Attention training normalises combat-related post-traumatic stress disorder effects on emotional Stroop performance using lexically matched word lists

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ABSTRACT
We examined two groups of combat veterans, one with post-traumatic stress disorder (PTSD) ($n = 27$) and another without PTSD ($n = 16$), using an emotional Stroop task (EST) with word lists matched across a series of lexical variables (e.g. length, frequency, neighbourhood size, etc.). Participants with PTSD exhibited a strong EST effect (longer colour-naming latencies for combat-relevant words as compared to neutral words). Veterans without PTSD produced no such effect, $t < .918, p > .37$. Participants with PTSD then completed eight sessions of attention training (Attention Control Training or Attention Bias Modification Training) with a dot-probe task utilising threatening and neutral faces. After training, participants—especially those undergoing Attention Control Training—no longer produced longer colour-naming latencies for combat-related words as compared to other words, indicating normalised attention allocation processes after treatment.

The Stroop task and its variants (e.g. the emotional Stroop task, EST) are used to measure attention allocation across multiple dimensions of task stimuli. In the classic Stroop task (Stroop, 1935), participants view colour words (e.g. red) in various ink colours (e.g. blue or green ink) and are asked to ignore the actual word, and instead indicate the ink colour. The congruency of the ink colour and the word influences the colour-naming response of participants. For example, participants are relatively faster to indicate that the word red is written in red ink, as compared to if the word is blue. This pattern of reaction time differences is assumed to reflect the greater attention and inhibition demands needed for incongruent as compared to congruent trials. Thus, the classic Stroop task is assumed to use extensive executive function and inhibition operations (e.g. Williams, Mathews, & Macleod, 1996).

Similarly, in the EST, participants identify the colour of ink in which a word is written, while ignoring the word’s meaning. However, in the EST, words vary in emotional salience rather than in their colour congruence with the ink. For example, EST trials usually contain words that are either negative (e.g. bomb, murder) or neutral (e.g. cat). Thus, emotionally salient words (bomb) could draw attention away from the colour-naming mechanism, and result in relatively longer reaction times compared with neutral words. This pattern of behaviour consistently is found in individuals with anxiety disorders and post-traumatic stress disorder PTSD (e.g. Cisler et al., 2011 for a recent review, but also see Kimble, Frueh, & Marks, ...
who question this assumption), but not in psychologically healthy individuals (e.g. Williams et al., 1996). Thus, the EST often is used as an indication of attentional bias in individuals with specific disorders such as PTSD (Williams et al., 1996).

Unfortunately, most EST studies have used questionable stimuli. Larsen, Mercer, and Balota (2006) found the majority of EST studies used stimuli lists that systematically varied such that emotionally salient lists (e.g. the threat lists) included words that were longer, less-frequent, and had more unusual spellings (i.e. smaller orthographic neighbourhoods) than words in other lists. Such differences could lead to longer reaction times for emotionally salient lists as compared to other lists. Thus, response time differences across lists may be more closely linked to lexical feature differences than to attention allocation patterns (Larsen et al., 2006). We know of no EST study in individuals with PTSD that has controlled for all of the lexical variables indicated by Larsen and colleagues (although Ashley, Honzel, Larsen, Justus, & Swick, 2013, controlled for some lexical features).

Thus, one goal of the current study was to verify the emotional Stroop effect in veterans with PTSD using word lists highly controlled in their lexical features. To this end, we used the English Lexicon Project (ELP, Balota et al., 2007) databases to verify that our lists were matched in frequency (Lund & Burgess, 1996), length, mean naming latencies, and mean lexical decision times. We also controlled for orthographic and phonological neighbourhood size (cf., Balota et al., 2007). By controlling for these lexical features, we will be able to verify that differences in our participants’ colour-naming latencies are due to semantic processing differences rather than to lexical factor differences.

**EST in PTSD**

EST performance in individuals with stress-related disorders suggests aberrant attention allocation. The delayed colour naming of threat-related words, suggests attention is focused on the meaning of the threatening word (e.g. bomb) rather than on the word’s colour. Such altered attention allocation could result from a hyperactive threat detection network due to hyperarousal of the amygdala and/or attenuated activity within the prefrontal cortex (PFC; Cisler et al., 2011) or a compromised attention network that is unable to reliably direct attention towards task demands and away from perceived threat (Bar-Haim, 2010). Either mechanism could lead to a preoccupation with threatening stimuli, which is consistent with the pattern of reaction times seen in the EST.

**Attention-training treatments for PTSD**

Recently developed computerised attention training may help individuals with limited abilities to direct attention to task demands in the face of threat, normalise attention allocation. Attention bias modification treatment (ABMT), is designed to reduce attention bias towards threat commonly observed in anxiety disorders. ABMT has benefitted patients with generalised anxiety disorder (Amir, Beard, Burns, & Bomyea, 2009), social anxiety disorder (Schmidt, Richey, Buckner, & Timpano, 2009), and, more recently, PTSD (Kuckertz et al., 2014). PTSD, however, is more complicated as some studies support attention bias towards threat for PTSD (Bryant & Harvey, 1997), while other studies suggest that threat avoidance is the more typical pattern (e.g. Bar-Haim et al., 2010). A variation on ABMT, termed attention control treatment (ACT), often is used as the control treatment within ABMT studies (e.g. Eldar et al., 2012), because the response stimulus is presented equally often in a space vacated by a preceding stimulus that is either threatening or non-threatening. Viewed as a training schedule, ACT implicitly encourages PTSD patients to disengage from threatening information and focus on the competing cognitive task, rather than specifically training attention away from threat as ABMT does. Due to the nature of the EST, in which the threat (e.g. combat-relevant word) and the task-relevant information (the ink colour) are displayed within the same stimulus, ACT should produce normalisation of EST performance because ACT helps patients to focus on current cognitive demands in the face of threat, not just to avoid threat.

Thus, the current study has two goals. First, we wanted to demonstrate an emotional Stroop effect (i.e. relatively slower reaction times for threatening stimuli) in PTSD when word lists were closely matched across lexical features. Second, we wanted to determine whether attention training improves attention allocation in the EST for patients with PTSD, and if so, whether ACT or ABMT resulted in a stronger normalising effect.

**Method**

**Participants**

Forty-one male US military veterans from the Omaha area with recent combat service in Iraq or Afghanistan...
participated in this study. Twenty-six had PTSD and 15 did not according to scores on the Clinician Administered PTSD Scale (CAPS) (Blake et al., 1995). The mean CAPS score was 75.31 for the PTSD group and 20.4 for the group without PTSD. The groups were matched in age, education level, ethnicity, and handedness. We used the Mini International Neuropsychiatric Interview (Sheehan et al., 1998) to establish that the non-PTSD group had no psychiatric diagnoses, and the PTSD group did not have additional psychiatric diagnoses other than anxiety or depression better explained by PTSD. Participants also were excluded if they had medical diagnoses that could better explained by PTSD. Participants also were excluded if they had medical diagnoses that could affect central nervous system functioning, history of significant brain trauma, or current substance dependence. Fourteen participants on stable doses of psychotropic medications for at least six months were allowed to remain in the study (four SSRI, four mood stabiliser, and six benzodiazepine). All participants gave written informed consent to participate. The Creighton University Institutional Review Board approved the study.

**Emotional Stroop task**

For the EST, we prepared three word lists, a combat-related threat list, a negative list, and a neutral list. Each list contained 30 monosyllabic words. The combat-related threat words included things encountered in war (e.g. bomb), the negative words were negative in valence, but not related to combat (e.g. tax). The neutral words were not threatening (e.g. tune). We determined if words were included in the appropriate lists based on our judgments, and those of a recent veteran to verify combat-relevance. The three word lists were equated across lexical features including: length, frequency, orthographic, and phonological neighbourhood size. Using the ELP database, we also equated word lists on average naming latency, naming accuracy, lexical decision time, and lexical decision accuracy (Balota et al., 2007). The three lists did not differ across these factors, all $F$'s < 1.09, $p$ > .34. However, the lists did differ according to their Arousal and Valence ratings, $F(2, 89) = 233.406, MSW = .111, p < .0001$; $F(2, 89) = 273.218, MSW = .283, p < .0001$, respectively. These arousal and valence ratings were taken from Estes and Adelman (2008). As expected, the combat-related words had higher arousal and lower valence ratings than neutral words (both $t$'s > 20.4 and $p$'s < .0001), but importantly, these combat-related words did not differ from the negative words in terms of arousal or valence (all $t$'s < 1.45, and $p$'s > .152). In addition, the negative words had higher arousal and lower valence ratings than the neutral words (both $t$'s > 19.22 and $p$'s < .0001).

The task contained 9 experimental blocks, each consisting of 30 colour word naming trials from one of our EST lists. We used a blocked design because, as Cisler et al. (2011) noted, they are more powerful and often lead to more robust emotional Stroop responses. Participants were naïve to the existence of the different word lists per block. The order of the words within each list was randomised across presentation blocks. Within each trial, participants first viewed a fixation cross for 1 s, which was replaced by a list item that remained on the screen for 2 s. An experimenter coded the participant’s response as correct (i.e. correct colour identification), incorrect (i.e. did not name a colour, named the wrong colour, or named the word), or as a noise trial (e.g. the participant coughed, etc.). The items were centred horizontally/vertically on a 43.5 by 35 cm (width x height) screen and positioned at eye-level approximately 110 cm from the head. Items were presented in red, blue, or green font, and item colour was randomly assigned. Reaction times were measured using a dual-plane accelerometer attached to the lower lip and digitised at 1 kHz using a Grass amplifier. Voice onset was determined by a sharp increase in the amplitude of the accelerometer signal, which produces response time accuracy near 1 ms.

**Attention training**

Participants with PTSD completed eight sessions of attention training within a month and returned for EST retesting using the same lists and procedures as the pre-training session. Seventeen of the 26 participants with PTSD had both pre- and post-training EST data. Regarding attrition, six participants dropped-out during training, and EST data for three participants was lost due to equipment failures (e.g. accelerometer) during either the pre- or post-testing sessions. Similar drop-out rates have been found in previous studies of individuals with PTSD, especially for multiple session studies (see Imel, Laska, Jakupcak, & Simpson, 2013, for a review). For attention training, we used a faces-based version of the dot-probe task in which one angry and one neutral face were displayed simultaneously, one above the other, on the computer screen. Each training trial began with a fixation cross (500 ms), followed by a face pair (500 ms), followed by a target display (“<” or “>”) in the
space vacated by one of the faces. Participants indicated the direction of the probe using a computer mouse. Eight participants completed ABMT in which they were trained away from threat by placing the target probes in the space previously occupied by a neutral face in each of the 160 trials. Nine participants completed ACT, which was identical to the ABMT version, except that the probe appeared equally behind angry and neutral faces in a fully counterbalanced fashion.

The only published randomised clinical trials of ABMT/ACT for PTSD have reached varied results, with a stand-alone clinical trial favouring ACT (Badura Brack et al., in press), an adjunctive treatment study favouring ABMT (Kuckertz et al., 2014), and a third showing no difference between groups (Schoorl, Putman, & Van der Does, 2013). Thus, we analysed the effects of attention training in two ways. First, we collapsed the ABMT and ACT groups into one overarching attention-training group to see if we found EST performance differences for participants after attention training. Second, we performed separate pre- and post-training analyses for the two treatment groups.

Results

Pre-analyses data-trimming

Before conducting colour-naming latency analyses, we performed standard data-trimming procedures. First, we excluded incorrect and noise trials. Next, we calculated each participant’s mean and SD of response times across all word lists. We trimmed scores that were 2.5 SD or more away from the participant’s response mean. This trimming procedure eliminated less than 5.1% of all trials.

Pre-training: comparison between PTSD and non-PTSD groups

To compare emotional Stroop performance of the two groups, we conducted a 2 (group: PTSD versus non-PTSD) × 3 (list: combat-related threat, negative, neutral) × 3 (block order) repeated measures ANOVA on the colour-naming latencies. We included block order because we used a fixed order of lists across participants, and wanted to ensure that any list effects were not due to list order, but rather to the lists’ semantic content. From this overall ANOVA, we did not find a three-way interaction of group, list, and block order. We also did not find an interaction of block order and list, an interaction of block order and group, or main effects of block or list (all $F$s $< 1.87$, all $p$s $> .161$). Most importantly, we found an interaction of group and list, $F(2, 80) = 4.094$, MSE = 2893.89, $p = .02$. We also found a marginal main effect of group, $F(1, 40) = 3.287$, MSE = 193132.02, $p = .077$, with the PTSD group producing overall longer response times than the non-PTSD group (731.34 (192.68), and 641.45 (99.67), respectively). In Table 1, we provide mean and SD colour-naming latencies across lists and blocks for both participant groups. These data clearly show differences between the two participant groups in colour-naming latencies per list, and also highlight the fact that there were no effects of block order for either group.

Next, because we found an interaction of group and list, we examined colour-naming latencies across lists within each group, separately. In post hoc paired samples $t$-tests, we found participants with PTSD were slower for combat-related compared to neutral words ($t(26) = 2.63, p = .014$), slower for the combat-related compared to negative words ($t(26) = 2.342, p = .027$), and marginally slower for the negative list compared to the neutral list ($t(26) = 1.801, p = .083$). For participants without PTSD, the average colour-naming times did not differ across lists, all t’s $< 1.33$ and p’s $> .20$. Mean response times for the combat-related, negative, and neutral lists for each group are shown in Figure 1.

We analysed the accuracy of the colour-naming task by conducting a 2 (group: PTSD versus non-PTSD) × 3 (list: combat-related, negative, neutral) × 3 (block order) repeated measures ANOVA on the colour-naming accuracy. From this, we found only a main effect of list, $F(2, 160) = 6.68$, MSE = .003, $p = .002$. Follow-up $t$-tests indicate that the Combat-related list had lower accuracy rates as compared to either of the other list, ($t > 2.858$, $p s < .007$), while the other lists did not differ from one another in accuracy rates, $t < .563$, $p > .57$. The mean accuracy rates were, 94.6%, 97.1%, and 97.3%, for the combat-relevant, negative, and neutral lists, respectively. We could not analyse these data for type of error due to the restricted range of values (i.e. ceiling effects) and would caution strong interpretation.

Pre- to Post-Training comparisons

First, we examined the effects of attention training on PTSD severity by comparing pre- and post-training
measures on the CAPS. We found that PTSD symptomatology improved after attention training (pre-training CAPS mean = 75.31, post-training CAPS mean = 51.12, \(t(16) = 4.642, p < .001\)). However, there was no interaction in the CAPS score change across the two treatment types (\(F < 1\)).

To examine the effect of attention training on attention allocation in the EST, we conducted a 2 (time: pre- versus post-treatment) × 3 (list: combat-related, negative, neutral) repeated measures ANOVA for the two training groups combined. We found a significant interaction between time and list, \(F(2, 32) = 3.44, MSE = 1850.95, p = .044\), and a main effect of time, \(F(1, 16) = 7.945, MSE = 18735.565, p = .012\), but no main effect of list (\(F < 1.07\)). Participants responded faster across all lists during the post-training session as compared to the pre-training session (all \(t s > 2.813\) and \(ps < .032\)), although the combat-related threat list had the greatest pre/post change in colour-naming latency (see Figure 1). Subsequent analyses revealed that after training, latencies for the combat-related list no longer differed from the other lists. In addition, we compared EST performance of the veterans with PTSD after training with our non-PTSD combat veterans and found that there were no longer group differences performance, all independent samples \(ts < .287\) and \(ps > .77\) (Figure 1).

Finally, we performed a series of planned analyses to examine the influence of ACT and ABMT on attention allocation. We conducted separate 2 (time) × 3 (List) repeated measures ANOVAs for the ACT and ABMT groups. For the ACT group, we found an interaction of time and list, \(F(2, 16) = 4.409, MSE = 832.41, p = .03\), and a marginal effect of time, \(F(1, 8) = 4.471, MSE = 5306.99, p = .067\), but no main effect of list (\(F < 1.475, p > .257\)). The interaction indicated there was a reliable decrease in colour-naming latencies for the combat-relevant list, \(t(8) = 3.562, p = .007\), but not the other two lists, both \(t's < 1.31\) and \(p's > .227\). In the ABMT group, the same repeated measures ANOVA indicated no interaction of these factors (\(F < 1\)) and no effect of list. There was a marginal main effect of time, \(F(1, 7) = 4.993, MSE = 31887.79, p = .061\), with a marginal decrease in colour-naming latencies across time.

### Discussion

Our initial comparison of combat veterans with PTSD to those without PTSD indicated that only those with PTSD exhibited a combat-related EST effect, as has been found in previous studies (e.g. Williams et al., 1996; and please see Cisler et al., 2011 for a review). Essentially, the veterans with PTSD showed longer colour-naming latencies for words semantically related to combat (e.g. bomb) compared to words unrelated to combat (e.g. tax), when using word lists with highly controlled lexical features. The group without PTSD showed similar response times across all three lists. This pattern of behaviour indicates participants with PTSD allocate more attentional resources towards combat-related threatening words relative to other words. These results coincide with a recent meta-analysis that revealed attention bias towards threat in anxiety disorders is greater.
towards disorder-congruent stimuli as compared to disorder-incongruent stimuli (Pergamin-Hight, Naim, Bakermans-Kranenburg, van IJsendoorn, & Bar-Haim, 2015). In fact, most previous studies of individuals with PTSD have shown a similar EST response (Cisler et al.), but Kimble and colleagues (2009) recently questioned the existence of such an EST effect in individuals with PTSD. Also, work by Larsen et al. (2006) questioned the existence of an EST effect secondary to using lists not matched on lexical factors. Thus, it is important to note that we found a reliable combat-related EST effect in participants with PTSD using lists of words highly controlled on important lexical features. These results provide strong evidence that participants with PTSD allocate more attention to combat-related threat words than to other words.

Our attention training results indicate that, after training, veterans with PTSD no longer produced longer colour-naming latencies for combat-related words as compared to other words. This suggests participants no longer allocated more attention to combat-related words than to other words, and in fact, EST performance of veterans with PTSD after treatment did not significantly differ from that of the combat control group, suggesting that attention training normalised attention allocation in these patients. However, these results should be taken with caution, as we did not have an overt control group of participants with PTSD who did not undergo any type of attention training and who were tested and re-tested eight-weeks apart. Thus, our results of improved EST performance after training could simply reflect practice effects. On the other hand, the two training groups, ABMT and ACT, differed in their pattern of EST performance after training, which we feel suggests that our results probably reflect more than placebo or simple practice effects.

Interestingly, this normalisation of attention allocation coincided with significantly improved PTSD symptomatology. Our separate analyses of the ACT and ABMT groups on EST performance suggest that ACT training may be particularly effective at normalising attention allocation. Because PTSD patients do not reliably demonstrate attention bias towards threat, treatments designed to reduce threat bias (ABMT) should not be expected to produce ideal therapeutic effects. Instead, higher levels of attention bias variability have been consistently associated with higher levels of PTSD symptomology (Iacoviello et al., 2014), and we recently demonstrated that reductions in this variability partially mediate reductions in PTSD severity associated with the efficacy of ACT (Badura-Brack et al., in press). Our current study echoes this recent evidence on normalised attention allocation patterns in PTSD after ACT. Given our EST results, we propose that veterans with PTSD have increased success disengaging from task irrelevant threat cues (combat words) to complete a competing cognitive task (colour naming) after ACT, relative to ABMT. Future research should follow-up on these preliminary findings, and the potential efficacy of ACT as an intervention specifically suited to address the dichotomous vigilant/avoidant symptom picture of PTSD.

Before closing, we note some limitations of the current study. First, we included only male combat veterans and our sample sizes were modest. Future studies should include women, larger samples, and other types of trauma. Second, we did not include an ideal comparison group of combat veterans with PTSD who completed an EST pre-test, eight-weeks of no-training visits to our lab, and then returned for the EST post-test. Such a PTSD comparison group would likely show an EST Effect both before and after the no-training visits, and thus supply converging validity that the dissipation of the EST Effect observed in the current study was because of the attention training and not practice or placebo effects. Because we did not include this ideal comparison group, our results should be viewed as promising, but preliminary. Another possible limitation is that the changes we observed in EST performance (i.e. a relative decrease in latencies for the combat-related lists) were not correlated with changes in CAPS scores. We believe this is because attention aberrations are just one component of PTSD symptomatology. The CAPS is designed to measure a much broader spectrum of PTSD symptoms, while the EST that we designed was only meant to gauge attention allocation aberrations. Thus, the pre- to post-training changes in EST performance suggest only that our training can help normalise this attentional component of PTSD.

Despite these limitations, we believe our findings can inform future research on the effects of behavioural training on attention allocation in both psychiatric patients and healthy participants. In the current study, we found changes in EST performance after training designed to normalise attention allocation processes in the face of threat; future studies should examine whether interventions designed to
enhance executive functioning without regard to threat would also improve EST performance. This seems especially relevant given the transfer of training across threat stimuli, from faces to words, in this study. Perhaps our EST results are tied specifically to threat-based training that allows veterans with PTSD to learn disengagement from threat, but these results could also reflect more general normalisation of attention allocation processes. Future research should assess whether training designed to enhance executive functioning (without a threat component) also normalises EST performance. This question could be examined using other methods of cognitive training. Of note, Owens, Koster, and Derakshan (2013) found that adaptive cognitive training helps participants with high levels of dysphoria improve their attentional control. Perhaps similar adaptive training would help normalise attention allocation in PTSD, as well.

In summary, our results indicate that veterans with PTSD responded more slowly to combat-related threat words during the EST using lexically matched word lists, and that attention training normalised EST performance in these veterans. Future studies should include a PTSD comparison group and should focus on the specific types of attention and/or executive function training that can normalise attention allocation in PTSD. Furthermore, future work should assess the neurocognitive mechanisms underlying PTSD-related differences in EST performance to determine which, if any, physiological changes are associated with improved EST performance after treatment.

Disclosure statement

No potential conflict of interest was reported by the authors.

References


Owens, M., Koster, E. W. H., & Derakshan, N. (2013). Improving attention control in dysphoria through cognitive training:


### Appendix

**Words lists**

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