effect only for PTSD-relevant words. Still, additional eye-tracking research incorporating trauma-specific and more general threatening/negative stimuli is clearly needed to further clarify generalizability of threat-related attention bias in PTSD. Relatedly, future eye-tracking research should better define trauma-specificity, especially when using facial stimuli. For example, while Armstrong *et al*. (2013) defined fearful faces as trauma-relevant for veterans, Lee and Lee (2014) considered fear faces as reflecting the general threat for DV survivors.

In contrast to the generalizability hypothesis, which received some preliminary support, the emotionality hypothesis, namely, the effects of emotional stimuli in general on attention, was not supported by any of the studies addressing this possibility. All studies examining attention to positive-valence stimuli found no evidence for biased attention on any of the examined attentional processes in PTSD (i.e. enhanced detection, sustained attention and avoidance).

The effects of mere trauma exposure on attentional processes can be inferred by exploring the differences between TEHC and HC participants. Studying trauma exposure is imperative, especially since research has shown subthreshold PTSD to be related to significant psychological and functional impairment (Mylle and Maes, 2004) compared with healthy individuals with no post-traumatic symptoms (Jakupcak *et al*., 2007). Again, we will focus our discussion on sustained attention as none of the studies that included both TEHC and HC groups have found group differences in enhanced threat detection or attentional avoidance. As described earlier, three out of four studies comparing these groups found evidence for group differences when using specific trauma-relevant stimuli, and only one when using more general threat/negative stimuli.

Taken together, while considering the findings regarding generalizability and the role of trauma-exposure, results suggest that

https://doi.org/10.1017/S0033291718002313 Published online by Cambridge University Press

trauma exposure may be sufficient to bias attention toward trauma-relevant stimuli only, while PTSD symptomology on a clinical level is 'required' or 'needed' for broadening this bias to further include general threat/negative stimuli. Put differently, trauma exposure produces sustained attention on specific threat-related stimuli, while PTSD extends this impairment to include other less relevant threatening and negative stimuli. This proposition is in line with fear-conditioning studies (a research analog for trauma-exposure; Shvil *et al*., 2013) demonstrating that learned fear associations may be sufficient to capture and hold attention even if one tries to resist (Mulckhuyse *et al*., 2013). It also echoes the clinical phenomenology of PTSD implicating fear overgeneralization for a broad range of circumstances in various degrees of separation from the original traumatic event (Kaczkurkin *et al*., 2017). Thus, future research should incorporate both trauma-exposed and non-trauma-exposed control participants to clarify the specific effects of mere trauma exposure and clinical PTSD. In a related vein, future research could also examine the association between attention bias indices and a continuous measure of PTSD symptomology as the categorical distinction between PTSD and TEHC may not necessarily reflect a corresponding categorical difference on attention measures. Including participants on a wide range of PTSD symptomology will further elucidate the relationship between PTSD symptomology and attentional processes.

Recommendations for future research

Several features related to study and participant characteristics need to be addressed in future studies. First, array size across studies ranged from one to a maximum of four stimuli presented at once, with usually only one of an emotional, and thus predictive, valence. The generalizability and ecological validity of such small set sizes in eye-tracking research have been called into question, emphasizing the need for using more complex visual displays presenting various competing threatening and non-threatening stimuli at once, thereby increasing resemblance to real-world situations (Ferrari *et al*., 2016; Lazarov *et al*., 2016; Price *et al*., 2016). Second, mean age of participants across studies was relatively low. However, age is an important variable to consider when examining attentional processes, as research using both RT-based tasks (Spaniol *et al*., 2008) and eye-tracking methodology (Mather and Carstensen, 2005; Isaacowitz, 2012) has found evidence for sustained attention away from threatening stimuli and toward positive ones in older adults. Some have also linked this attentional pattern to clinical findings of lower reported PTSD symptoms among older veterans (Konnert and Wong, 2015). It is, therefore, possible to assume that age-related shift in attention away from negative and toward positive stimuli might increase resilience to trauma in older adults, as research has also shown lower risk for adverse outcomes following trauma exposure among older adults (Acierno *et al*., 2006). Thus, future research should aim to recruit also elderly PTSD patients to further elucidate the associations between age, attention, and PTSD. Third, while seven studies reported using a clinical sample of PTSD patients, only four used a clinical interview to support PTSD diagnosis. As significant psychological and functional impairment differences have been noted between clinical PTSD and subclinical analogue samples (Breslau *et al*., 2004), more research employing rigorous clinical assessment is needed. Finally, the sample size was relatively small in most studies hampering study quality and raising doubts about some of the reported null results, which might have been due to lack of statistical power to detect existing group differences. Notably, none of the reviewed studies conducted an informed power analysis to determine the sample size that would be powered to detect also more subtle group differences. Studies with greater statistical power and larger sample sizes would yield stronger, more reliable conclusions.

While solid psychometric properties are essential for increasing confidence in research methodology and theory, none of the reviewed studies examined the psychometric properties of the tasks/measures used to examine attention biases, which are essential for increasing confidence in research methodology and theory. Importantly, eye-tracking studies in other fields have shown good internal consistency and test-retest reliability for total dwell time indices, but not for first fixation measures (Waechter *et al*., 2014; Lazarov *et al*., 2016; Skinner *et al*., 2017; Lazarov *et al*., 2018), which correspond nicely with the findings of the current review implicating sustained attention in PTSD. However, as reliability estimates are specific to the sample examined and for the outcome measures used (Skinner *et al*., 2017), it is essential that attentional research in PTSD acknowledge this issue and examine the psychometrics of tasks and measures used in research.

Lack of heterogeneity in experimental paradigms across studies also necessitates further research as all reviewed studies employed the free-viewing paradigm. As mentioned earlier, while being highly beneficial in attentional research (Armstrong and Olatunji, 2012), the free-viewing paradigm only measures spontaneous viewing behavior as participants are not required or directed to look towards or away from specific threat/neutral stimuli. Neither attentional engagement nor attentional disengagement is *necessary* to complete the task at hand. Thus, free-viewing tasks do not examine participants' ability to actively regulate their attention in light of explicit task-demands to redirect attention away from or toward the threatening stimulus. Indeed, eye-tracking research focusing on attentional biases in other anxiety disorders have used additional paradigms and tasks such as visual search tasks (Rinck *et al*., 2005; Huijding *et al*., 2011), the remote distracter paradigm (Richards *et al*., 2012) and anti-saccade tasks (Reinholdt-Dunne *et al*., 2012; Chen *et al*., 2014) to explore different threat-related attentional processes. Using additional paradigms could increase convergent validly of findings, enhance our understanding of different attentional processes and biases in PTSD, and enable the exploration of attentional features less easily tapped by free-viewing paradigms. In a related vein, future research could also examine the specificity of extant results to PTSD by using the same tasks in other psychopathologies. For example, increased dwell time on threat stimuli, reflecting sustained attention, has been demonstrated also in social anxiety disorder (Schofield *et al*., 2012; Lazarov *et al*., 2016).

Finally, the results of the present review implicate most clearly sustained attention on threat in PTSD as reflected in total dwell time. Notably, our analyses further showed medium-to-large effect sizes for group differences on this measure across studies. Moreover, previous research in the field has shown that this eye-tracking-based measure is also more reliable compared with first fixation measures (Waechter *et al*., 2014; Lazarov *et al*., 2016; Skinner *et al*., 2017). Hence, we believe that future research in PTSD should focus on this aberration, aiming to better understand the specific conditions giving rise this phenomenon.

https://doi.org/10.1017/S0033291718002313 Published online by Cambridge University Press

Limitations

The current review has several limitations. First, we excluded correlational studies, which may have contributed to the body of knowledge of attentional biases in PTSD. However, this decision was made intentionally to increase the precision of our research question, namely, whether individuals with high PTSD symptomology *differ* from controls on threat-related attentional processes and biases. Second, we could not examine the association between the different attentional processes and specific PTSD symptom clusters, as most studies did not provide sub-scale scores of PTSD measures. Future research should test the associations of different potential threat-related attention biases to individual PTSD symptom clusters (Blake *et al*., 1995; American Psychiatric Association, 2013), such as estimating the association between attentional avoidance and Cluster C (i.e. avoidance) and enhanced threat detection and/or sustained attention on threat and scores on Cluster E (i.e. arousal). Finally, since the utilization of eye tracking research is relatively new, this review comprises only 11 studies. Although data from 195 subjects with PTSD, 141 trauma-exposed controls, and 120 non-trauma exposed controls were included in this review, for a total of 456 subjects, more eye-tracking research is still needed to further deepen our understanding of attentional biases in PTSD. In a related vein, heterogeneity in study design across the reviewed studies precluded the option of statistically examining our hypotheses using meta-analytic procedures. However, a coherent result pattern across studies did emerge, highlighting sustained attention on threat as a promising target for exploration in future research. Thus, we believe the current review could serve as a preliminary road-map for clinicians and researches aiming at exploring attentional processes in PTSD thus guiding future research in the field.

Conclusions

This review is the first to systematically analyze existing eye-tracking-based evidence for threat-related attentional biases in individuals with high PTSD symptoms compared with TEHC and HC participants. Evidence for enhanced threat detection, including the related processes of hypervigilance, was relatively weak and was found in only two studies using words as stimuli. Attentional avoidance received no empirical support. Conversely, evidence consistently implicated sustained attention on threatening stimuli in PTSD, which was found regardless of stimulus type, array size, presentation time, clinical status, or comparison group. Thus, increased dwell time on threat stimuli in PTSD could serve as a potential target for future intervention and as an important stepping stone in developing novel gaze-contingent therapeutic procedures for PTSD. Extant research in other psychopathologies characterized by sustained attention on threat has shown the potential of gaze-contingent procedures in modifying attentional processes and reducing sustained attention on threat (Ferrari *et al*., 2016; Price *et al*., 2016), leading to a corresponding reduction in anxiety symptoms (Lazarov *et al*., 2017*b*).

Supplementary material. The supplementary material for this article can be found at https://doi.org/10.1017/S0033291718002313

Acknowledgements. This work was supported by the National Institutes of Mental Health - Institutional stipend grant T32 (Amit Lazarov, grant number MH020004, and Benjamin Suarez-Jimenez, grant number MH015144), National Institutes of Health grant U24AG052175 and contract S15-0142 from the Value Institute of New York-Presbyterian Hospital (Louise Falzon), Stand for the Troops Foundation and the New York State Psychiatric Institute (Neria). These funding agencies had no role in the study design; in the collection, analysis and interpretation of the data; in the writing of the manuscript; or in the decision to submit the article for publication.

Conflict of interest. None.

Ethical standards. The authors assert that all procedures contributing to this work comply with the ethical standards of the relevant national and institutional committees on human experimentation and with the Helsinki Declaration of 1975, as revised in 2008.

References

Acierno R, Ruggiero KJ, Kilpatrick DG, Resnick HS and Galea S (2006) Risk and protective factors for psychopathology among older versus younger adults after the 2004 Florida hurricanes. *The American Journal of Geriatric Psychiatry* **14**, 1051–1059.

American Psychiatric Association (2000) *Diagnostic and Statistical Manual of Mental Disorders* 4th Edn. *text revised*. Washington, DC: American Psychiatric Publishing.

American Psychiatric Association (2013) *Diagnostic and Statistical Manual of Mental Disorders* 5th Edn. Washington, DC: American Psychiatric Publishing.

Armony JL, Corbo V, Clement MH and Brunet A (2005) Amygdala response in patients with acute PTSD to masked and unmasked emotional facial expressions. *American Journal of Psychiatry* **162**, 1961–1963.

Armstrong T and Olatunji BO (2012) Eye tracking of attention in the affective disorders: a meta-analytic review and synthesis. *Clinical Psychology Review* **32**, 704–723.

Armstrong T, Bilsky SA, Zhao M and Olatunji BO (2013) Dwelling on potential threat cues: an eye movement marker for combat-related PTSD. *Depression and Anxiety* **30**, 497–502.

Ashley V, Honzel N, Larsen J, Justus T and Swick D (2013) Attentional bias for trauma-related words: exaggerated emotional stroop effect in Afghanistan and Iraq war veterans with PTSD. *BMC Psychiatry* **13**, 86.

Aupperle RL, Melrose AJ, Stein MB and Paulus MP (2012) Executive function and PTSD: disengaging from trauma. *Neuropharmacology* **62**, 686–694.

Bar-Haim Y (2010) Research review: attention bias modification (ABM): a novel treatment for anxiety disorders. *Journal of Child Psychology and Psychiatry* **51**, 859–870.

Bar-Haim Y, Lamy D, Pergamin L, Bakermans-Kranenburg MJ and van Ijzendoorn MH (2007) Threat-related attentional bias in anxious and non-anxious individuals: a meta-analytic study. *Psychological Bulletin* **133**, 1–27.

Bar-Haim Y, Holoshitz Y, Eldar S, Frenkel TI, Muller D, Charney DS, Pine DS, Fox NA and Wald I (2010) Life-threatening danger and suppression of attention bias to threat. *American Journal of Psychiatry* **167**, 694–698.

Bardeen JR and Orcutt HK (2011) Attentional control as a moderator of the relationship between posttraumatic stress symptoms and attentional threat bias. *Journal of Anxiety Disorders* **25**, 1008–1018.

Bardeen JR, Tull MT, Daniel TA, Evenden J and Stevens EN (2016) A preliminary investigation of the time course of attention bias variability in posttraumatic stress disorder: the moderating role of attentional control. *Behaviour Change* **33**, 94–111.

Beck AT, Ward CH, Mendelson M, Mock J and Erbaugh J (1961) An inventory for measuring depression. *Archives of General Psychiatry* **4**, 561–571.

Beck AT, Steer RA and Garbin MG (1988) Psychometric properties of the beck depression inventory: twenty-five years of evaluation. *Clinical Psychology Review* **8**, 77–100.

Beck JG, Freeman JB, Shipherd JC, Hamblen JL and Lackner JM (2001) Specificity of stroop interference in patients with pain and PTSD. *Journal of Abnormal Psychology* **110**, 536–543.

Beevers CG, Lee HJ, Wells TT, Ellis AJ and Telch MJ (2011) Association of predeployment gaze bias for emotion stimuli with later symptoms of PTSD and depression in soldiers deployed in Iraq. *American Journal of Psychiatry* **168**, 735–741.

Blake DD, Weathers FW, Nagy LM, Kaloupek DG, Gusman FD, Charney DS and Keane TM (1995) The development of a clinician-administered PTSD scale. *Journal of Traumatic Stress* **8**, 75–90.

Bradley R, Greene J, Russ E, Dutra L and Westen D (2005) A multidimensional meta-analysis of psychotherapy for PTSD. *American Journal of Psychiatry* **162**, 214–227.

Bradley MM, Miccoli L, Escrig MA and Lang PJ (2008) The pupil as a measure of emotional arousal and autonomic activation. *Psychophysiology* **45**, 602–607.

Bremner JD, Vermetten E, Vythilingam M, Afzal N, Schmahl C, Elzinga B and Charney DS (2004) Neural correlates of the classic color and emotional stroop in women with abuse-related posttraumatic stress disorder. *Biological Psychiatry* **55**, 612–620.

Breslau N, Lucia VC and Davis GC (2004) Partial PTSD versus full PTSD: an empirical examination of associated impairment. *Psychological Medicine* **34**, 1205–1214.

Brewin CR and Holmes EA (2003) Psychological theories of posttraumatic stress disorder. *Clinical Psychology Review* **23**, 339–376.

Brewin CR, Rose S, Andrews B, Green J, Tata P, McEvedy C, Turner S and Foa EB (2002) Brief screening instrument for post-traumatic stress disorder. *British Journal of Psychiatry* **181**, 158–162.

Bryant RA and Harvey AG (1997) Attentional bias in posttraumatic stress disorder. *Journal of Traumatic Stress* **10**, 635–644.

Bryant RA, Harvey AG, Gordon E and Barry RJ (1995) Eye movement and electrodermal responses to threat stimuli in post-traumatic stress disorder. *International Journal of Psychophysiology* **20**, 209–213.

Buckley TC, Blanchard EB and Neill WT (2000) Information processing and PTSD: a review of the empirical literature. *Clinical Psychology Review* **20**, 1041–1065.

Cascardi M, Armstrong D, Chung L and Pare D (2015) Pupil response to threat in trauma-exposed individuals with or without PTSD. *Journal of Traumatic Stress* **28**, 370–374.

Cassiday KL, McNally RJ and Zeitlin SB (1992) Cognitive processing of trauma cues in rape victims with post-traumatic stress disorder. *Cognitive Therapy and Research* **16**, 283–295.

Chemtob CM, Roitblat HL, Hamada RS, Carlson JG and Twentyman CT (1988) A cognitive action theory of post-traumatic stress disorder. *Journal of Anxiety Disorders* **2**, 253–275.

Chen NTM, Clarke PJF, Watson TL, MacLeod C and Guastella AJ (2014) Biased saccadic responses to emotional stimuli in anxiety: an antisaccade study. *Plos One* **9**, e86474.

Cisler JM and Koster EHW (2010) Mechanisms of attentional biases towards threat in anxiety disorders: an integrative review. *Clinical Psychology Review* **30**, 203–216.

Cisler JM, Wolitzky-Taylor KB, Adams Jr TG, Babson KA, Badour CL and Willems JL (2011) The emotional stroop task and posttraumatic stress disorder: a meta-analysis. *Clinical Psychology Review* **31**, 817–828.

Constans JI, McCloskey MS, Vasterling JJ, Brailey K and Mathews A (2004) Suppression of attentional bias in PTSD. *Journal of Abnormal Psychology* **113**, 315–323.

Dalgleish T, Moradi AR, Taghavi MR, Neshat-Doost HT and Yule W (2001) An experimental investigation of hypervigilance for threat in children and adolescents with post-traumatic stress disorder. *Psychological Medicine* **31**, 541–547.

De Ruiter C and Brosschot JF (1994) The emotional stroop interference effect in anxiety: attentional bias or cognitive avoidance? *Behaviour Research and Therapy* **32**, 315–319.

Derakshan N and Koster EHW (2010) Processing efficiency in anxiety: evidence from eye-movements during visual search. *Behaviour Research and Therapy* **48**, 1180–1185.

Derryberry D and Rothbart MK (1997) Reactive and effortful processes in the organization of temperament. *Development and Psychopathology* **9**, 633–652.

Devineni T, Blanchard EB, Hickling EJ and Buckley TC (2004) Effect of psychological treatment on cognitive bias in motor vehicle accident-related posttraumatic stress disorder. *Journal of Anxiety Disorders* **18**, 211–231.

Difede J, Olden M and Cukor J (2014) Evidence-based treatment of post-traumatic stress disorder. *Annual Review of Medicine* **65**, 319–332.

Duchowski AT (2007) *Eye Tracking Methodology Theory and Practice*. London: Springer.

Echiverri AM, Jaeger JJ, Chen JA, Moore SA and Zoellner LA (2011) 'Dwelling in the past': the role of rumination in the treatment of post-traumatic stress disorder. *Cognitive and Behavioral Practice* **18**, 338–349.

Egeth HE and Yantis S (1997) Visual attention: control, representation, and time course. *Annual Review of Psychology* **48**, 269–297.

Ehlers A and Clark DM (2000) A cognitive model of posttraumatic stress disorder. *Behaviour Research and Therapy* **38**, 319–345.

Ehring T, Frank S and Ehlers A (2008) The role of rumination and reduced concreteness in the maintenance of posttraumatic stress disorder and depression following trauma. *Cognitive Therapy and Research* **32**, 488–506.

Eide P, Kemp A, Silberstein RB, Nathan PJ and Stough C (2002) Test-retest reliability of the emotional stroop task: examining the paradox of measurement change. *The Journal of Psychology* **136**, 514–520.

Fani N, Bradley-Davino B, Ressler KJ and McClure-Tone EB (2011) Attention bias in adult survivors of childhood maltreatment with and without posttraumatic stress disorder. *Cognitive Therapy and Research* **35**, 57–67.

Fani N, Jovanovic T, Ely TD, Bradley B, Gutman D, Tone EB and Ressler KJ (2012*a*) Neural correlates of attention bias to threat in post-traumatic stress disorder. *Biological Psychology* **90**, 134–142.

Fani N, Tone EB, Phifer J, Norrholm SD, Bradley B, Ressler KJ, Kamkwalala A and Jovanovic T (2012*b*) Attention bias toward threat is associated with exaggerated fear expression and impaired extinction in PTSD. *Psychological Medicine* **42**, 533–543.

Felmingham KL, Bryant RA and Gordon E (2003) Processing angry and neutral faces in post-traumatic stress disorder: an event-related potentials study. *Neuroreport* **14**, 777–780.

Felmingham KL, Rennie C, Manor B and Bryant RA (2011) Eye tracking and physiological reactivity to threatening stimuli in posttraumatic stress disorder. *Journal of Anxiety Disorders* **25**, 668–673.

Ferrari GRA, Mobius M, van Opdorp A, Becker ES and Rinck M (2016) Can't look away: an eye-tracking based attentional disengagement training for depression. *Cognitive Therapy and Research* **40**, 672–686.

Foa EB, Steketee G and Rothbaum BO (1989) Behavioral cognitive conceptualizations of post-traumatic stress disorder. *Behavior Therapy* **20**, 155–176.

Foa EB, Feske U, Murdock TB, Kozak MJ and Mccarthy PR (1991) Processing of threat-related information in rape victims. *Journal of Abnormal Psychology* **100**, 156–162.

Foa EB, Cashman L, Jaycox L and Perry K (1997) The validation of a self-report measure of posttraumatic stress disorder: the posttraumatic diagnostic scale. *Psychological Assessment* **9**, 445–451.

Fox E (1994) Attentional bias in anxiety: a defective inhibition hypothesis. *Cognition and Emotion* **8**, 165–195.

Fox E (2004) Maintenance or capture of attention in anxiety-related biases? and Yiend J (ed.), *Cognition, Emotion and Psychopathology: Theoretical, Empirical and Clinical Approaches*. Cambridge: Cambridge University Press, pp. 86–105.

Fox E, Russo R, Bowles R and Dutton K (2001) Do threatening stimuli draw or hold visual attention in subclinical anxiety? *Journal of Experimental Psychology: General* **130**, 681–700.

Freeman JB and Beck JG (2000) Cognitive interference for trauma cues in sexually abused adolescent girls with posttraumatic stress disorder. *Journal of Clinical Child Psychology* **29**, 245–256.

Gerdes ABM, Alpers GW and Pauli P (2008) When spiders appear suddenly: spider-phobic patients are distracted by task-irrelevant spiders. *Behaviour Research and Therapy* **46**, 174–187.

Goodwin H, Yiend J and Hirsch CR (2017) Generalized anxiety disorder, worry and attention to threat: a systematic review. *Clinical Psychology Review* **54**, 107–122.

Harvey AG, Bryant RA and Rapee RM (1996) Preconscious processing of threat in posttraumatic stress disorder. *Cognitive Therapy and Research* **20**, 613–623.

Hayes JP, Vanelzakker MB and Shin LM (2012) Emotion and cognition interactions in PTSD: a review of neurocognitive and neuroimaging studies. *Frontiers in Integrative neuroscience* **6**, 89.

Hayhoe M and Ballard D (2005) Eye movements in natural behavior. *Trends in Cognitive Sciences* **9**, 188–194.

Hermans D, Vansteenwegen D and Eelen P (1999) Eye movement registration as a continuous index of attention deployment: data from a group of spider anxious students. *Cognition and Emotion* **13**, 419–434.

Huijding J, Mayer B, Koster EHW and Muris P (2011) To Look or Not to Look: an eye movement study of hypervigilance during change detection in high and low spider fearful students. *Emotion* **11**, 666–674.

Iacoviello BM, Wu G, Abend R, Murrough JW, Feder A, Fruchter E, Levinstein Y, Wald I, Bailey CR, Pine DS, Neumeister A, Bar-Haim Y and Charney DS (2014) Attention bias variability and symptoms of post-traumatic stress disorder. *Journal of Traumatic Stress* **27**, 232–239.

In-Albon T and Schneider S (2010) Using eye tracking methodology in children with anxiety disorders. In Hadwin JA and Field AP (eds), *Information Processing Biases and Anxiety: A Developmental Perspective*. Chichester, UK: John Wiley & Sons Ltd, pp. 129–149.

Isaacowitz DM (2012) Mood regulation in real time: age differences in the role of looking. *Current Directions in Psychological Science* **21**, 237–242.

Isaacowitz DM and Choi Y (2012) Looking, feeling, and doing: are there age differences in attention, mood, and behavioral responses to skin cancer information? *Health Psychology* **31**, 650–659.

Jakupcak M, Conybeare D, Phelps L, Hunt S, Holmes HA, Felker B, Klevens M and McFall ME (2007) Anger, hostility, and aggression among Iraq and Afghanistan war veterans reporting PTSD and subthreshold PTSD. *Journal of Traumatic Stress* **20**, 945–954.

Jarde A, Losilla JM, Vives J and Rodrigo MF (2013) Q-Coh: a tool to screen the methodological quality of cohort studies in systematic reviews and meta-analyses. *International Journal of Clinical and Health Psychology* **13**, 138–146.

Just MA and Carpenter PA (1976) Eye fixations and cognitive-processes. *Cognitive Psychology* **8**, 441–480.

Kaczkurkin AN, Burton PC, Chazin SM, Manbeck AB, Espensen-Sturges T, Cooper SE, Sponheim SR and Lissek S (2017) Neural substrates of overgeneralized conditioned fear in PTSD. *American Journal of Psychiatry* **174**, 125–134.

Kaspi SP, McNally RJ and Amir N (1995) Cognitive processing of emotional information in posttraumatic stress disorder. *Cognitive Therapy and Research* **19**, 433–444.

Kimble MO, Frueh BC and Marks L (2009) Does the modified stroop effect exist in PTSD? Evidence from dissertation abstracts and the peer reviewed literature. *Journal of Anxiety Disorders* **23**, 650–655.

Kimble MO, Fleming K, Bandy C, Kim J and Zambetti A (2010) Eye tracking and visual attention to threating stimuli in veterans of the Iraq War. *Journal of Anxiety Disorders* **24**, 293–299.

Kimble MO, Boxwala M, Bean W, Maletsky K, Halper J, Spollen K and Fleming K (2014) The impact of hypervigilance: evidence for a forward feedback loop. *Journal of Anxiety Disorders* **28**, 241–245.

Knight M, Seymour TL, Gaunt JT, Baker C, Nesmith K and Mather M (2007) Aging and goal-directed emotional attention: distraction reverses emotional biases. *Emotion* **7**, 705–714.

Konnert C and Wong M (2015) Age differences in PTSD among Canadian veterans: age and health as predictors of PTSD severity. *International Psychogeriatrics* **27**, 297–304.

Kowler E, Anderson E, Dosher B and Blaser E (1995) The role of attention in the programming of saccades. *Vision Research* **35**, 1897–1916.

Kruijt AW, Field AP and Fox E (2016) Capturing dynamics of biased attention: are new attention variability measures the way forward? *Plos ONE* **11**, e0166600.

Krystal JH, Davisd LL, Neylanf TC, Raskindj MA, Schnurrl PP, Steinh MB, Vessicchiob J, Shinerl B, Gleasona TD and Huangn GD (2017) It is time to address the crisis in the pharmacotherapy of posttraumatic stress disorder: a consensus statement of the PTSD psychopharmacology working group. *Biological Psychiatry* **82**, e51–e59.

Lang PJ, Bradley MM, Fitzsimmons JR, Cuthbert BN, Scott JD, Moulder B and Nangia V (1998) Emotional arousal and activation of the visual cortex: an fMRI analysis. *Psychophysiology* **35**, 199–210.

Lang PJ, Bradley MM and Cuthbert BN (2008) *International affective picture system* (*IAPS*)*: Affective ratings of pictures and instruction manual* (Technical Report A-8). Gainesville, FL: University of Florida.

Lazarov A, Abend R and Bar-Haim Y (2016) Social anxiety is related to increased dwell time on socially threatening faces. *Journal of Affective Disorders* **193**, 282–288.

Lazarov A, Neria Y, Edmondson DE, Falzon L and Tamman A (2017*a*) *Eye tracking of attention to threat in post-traumatic stress disorder* (*PTSD*). PROSPERO 2017 CRD42017056785.

Lazarov A, Pine DS and Bar-Haim Y (2017*b*) Gaze-contingent music reward therapy for social anxiety disorder: a randomized controlled trial. *American Journal of Psychiatry* **174**, 649–656.

Lazarov A, Ben-Zion Z, Shamai D, Pine DS and Bar-Haim Y (2018) Free viewing of sad and happy faces in depression: a potential target for attention bias modification. *Journal of Affective Disorders* **238**, 94–100.

Lee JH and Lee JH (2012) Attentional bias to violent images in survivors of dating violence. *Cognition and Emotion* **26**, 1124–1133.

Lee JH and Lee JH (2014) Attentional bias towards emotional facial expressions in survivors of dating violence. *Cognition and Emotion* **28**, 1127–1136.

Litz BT and Keane TM (1989) Information processing in anxiety disorders: application to the understanding of post-traumatic stress disorder. *Clinical Psychology Review* **9**, 243–257.

Macatee RJ, Albanese BJ, Schmidt NB and Cougle JR (2017) Attention bias towards negative emotional information and its relationship with daily worry in the context of acute stress: an eye-tracking study. *Behaviour Research and Therapy* **90**, 96–110.

MacLeod C, Mathews A and Tata P (1986) Attentional bias in emotional disorders. *Journal of Abnormal Psychology* **95**, 15–20.

Martinson AA, Sigmon ST, Craner J, Rothstein E and McGillicuddy M (2013) Processing of intimacy-related stimuli in survivors of sexual trauma: the role of PTSD. *Journal of Interpersonal Violence* **28**, 1886–1908.

Mather M and Carstensen LL (2005) Aging and motivated cognition: the positivity effect in attention and memory. *Trends in Cognitive Sciences* **9**, 496–502.

Matlow RB (2013) *Attentional processes associated with victimization history and posttraumatic symptomatology in women exposed to intimate partner violence* (Doctoral dissertation). University of Denver.

McNally RJ (2018) Attentional bias for threat: crisis or opportunity? *Clinical Psychology Review*. https://doi.org/10.1016/j.cpr.2018.05.005

McNally RJ, Kaspi SP, Riemann BC and Zeitlin SB (1990) Selective processing of threat cues in posttraumatic stress disorder. *Journal of Abnormal Psychology* **99**, 398–402.

McNally RJ, Amir N and Lipke HJ (1996) Subliminal processing of threat cues in posttraumatic stress disorder? *Journal of Anxiety Disorders* **10**, 115–128.

Michael T, Halligan SL, Clark DM and Ehlers A (2007) Rumination in post-traumatic stress disorder. *Depression and Anxiety* **24**, 307–317.

Miltner WHR, Krieschel S, Hecht H, Trippe R and Weiss T (2004) Eye movements and behavioral responses to threatening and nonthreatening stimuli during visual search in phobic and nonphobic subjects. *Emotion* **4**, 323–339.

Mogg K and Bradley BP (2004) A cognitive-motivational perspective on the processing of threat information and anxiety. In Yiend J (ed.), *Cognition, Emotion and Psychopathology: Theoretical, Empirical and Clinical Approaches*. Cambridge: Cambridge University Press, pp. 68–85.

Mogg K, Bradley BP, De Bono J and Painter M (1997) Time course of attentional bias for threat information in non-clinical anxiety. *Behaviour Research and Therapy* **35**, 297–303.

Moher D, Liberati A, Tetzlaff J, Altman DG and Group P (2009) Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. *BMJ* **339**, b2535.

Most SB, Chun MM, Widders DM and Zald DH (2005) Attentional rubbernecking: cognitive control and personality in emotion-induced blindness. *Psychonomic Bulletin & Review* **12**, 654–661.

Mulckhuyse M, Crombez G and Van der Stigchel S (2013) Conditioned fear modulates visual selection. *Emotion* **13**, 529–536.

Mulkens SAN, deJong PJ and Merckelbach H (1996) Disgust and spider phobia. *Journal of Abnormal Psychology* **105**, 464–468.

Mylle J and Maes M (2004) Partial posttraumatic stress disorder revisited. *Journal of Affective Disorders* **78**, 37–48.

Naim R, Abend R, Wald I, Eldar S, Levi O, Fruchter E, Ginat K, Halpern P, Sipos ML, Adler AB, Bliese PD, Quartana PJ, Pine DS and Bar-Haim Y (2015) Threat-related attention bias variability and posttraumatic stress. *American Journal of Psychiatry* **172**, 1242–1250.

Nikitin J and Freund AM (2011) Age and motivation predict gaze behavior for facial expressions. *Psychology and Aging* **26**, 695–700.

Ohman A, Flykt A and Esteves F (2001) Emotion drives attention: detecting the snake in the grass. *Journal of Experimental Psychology-General* **130**, 466–478.

Olatunji BO, Armstrong T, McHugo M and Zald DH (2013) Heightened attentional capture by threat in veterans with PTSD. *Journal of Abnormal Psychology* **122**, 397–405.

Pineles SL, Shipherd JC, Welch LP and Yovel I (2007) The role of attentional biases in PTSD: Is it interference or facilitation? *Behaviour Research and Therapy* **45**, 1903–1913.

Pineles SL, Shipherd JC, Mostoufi SM, Abramovitz SM and Yovel I (2009) Attentional biases in PTSD: more evidence for interference. *Behaviour Research and Therapy* **47**, 1050–1057.

Posner MI (1980) Orienting of attention. *Quarterly Journal of Experimental Psychology* **32**, 3–25.

Price RB, Kuckertz JM, Siegle GJ, Ladouceur CD, Silk JS, Ryan ND, Dahl RE and Amir N (2015) Empirical recommendations for improving the stability of the dot-probe task in clinical research. *Psychological Assessment* **27**, 365–376.

Price RB, Greven IM, Siegle GJ, Koster EHW and De Raedt R (2016) A novel attention training paradigm based on operant conditioning of eye gaze: preliminary findings. *Emotion* **16**, 110–116.

Reid LM, McMillan TM and Harrison AG (2011) PTSD, attention bias, and heart rate after severe brain injury. *The Journal of Neuropsychiatry and Clinical Neurosciences* **23**, 454–456.

Reinholdt-Dunne ML, Mogg K, Benson V, Bradley BP, Hardin MG, Liversedge SP, Pine DS and Ernsts M (2012) Anxiety and selective attention to angry faces: an antisaccade study. *Journal of Cognitive Psychology* **24**, 54–65.

Richards HJ, Benson V and Hadwin JA (2012) The attentional processes underlying impaired inhibition of threat in anxiety: the remote distractor effect. *Cognition and Emotion* **26**, 934–942.

Rinck M, Reinecke A, Ellwart T, Heuer K and Becker ES (2005) Speeded detection and increased distraction in fear of spiders: evidence from eye movements. *Journal of Abnormal Psychology* **114**, 235–248.

Rodebaugh TL, Scullin RB, Langer JK, Dixon DJ, Huppert JD, Bernstein A, Zvielli A and Lenze EJ (2016) Unreliability as a threat to understanding psychopathology: the cautionary tale of attentional bias. *Journal of Abnormal Psychology* **125**, 840–851.

Sanchez A, Vazquez C, Marker C, LeMoult J and Joormann J (2013) Attentional disengagement predicts stress recovery in depression: an eye-tracking study. *Journal of Abnormal Psychology* **122**, 303–313.

Sarapas C, Weinberg A, Langenecker SA and Shankman SA (2017) Relationships among attention networks and physiological responding to threat. *Brain and Cognition* **111**, 63–72.

Schmukle SC (2005) Unreliability of the dot probe task. *European Journal of Personality* **19**, 595–605.

Schofield CA, Johnson AL, Inhoff AW and Coles ME (2012) Social anxiety and difficulty disengaging threat: evidence from eye-tracking. *Cognition and Emotion* **26**, 300–311.

Schoorl M, Putman P and van Der Does W (2013) Attentional bias modification in posttraumatic stress disorder: a randomized controlled trial. *Psychotherapy and Psychosomatics* **82**, 99–105.

Sergerie K, Chochol C and Armony JL (2008) The role of the amygdala in emotional processing: a quantitative meta-analysis of functional neuroimaging studies. *Neuroscience and Biobehavioral Reviews* **32**, 811–830.

Shechner T, Jarcho JM, Britton JC, Leibenluft E, Pine DS and Nelson EE (2013) Attention bias of anxious youth during extended exposure of emotional face pairs: an eye-tracking study. *Depression and Anxiety* **30**, 14–21.

Sheehan DV, Lecrubier Y, Sheehan KH, Amorim P, Janavs J, Weiller E, Hergueta T, Baker R and Dunbar GC (1998) The Mini-International Meuropsychiatric Interview (MINI): the development and validation of a structured diagnostic psychiatric interview for DSM-IV and ICD-10. *Journal of Clinical Psychiatry* **59**, 22–33.

Shin LM, Whalen PJ, Pitman RK, Bush G, Macklin ML, Lasko NB, Orr SP, McInerney SC and Rauch SL (2001) An fMRI study of anterior cingulate function in posttraumatic stress disorder. *Biologocal Psychiatry* **50**, 932–942.

Shvil E, Rusch HL, Sullivan GM and Neria Y (2013) Neural, psychophysiological, and behavioral markers of fear processing in PTSD: a review of the literature. *Current Psychiatry Reports* **15**, 358.

Sipos ML, Bar-Haim Y, Abend R, Adler AB and Bliese PD (2014) Postdeployment threat-related attention bias interacts with combat exposure to account for PTSD and anxiety symptoms in soldiers. *Depression and Anxiety* **31**, 124–129.

Skinner IW, Hubscher M, Moseley GL, Lee H, Wand BM, Traeger AC, Gustin SM and McAuley JH (2017) The reliability of eyetracking to assess attentional bias to threatening words in healthy individuals. *Behavior Research Methods*, 1–15.

Smith DT, Rorden C and Jackson SR (2004) Exogenous orienting of attention depends upon the ability to execute eye movements. *Current Biology* **14**, 792–795.

Spaniol J, Voss A and Grady CL (2008) Aging and emotional memory: cognitive mechanisms underlying the positivity effect. *Psychology and Aging* **23**, 859–872.

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

Spitzer RL, Williams JB, Gibbons M and First M (1996) *Structured Clinical Interview for the DSM-IV. Axis I Disorders*. New York: Biometrics Research Department, New York State Psychiatric Institute.

Staugaard SR (2009) Reliability of two versions of the dot-probe task using photographic faces. *Psychology Science* **51**, 339–350.

Stewart LH (2012) *Capturing hypervigilance: attention biases in elevated trait anxiety and posttraumatic stress disorder* (Doctoral dissertation). UCL (University College London).

Strauss GP, Allen DN, Jorgensen ML and Cramer SL (2005) Test-retest reliability of standard and emotional stroop tasks - An investigation of color-word and picture-word versions. *Assessment* **12**, 330–337.

Thomas BH, Ciliska D, Dobbins M and Micucci S (2004) A process for systematically reviewing the literature: providing the research evidence for public health nursing interventions. *Worldviews on Evidence-Based Nursing* **1**, 176–184.

Thomas CL, Goegan LD, Newman KR, Arndt JE and Sears CR (2013) Attention to threat images in individuals with clinical and subthreshold symptoms of post-traumatic stress disorder. *Journal of Anxiety Disorders* **27**, 447–455.

Tolin DF, Lohr JM, Lee TC and Sawchuk CN (1999) Visual avoidance in specific phobia. *Behaviour Research and Therapy* **37**, 63–70.

Verwoerd J, Wessel I, de Jong PJ and Nieuwenhuis MMW (2009) Preferential processing of visual trauma-film reminders predicts subsequent intrusive memories. *Cognition and Emotion* **23**, 1537–1551.

Verwoerd J, Wessel I and de Jong PJ (2010) Attentional bias for trauma-film reminders: towards a laboratory analogue for studying the role of attention in the persistence of intrusive memories. *Applied Cognitive Psychology* **24**, 425–436.

Waechter S and Stolz JA (2015) Trait anxiety, state anxiety, and attentional bias to threat: assessing the psychometric properties of response time measures. *Cognitive Therapy and Research* **39**, 441–458.

Waechter S, Nelson AL, Wright C, Hyatt A and Oakman J (2014) Measuring attentional bias to threat: reliability of dot probe and eye movement indices. *Cognitive Therapy and Research* **38**, 313–333.

Wald I, Shechner T, Bitton S, Holoshitz Y, Charney DS, Muller D, Fox NA, Pine DS and Bar-Haim Y (2011) Attention bias away from threat during life threatening danger predicts ptsd symptoms at one-year follow-up. *Depression and Anxiety* **28**, 406–411.

Wald I, Degnan KA, Gorodetsky E, Charney DS, Fox NA, Fruchter E, Goldman D, Lubin G, Pine DS and Bar-Haim Y (2013) Attention to threats and combat-related posttraumatic stress symptoms prospective associations and moderation by the serotonin transporter gene. *JAMA Psychiatry* **70**, 401–409.

Wald I, Fruchter E, Ginat K, Stolin E, Dagan D, Bliese PD, Quartana PJ, Sipos ML, Pine DS and Bar-Haim Y (2016) Selective prevention of combat-related post-traumatic stress disorder using attention bias modification training: a randomized controlled trial. *Psychological Medicine* **46**, 2627–2636.
Weathers F, Litz BT, Huska JA and Keane TM (1991). *The PTSD Checklist (PCL)*. Boston VA Medical Centre: Boston: National Centre for PTSD.
Weierich MR, Treat TA and Hollingworth A (2008) Theories and measurement of visual attentional processing in anxiety. *Cognition and Emotion* **22**, 985–1018.
Wermes R, Lincoln TM and Helbig-Lang S (2017) How well can we measure visual attention? Psychometric properties of manual response times and first fixation latencies in a visual search paradigm. *Cognitive Therapy and Research* **41**, 588–599.
Williams JMG, Mathews A and MacLeod C (1996) The emotional stroop task and psychopathology. *Psychological Bulletin* **120**, 3–24.
Wolfe J, Kimerling R, Brown PJ, Chrestman KR and Levin K (1996). Psychometric review of the life stressor checklist-revised. In Stamm BH (ed.), *Measurement of Stress, Trauma, and Adaptation*. Lutherville, MD: Sidran Press, pp. 198–201.
Wright RD and Ward LM (2008) *Orienting of Attention*. Oxford, New York: Oxford University Press.
Yiend J (2010) The effects of emotion on attention: a review of attentional processing of emotional information. *Cognition and Emotion* **24**, 3–47.