Inhibitory Control Deficits and Post-Traumatic Stress Disorder: Evidence from Eye Blink Rate

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Inhibitory Control Deficits and Post-Traumatic Stress Disorder:
Evidence from Eye Blink Rate

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INHIBITORY CONTROL DEFICITS AND POST-TRAUMATIC STRESS DISORDER: EVIDENCE FROM EYE BLINK RATE

Abstract

Inhibitory control deficits have been previously associated with symptoms of post-traumatic stress disorder (PTSD). While eye blink rate (EBR) has been used as physiological index of a number of different disorders, it has not been examined in PTSD. EBR is thought to reflect central dopamine activity and cognitive load. In the current study, the EBR of individuals with PTSD (n=19), trauma exposed healthy controls (n=16), and non-trauma exposed healthy controls (n=15) was measured during a modified version of the Eriksen Flanker Task. EBR data was collected with electro-oculogram measurements. There were no significant differences in overall blink rates between groups. However, for the PTSD group EBR was positively correlated with inhibitory control, and accounted for 10% of the variation in interference. Furthermore, EBR was positively correlated with the avoidance/numbing subscale in PTSD. The results suggest EBR may provide a supplementary physiological index for behavioral and clinically relevant measures. However, further research is needed to address gaps in the EBR literature.
Introduction

1. Attention

Attention is at the core of how we interpret and consequently understand everyday experiences. While much occurs outside of conscious attention, the ability to focus on, and orient to, a single event – or series of events – and use information from both the present and the recent past to interpret the event, facilitates decision-making. William James (1890) called this active or voluntary attention, characterizing it as the ability to briefly (for only a few seconds at most) consciously direct attention – to focus it on an object. When concentrated attention is paid to an object, perception is “accelerated;” however, if distraction is present then perception is hindered (James, 1890). In other words, when attention is decisively oriented, perception and subsequent responses are made more quickly and accurately. In some psychological disorders there seems to be a breakdown in the ability to regulate, or moderate, the focus of voluntary attention, including how well distraction is ignored.

The current study considers how attention is influenced more specific cognitive and emotional demands. Eye blink rate (EBR) is one method that has been used in past research on attention to examine the interaction between attention and response during experimental tasks. This presents a question on attentional focus, but by introducing multiple elements (i.e. emotional variability and task demands) the study of attention begins to emerge as more richly complex. Multiple factors converge concerning the ability to “focus” in more dynamic and varied contexts, as well as reflecting a more clinically relevant interaction with psychological symptoms. The disorder of interest here is post-traumatic stress disorder (PTSD); it presents with a range of attentional issues, of
which the inability to appropriately ignore irrelevant information is central. In the present study EBR will be measured in the context of a task that varies in emotional and cognitive task demands.

A discussion of PTSD will be followed by the neurological indices related to PTSD as well as how these interact in the context of EBR. Together, the current research suggests that EBR may be a novel way to examine PTSD in the context of attention.

1.1 Post-Traumatic Stress Disorder

Post-traumatic stress disorder (PTSD) is characterized by the experience of a traumatic event along with subsequent development of symptoms within three clusters: re-experiencing (involving intrusive thoughts, flashbacks etc.), avoidance and numbing (involving the avoidance of stimuli related to the trauma as well as more general emotional detachment), and hyperarousal (including hypervigilance and difficulty concentrating) (Diagnostic and Statistical Manual of Mental Disorders, 2000, 4th Ed., text rev). Over the course of the current study DSM-5 was released. However, because the clinical diagnoses used for PTSD vary between the DSM-IV-TR and DSM-5, the criteria for PTSD from the DSM-IV were used in the current study.

While the experience of traumatic events is fairly common (approximately 50% of the population has experienced at least one) (Cisler et al., 2011), only approximately 10%-20% of individuals who experience a traumatic event go on to develop PTSD (Brunello, Davidson, Deahl & Kessler, 2001). In certain traumatic contexts, namely sexual assault, the likelihood of developing a subsequent trauma related anxiety disorder may be as high as 20% (Cisler et al., 2011). The prevalence of PTSD in the general population is estimated to be 7.8% in the National Comorbidity Survey (Leskin & White,
2007). Women are diagnosed with PTSD two to three times more frequently than men (10.4% vs. 5.0%) (Leskin & White, 2007), which may be influenced by the impact and frequency of sexual assault and domestic abuse related traumas.

1.1.1 Comorbidity

Individuals with PTSD have been shown to have a comorbid psychiatric disorder approximately 80% of the time. These comorbid disorders commonly include depressive disorders, substance use disorders (SUD), and mood disorders. Rytwinski, Scur, Feeny, and Youngstrom (2013) point out in a meta-analysis that rates of major depressive disorder comorbidity in PTSD range from 19% to 89%. Rates of individuals with PTSD with a comorbid SUD range from 14% to 60% (Haller & Chassin, 2014). Some research on SUDs and PTSD has indicated that there may be specific neurological or genetic links that make an individual with PTSD more susceptible to substance abuse (Walsh, et al. 2014), suggesting a sub-category of individuals susceptible to both PTSD and SUD. It is also relevant to note that one hypothesized cause of SUDs in PTSD is self-medication (Dell’Osso et al., 2014). The functional impairment that may result from the development of PTSD is also heightened in the context of a comorbidities.

Galatzer-Levy, Nickerson, Litz, and Marmar (2013) conducted a latent class analysis of comorbidities within PTSD. They found that individuals with PTSD could be separated into different groups based on the probability of developing comorbid disorders. Even in individuals with a low probability of developing a comorbid disorder, the likelihood of developing a depressive disorder remains fairly high.

In a review of the literature on PTSD and depression in military populations Stander, Thomsen, and Highfill-McRoy (2014) separated individuals with PTSD into
three comorbid subtypes. Finding that one group had a very high probability of
developing depression, another group had a high probability of developing a lifetime
substance dependence disorder (along with depressive disorders), and the third group
includes individuals who had a high probability of developing anxiety and mood
disorders (but not a substance use disorder). The division of comorbid subtypes may help
to explain the varying accounts of comorbidity found in the literature.

1.1.2 Risk factors

There are two critical conditions for PTSD: experiencing a traumatic event (e.g. as a
result of living in war zone, being an emergency aid worker, etc.), and predisposition to
developing PTSD following a traumatic event. While previous stress exposure (e.g.
childhood abuse) is considered one of the strongest risk factors for PTSD when a new
trauma is experienced (Brewin, Andrews & Valentine, 2000), other risk factors have
garnered less consensus. For instance, there has been debate over whether intelligence
(IQ) plays a role; the results have been mixed although it appears that high IQ is a
protective factor (Leskin & White, 2007). Gender, race, and socio-economic status may
also play roles – although there is a great deal of contradictory evidence (Brewin,
Andrews & Valentine, 2000).

Accounts regarding the neurological risk factors for PTSD have also been
conflicted, although this is mostly due to the difficulty untangling the effects of the
development of PTSD from pre-existing neurological and structural differences. In a
review of the literature aimed at precisely this question, Admon, Milad, and Hendler
(2013) found reduced rostral anterior cingulate cortex (rACC) volumes in individuals
with PTSD. The authors also found that functional issues in the amygdala and dorsal
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anterior cingulate cortex (dACC) are significant risk factors for developing PTSD. This supports research by Bush et al. (2011), which found that in individuals with PTSD dACC activity is correlated with symptom severity.

There are also genetic risk factors involving the serotonergic and dopaminergic systems; however, these are not as clearly related to PTSD specifically as they overlap with depression and SUD. Researchers also point out that dysfunctional interactions between the hippocampal-ventromedial prefrontal cortex interactions as a result of trauma exposure may strongly contribute to the development of PTSD (Admon, et al., 2013).

2. Cognitive control

Cognitive control is reflected in some of the neural systems underlying executive function, which include adjustments of perception, response bias and maintenance of task-relevant information (which reflects working memory functioning) (Botvinick, Braver, Barch, Carter & Cohen, 2001).

2.1 Neural bases of Cognitive control

2.1.1 Prefrontal cortex

The prefrontal cortex (PFC) has been related to both the manipulation of traumatic memories (Depue, Curran & Banich, 2007), as well as the neural locus for working memory and response initiation (Miller & Cohen, 2001), making it a particularly salient region of interest in research on PTSD.

The dorsolateral prefrontal cortex (DLPFC) has been linked to top-down control (Miller & Cohen, 2001). An observed increase in activation has been related to improved attentional control (Carter & Veen, 2009). Researchers have also demonstrated that
increased activation of the DLPFC corresponds to the maintenance of relevant information in working memory (Morey et al., 2009).

The ventrolateral prefrontal cortex (VLPFC) becomes more activated when there is a conflict in a cognitive task, and is thought to be activated as part of the selection of relevant responses (Ochsner et al., 2014).

The ventromedial prefrontal cortex (VMPFC) has been related to emotional processing and memory function (encoding processes). For example, higher activation of the VMPFC was related to recall of prior items (Dickie, Brunet, Akerib, & Armony, 2008, 2011).

### 2.1.2 Anterior Cingulate Cortex

The anterior cingulate cortex (ACC) is thought to be the neural substrate directly related to conflict monitoring, detection, and control (Botvinick, Cohen & Carter, 2004); there are two relevant sub-divisions of the ACC here: the dorsal ACC (dACC) and the rostral ACC (rACC).

Researchers have indicated that the rACC is linked to the mediation of emotional arousal and the resolution of emotional conflict and that these functions are significantly intertwined with amygdala functioning (Shin et al., 2001; Etkin, Egner, Peraza, Kandel & Hirsch, 2006).

In a literature review, Carter and van Veen (2007) indicate that the dACC is involved in detecting conflict between competing cognitive representations and that the DLPFC plays a role in resolving this conflict.
2.1.3 Insula

The insula is thought to play a role in processing emotions such as fear, anger, and disgust. In PTSD decreased activation can indicate avoidance or dissociation of affective states (Thomaes et al., 2012).

2.1.4 Amygdala

The amygdala is considered a central neural component in processing of emotion, especially fear. Researchers have indicated that amygdala activity is mediated by the VMPFC (Felmingham et al., 2007) and that it is regulated by the rACC (Etkin et al., 2006).

2.3 Neurochemical bases of cognitive control

2.3.1 Serotonin

Morey et al. (2011) linked serotonin transporter gene expression to functional differences in neural activation in the PFC and amygdala. The researchers used a working memory task with emotional image distracters (trauma or non-trauma related) and found that serotonin transporter gene variations reflected differential activation of the VLPFC and amygdala in individuals with PTSD when compared with trauma-exposed controls. Rahm, Liberg, Kristoffersen-Wiberg, Aspelin, and Msghina (2014), manipulated serotonin levels with a selective serotonin reuptake inhibitor (increasing levels of serotonin) and found that there was increased activity in the rACC, reflecting decreased emotional interference in the emotional Stroop task (to be discussed below).

2.3.2 Dopamine

Seamans and Yang (2004) argue that dopamine (DA) acts on the PFC to influence, in part, information held in working memory buffers within broader PFC networks. Cools
and D’Esposito (2011) investigated optimal levels of DA in the context of cognitive control; they found the highest concentration of DA in the PFC and frontal regions, suggesting that the optimal amount of DA differs in different regions of the brain; further, that optimal levels fall within an inverted U-shaped curve. More specifically, excess dopamine (pharmacologically induced by the use of Haloperidol, a dopamine antagonist) has been shown to decrease activation in the ACC and lead to decreased task accuracy presumably because of impaired inhibitory control (Luijten et al., 2012). On the other hand Kane and Engle (2003) point out that decreased dopamine levels in the PFC diminishes an individuals ability maintain task goals, resulting in increased interference (i.e. decreased interference control).

3. Inhibitory control and PTSD

One extremely salient widely examined aspect of cognitive control is inhibitory control. While cognitive control reflects a complex network of intertwined cognitive functions, inhibitory control is specifically linked to a number of experimental paradigms that use behavioral data in conjunction with neural activity. Inhibitory control reflects the ability to respond accurately during a behavioral task, despite any distracters or increases in the difficulty of the task – i.e. inhibition of attention to the distracting stimuli or inhibition of undesired responses; this makes it relatively simple to examine experimentally.

3.1 Executive function and working memory

Executive function involves attention mechanisms, in particular selective attention, but also encompasses planning, response inhibition, and the manipulation of information (Leskin & White, 2007). A key overlap in the context of PTSD is with inhibitory control. Leskin and White (2007) point out that behavioral tasks that focus on inhibitory control
tap a construct that is directly related to each of the major symptom clusters of PTSD. In other words the inability to inhibit information related to the traumatic event may contribute directly to the development of PTSD; thus, a task that specifically targets inhibitory control is focusing on a key cognitive process in PTSD.

One mechanism strongly related to attention and executive function is working memory. Baddeley and Hitch (1974) modeled working memory to integrate memory maintenance and attentional control in the context of higher cognitive functions (Kane & Engle, 2003); working memory represents the ability to manipulate information across time and space. In PTSD, deficits in working memory have been directly linked to a failure to inhibit irrelevant information (Vasterling et al. 1998; Vasterling et al. 2002). Furthermore, Hester and Garavan (2005) found that sustained high working memory load leads to a decline in an individual’s ability to exert inhibitory control, pointing to the interaction between working memory and the executive functioning system in the context of inhibitory control.

### 3.2 Behavioral tasks and inhibitory control

There are a wide variety of tasks that reflect inhibitory control including the Stroop Task, the Eriksen Flanker Task, the Dot Probe Task, and the Go/No-Go task. Each basic task has also been modified in a number of different ways. One of the most relevant alterations is of the emotional valence of the task. This may be done by manipulating the stimulus itself to elicit different emotions, using an emotional stimulus as a cue, presenting an emotional stimulus simultaneously with the emotionally neutral (like a color word) target, or presenting an emotional stimulus at the very beginning of the trial (i.e. as a fixation point in the center of the screen). There is an important difference
between inhibitory action control (Go/NoGo task) and inhibitory interference control (Stroop, Eriksen etc.). Action control reflects the inhibition of an actual response; interference control reflects the cognitive inhibition of irrelevant stimuli within the context of a specific task. While both types of inhibition have been investigated in PTSD, the current study focuses on interference control.

3.2.1.1 Stroop

In the classical Stroop task (Stroop, 1935), words are presented that name a color, while the lettering is also colored – either the same as the word, or differently. When the word is the same as the color, it is congruent (red); when the word is different than the color (red) it is incongruent. The basic finding has been that when individuals face an incongruent trial (red) they are slower to give the correct response than when they have a congruent trial (red). This general finding reflects the basic idea behind interference control: that the incongruency of the (red) trial makes it more difficult (interferes with) an individual’s ability to make the correct connection to the word and respond ‘red’. The classical Stroop paradigm has been modified to create different kinds of interference in order to examine whether certain clinically defined populations respond differently in certain scenarios. One of the most common variations is a type of emotional Stroop task where individuals need to name a color (as in the task above), but the words presented have negative emotional valence (death) as opposed to neutral or positive emotional valence (flower). The idea is that for some individuals (for example, individuals who have experienced trauma) the word death creates more interference than the word flower – similar to the congruent/incongruent condition in the original Stroop (McNally, Kaspi, Riemann, & Zeitlin 1990).
3.2.1.2 Eriksen Flanker Task

The traditional Eriksen Flanker Task (Eriksen & Eriksen, 1974) requires subjects to say what the orientation of a target arrow (> or <) is when it is surround by other arrows. For example, >> > >> is a congruent trial, while >> < >> is an incongruent trial. The subject’s task is to suppress the flanking arrows. Incomplete suppression produces faster and more accurate response in the congruent conditions, and slower and less accurate responses in the incongruent conditions compared to conditions where the flankers are direction neutral (eg tt>tt).

3.2.1.3 Dot Probe Task

In the Dot Probe task (MacLeod, Mathews & Tata, 1986), subjects are shown a cue indicating the location of the upcoming location of the target (generally on the left or right). The target then either appears on the same side as the cue (a congruent trial) or the opposite side of the cue (an incongruent trial). The Dot probe has been used to explore attention bias in the context of emotional stimuli; for example, if cued with a sad face on the right, and subjects respond faster to the target when it is on the left (incongruent) than on the right (congruent) they are showing an attentional bias away from the sad stimulus; similarly if they are cued with a happy face on the right and they respond faster when the target is on the right, they are showing an attentional bias towards the happy stimulus.

3.2.2 Neural correlates of interference control in PTSD

The above tasks have been used to examine interference control in PTSD. In contemporary research, accompanying measures of neural activity provide important evidence pointing to underlying relationships between neural activity and behavioral outcomes.
Research measuring responses during emotionally valenced behavioral tasks have used functional magnetic resonance imaging (fMRI) to indicate that compared with controls, individuals with PTSD do not show comparable activity in the rACC or VLPFC (Shin et al., 2001; Etkin et al., 2006). Additionally, individuals with PTSD show heightened DLPFC, dACC, and left insula activity (Fani et al., 2012; Thomaes et al., 2012) during these tasks. Taken together these findings suggest that for individuals with PTSD cognitive interference tasks reflect overall deficits in interference control linked to hyperactivity in regions related to response selection (DLPFC) and inhibition (dACC); as well as dysregulation in emotional conflict control (VLPFC), and emotional inhibition (rACC; left insula).

3.3 Physiological measures

3.3.1 Overview of the eye blink

The eye blink has been studied since the early 20th century, as an index of cognitive processes (Ponder & Kennedy, 1927). Eye blinks are an automatic response that protects the eyes by cleansing them, keeping them moist, and keeping them free of external objects (small particulate matter etc.) (McEwan, 1962; Doane, 1980). There are three other types of blinks that have been explicitly categorized in research on eye blinks: there is the voluntary blink that results from a conscious decision to blink (Stern, 1984). There is the reflex blink, or startle blink, which is in response to a sudden and intense stimulus, such as a loud noise, a mild electric shock, or a bright light being flashed (Pole et al., 2009; Ruiz-Padial & Vila, 2007; Filion, Dawson, & Schell, 1998; Blumenthal et al., 2005). And there is the endogenous blink or spontaneous blink, which is an eye blink that occurs in the absence of an identifiable stimulus. However, research has indicated that
endogenous blinks are not due simply to the “automatic response” that protects the eye – instead reflecting other (e.g. cognitive or emotional) factors (Pivik & Dykman, 2004; Elsworth et al., 1991). More specifically, EBR may be related to cognitive load – during periods of cognitive load there are relatively few blinks, while in the periods that alleviate the cognitive load there are an increase in blinks (Siegle et al., 2008); furthermore EBR has been shown to be a salient measure of inhibitory action control (Colzato et al., 2009).

It is important to note that no blink response is evoked in the context of an image presentation itself – the image only influences the blink rate indirectly. This is true for both the reflex/startle blink as well as the endogenous blink. To emphasize this point, several studies the reflex/startle blink, are examined in order to explain how emotional images modulates blink rate in PTSD; however, it is relevant to note that no study has examined PTSD and spontaneous blink rate.

In studies on the reflex/startle blink, the connection has been clearly made between blink amplitude and aversive pictures – heightened responsivity is considered a measure of defensive reaction to threat in individuals with PTSD (Vaidyanathan, Patrick & Bernat, 2009). Ruiz-Paidal and Vila (2007) even show that this heightened blink response may be modulated by aversive stimuli that are presented so as to be nonconsciously perceived and processed. Recalling that the reflex or startle blink is motivated by a physical stimulus, it is important to note that it is not the images themselves that cause the blink response – if participants are shown the image alone, they do not blink; instead the aversive image modulates the response to a startling stimulus such as a loud noise or mild electric shock.
3.3.1 Endogenous Blink

The endogenous blink, initially defined by Stern, Walrath, and Goldstein (1984) may be understood as a broad index of information processing. In the literature spontaneous eye blink is sometimes used interchangeably with endogenous eye blink. The central difference is that the endogenous blink is specifically intended to reflect that the blink represents an internal psychological process, while in some cases spontaneous eye blink is used to refer to a resting blink rate, not unlike the automatic responses of cleansing the eye. However, Elsworth et al. (1991) and Pivik and Dykman (2004), among others, point out that spontaneous blinks occur more frequently than the necessary rate to lubricate the eyeball (which they take from Doane (1980)). Thus, the terms endogenous blink generally refers to the type (category) of blink, while spontaneous blink generally refers to the measure of blink rate; however, they are relatively interchangeable.

3.3.2 Emotional arousal and blink rate

Researchers have shown that increased arousal is also implicated in blink rate. In an early study on this question, Monster, Chan, and O’Connor (1978) found a relationship between spontaneous eye blinks at rest and emotional arousal. Stern et al. (1984) in a literature review found that both direct (measures of arousal) and indirect (task demands) measures of arousal were related to increased blink rate. They also point to specific findings indicating that vocalization is consistently linked to increased blink rate (Schuri & von Cramon, 1981; von Cramon & Schuri, 1980). Thus, in the article by Monster et al. (1978), the positive relationship may be due to the vocalization of responses, and not to emotional arousal. In fact, a later study by Tanaka (1999) showed that increased arousal was linked to a decrease in blink rate in the absence of vocalized responses. While
arousal may also play a role in endogenous blink rate – the relationship is less clear, because there is no direct index of the influence of an arousing stimulus (as with reflex blinks). The influence suggested by the literature, however, is that arousal interacts with task demands to influence overall blink rate.

### 3.3.3 Dopamine and blink rate

Karson (1983) found that spontaneous eye blink rate was linked with the dopaminergic system. More specifically, the researcher found that when a D2 dopamine receptor antagonist was used and followed by a non-selective dopamine agonist the blink rate did not increase. Research by Lawrence and Redmond (1991) has supported the influence of D2 on blink rate. They used a selective D2 agonist and still found no increase in blink rate when a D2 antagonist was used first. Elsworth et al. (1991) investigated whether the D1 dopamine receptor was also influential in regulating eye blink rates. They found that when they used a D1 agonist and a D2 antagonist, they still observed an increase in blink rate. As a result they suggest that both dopamine receptors have the same influence on blink rate, but function independently.

Consequent research investigated various clinical conditions using eye blink rate as a non-invasive measure of dopamine functioning. Patients with disorders that have hyperdopaminergic states, for example, schizophrenia, Tourette’s syndrome, and Huntington’s disease show higher blink rates than healthy controls, while those with disorders that have hypodopaminergic states, such as Parkinson’s disease, show lower blink rates (Caplan, Guthrie & Como, 1996).

Barbato, Monica, Costanzo, and De Padova (2012) investigated the relationship between personality traits and dopamine activity by measuring blink rate at baseline
levels (subjects stared at a blank wall). They found that neuroticism was positively correlated with blink rate – they subsequently make an additional connection to research relating neuroticism to the dopaminergic system.

3.3.4 Cognitive load and blink rate

The relationship between eye blinks and cognitive load is moderated by several factors. Chief among these is the nature of the task. Pivik and Dykman (2004) used an inhibitory control task and found that endogenous blinks are highly regulated in the context of predictable visual information. Furthermore, they occur at intervals that facilitate perception of the task. This finding supports earlier studies (Goldstein, Bauer, & Stern, 1992; Tanaka & Yamaoka, 1993; Ohira, 1996). The positive relationship between task difficulty and blink rate is supported by more recent research by Sugiyama, Watanabe, and Tada (2013) who found a significant main effect for task difficulty during a reading span task. They also found that overall blink rates increased during the reading span task and decreased when the participants were allowed to rest between blocks. However, participants vocalized their responses, and since vocalization has been linked with increased blink rate (Stern et al., 1984) it is not clear whether their results were because of the increased difficulty of the reading span task or the vocalization.

Research by Siegle et al. (2008) suggests why there might be varying accounts of blink rates in the context of high task demands. The researchers used a digit-sorting task and a Stroop task to quantify the timing of blinks during the tasks. They found that blinks reliably flank periods of increased cognitive load. The increase in blinks after the end of a trial may represent the release of information from working memory (Ichikawa & Ohira, 2004).
During a continuous, uninterrupted task, eye blink rate decreases – one example given in the literature of such a task is reading (Stern et al., 1984). However, during breaks in the task, including turning the page, there is a flurry of blinks. This suggests that many of the findings regarding task difficulty relate to the fact that they sustain cognitive load over an extended period of time as opposed to discrete trials. Of interest is the fact that Seigle et al. (2008) also found increases in blinks before the trial – they suggest that blinks represent the initiation of cognitive load, which is also proportional to its expenditure over the course of the trial; so blinks not only signify the release of cognitive load but also serve a preparatory function. The authors also note that increasing cognitive load by altering states of arousal may influence these how blink rate functions (although they do not make any hypotheses).

4. Present Study

The intention of the present study is to use EBR as a physiological index of cognitive control in individuals with PTSD as compared with trauma exposed healthy controls (TEHC) and non-trauma exposed controls.

The ways in which PTSD might be related to cognitive control is not completely clear. One factor influencing this relationship is cognitive load – EBR appears to reflect the allocation and relief of cognitive load. In healthy populations the higher the cognitive load, the higher the blink rate. However, this observation has not been made in the context of psychopathological symptoms. A second factor influencing blink rate is dopamine, which has been used as a proxy for blink rate; dopamine in turn is variable factor in a number of pathologies. In other words, in pathologies with low dopamine researchers have found low blink rate, in pathologies with high dopamine researchers
have found high blink rate. The only two papers on PTSD and dopamine levels (Hamner & Diamond, 1993; Glover, Powers, Bergman, Smits, Telch, & Stuber, 2003) point to increased levels of dopamine in individuals with PTSD; however, dopamine has not been directly measured simultaneously with blink rate in individuals with PTSD. Taken together, the research on cognitive control and dopamine, suggest that EBR may differ in individuals with PTSD, however, the direction of this finding cannot be adequately predicted based on the existing research.

Beyond basic differences in blink rate, there is also the relationship between blink rate and the central measure of the task: interference control. It is not totally clear what modulates interference control, and regardless of baseline differences in EBR, it is also likely that there are other factors modulating interference within individuals groups. The central question of this paper is, then, does EBR reveal a facet of interference control in PTSD?

Under increased working memory load (high task difficulty), individuals show greater activation of neural loci (Lavie, 2010). However, in the context of emotional perception, high working memory load has been related to increased inhibition of perception of emotional faces; in other words emotional faces are more distracting under low load than high load (Van Dillen & Derks, 2012). Because the current study is examining the interaction between emotional valence and task difficulty, emotional valence may also play a role in modulating interference control in the context of EBR.

4.1 The Temporal Flanker Task (TFT)

In the current study, the use of a modified version of the Eriksen Flanker task, the Temporal Flanker Task (TFT), is intended to more clearly focus on cognitive as opposed
to perceptual aspects of interference control. In the task, the distracters occur several hundred milliseconds before and after the target; thus, the subject is required to hold the correct response in working memory, while inhibiting the distracters.

Earlier research used a version of the TFT in order to investigate visual priming (Kunde, 2003; Neumann & Klotz, 1994). More recently, the use of temporal as opposed to spatial differences has been used to analyze the influence of trial sequence on response characteristics in both auditory and visual tasks – the use of temporal separation of distracters facilitating the comparison between the two stimulus modalities (Hazeltine, Lightman, Schwarb, & Schumacher, 2011). Schumacher, Schwarb, Lightman, and Hazeltine (2011) found that the visual version of the TFT differed in many respects from the auditory version – although the authors used fMRI, they only investigated ROI’s corresponding to differences between the modalities, not the specific regions implicated in the task. Earlier research on response selection, however, points specifically to the DLPFC as implicated in non-spatial response selection (Nagel, Schumacher, Goebel, & D’Esposito, 2008).

In the current study a novel iteration of the TFT was developed to specifically manipulate both task difficulty and emotional valence. The TFT contains two levels each of task difficulty (baseline/filtering), emotional valence (neutral/fearful), and image type\(^1\) (Faces or International Affective Pictures System (IAPS)) – see Table 1.

---

\(^1\) This study was part of a broader study. One area the larger study investigated was whether individuals with PTSD who had been exposed to interpersonal traumas (such as assault) would react more strongly to images depicting interpersonal violence. In order to examine this question, two sets of images were used: the IAPS image and the Faces image set. The IAPS set contained images related to both interpersonal violence and images related to other traumatic experiences (such as a natural disaster). The Faces images were not trauma specific but still varied in terms of emotional valence (fearful or neutral).
### 4.2 Expectations and Hypotheses

It is expected that the higher task difficulty will correspond to increased exertion of cognitive control, and thus a higher blink rate for all groups in the filtering condition than the baseline condition.

Based on research indicating that individuals with PTSD differ from TEHC and controls on tasks related to emotional valence (McNally et al., 1990), the PTSD group is expected to blink more in one emotional condition than the other – while the control groups are expected to blink approximately the same regardless of emotion (between neutral and fearful conditions).

Based on prior research (see Fani et al., 2012; Dennis et al., 2007) it seems that when faced with fearful images, individuals with PTSD may be biased away from the threat, reflecting enhanced interference control. This is more likely to occur under low load than high load, due to the decreased inhibition of emotion under low load (Van Dillen & Derks, 2012). In terms of blink rate this may mean a lower blink rate in the fearful conditions. Furthermore, within the PTSD group blink rate might appear as an interaction between emotional and cognitive task demands – this is supported by research.
indicating that spontaneous blink rates vary in relation to specific stimulus types (Pivik & Dykman, 2004) – the control groups might only show within group differences in terms of condition, regardless of emotional valence.

Furthermore, bias away from threat may be reflected in clinical measures (subscales in both the CAPS and the MDI) that point to avoidance or emotional numbing. More avoidance, which reflects greater cognitive control, may be associated with lower blink rates. Another question raised by this study is whether depression might be related to cognitive control, as many of the areas related to inhibitory control and PTSD may also have some relationship with depression. And while the present study sought to control for several of the highly present comorbidities in PTSD (SUD and mood disorders), depression is so widely prevalent that it remains difficult to control for.

Table 2
Predicted blink rates in PTSD – bias away from threat

<table>
<thead>
<tr>
<th>Image Type</th>
<th>Faces</th>
<th>IAPS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Baseline</td>
<td>Filtering</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Task Difficulty</th>
<th>Baseline</th>
<th>Filtering</th>
<th>Baseline</th>
<th>Filtering</th>
</tr>
</thead>
<tbody>
<tr>
<td>Emotional Task Demands</td>
<td>Neutral</td>
<td>Medium</td>
<td>Medium</td>
<td>Medium</td>
</tr>
<tr>
<td></td>
<td>Fearful</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
</tr>
</tbody>
</table>

Because there is no pre-existing research on which to base hypotheses regarding blink rate and PTSD, the hypotheses generated rely on existing literature on blink rate as well as research on inhibitory control.
4.2.1 Hypotheses

Hypothesis 1: Individuals with PTSD will have a different overall blink rate than controls.

Hypothesis 2: Blink rate will be positively correlated with task interference, reflecting the relationship between blink rate and cognitive load/interference control.

Hypothesis 3: Blink rate will be associated with symptom severity, perhaps reflecting how emotional images relate to enhanced cognitive control.

Hypothesis 3.1: Blink rate will be associated with depression scores, reflecting overlapping facets in cognitive control.
5.1 Participants:

Fifty individuals were recruited via online and print advertisements to participate in the present study. See Table 3 below for demographic information.

In the advertisements individuals were asked to contact the project manager who provided additional details regarding the study and its procedures. If the participant indicated interest they were asked for verbal consent to participate in an initial phone screening. A trained research assistant then contacted participants for a phone screen. In addition to an initial phone screen, there was an assessment phase to determine into which group individuals would fit for the experimental task. The PTSD group was categorized based on a CAPS score > 30 (Weathers, Keane & Davidson, 2001). The TEHC group met Criterion A in CAPS, and the non-trauma exposed control group met no criteria for trauma exposure in the CAPS.

<table>
<thead>
<tr>
<th>Table 3</th>
<th>Demographic information and comparisons between participants</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>PTSD (n=19)</td>
</tr>
<tr>
<td>Gender</td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>10</td>
</tr>
<tr>
<td>Female</td>
<td>9</td>
</tr>
<tr>
<td>Age M (SD)</td>
<td>35.3 (10.1)</td>
</tr>
<tr>
<td>Education (years) M(SD)</td>
<td>14.7 (1.9)</td>
</tr>
<tr>
<td>Race/Ethnicity</td>
<td></td>
</tr>
<tr>
<td>White</td>
<td>3</td>
</tr>
<tr>
<td>Black</td>
<td>8</td>
</tr>
<tr>
<td>Latino</td>
<td>6</td>
</tr>
<tr>
<td>Asian</td>
<td>1</td>
</tr>
<tr>
<td>Other</td>
<td>1</td>
</tr>
</tbody>
</table>
Trauma type (LEC) & \chi^2(2, N=50) = 5.93 \\
Physical Abuse/Assault & 16 & 11 & 3 \\
Sexual Trauma & 17 & 11 & 1 \\
Natural Disaster & 6 & 6 & 7 \\
War/Combat & 2 & 2 & 2 \\
Other & 36 & 44 & 24 \\
BDI & 11.3 (7.9) & 3.8 (5.4) & .47 (.92) \\

| 5.1.1 Assessment Interview (Phase One) |

Participants were interviewed at City College and given a detailed verbal explanation of the project as well as a written copy of the consent form. Following their written consent, participants were given a breathalyzer/urine toxicology screen, a demographics form, and the life events checklist (LEC). The clinician then administered the PTSD scale for DSM-IV (CAPS), and the Multiscale Dissociation Inventory (MDI). In order to be eligible for phase two, the participants needed to meet the eligibility criteria and not meet any of the exclusion criteria (see sections below; note that non-trauma exposed controls did not need to meet all eligibility criteria). Each participant was reimbursed $30 and a roundtrip metrocard for their time.

| 5.1.1.1 Eligibility Criteria for Participants |

Eligibility criteria include: 1) Appears physically healthy, no serious medical problems; 2) normal or corrected normal visual acuity; 3) aged 18-65; 4) fluent in English; 5) able to provide informed consent; 6) Either has been experienced a traumatic event (criterion A for PTSD in DSM-IV, or meets full criteria for PTSD. Healthy controls only meet criteria 1-5.
INHIBITORY CONTROL DEFICITS AND POST-TRAUMATIC STRESS DISORDER: EVIDENCE FROM EYE BLINK RATE

5.1.1.2 Exclusion Criteria for Participants

Exclusion criteria include: past or present psychotic disorder or bipolar disorder; current substance abuse or dependence (cutoff for prior abuse – 3 months); poor visual acuity; significant risk of suicide based on current mental health state or history.²

5.1.2 Experimental task (Phase Two)

Participants were divided into one of three groups on the basis of their trauma exposure and presence of PTSD symptoms (see above for more details). An attempt was made to match participants based on demographic information such as age and gender for all three groups (refer to table 3 above for more details).

Participants who were eligible returned a second day to complete a visual attention task, measured with the use of EEG. Participants at this point had been separated into three groups: PTSD, trauma exposed healthy controls (TEHC) and non-trauma exposed healthy controls. Research assistants were not blind to the diagnoses. If participants used glasses/contacts, they were asked to wear their glasses. Participants also completed the State-Trait Anxiety Inventory (STAI) and Profile of Mood States (POMS), but those data are not included in the current study. Trained research assistants prepared the participant for the EEG recording.

5.1.2.1 EEG data collection

Participants were seated comfortably while trained research assistants placed an EEG cap on the participants’ head and applied electrolyte gel to the scalp before attaching the electrodes. This study was part of a larger EEG study and the entire electrode array (169

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² Individuals who had a history of suicide attempts were excluded because the present study could have represented an extraneous stressor. In cases where suicide risk was immediate, the interviewing clinician would have given an immediate referral to the interviewee; however, no such cases occurred.
INHIBITORY CONTROL DEFICITS AND POST-TRAUMATIC STRESS DISORDER: EVIDENCE FROM EYE BLINK RATE

electrodes) was used, but the full EEG data were not analyzed for the current study. For the purposes of this study two external electrodes were placed, one above and one below, the participant’s right eye. Once all the electrodes were placed, participants were led to an insulated EEG Booth, where the only light in the room was from the computer screen used in the task. Participants were seated 60 cm away from the computer screen. Electrical impedances and signal clarity were checked and manually corrected by the researchers prior to the start of the experiment (impedances were corrected to be less than 15 Ω’s; noisy signals were generally an issue of poor connection between the scalp and electrode and more gel was added to improve signal strength).

Participants were told to read the instructions on the computer screen in front of them. The instructions explained that the task of the participant was to respond to the target of a horizontal or vertical line, by pressing one mouse button for a vertical line and the other for a horizontal line. The instructions also explained that there would be two distracters – one before and one after the target, but that the participant should ignore these and focus on the second line in the sequence. The assignment of mouse button to line orientation was randomized for all participants; for example, for one subject the right mouse button might correspond to the horizontal lines and the left mouse button to the vertical lines and for another this would be reversed. Participants completed a series of training trials with feedback in order to become familiar with the task. Once they had reached an accuracy of 80% or higher the experimental task and EEG recording began. There were eight conditions and each condition was repeated three times for a total of 24 blocks; each block consisted of 100 trials. EEG recording was stopped between blocks, and initiated 10 seconds before each block and stopped 10 seconds after each block. The
task took approximately 1-2 hours to complete. Research has shown that blink rate
increases during the evening (Barbato et al., 2000), and researchers collected data in the
late morning to early afternoon. The order of the blocks was randomized for each
participant. Subjects were asked not to blink during individual trials. There was a
scheduled break halfway through the experiment, and participants were told they could
ask for a break at any point. Participants were told that they could choose to stop the
experiment at any point.

Participants were reimbursed $70 for their participation in phase two and also
given a roundtrip metrocard.

5.2 Materials

5.2.1 Temporal Flanker Task

The Temporal Flanker Task (TFT) is a modification of the Eriksen Flanker Task (Eriksen
& Eriksen, 1974). In the temporal flanker task the distracters are located 200 ms (with
jitter of X) before and after the target. Unlike the traditional Eriksen Flanker Task, the
location of the distracter is the same as the location of the target. Similar to the Eriksen
Flanker Task, there are both congruent and incongruent conditions based on whether the
target is the same or different from the distracters. The target in the TFT is either a
vertical or horizontal line. There are three different distracters: a vertical line, a horizontal
line, and a cross (neutral), which is a combination of the two distracters. In baseline
conditions there were only neutral trials – utilizing the cross as the distracter. In filtering
conditions, there were congruent, incongruent and neutral distracters. Furthermore, the
target was superimposed on an image of a face. There were two different groups of
images from different sources: Faces or International Affective Picture System (IAPS).
Each image was either fearful or neutral. Thus in total there were eight conditions based on the trial distracters, image set, and emotional valence, see Table 1 above for reference.

### 5.2.2 EEG recording equipment

EEG data were captured using BioSemi equipment. A 160 channel electrode cap, with corresponding pin-type electrodes and flat-type active electrodes for external use (i.e. to capture eye blinks) was used for recording. Electrodes were inserted into an AD-box, which amplified the signal and sent it to a USB2 receiver. The receiver was connected to an Optiplex GX260 Dell, with a 17 inch monitor. Data were viewed and captured for offline storage and analysis using Actiview.

The TFT task was displayed using Presentation v 16.0 software, and behavioral data were captured on the Dimension 5150 Dell desktop computer with a 17 inch monitor.

Participants were seated in front of a 17 inch Dell desktop, which was connected in parallel with the computer used to run the TFT task.
5.2.3 Questionnaires

Life Events Checklist (LEC)
The Life Events Checklist was developed alongside CAPS and was intended to help identify events that were empirically related to the development of PTSD. The LEC is a self-report checklist, which consists of 16 items with sub-categories related to specific traumatic experiences, as well as a more general “other” experiences category. It was not established to diagnose symptom severity meeting DSM-IV cutoffs for traumatic exposure. It functions predominantly as a screening measure, prior to the CAPS (Gray et al. 2004).

The Beck Depression Inventory (BDI)
The BDI consists of a 21-item measure of depressive symptoms and symptom severity. It is not used as a diagnostic tool, although it is widely used in the studies on treatment outcomes and studies on trauma-exposed individuals.

The Multiscale Dissociation Inventory (MDI)
The MDI is a 30-item self report measure for dissociation. There are six subscales measure types of dissociative responses: disengagement, depersonalization, derealization, emotional constriction, memory disturbance, and identity dissociation. Specific symptoms are rated by frequency of occurrence over the past month (from 1 – never, to 5 – very often) (Briere, Weathers & Runtz, 2005).

The Clinician-Administered PTSD Scale (CAPS)
Clinicians rate individuals on each of the 17 diagnostic categories of PTSD found in the DSM-IV; these generally fall into one of three dimensions: intrusion or re-experiencing (criterion B), avoidance (criterion C), and hyperarousal (criterion D). Symptoms are rated
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on intensity and frequency, with a scale from 0-4. It has been found to a robust and accurate assessment for PTSD.

5.3 Data Analysis

5.3.1 Automated blink count

An automated system was used to preprocess and count the blinks. First, the raw data from the two vertical electrode sites were rereferenced and converted to single channel in Matlab using Fieldtrip, to prepare it for blink analysis. In order to find the blinks, the data were analyzed using a Matlab function called Peakfinder. Peakfinder finds peaks within a noisy 1-D vector by using a user-defined magnitude threshold in order to compare surrounding peaks. In the channel being analyzed, these peaks are the blinks. Blinks were defined as magnitudes greater than 100 µV (Barbato et al., 2012). The blink detection threshold was manually set in Peakfinder correspondently to detect blinks that were greater than 100 µV. In 30 blocks manually checked no blinks were detected at a threshold lower than 100 µV. The number of blinks in the three blocks for each condition was summed to provide an overall number of blinks per condition. The time in seconds for each block for each condition was summed and divided by 60 to provide an overall time for each condition. Number of blinks for each condition was divided by time in minutes for each condition to provide a blink rate per minute for each condition.

5.3.1.1 Manual Checks for accuracy

The automated blink detection was checked for accuracy by two trained raters independently scoring a random selection of 30 blocks. See figures 1 and 2 in the appendix for a visual comparison. The raters had 98% agreement, and the manual counts were 92% similar to automated ones.
6.1 Behavioral data

To assess whether the behavioral data conformed to expectations regarding interference (i.e. that individuals are slower and less accurate when responding to incongruent trials than congruent trials) a series of mixed model ANOVA’s was carried out.

6.1.1 Reaction time

A 3x2x2x2 mixed model was carried out comparing group x image type (IAPS/faces) x emotion (fear/neutral) x interference level (congruent/incongruent). There was a significant within groups difference for interference level $F(1, 47)=83.529, p<.001$; a visual examination of plotted data indicated that participants were significantly slower on incongruent trials than congruent trials (see figure 1 below). There was also a significant interaction between image and emotion $F(2, 47)=7.579, p=.008$, suggesting some differences in response to certain image types. There were no significant group differences.

6.1.2 Accuracy

A 3x2x2x2 mixed model was carried out comparing group x image type (IAPS/faces) x emotion (fear/neutral) x interference level (congruent/incongruent). There was a significant within groups difference for interference level $F(1, 47)=80.737, p<.001$; a visual examination of plotted data indicated that participants were significantly less accurate on incongruent trials than congruent trials (see figure 2 below). There was also a significant main effect for image type $F(1, 47)=8.487, p<.001$, as well as a main effect between image and emotion $F(2, 47)=7.489, p=.007$; these results suggest some
differences in response to certain image types. There were no significant group differences.

Figure 1. Reaction time during the TFT

![Reaction time graph](image)

Figure 2. Accuracy during the TFT

![Accuracy graph](image)
6.2 Group Differences

The group differences in terms of blink rate were examined. See Tables 5, 6, & 7 for the mean blink rates by condition for each group.

Table 5. Blink rates in PTSD group

<table>
<thead>
<tr>
<th>Image Type</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Faces</td>
<td>IAPS</td>
<td>Task Difficulty</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Baseline</td>
<td>Filtering</td>
<td>Baseline</td>
<td>Filtering</td>
</tr>
<tr>
<td>Emotional Task Demands</td>
<td>Neutral</td>
<td>16.01</td>
<td>15.90</td>
<td>17.61</td>
</tr>
<tr>
<td></td>
<td>Fearful</td>
<td>15.31</td>
<td>15.20</td>
<td>16.75</td>
</tr>
</tbody>
</table>

Table 6. Blink rates in TEHC group

<table>
<thead>
<tr>
<th>Image Type</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Faces</td>
<td>IAPS</td>
<td>Task Difficulty</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Baseline</td>
<td>Filtering</td>
<td>Baseline</td>
<td>Filtering</td>
</tr>
<tr>
<td>Emotional Task Demands</td>
<td>Neutral</td>
<td>17.80</td>
<td>20.80</td>
<td>20.26</td>
</tr>
<tr>
<td></td>
<td>Fearful</td>
<td>19.69</td>
<td>20.06</td>
<td>17.96</td>
</tr>
</tbody>
</table>

Table 7. Blink rates in Control group

<table>
<thead>
<tr>
<th>Image Type</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Faces</td>
<td>IAPS</td>
<td>Task Difficulty</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Baseline</td>
<td>Filtering</td>
<td>Baseline</td>
<td>Filtering</td>
</tr>
<tr>
<td>Emotional Task Demands</td>
<td>Neutral</td>
<td>18.66</td>
<td>19.40</td>
<td>17.30</td>
</tr>
<tr>
<td></td>
<td>Fearful</td>
<td>18.52</td>
<td>19.64</td>
<td>17.46</td>
</tr>
</tbody>
</table>
Initially a 3x1 (group x blink rate) one-way ANOVA was run to test the hypothesis that the PTSD group would blink more than the control groups. The findings indicated no significant difference between the PTSD and control groups in terms of EBR. F(3, 47)=1.253, p=.302. However, several mixed model ANOVA’s were performed to examine whether salient aspects of the task such as emotion and task difficulty interacted with blink rate.

6.2.1 Emotion
A 3x2 mixed measures ANOVA was performed examining differences between blink rates in neutral and fearful conditions. Neither the main effect of emotion (F(2, 47)=2.066, p=.157), nor its interaction with group (F(2, 47)=.609, p=.548) reached significance.

6.2.2 Task Difficulty
A 3x2 mixed measures ANOVA was performed examining differences between blink rates in baseline and filtering conditions. Neither the main effect (F(1, 47)=2.534, p=.118), and nor its interaction (F(2, 47)=1.296, p=.283) with group reached significance.

6.2.3 Image Type
A 3x2 mixed measures ANOVA was performed examining differences between Face and IAPS images. There was no significant main effect F(1, 47)=.238, p=.628; and there was no interaction F(2, 47)=1.617, p=.209.

6.3 Correlations
EBR was correlated with both task interference scores (a measure of reaction time) and clinical measures. The significance level was set at $\alpha = .05$. Interference correlations
were performed separately on groups. Clinical correlations were only performed on the PTSD group.

6.3.1 Interference Calculations

Task interference was calculated by taking mean reaction times for each subject to congruent and incongruent trials (which only occurred during filtering conditions), and subtracting the congruent reaction time from the incongruent reaction time; the difference score is a measure of how much longer it took (on average) for participants to respond during incongruent trials than congruent trials. Results for task interference were averaged into a grand total for interference and also separated by condition (Fearful faces, Neutral faces, Fearful IAPS, Neutral IAPS). Results for blink rate were aggregated into overall blink rate, neutral blink rate, and fearful blink rate for filtering trials (as baseline trials do not correspond to measures of interference). The four individual filtering conditions were also compared.

6.3.2 Interference and Blink Rates

One-tailed correlations between EBR and interference scores were carried out to assess the hypothesis that increased EBR was positively correlated with increased interference. Overall interference correlated strongly with blink rate in the PTSD group $r(17)=.428$, $p=.034$. The correlation between interference and blink rate was negative for both the TEHC and non-trauma exposed control groups; however, the overall correlations were not significant. Further analyses were conducted regarding more detailed aspects of the task. For the PTSD a number of correlations between interference and blink rate were significant at the individual condition level. For the control groups there were no
significant correlations at any level (See Tables 1-3 in the appendix for the complete correlation matrices).

A hierarchical linear regression model was used to determine how much of the variability in interference was explained by EBR. Preliminary analyses were carried out to see whether variables of age, sex, trauma exposure (LEC), or education had any significant associations with EBR or interference scores; there were no significant correlations. An examination of Mahalanobis distance scores and Durbin-Watson residuals indicated two outliers (at greater than 3 SD’s), which were removed from further analyses. Blink rate and group were entered into the first step of the regression model. The interaction between blink rate and group was entered into the second step of the model. The interaction between blink rate and group accounted for 10% of the blink rate, $\Delta r^2 = .10, \Delta F(1, 44) = 5.008 \ p = .030$ (see Table 4 in appendix). The results suggest that an increase in 1 blink/minute corresponds with an increase of 15 ms of interference. Figure 3 (below) represents the correlations of all three groups.

Figure 3. Interference and overall EBR (all groups)
6.3.3 Clinical correlations to Blink Rate

One-tailed correlations were carried out between EBR and clinical measures only in the PTSD group. Several clinical measures were correlated with overall blink rate, as well as aggregated neutral and fearful blink rates, in participants with PTSD.

Correlations between overall blink rate and total CAPS score not strong $r(17)=-.251$, $p=.150$; however, Criterion C (avoidance/numbing) was significantly correlated $r(17)=-.397$, $p=.047$. Furthermore, there was also a correlation between blink rate and the emotional numbing ($r(17)=-.482$, $p=.018$) subscale in the MDI. Interestingly, BDI was not correlated with blink rate, despite research indicating that it represents a major comorbid factor in PTSD $r(17)=-.206$, $p=.199$. (See Table 5 in the appendix for further details).

Figure 4. Correlation between Avoidance/Numbing in CAPS and Blink rate
Discussion

7.1 Aims of this study

The primary goal of this study was to examine spontaneous EBR in the context of PTSD, something that has not been done before. One question this study sought to answer was whether blink rate might relate to differences between individuals with PTSD and healthy controls in terms of dopamine level; research suggested that individuals with PTSD would have higher levels of dopamine than TEHC and non-trauma exposed healthy controls and thus show higher blink rates. However, because the experimental paradigm utilized in the study is intended to robustly target interference in working memory, the central question this paper sought to answer was whether spontaneous blink rates represents an effective index of interference control in PTSD or healthy control groups. Further, we sought to examine whether there are specific factors (such as emotional valence) that might contribute to interference control. Furthermore, because this study is uniquely positioned to explore blink rates in the context of PTSD, clinical measures relevant to PTSD were examined in the context of blink rate.

7.2 Findings

7.2.1 Behavioral results

The results for interference differences between congruent and incongruent trials in terms of both reaction time (RT) and accuracy validate the use of the Temporal Flanker Task in the examination of interference the present study. Furthermore, there was no speed-accuracy tradeoff. However, the findings do not reflect past findings regarding emotional valence and PTSD – where it would be expected that the RT is longer for individuals with PTSD (McNally et al., 1990). However, the task involved several other variables,
not only emotion. One possibility is that task demands overshadowed the influence of the emotional valence of the task. Also, the results showed an interaction between image type and emotion influences both RT and accuracy, which may reflect some of the differential findings in terms of blink rate – with blink rate varying the most between image types (although direct comparisons of blink rate and image type or emotion were not significant).

7.2.2 Group Differences

In the current study, the use of EBR as a measure of centralized dopamine levels does not seem to connect the literature of dopamine and blink rate with the literature on elevated dopamine in individuals with PTSD. Not only are the differences not significant, but also the PTSD group actually has the lowest blink rate, which is contrary to expectations based on prior research using blink rate as a proxy for dopamine levels. Steudte-Schmiedgen et al. (2014) elaborates on past research by pointing out that trauma exposure (particularly the number of times trauma has been experienced), irrespective of PTSD diagnosis may constitute a significant influence on cognitive control mechanisms. However, the PTSD group actually blinked less overall than the control groups, despite relatively greater trauma exposure.

This may have been due to the complex nature of the task; one of the most significant flaws of the current study was the lack of a true baseline condition (i.e. staring at a blank wall) with which to assess spontaneous blink rates of individual participants. One suggestion, which is supported by the discussion of the correlations below, is that individuals with PTSD exhibited the greatest exertion of cognitive control, which is actually related to hypodopaminergic states, reflecting the lowered blink rates. Another
possibility is that in this population the PTSD group had a lower tonic level of dopamine; while this is contrary to prior research on dopamine levels in PTSD, in past research groups were composed either entirely of male combat veterans with PTSD (Hamner & Diamond, 1993) or traumatized mothers whose children had cancer (Glover et al., 2003). While these groups represent very specific trauma types, in the current study the traumas within the group varied much more widely (see the demographics table above) and there were, in many cases, multiple trauma events.

Interestingly, while there are no significant gender differences for blink rate, a visual examination of the data suggests an interesting possibility: Basu, Levendosky and Lonstein (2013) point out cortisol awakening is inversely correlated with dissociative symptom severity in women who have been exposed to intimate partner violence (which involves both physical and sexual traumas); and who have been, in many cases, already exposed to traumatic experiences in childhood. Furthermore, cortisol levels are positively correlated with dopamine levels in response to stress (Wand et al., 2007). In the current study it appears that in the PTSD group only, women blink less than men (see figure 5 below); while research has indicated that while there are not usually significant differences (Colzato et al., 2009) women tend to blink more than men on cognitive tasks (Bentivoglio et al., 1997). Perhaps in the current study, differences in sex and trauma type interacted to provide a more complex account of cognitive activity. In the future more research could be done on sex and trauma type to examine how neurotransmitter modulation differs.
Figure 5. Blink rate by sex and group

### 7.2.3 Interference and blink rate

Inhibitory control is comprised of a system of cognitive structures and resources that contribute to overall functioning in the context of behavioral inhibition. Thus far, the only research linking blink rate to inhibitory control mechanisms has specifically focused on inhibitory action control (and in a healthy sample).

Colzato et al. (2009) found that EBR and stop-signal response time (SSRT) in a Go/NoGo task were positively correlated with healthy individuals (in which subjects are told to respond to a certain stimulus and inhibit a response to a different stimulus; for example to respond to a circle and inhibit response to a triangle). While the Go/NoGo task reflects inhibitory action control, the neural response associated with the Go/NoGo is in PTSD is in some respects similar and in others different than during inhibitory interference control tasks. While Go/NoGo findings of decreased activation in the VLPFC are similar to activation patterns in interference control tasks, researchers found
hypoactivity in the dACC (Falconer et al., 2008) – the opposite of what researchers have found in studies on interference control (Fani et al., 2012). However, one explanation is that the researchers utilizing the Go/NoGo task did not manipulate emotion (using only neutral stimuli) – research on interference control has pointed out that induced emotional reactions (like fear) contribute to heightened cognitive control. The current paradigm was intended to enhance the cognitive interference produced by the Eriksen Flanker Task, by resolving the spatial component, and introducing a temporal one, as well as to engage recruitment of cognitive faculties in response to emotional conflict.

In the PTSD group, the positive correlation between blink rate and interference suggests a connection to inhibitory control mechanisms in terms of neurocognitive regulation. Dopamine appears to be released during the classical Eriksen Flanker Task in healthy control subjects (Badgaiyan et al., 2011). Researchers have indicated that optimal levels of dopamine fall within an inverted U-shaped curve (Cools & D’Esposito, 2011).

Elaborating on the discussion of group differences in the section above, one possible explanation for the positive correlation between EBR and interference is that heterogeneous trauma-types, along with a mix of female and male participants, contribute to greater differences in interference control. However, it is relevant to point out that EBR only seems to account for a relatively small percentage of interference (10%). It is almost more interesting, then, that the control groups show almost no relationship between interference and EBR. One possibility is that for individuals without PTSD moderate differences in dopamine levels does not reflect differences in interference control – while these differences do appear to influence inhibitory action control (Colzato et al., 2009).
This suggests that in PTSD the capacity to regulate interference control is reflected by dopaminergic regulation, while in healthy individuals dopamine activity does not act strongly to dysregulate these systems. This may be related to the hyper-activation of the dACC in PTSD during interference control tasks (Fani et al., 2012; Thomaes et al., 2012) reflecting a poorer ability to inhibit distracters – the greater the activation of the dACC, which this study suggests may be partially linked to increased dopamine levels, the greater the interference.

### 7.2.4 Blink rate and symptom severity

The total CAPS symptom severity only showed a trend with blink rate, but no statistically significant relationship. However, the relationship between blink rate, Criterion C of CAPS – avoidance/numbing – and the emotional constriction subscale in the MDI was much stronger. Furthermore, avoidance/numbing in CAPS was significantly correlated with emotional constriction, which reflects previous findings showing a relationship between CAPS scores and dissociation (Briere et al., 2005).

Avoidance/numbing, which is characterized by general as well as more specific emotional detachment, was clearly related to the MDI category of emotional numbing, as the item of emotional constriction is characterized by “knowing you must be upset, but not being able to feel it” or “feeling frozen inside without feelings” (Briere et al., 2005).

Hopper, Frewen, van der Kolk, and Lanius (2007) found that rACC activity was negatively correlated with the avoidance sub-scale of the CAPS. The current results mirror the direction of the findings of Hopper et al. (2007), perhaps suggesting that EBR reflects diminished rACC activity – one possibility is that this occurs in the context of differential dopamine activity. Along the same line, prior research has linked
hypodopaminergic states with emotional deficits (Tessitore et al., 2002). Thus, the low EBR (low dopamine) reflects the highest avoidance/numbing score because higher rACC activation may reflect a heightened exertion of emotional control over the amygdala; which reflects previous neuroimaging findings (Etkin et al., 2006).

Conclusion

8.1 Conclusion

The current study examined how EBR reflects group differences, interference control, and symptom severity. This study approached PTSD from a novel direction – that of EBR, and while the study of EBR has been in progress for nearly a century, there are many ways in which the extant literature could be bolstered.

While no group differences emerged, examining the role that EBR plays in predicting experimental and clinical results offers potentially exciting ways in which to think about the integration of physiological and behavioral research.

Generally during EEG research eye blink data is thrown out because it creates noise in the signals that needs to be reduced. However, the data in the current study was derived from this “noise” and despite some significant limitations, also provides some potentially valuable insight. Future studies utilizing EEG, especially with clinical populations, might easily collect and analyze EBR data, which would provide more points of comparison for existing research utilizing EBR.

8.2 Limitations

Some of the limitations of this study were the lack of a baseline (no task) blink condition, and a relatively small sample size. Groups were not fully matched on sex or education. Also, the blink rate in filtering conditions includes neutral trials, which could have
influenced the interference results (although a quick check showed that the direction of correlations between baseline trials in the filtering condition were in line with the rest of the correlations). While the automatic blink detection program may have been fairly accurate, it still represents an additional area that may have produced an influence on the results.
INHIBITORY CONTROL DEFICITS AND POST-TRAUMATIC STRESS DISORDER: EVIDENCE FROM EYE BLINK RATE

References


INHIBITORY CONTROL DEFICITS AND POST-TRAUMATIC STRESS DISORDER: EVIDENCE FROM EYE BLINK RATE


INHIBITORY CONTROL DEFICITS AND POST-TRAUMATIC STRESS DISORDER: EVIDENCE FROM EYE BLINK RATE


doi:10.1111/j.1467-9280.2007.01860.x


INHIBITORY CONTROL DEFICITS AND POST-TRAUMATIC STRESS DISORDER: EVIDENCE FROM EYE BLINK RATE


doi:10.1177/0963721410370295


doi:10.1037/0894-4105.21.3.275


Analysis of the Elements of Attention: A Neuropsychological Approach.


Neuroimage, 43(4), 801–807.


INHIBITORY CONTROL DEFICITS AND POST-TRAUMATIC STRESS DISORDER: EVIDENCE FROM EYE BLINK RATE


nicotine, and marijuana dependence: results from an Israeli household sample.

*Comprehensive Psychiatry, 54*(8), e38–e39. doi:10.1016/j.comppsych.2013.07.071


Appendix

Table 1

Control group Interference Correlations

<table>
<thead>
<tr>
<th>Blink Rate</th>
<th>Interference Overall</th>
<th>Interference neutral</th>
<th>Interference fearful</th>
<th>Neutral</th>
<th>Fear IAPS</th>
<th>Fear IAPS</th>
<th>Fear Faces</th>
<th>Neutral Faces</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall blink rate</td>
<td>Pearson Correlation</td>
<td>-.222</td>
<td>-.239</td>
<td>-.214</td>
<td>-.329</td>
<td>-.198</td>
<td>-.204</td>
<td>-.234</td>
</tr>
<tr>
<td>Neutral blink rate</td>
<td>Pearson Correlation</td>
<td>-.217</td>
<td>-.233</td>
<td>-.194</td>
<td>-.355</td>
<td>-.255</td>
<td>-.204</td>
<td>-.189</td>
</tr>
<tr>
<td>Fearful blink rate</td>
<td>Pearson Correlation</td>
<td>-.225</td>
<td>-.243</td>
<td>-.199</td>
<td>-.356</td>
<td>-.268</td>
<td>-.203</td>
<td>-.206</td>
</tr>
<tr>
<td>Neutral IAPS</td>
<td>Pearson Correlation</td>
<td>-.256</td>
<td>-.275</td>
<td>-.231</td>
<td>-.261</td>
<td>-.250</td>
<td>-.208</td>
<td>-.191</td>
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<tr>
<td>Fearful IAPS</td>
<td>Pearson Correlation</td>
<td>-.291</td>
<td>-.221</td>
<td>-.256</td>
<td>-.290</td>
<td>-.292</td>
<td>-.220</td>
<td>-.246</td>
</tr>
<tr>
<td>Fearful Faces</td>
<td>Pearson Correlation</td>
<td>-.240</td>
<td>-.244</td>
<td>-.226</td>
<td>-.205</td>
<td>-.236</td>
<td>-.267</td>
<td>-.243</td>
</tr>
<tr>
<td>Neutral Faces</td>
<td>Pearson Correlation</td>
<td>-.259</td>
<td>-.266</td>
<td>-.240</td>
<td>-.237</td>
<td>-.258</td>
<td>-.176</td>
<td>-.157</td>
</tr>
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</table>

Note. N=15, * p<.05.
### Table 2

**TEHC Interference Correlations**

<table>
<thead>
<tr>
<th>Blink Rate</th>
<th>Interference Overall</th>
<th>Interference neutral</th>
<th>Interference fearful</th>
<th>Neutral IAPS</th>
<th>Fear IAPS</th>
<th>Fear Faces</th>
<th>Neutral Faces</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall blink rate</td>
<td>Pearson Correlation</td>
<td>-.275</td>
<td>-.326</td>
<td>-.221</td>
<td>-.297</td>
<td>-.290</td>
<td>-.120</td>
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<tr>
<td>Neutral blink rate</td>
<td>Pearson Correlation</td>
<td>-.292</td>
<td>-.262</td>
<td>-.218</td>
<td>-.253</td>
<td>-.283</td>
<td>-.112</td>
</tr>
<tr>
<td>Fearful blink rate</td>
<td>Pearson Correlation</td>
<td>-.290</td>
<td>-.334</td>
<td>-.241</td>
<td>-.323</td>
<td>-.294</td>
<td>-.157</td>
</tr>
<tr>
<td>Neutral IAPS</td>
<td>Pearson Correlation</td>
<td>-.394</td>
<td>-.445*</td>
<td>-.336</td>
<td>-.430*</td>
<td>-.410</td>
<td>-.219</td>
</tr>
<tr>
<td>Fearful IAPS</td>
<td>Pearson Correlation</td>
<td>-.232</td>
<td>-.273</td>
<td>-.188</td>
<td>-.226</td>
<td>-.273</td>
<td>-.071</td>
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<tr>
<td>Fearful Faces</td>
<td>Pearson Correlation</td>
<td>-.279</td>
<td>-.318</td>
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<td>-.283</td>
<td>-.255</td>
<td>-.191</td>
</tr>
<tr>
<td>Neutral Faces</td>
<td>Pearson Correlation</td>
<td>-.185</td>
<td>-.240</td>
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<td>-.260</td>
<td>-.161</td>
<td>-.028</td>
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*Note.* \( N=16, \) \( *p<.05. \)
### Table 3

**PTSD Interference Correlations**

<table>
<thead>
<tr>
<th>Blink rate</th>
<th>Interference</th>
<th></th>
<th></th>
<th>Neutral</th>
<th>Fear IAPS</th>
<th>Fear IAPS</th>
<th>Neutral</th>
<th>Fear Faces</th>
<th>Fear Faces</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall</td>
<td>Pearson Correlation</td>
<td>.428*</td>
<td>.437*</td>
<td>.404*</td>
<td>.379</td>
<td>.347</td>
<td>.428*</td>
<td>.414*</td>
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<tr>
<td>Blink rate</td>
<td>Neutral Blink rate</td>
<td>Pearson Correlation</td>
<td>.422*</td>
<td>.429*</td>
<td>.490*</td>
<td>.376</td>
<td>.359</td>
<td>.471*</td>
<td>.475*</td>
</tr>
<tr>
<td>Fearful</td>
<td>Pearson Correlation</td>
<td>.425*</td>
<td>.427*</td>
<td>.499*</td>
<td>.322</td>
<td>.303</td>
<td>.447*</td>
<td>.520*</td>
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</tr>
<tr>
<td>Blink rate</td>
<td>Neutral IAPS</td>
<td>Pearson Correlation</td>
<td>.429*</td>
<td>.462*</td>
<td>.378</td>
<td>.394*</td>
<td>.309</td>
<td>.415*</td>
<td>.446*</td>
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<tr>
<td>Fearful</td>
<td>IAPS</td>
<td>Pearson Correlation</td>
<td>.476*</td>
<td>.495*</td>
<td>.439*</td>
<td>.387</td>
<td>.409*</td>
<td>.433*</td>
<td>.510*</td>
</tr>
<tr>
<td>Faces</td>
<td>Pearson Correlation</td>
<td>.316</td>
<td>.305</td>
<td>.318</td>
<td>.254</td>
<td>.259</td>
<td>.350</td>
<td>.300</td>
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</tr>
<tr>
<td>Neutral</td>
<td>Faces</td>
<td>Pearson Correlation</td>
<td>.350</td>
<td>.341</td>
<td>.349</td>
<td>.363</td>
<td>.293</td>
<td>.376</td>
<td>.257</td>
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</tbody>
</table>

*Note.* N=19, *p*<.05.
**Table 4**

*Regression model of blink rate as a predictor of interference in PTSD*

<table>
<thead>
<tr>
<th>Predictors</th>
<th>$B$</th>
<th>$SE$</th>
<th>$\beta$</th>
<th>$r^2$</th>
<th>$\Delta r^2$</th>
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</thead>
<tbody>
<tr>
<td>Model 1</td>
<td></td>
<td></td>
<td></td>
<td>.000</td>
<td>.008</td>
</tr>
<tr>
<td>Group</td>
<td>1.541</td>
<td>4.797</td>
<td>.004</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Blink rate</td>
<td>.205</td>
<td>5.362</td>
<td>.006</td>
<td></td>
<td></td>
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<tr>
<td>Model 2</td>
<td></td>
<td></td>
<td></td>
<td>.102</td>
<td>.102</td>
</tr>
<tr>
<td>Group</td>
<td>-249.70</td>
<td>123.50</td>
<td>-.699*</td>
<td></td>
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<tr>
<td>Blink rate</td>
<td>-1.190</td>
<td>4.64</td>
<td>-.037</td>
<td></td>
<td></td>
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<tr>
<td>Group x Blink rate</td>
<td>14.282</td>
<td>6.382</td>
<td>.768*</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Note.* $N = 48$, *p < .05, ** p < .01
Table 5
Clinical correlations to blink rate

<table>
<thead>
<tr>
<th></th>
<th>Overall blink rate</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>CAPS(^1) scores</strong></td>
<td></td>
</tr>
<tr>
<td>CAPS total score</td>
<td>-.251</td>
</tr>
<tr>
<td>Re-experiencing subscale</td>
<td>-.092</td>
</tr>
<tr>
<td>Avoidance/numbing subscale</td>
<td>-.397*</td>
</tr>
<tr>
<td>Hyperarousal subscale</td>
<td>-.089</td>
</tr>
<tr>
<td>BDI(^2) score</td>
<td>-.206</td>
</tr>
<tr>
<td><strong>MDI(^3) scores</strong></td>
<td></td>
</tr>
<tr>
<td>MDI total score</td>
<td>-.140</td>
</tr>
<tr>
<td>Disengagement Sub-score</td>
<td>-.305</td>
</tr>
<tr>
<td>Depersonalization Sub-score</td>
<td>-.284</td>
</tr>
<tr>
<td>Derealization Sub-score</td>
<td>-.225</td>
</tr>
<tr>
<td>Emotional Constriction Sub-score</td>
<td>-.482*</td>
</tr>
<tr>
<td>Memory Disturbance Sub-score</td>
<td>-.244</td>
</tr>
<tr>
<td>Identity Dissociation Sub-score</td>
<td>-.085</td>
</tr>
</tbody>
</table>

*Note. N=19, *p<.05
\(^1\) Clinician-Administered PTSD Scale; \(^2\) Beck’s Depression Inventory; \(^3\) Multiscale Dissociation Inventory
Figure 1. Graphed automatic blink count (blinks indicated by red circles) for one block

Note. Number of blinks automatically counted = 112

Figure 2. Visualization of blinks in a single block

Note. Number of blinks manually counted = 108