

The blink and the body: The role of interoception in the perception of emotionally salient words
in an attentional blink paradigm

By

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Abstract

Interoception is the perception of internal bodily states. Individuals with heightened interoceptive accuracy (IA) have been found to have more frequent and intense emotional experiences than those with average or poor IA. One proposed mechanism for these differences is a positive association between IA and attention more broadly. The goal of the present study is to explore attentional processes as a function of IA via the Attentional Blink (AB). The AB is defined as a reduced accuracy when two targets occur in short succession from each other in a rapid stream of stimuli. Emotional stimuli at the second target reduces the AB while emotional stimuli at the first target enhances the AB. The present study examined how behavioral performance and the P300 component of event-related potentials in an AB paradigm is impacted by IA. Healthy undergraduates completed a cardiac awareness task, in which they counted the number of heartbeats they felt without taking their pulse, which was then compared to an objective count of their heartbeats. Based on previously-validated cut scores, 19 high perceivers and 19 average perceivers (matched for age and sex) then completed an AB task with emotional and/or neutral lexical stimuli at T1 and/or T2. Results showed that individuals with average IA performed worse when T1 and T2 were incongruent in terms of affect; similarly, their P300 amplitude to the second target in these conditions was significantly attenuated. Individuals with high IA, however, did not elicit a modulated P300 in any condition; behaviorally, they performed better when both stimuli were congruent in terms of affect. The implications and applications of the study of interoception, cognition, and emotion are discussed.

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Introduction

Precisely what is an emotion, and where it comes from, is a matter of ongoing debate (Izard, 2011). One key controversy around the origin and experience of emotions centers on whether emotions are the interpretation of bodily signals, or if the body, instead, responds as an interpretation of thoughts (Dalgleish, 2004). Cognitive science has emerged as an important contributor to this debate. The sub-field of *affective neuroscience* addresses the interaction of mind, body, and brain to better understand both emotions and cognition (Dalgleish, 2004; Ochsner & Gross, 2005). Individual differences in emotional experience rely on perception of both exogenous (e.g., presence of threatening or pleasant stimuli) and endogenous variables (e.g., state- and trait-level cognitive and psychological processes), and have been demonstrated in ample laboratory studies (Doré, Zerubavel, & Ochsner, 2014; Lindquist, Wager, Kober, Bliss-Moreau, & Barrett, 2012; Pourtois, Schettino, & Vuilleumier, 2013). One cognitive process that has gained increased attention in the literature is that of *interoception*, the perception of internal physiological bodily states, which has been used as an index of emotional sensitivity and psychopathology (Craig, 2010; Dalgleish, 2004; Paulus, 2015; Paulus & Stein, 2010; Seth, 2013; Wiens, 2005). The goal of the present study is to explore the connection between interoception, perception of emotional stimuli, and attention.

The Role of the Body in Emotion

The systematic study of body-emotion interaction began with Darwin (1872), who suggested that there are basic and universal human emotions that are expressed using bodily signals. Following this postulation, James (1884) suggested that emotion is the direct interpretation of bodily sensations: one feels sad because one cries, and not the other way around. Cannon (1931) stated that emotional experience happens too rapidly for the brain to

interpret every visceral signal, and that emotions occur regardless of neural connections to the body; therefore, emotions and bodily signals occur simultaneously. A final, and still influential, theory is presented by Schacter and Singer (1962) who suggested that the context of arousal matters in determining the emotional label of its experience: a racing heart on the battlefield is different than a racing heart from sexual arousal. There have also been additional theories and models of emotion that extend these three main examples (Dalgleish, 2004; Friedman, 2010). For example, the Somatovisceral Afference Model of Emotion (SAME) has been proposed as a compromise that suggests that each of the main theories of emotion occurs as, and if, appropriate. However, the more ambiguous the emotion, the more cognitive the processing is (Norman, Berntson, & Cacioppo, 2014). While it is beyond the scope and purpose of this paper to fully address the controversies and evidence of any of the theories of emotion, central to each of these theories is that perceiving bodily signals is essential to emotional experience in some way (Dalgleish, 2004; Friedman, 2010). It is notable, though, that the field is still deciding how to answer basic questions that Darwin, James, and Cannon posed in the late 19th century: what is an emotion, what is the role of the body in its generation, and what is its impact on the human experience? Norman and colleagues (2014, p. 121) suggest that these were questions posed ahead of their time, before the field was equipped to properly investigate them. It is only in the past several decades that these questions can adequately be explored. The present study aims to further our understanding of the relation of emotion, cognition, and the body.

Interoception: the perception of bodily states

The process of perceiving bodily signals is known as *interoception* (Craig, 2002). Interoception is distinct from proprioception (an awareness of the body's place in space and time) and exteroception (the awareness of external stimuli) (Craig, 2002, 2003). In the late 19th

Century, philosophers and physiologists (e.g., Weber, Sherrington, and James) suggested that there is a separation between the perception obtained via the five main sensory inputs and those that perceive internal states and correspond to arousal and self-regulation (Craig, 2002).

Increasing data from humans and non-humans at the time suggested that this distinction is what defined consciousness as an internal function rather than the consequence of external sources. In short, these individuals suggested that interoception was the foundation and basis of consciousness. Contemporary psychological and neuroimaging studies continue to confirm these original postulations and now include interoception as key to self-regulation and maintaining homeostasis (Craig, 2002, 2003, 2010; Garfinkel & Critchley, 2013).

Interoception was initially proposed to be the perception of visceral signals, though the list of systems included in the construct now include a wide range of sensations ranging from temperature and pain to satiety (thirst, hunger, etc.) and fatigue (Craig, 2002). Interoception is a diffuse process that relies on afferent and efferent neurons located throughout the body and every layer of the nervous system: in short, it is the integration of sensations from the entire body (Craig, 2003). Within the Central Nervous System, the main sources of sensory integration are those most strongly associated with individual differences in interoception, including the hypothalamus, anterior cingulate cortex (ACC), supplementary motor areas (SMA), amygdala, and insula (Craig, 2002, 2003; Critchley, Wiens, Rotshtein, Ohman, & Dolan, 2004). These sites integrate the multimodal inputs that pertain to bodily sensations (Craig, 2003). The function of these sites, particularly the insula, are consistently observed in the study of emotion, to the point where they have been found to be activated in “virtually every imaging study of human emotions” providing a sense of a physical self and a basis for which consciousness and emotion may develop (Craig, 2003, p. 503).

The measurement of interoception corresponds to individual differences in a host of cognitive and emotional processes (Garfinkel & Critchley, 2013). Interoception itself is proposed to be comprised of three components: interoceptive sensibility, interoceptive sensitivity, and interoceptive awareness (Garfinkel & Critchley, 2013; Garfinkel, Seth, Barrett, Suzuki, & Critchley, 2015). Garfinkel and Critchley (2013) define interoceptive sensibility as the self-report of bodily sensations and perceptions; interoceptive sensitivity as an objective measure (e.g., through cardiac awareness, described further below); and interoceptive awareness as an individual's cognizance of their own interoceptive abilities (i.e., metacognition), such that this variable is as a ratio of an individual's objective accuracy and their self-reported confidence in their perception. Emerging research supports that interoceptive sensibility, sensitivity, and awareness are distinct (Garfinkel et al., 2015; Meessen et al., 2016). Interoceptive sensitivity, as Garfinkel and colleagues define it, is commonly referred to as Interoceptive Accuracy (IA). For ease of presentation and consistency with previous literature, an individuals' accurate perception of bodily sensations via objective measure are referred to in this manuscript as IA. Garfinkel and colleagues found that only IA predicted increases in the other domains of interoception; thus, objective measures predict subjective measures of interoception, and not the other way around.

One of the most widely used measurements of IA is cardiac awareness, in which a participant is typically asked to estimate how many heartbeats they felt in a particular period of time (Schandry, 1981). The count is then compared to an objective measure of heartbeats obtained by electrocardiogram or heartrate monitor. The closer in accuracy an individual is to estimating their objective heart rate, the better their IA score. The implications for this assessment are wide, and are discussed in greater detail below. However, there are several limitations of this method: (a) it is limited in ecological validity since the individual is typically

measuring their heart rate while at rest (when it is most difficult to attend to interoceptive cues); (b) there is an over focus on cardiac perception leaving other modalities of interoceptive awareness unexplored (e.g., challenge tasks); and (c) its clinical utility has been infrequently explored (Khalsa & Lapidus 2016). Despite these limitations, increasing evidence supports that cardiac perception is an important individual difference in emotional processing (Garfinkel & Critchley, 2016) and psychopathology (Khalsa & Lapidus 2016). High IA has been linked to improved cognition (Matthias, Schandry, Duschek, & Pollatos, 2009), decision making (Werner, Jung, Duschek, & Schandry, 2009), and therapeutic outcomes (Masdrakis et al., 2013).

Interoception in Emotion.

Interoception has long been found to play a key role in the experience of emotions, and there are ample studies demonstrating key neurological and psychological overlap in self-reported IA and emotional experience (Barrett, Quigley, Bliss-Moreau, & Aronson, 2004; Craig, 2010; Dalgleish, 2004; Domschke, Stevens, Pfleiderer, & Gerlach, 2010; Herbert, Herbert, & Pollatos, 2011; Wiens, 2005; Zaki, Davis, & Ochsner, 2012). It is well established that there is a role of interoception processing in the generation and recognition of emotions (Wiens, 2005), and that IA may be involved in the pathogenesis of a variety of psychopathologies, particularly mood and anxiety disorders (Domschke et al., 2010; Fustos, Gramann, Herbert, & Pollatos, 2013; Herbert et al., 2011). More specifically, individuals with increased IA are prone to more frequent and intense emotional experiences and are more likely to label a physiological symptom as emotional than those with lower IA (Barrett et al., 2004; Craig, 2010; Schandry, 1981). Perhaps as a result, IA is positively associated with emotional lability (Barrett et al., 2004; Schandry, 1981) and anxiety (Domschke et al., 2010; Paulus & Stein, 2006). Conversely, decreased and/or dysfunctional IA is associated with increased depression, negative affect, and

alexithymia, or difficulty identifying and describing emotions (Harshaw, 2015; Herbert et al., 2011; Paulus & Stein, 2010), though this relationship is complex (Dunn et al., 2010). It is suggested that individuals with dysfunctional IA are less likely to experience sensations related to emotion, resulting in emotional blunting while also being less likely to experience pleasurable sensations, resulting in anhedonia (Harshaw, 2015; Paulus & Stein, 2010). It is unclear if depression is cause or consequence of deficient IA: those who are depressed may have lower sensitivity to arousing stimuli, including hedonic stimuli, or if lower levels of IA are a risk factor for depression due to decreased perception of pleasure and increased perception of aversion and disgust (Dunn, Dalgleish, Ogilvie, & Lawrence, 2007; Harshaw, 2015; Paulus & Stein, 2010). Another complimentary possibility is that individuals with decreased IA may then become reliant on exteroceptive signals (e.g., achievement or social inclusion) to elicit hedonic response, ultimately resulting in decreased self-regulation and self-sufficiency (Harshaw, 2015; Joormann & Vanderlind, 2014; Nolen-Hoeksema, 2012).

Some of the links between interoception and depression and anxiety may have a social and environmental influence. For example, gender differences in depression and anxiety begin at adolescence, a time when girls are socialized to attend to their body at increased frequency and intensity (e.g., for weight management or due to menstruation). Indeed, girls in young adolescence report increased pain, including headaches and abdominal pain, at increased levels compared to boys, and this difference extends into adulthood (Beck, J. E., 2008). Evidence has shown that women reported increased IA compared to men, though women's objective cardiac awareness scores were significantly lower than men's (Grabauskaite, Baranauskas, & Griskova-Bulanova, 2017; Koch & Pollatos, 2014). As a result of increased vigilance and inaccurate reporting, girls and women may misinterpret bodily signals as aversive and/or associated with

unpleasant experiences, even if these sensations have no objective link (Harshaw, 2015; Paulus & Stein, 2010). Cross-culturally, Western cultures tend to de-emphasize somatic complaints associated with psychological distress whereas Non-Western cultures tend to have increased IA and are more likely to report somatic complaints when experiencing psychological distress (Ma-Kellams, 2014). Western de-emphasis of bodily awareness has been suggested as a partial explanation for the higher prevalence of psychological distress in these cultures (Kirmayer & Ryder, 2016; Ma-Kellams, 2014).

Electroencephalography and Emotion.

Contemporary research methods in neuropsychology and neuroimaging have provided greater insight into the origin, time course, and discrete expression of emotions and cognition. Electroencephalography (EEG) and Event-Related Potentials (ERPs) have been particularly useful tools in better understanding the neural processing of stimuli across populations largely due to their non-invasiveness, cost effectiveness, and high temporal resolution (Luck, 2014). When averaged together, particular ERP waveforms, referred to as *components*, provide data on the time course, intensity, and possible location of neural responses to an event, stimulus, or response (Fabiani, Gratton, & Coles, 2000). Components are the central data points for most ERP studies. The nomenclature and taxonomy of most components reflect either, or both, their temporal expression and polar direction. For example, the “P100” or “P1” is both the first positive-going deflection after a stimulus, and is also generally observed at around 100ms, while the “N100” or “N1” occurs immediately thereafter in a negative direction (Earls, Curran, & Mittal, 2016; Luck, 2014). The most commonly examined components within research on emotion and attention are the P300 and Late Positive Potential (LPP) (Hajcak, MacNamara, & Olvet, 2010), though the N1, P1, and numerous others have also received a sizable amount of

interest in the literature (Citron, 2012; Earls et al., 2016; Ferreira-Santos et al., 2012; Hajcak et al., 2010; Mingtian, Xiongzhaoh, Jinyao, Shuqiao, & Atchley, 2011).

The P300 (sometimes referred to as the P3) is the third pronounced positive deflection in a typical ERP waveform, peaking at around 300-500ms after stimulus onset, though the precise time and duration of the component varies (Luck, 2014; Picton, 1992; Polich, 2007). Amplitude, latency, and duration of the P300 is influenced by introspection, personal relevance of stimuli, and/or executive functioning capacity of the participant (e.g., working memory, attention; described further below) (Hajcak et al., 2010; Picton, 1992; Polich, 2007). The P300 is most clearly elicited when a rare target stimulus is encountered after a sequence of frequent, non-target stimuli as response requires updated working memory (i.e., “context updating”), which is a key component of cognitive control (discussed further below) (Polich, 2007). The P300 is further divided into two additional components: the P3a is recorded in anterior electrodes, likely corresponding to Cingulate Cortex; the P3b is generated in temporoparietal electrodes, likely reflecting greater spread of neural activity, including limbic and broader frontal lobe activation (Polich, 2007; Volpe et al., 2007). In healthy individuals, the P300 is enhanced by emotionally arousing stimuli, particularly if the stimuli are personally relevant, but not the P3a, suggesting the P3b reflects recruitment of neural resources intended to evaluate motivational salience (i.e., approach or avoid systems) (Delplanque, Silvert, Hot, & Sequeira, 2005). The generators of the P3a and P3b have not yet been fully established, and the discreet functioning of the components is not yet fully understood (Linden, 2005). For the purposes of this study, the P3b is what is referenced when discussing the P300.

Emotional stimuli, particularly negative emotional stimuli, have been found to generate larger P300 amplitudes reflecting “motivated attention,” wherein the stimulus reflects a

motivationally salient response, such as threat to be avoided or reward to be sought (Delplanque et al., 2005; Hajcak et al., 2010). Some have suggested that there is a stronger bias toward positive information than negative information, or that emotional information has an equal degree of bias regardless of valence (Carretie et al., 2008; Smith, Cacioppo, Larsen, & Chartrand, 2003; Wadlinger & Isaacowitz, 2006). Research indicates that the P300 also provides evidence for a bias toward negative interpersonal information, such as facial expressions (Gotlib, Krasnoperova, Yue, & Joormann, 2004). Moreover, other findings suggest that the P300 and LPP show biases less to valence, but more to the personal relevance of a stimulus that generates a larger P300 while the state- and trait-level emotions of the participant then dictate its amplitude (Gray, Ambady, Lowenthal, & Deldin, 2004; Moran, Macrae, Heatherton, Wyland, & Kelley, 2006; Nakao, Takezawa, Shiraishi, & Miyatani, 2009). Thus, the perception of threat or pleasantness within stimuli may be reliant on the perception of self-relevance by the participant.

Interoception and Electroencephalography

The attentional biases described above are enhanced in individuals with high IA (Domschke et al., 2010; Pollatos, Kirsch, & Schandry, 2005). Those with increased IA show larger P300 amplitudes to emotional stimuli regardless of valence (Herbert, Pollatos, & Schandry, 2007; Pollatos, Matthias, & Schandry, 2007). Compared to individuals with lower levels of IA, individuals with high IA have been shown to be more sensitive to emotional stimuli in a variety of modalities, regardless of psychopathology (Herbert, Pollatos, Flor, Enck, & Schandry, 2010; Pollatos et al., 2005; Werner, Peres, Duschek, & Schandry, 2010). These biases were compounded when stimuli contained an element of the body (e.g., *ugly*) compared to when they did not (e.g., *stupid*), suggesting not only a bias to emotional and threatening stimuli, but to stimuli referring to the body itself (Benau & Atchley, Under Review).

The mechanisms of the association between IA and sensitivity to emotional stimuli are only starting to be understood. The neural systems associated with P300 activation are also associated with those that are involved in IA (Herbert et al., 2007; Pollatos et al., 2007). Pollatos et al. (2005) suggest that individuals with higher IA have heightened neural connections and reactivity in brain regions, namely the insula, associated both with emotional perception and visceral perception. One proposed mechanism for this link is that individuals with heightened IA may find that physiological reactions (e.g., increased heart rate) in certain situations (e.g., exposure to a phobic stimulus) and they may find their experiences to be much more unpleasant than those with lower IA (Critchley et al., 2004; Wiens, 2005). As a result of these associations, the mounting evidence investigating IA support the theory of James (1884), that emotional experience is contingent and secondary to bodily sensations. Thus, individuals with heightened IA are more likely to perceive their bodily signals (particularly heartbeats), increasing the likelihood of experiencing threat, resulting in increased frequency and intensity of major negative emotions such as fear and anxiety (Garfinkel & Critchley, 2016; Paulus, 2015; Paulus & Stein, 2006, 2010; Stern, 2014).

Interestingly, those with higher IA have also been found to be able to reappraise emotional stimuli following training to do so, despite having greater reactivity to those stimuli prior to training (Fustos et al., 2013). The comparatively speedier reappraisal is suggested to be a result of a sensitivity to the underlying hyperactive somatosensory inputs in that population (Fustos et al., 2013; Herbert et al., 2011). The results of Fustos and colleagues suggest that those with increased IA are not only more likely to experience heightened emotions, but also have increased top-down abilities to regulate them.

Cognition and Emotion

In addition to, and in conjunction with, the role of bodily sensations, cognitive function itself is a key contributor to the experience of emotions (Critchley, Eccles, & Garfinkel, 2013; Uddin, Kinnison, Pessoa, & Anderson, 2014). Initially framed as peripheral to each other, the interaction of cognition with mood and pathology are becoming increasingly important and informative avenues of research (Critchley et al., 2013; Ochsner & Gross, 2005). The evidence supports the postulation that emotion is both a bottom-up and top-down mechanism: while a stimulus may trigger bodily sensations that correspond to emotions in some capacity, humans can modify their perception of, and reaction to, those stimuli cognitively or behaviorally (Banich et al., 2009; Ochsner & Gross, 2005). Better understanding the mechanisms of these processes, and what is and is not able to be consciously manipulated, can lead to improved targeted treatments (Bowie, Gupta, & Holshausen, 2013; Siegle, Ghinassi, & Thase, 2007; Wykes & Spaulding, 2011). However, before these interventions can be implemented effectively, there is still much more research needed to understand basic cognitive processes, and their interaction with emotional experience and pathology (Koziol, Barker, & Jansons, 2015; Snyder, Miyake, & Hankin, 2015; Suchy, 2009).

The role of attention as an executive function (discussed further below) has been the most consistent target of research in pathology and emotion (Banich et al., 2009; Heeren, Billieux, Philippot, & Maurage, 2015; Ochsner & Gross, 2005; Snyder et al., 2015). An assumption of research pertaining to cognitive function and emotion is that, barring intervention, attentional biases are reflexive and involuntary means of giving preference for particular stimuli to enter consciousness (Cisler & Koster, 2010). It has been suggested that humans are particularly sensitive to threatening and negative stimuli (Carretie, Albert, Lopez-Martin, & Tapia, 2009), but

it may be that humans may be sensitive to emotional stimuli in general (Schupp, Flaisch, Stockburger, & Junghöfer, 2006; Vuilleumier & Huang, 2009). A bias to negative attention may be adaptive in that it evaluates threat; however, excessive biases to these stimuli can be deleterious (Mehu & Scherer, 2015; Peckham, McHugh, & Otto, 2010; Van Bockstaele et al., 2014). Early cognitive models suggested that excessive attentional biases to negative information are learned through development and are a primary risk factor for mental illness, particularly mood disorders (Browning, Holmes, & Harmer, 2010).

Attentional biases are proposed to be composed of three characteristics: (a) difficulty with disengagement; (b) facilitated and/or automatic attention to a particular stimulus; and (c) avoidance (Cisler & Koster, 2010). Difficulty with disengagement is the inability to deflect attention from a stimulus. Facilitated engagement is reflexively attending to aversive stimuli. Avoidance is an inability to engage with stimulus that is typically viewed as aversive or threatening stimulus (Cisler & Koster, 2010). Exhibiting an attentional bias to aversive or otherwise affective stimuli is not necessarily problematic, while the appraisal associated with the bias is. For example, those with mood disorders often exhibit comparable attentional biases to negative stimuli as healthy controls, but those with depression are likely to exhibit greater affective responses than controls (Joormann & Vanderlind, 2014; Mehu & Scherer, 2015).

Attention may be under more voluntary control than initially proposed (Diamond, 2013). Attention is part of a broader network of cognitive functions broadly called *executive functioning*, which is primarily involved in goal pursuit, planning, and activity completion (Banich et al., 2009; Bunge, 2004; Diamond, 2013; Miyake et al., 2000). The consequences of maladaptive executive functioning can be profound and are associated with a variety of cognitive and emotional difficulties. Deficits in executive functioning result in increased cognitive rigidity

and perseveration (Dreisbach, 2012) and are associated with distress-proneness (Mehu & Scherer, 2015), negative affect (Pe, Raes, & Kuppens, 2013), and a variety of psychopathologies (Banich et al., 2009; Ochsner & Gross, 2005; Ravizza & Salo, 2014). A proposed mechanism for this association is that individuals with decreased executive functioning are less able to disengage attention mechanisms from negative stimuli and then engage with positive stimuli (Foland-Ross & Gotlib, 2012; Koster, De Lissnyder, Derakshan, & De Raedt, 2011).

Attention is broadly defined as the mechanism wherein information is selected to remain in consciousness and/or stored in memory (Posner & Snyder, 2004), though there is some debate about attention's composition and precise placement in the hierarchy of cognition (Koziol et al., 2015; Petersen & Posner, 2012). Some have suggested that there is limited consensus on the definition of attention "since everyone knows what [it] is" (Ridderinkhof & van der Stelt, 2000), and, as a result, there is limited research into defining and understanding attention. Some have argued that attention is not a unitary construct, and it is often defined as whatever the dependent variable is within a particular study (Parasuraman & Yantis, 1998; Plude, Enns, & Brodeur, 1994). An initial proposal suggested that there were three main processes underlying attention: alerting, orienting, and executive (Posner & Dehaene, 1994; Posner & Petersen, 1989). Alerting is the basic element of arousal wherein a stimulus enters sensory input and the requisite neuroanatomical structures are activated to engage the other systems. Orienting is the process by which resources are allocated to maintain awareness of the stimulus. The third system, the executive, was thought to control focus on stimuli.

Updates to the model of attention discussed above suggest that, based on decades of human and non-human neurobiological and neuropsychological research, in fact, the executive aspect of attention is more likely a top-down mechanism, driven by functions and modalities both within,

and outside of, attention (Petersen & Posner, 2012). Initially framed as subordinate to attention, a substantial body of research suggests that executive control is the dominant system that utilizes attentional resources to match a stimulus and/or response to an expected template; matching that template corresponds to continued engagement in that task, whereas mismatch corresponds to changing of strategy and behavior in order to facilitate attention (Botvinick, Braver, Barch, Carter, & Cohen, 2001; Botvinick & Cohen, 2014). For example, in a typical Eriksen flanker task, in which the participant is to identify the direction of a central arrow in a row of arrows, should the participant make an error, the participant is more than likely to attempt to correct that error and slow their responses on subsequent trials (Carter & Krug, 2011).

Heightened salience and attentional capture of emotional stimuli is essential for survival. Increased threat detection corresponds to increased likelihood to respond to threat; however, excessive focus on emotional stimuli can be deleterious, particularly in contemporary industrialized environments (Treynor, Gonzalez, & Nolen-Hoeksema, 2003; Watkins & Brown, 2002). Excessive focus on negative stimuli has been found to be associated with a variety of psychopathologies, chiefly depression and anxiety, and has been identified as a risk factor and endophenotype for the onset and maintenance of those disorders (Meiran, Diamond, Toder, & Nemets, 2011; Nolen-Hoeksema, Wisco, & Lyubomirsky, 2008; Pe et al., 2013; Rock, Roiser, Riedel, & Blackwell, 2013; Snyder, 2013). When targeted in treatment, deficits in attention have shown improvement alongside symptom reduction (Siegle, 2011; Sole et al., 2015; Wykes & Spaulding, 2011). However, far more research is needed into the mechanisms and underpinnings of attentional biases to enhance their effectiveness in treatment.

The Attentional Blink. The Attentional Blink (AB; Raymond, Shapiro, & Arnell, 1992) is one of the most popular paradigms to assess the temporal dynamics of attention (Dux & Marois,

2009; Martens & Wyble, 2010; McHugo, Olatunji, & Zald, 2013). In a typical AB paradigm, the participant is presented with a series of stimuli in a Rapid Serial Visual Presentation (RSVP) stream. In this stream, about 20 stimuli are presented for a fleeting duration (typically less than 100ms). The participant is asked to identify the first target (T1) and a second target (T2), that are unique to the rest of the stimuli in some way. Usually, the targets are simple symbols, such as letters, while the remaining filler stimuli are of some other type, such as numbers. The participant is then told to recall the number of targets they saw (some trials have one or no targets in it) and what those targets were. The T2 is also presented at different time points in the stream ranging from immediately after the T1 (referred to as “Lag1”), one stimulus away (“Lag2”), two stimuli (“Lag3”), and so on. What has been found is that there is a window of time after T1 in which recalling the correct stimuli reduces substantially. Interestingly, Lag1 is usually recalled at better rates than L2 and Lag3. In other words, for several hundred milliseconds, the capacity of the brain to encode stimuli “blinks” after the presentation of an initial stimulus (Martens & Wyble, 2010).

The mechanisms and origins of the AB are controversial topics. It is beyond the scope and purpose of this paper to provide a thorough discussion of the different hypotheses that have been proposed (for reviews, see: Dux & Marois, 2009; Martens & Wyble, 2010). However, the main models of the AB can be understood in two larger themes: (a) a depletion of attentional resources at the onset of T1 that began with the onset of the stream of stimuli; or (b) AB reflects a modification of cognitive control needed to reorient attention and is unable to do so due to the processes involved in attending to, and encoding, T1 (Dux & Marois, 2009). Some suggest these themes are not mutually exclusive, and there is evidence that both occur simultaneously (Kawahara, Enns, & Di Lollo, 2006). A final model, the “Boost and Bounce” model, suggests

that the AB occurs because the perception of T1 enhances attention to immediately-subsequent stimuli, and the blink occurs when working memory sources are over-fixated on filtering out other stimuli (Olivers, 2010). Hence, when T2 immediately succeeds T1 (Lag1), it is typically not blinked, but it is blinked when T2 is at Lag2. The filtering sources continue to be “boosted” from having seen T1, but “bounce” to baseline following a non-target immediately succeeding T1 (Lunau & Olivers, 2010; Olivers, 2010). Primary evidence for this comes three- and four-target conditions wherein the blink does not occur if all three targets occur after each other, but the blink does occur if a distracter occurs between (or after) any of the targets (Asplund, Todd, Snyder, Gilbert, & Marois, 2010; Di Lollo, Kawahara, Shahab Ghorashi, & Enns, 2005; Kawahara et al., 2006; Most, Smith, Cooter, Levy, & Zald, 2007; Olivers, van der Stigchel, & Hulleman, 2007).

Reducing an over-focus on T2 also attenuates the blink, supporting the Boost and Bounce model. When attentional resources are diffused by way of distraction the blink effect has been found to reduce considerably (Arend, Johnston, & Shapiro, 2006), as does adding a blank-screen delay between T1 and Lag1 (Brisson & Bourassa, 2014). However, others have found that distraction is more of a selective process, as some distractors reduce AB (i.e., task-irrelevant stimuli improve performance while task-relevant distractors do not), and some are a matter of individual difference (i.e., habitual blinkers will do worse, while habitual non-blinkers will do better) (Dux & Marois, 2008; Folk, Leber, & Egeth, 2002; Martens & Valchev, 2009). Finally, when a distractor is emotional, it enhances the attentional blink (Asplund et al., 2010; Kennedy & Most, 2015; Most, Chun, Widders, & Zald, 2005a; Most & Jungé, 2008; Most et al., 2007; Yiend, 2010).

The extant research examining individual differences in the AB have found somewhat paradoxical results compared to standard experimental psychology paradigms. Those in more negative moods, those with depression, and/or who those who are not motivated to perform well on the AB task will perform better than those who are in positive moods and/or are incentivized to perform well on the AB task (Arend & Botella, 2002; Biggs, Adamo, & Mitroff, 2015; Di Lollo et al., 2005; Dijksterhuis & Aarts, 2010; Dux & Marois, 2009; Martens & Wyble, 2010; McHugo et al., 2013; Rokke, Arnell, Koch, & Andrews, 2002). For example, dysphoric undergraduates who were presented a negative word as their T1 were less likely to identify a neutral T2 than controls, suggesting that dysphoria enhances the effect of either attentional depletion or increased sensory gating that underlies the AB (Koster, De Raedt, Verschuere, Tibboel, & De Jong, 2009). It is thought that individuals who have a higher level of engagement in the task are more likely to expend their attentional resources on T1 and have a longer refractory period than those who are less engaged (Martens & Wyble, 2010; Taatgen, Juvina, Schipper, Borst, & Martens, 2009). Another suggestion is that individuals who are less prone to blink have a wider area of attentional focus or perhaps have improved verbal abilities allowing them to encode T1 faster and not “blink” at T2 (Willems, Wierda, van Viegen, & Martens, 2013).

Stimuli in a typical AB task are usually simple symbols that are distinguished on some surface feature, for example, identifying a red symbol in a gray stream of symbols, and/or identifying a letter in a stream of numbers. However, lexical stimuli have also been used to explore the AB. For example, when words were used in a stream of random symbols and letters, words that belonged to a similar semantic category (e.g., *thunder* and *lightning*) were blinked at a greater rate than those from different categories (e.g., *thunder* and *ankle*) (Tibboel, De Houwer,

Spruyt, & Crombez, 2011). Similar effects were found using pictures. The N400, which is typically larger in cases of semantic incongruity, was larger for two words that were unrelated (e.g., doctor/flower) than for words that were related (e.g., doctor/nurse), regardless of correct recall of the words (Luck, Vogel, & Shapiro, 1996; Rolke, Heil, Streb, & Hennighausen, 2001; Vogel, Luck, & Shapiro, 1998). Similarly, target images that were conceptually similar had impaired accuracy compared to target images that were conceptually distinct (i.e., same color, different content), suggesting that conceptual binding is a component of the AB process (Einhauser, Koch, & Makeig, 2007; Most et al., 2001; Wyble, Folk, & Potter, 2013). A comparable effect was shown for neutral faces of the same person compared to objects of the same color (Harris, McMahon, & Woldorff, 2013). Additional studies have shown that more complex T1 (e.g., words with additional syllables, shapes with more dimensions to identify), T1 enhance the blink, whereas simpler T1 stimuli reduce the blink magnitude (Dux & Marois, 2009).

The valence and emotional content of stimuli is also an important factor in the AB (McHugo et al., 2013; Yiend, 2010). Aversive T1 stimuli increase the AB, while an aversive T2 attenuates the blink regardless of T1 content, though this effect is greater for pictures than for words (Anderson, 2005; McHugo et al., 2013; Schwabe et al., 2011; Schwabe & Wolf, 2010). Words and names that convey power at T1 enhance the blink for men (e.g., *boss* or the idiographic name of their superior), but not for women, compared to neutral words (Mason, Zhang, & Dyer, 2010). The hypothesis for this effect, dubbed the Emotional Attentional Blink, is that content of stimuli that are emotional and/or arousing will increase attentional capture and “break through” whatever filtering mechanism may underlie the AB (McHugo et al., 2013). Further evidence of this is provided by individuals with anxious pathology associated with increased baseline

hypervigilance (e.g., Obsessive-Compulsive Disorder, Generalized Anxiety Disorder, and Post-Traumatic Stress Disorder) who show comparatively minimal blinks when T2 stimuli are emotional compared to when they are neutral; they generally do not differ from non-anxious controls when T2 stimuli are neutral (McHugo et al., 2013; Van Bockstaele et al., 2014). Therefore, the content of the stimuli for the AB paradigm is as important as the surface features of the targets and the individual differences of the participants.

Interoception and Attention. There is little research regarding the role of interoception and basic attentional functioning. In fact, the authors of a recent review stated they were unaware of any studies that explored attention and interoceptive processes, specifically (Paulus & Stewart, 2014, p. 344). However, there are a few studies that can offer insight into how IA influences, or is influenced by, attention. In a test of attention, individuals with higher IA performed better in tests of selective and divided attention (Matthias et al., 2009). They also were better attuned at identifying a number of external physical signals, including external discrimination of audible, non-linguistic tones; this difference was enhanced after a training for high perceivers only (Katkin, Morell, Goldband, Bernstein, & Wise, 1982). Thus, individuals with increased IA have increases in attention to other external stimuli, which may reduce bias and increase focus on task-related demands (Bechara, Damasio, Tranel, & Damasio, 1997; Garfinkel & Critchley, 2013). When assessed using retrospective data, there was no association between IA and metacognition and memory (Meessen et al., 2016). Meessen and colleagues attained their information regarding cognitive functioning using retrospective data on cognition, and prospective data on interoception by using a heartbeat detection task. Therefore, it is unclear to what degree their null findings are based on errors in self-report. Similarly, Garfinkel et al. (2015) also reported a series of null findings in correlating self-reported interoception abilities to

self-reported cognitive strengths. Therefore, when it comes to experimentally investigating the role of interoception in emotion and cognition, it is important to distinguish interoceptive accuracy (data attained prospectively) and interoceptive awareness (data obtained by self-report) (Garfinkel et al., 2015).

One way that interoception and executive functioning have been compared and/or experimentally manipulated is through training in mindfulness, or the non-judgmental awareness of events, space, and time (Holzel et al., 2011). Those who are engaged in mindfulness-based training often report increased IA compared to those who do not (Tang, Holzel, & Posner, 2015). Individuals who are naïve to mindfulness training have exhibited increased IA following mindfulness training (Bornemann & Singer, 2017; Farb, Segal, & Anderson, 2013); however, others did not find the link between mindfulness and IA following mindfulness based stress reduction training (Parkin et al., 2013). Time perception, which is a confluence of multiple components of executive functioning, particularly attention (Brown, 2006; Zakay & Block, 2004), is positively associated with IA (Merchant, Harrington, & Meck, 2013; Pollatos, Laubrock, & Wittmann, 2014; Wittmann, 2013). Attention and other executive functions have been found to predict self- and emotion-regulation (Bernier, Carlson, & Whipple, 2010; Hofmann, Schmeichel, & Baddeley, 2012), yet it inconsistently predicts distress tolerance, an index of IA (Sutterlin et al., 2013a).

Interoception and the Attention Blink. There is little research that explores the role of interoception in the AB. In an emotional AB paradigm, in which target words were affective (e.g., “murder”) in a stream of neutral words (e.g., “supergalaxy”), Garfinkel et al. (2013) found that IA positively correlated with recall accuracy, with the largest r corresponding to memory for positive words. Interestingly, the authors only found this association when participants’ heart

was in systole; no associations were found when participants' hearts were in diastole. Similarly, in an fMRI study, Garfinkel et al. (2014) found that the processing of sad faces, specifically, were recalled better in an AB paradigm when the faces were presented at systole than at diastole. The authors also found that the ratings of the faces' intensity were greater at systole than at diastole. Results of the fMRI data indicate heightened amygdala and hippocampus activity during systole at the time of fearful –and only fearful - face presentation. However, to my knowledge, those are the only two studies at present that have investigated individual differences in IA as they relate to the AB. Although they did not directly measure IA, Kever, Pollatos, Vermeulen, and Grynberg (2015b) manipulated physical arousal of their participants prior to completing an EAB task: half of their sample engaged in an exercise task (7.5 minutes of intense stationary cycling while maintaining a heart rate of 220 BPM) for the high-arousal condition, and the other half engaged in 7.5 minutes of relaxation (reclined in an armchair while listening to relaxing music) for the low-arousal condition. Kever and colleagues found that those in the high arousal condition had a significantly attenuated blink for emotional stimuli compared to the relaxed condition. Thus, these studies highlight a key role in somatic signals in attentional bias to emotional stimuli.

EEG studies of the Attentional Blink.

The use of EEG has elucidated the time course and mechanisms of the AB. Due to the nature of the task involving working memory updating and attentional allocation, the P3b is typically what is assessed as the P3a is more anterior and is not generally seen to fluctuate in any condition of the AB (Sergent, Baillet, & Dehaene, 2005). For ease of presentation, since studies of electrophysiological correlates vary in their terminology of the component, it will be referred to as the “P300,” despite this being a non-ideal nomenclature. Typically, the P300 is attenuated

in trials in which the T2 was not detected (i.e., the blink) (Kranczioch, Debener, & Engel, 2003; Vogel et al., 1998). The P300 amplitude and peak latency also increase as a function of Lag and, therefore, Blink likelihood: when T2 was detected, Lag2 corresponded to the smallest P300, followed by Lag1 and then Lag8, while when T2 was missed, the P300 was comparable across lags (Kranczioch et al., 2003; Martens, Munneke, Smid, & Johnson, 2006b; Sessa, Luria, Verleger, & Dell'Acqua, 2007). However, the role of the P300 may be more complicated as the P300 does not always correspond to T2 accuracy, particularly at the later Lags, which are considered outside the Blink window (Batterink, Karns, & Neville, 2012). Therefore, the P300 and the psychological processes that underlie it are important components of the Blink, but there are additional aspects of the process that are important to consider.

Vogel and colleagues, found an attenuated P2, while early components related to attentional orientation (e.g., N1, P1) were not attenuated; this indicates that the T2 was seen, but not encoded sufficiently in memory. More recent research, however, indicates that the P2 is not suppressed (Kranczioch et al., 2003; Martens & Valchev, 2009). The function of the P2 is not well-established, but it is thought that the P200 corresponds to updating (i.e., an index of the executive component of attention) while the P300 corresponds to encoding of information (Zhao, Zhou, & Fu, 2013). Supporting the so-called “Bump and Boost” model of the AB (Olivers, 2010), the peak amplitude of the P300 to T1 has been significantly correlated to the P300 to individual differences in blink magnitude (Shapiro, Schmitz, Martens, Hommel, & Schnitzler, 2006). In other words, Shapiro and colleagues found that the propensity for an individual to blink was determined by resource allocation to the encoding of T1. When the masking effect of the stimulus in Lag1 is removed by adding a blank screen between T1 and the next stimulus, the P300 significantly increases (Brisson & Bourassa, 2014). In the lead up to a T1, event-related

alpha desynchronization was negatively associated with T2 ultimately not being encoded; in other words, increased anticipatory neuroelectrical activity to T1 corresponded to decreased activity (Maclean & Arnell, 2011). Individuals who are less prone to blink are shown to have a smaller earlier P300 to T1, therefore they are able to diffuse their attention and/or consolidate and encode the stimuli into memory faster and more efficiently (Martens et al., 2006b).

Current Research

The overarching goal of the present study is to further elucidate how IA may impact the time course and intensity of attentional biases to emotional stimuli. It is clear that there is a mutual influence of interoception and attention and emotional experiences. However, few studies have examined individual differences in interoception so as to predict the modulation of attentional function during the processing of emotional stimuli. More specifically, there is a dearth of studies that have utilized the AB to explore individual differences of attentional bias to emotional stimuli as a function of IA. No study could be found that has combined these variables using EEG to measure the time course of these attentional biases in brain and mind. More specific aims and goals of the present research are discussed further below.

Aim 1. The present study aims to significantly extend previous work exploring the Emotional Attention Blink. In addition, several important replications are expected. Previous work infrequently has utilized lexical stimuli in an AB paradigm, and fewer have used words that were emotional compared to neutral words. In studies that have utilized emotional stimuli in an AB — either pictorial or lexical — a consistent finding is that emotional stimuli at T2 attenuates the blink, regardless of T1 content or Lag (McHugo et al., 2013). This will be seen in the present study by showing fewer blinks at all conditions with an affective T2. To my knowledge, no study has explored this phenomenon using EEG. In accordance to fewer blinks to affective T2, P300

amplitude to emotional T2 stimuli will significantly larger than neutral T2 stimuli. Novel to the present study is modifying the content T1 stimuli. No previous research could be found that has included both neutral and emotional T1 stimuli. If the Boost and Bounce hypothesis is correct, affective T1 stimuli should enhance attentional priming for emotional T2 and reduce the blink, particularly if T2 is affective. A final replication in the present study will be that the P300 amplitude to T1 stimuli will negatively correlate with the amplitude to T2; these correlations will be calculated within each of the four trial types.

Aim 2. The second aim of this study is to explore the influence of interoception on attention and memory specifically in an AB paradigm. While there is sufficient behavioral and neuroimaging evidence to suggest that IA is positively related to attention to emotional stimuli and emotional experiences (Barrett et al., 2004; Benau & Atchley, Under Review; Garfinkel & Critchley, 2016; Herbert et al., 2010; Werner et al., 2010), the time course and sensitivity of these associations are not fully explored. Specifically, no study to date has examined individual differences in IA as predictive of AB magnitude or the EEG response to an AB paradigm. Therefore, the present study will examine if improved IA, in general, will increase vigilance in an AB paradigm. Additionally, while it is predicted that an affective T2 will correspond to a reduced blink and larger P300 amplitude, those with higher IA should have a further reduction in blink magnitude and increased P300 amplitude, respectively. It is expected that these effects will be seen independent of measures of anxiety and depression.

Methods

Participants. A total of 39 self-selected participants (21 women) completed the study in exchange for course credit or \$20 payment ($n = 4$)¹. Participants were recruited from the University of Kansas participant pool and were 17-31 years old ($M = 19.0$, $SD = 2.32$). By self-report, all participants were native speakers of English and had no history of traumatic brain injury or major psychopathology, including current depression (all Beck Depression Inventory scores < 13).

Procedure. Upon arrival to the lab, participants completed informed consent procedures, demographic questionnaires, and a Beck Depression Inventory II (BDI) (Beck, A. T., Steer, & Brown, 1996). Participants were then instructed on how to apply the heart rate monitor on their sternum and were offered a private room to apply the monitor. After the heart rate monitor was applied, a trained researcher conducted the cardiac awareness task. After the cardiac awareness task, participants were fitted with EEG equipment prior to completing the AB task. After task completion, participants were debriefed on the nature and purpose of the task. Each of these steps are described in further detail below. All procedures were approved by the Institutional Review Board at the University of Kansas.

Cardiac Apparatus and Awareness Task. In the cardiac awareness task, participants were asked to count their heartbeats for a given time. After the heart rate monitor was applied, a trained researcher then conducted the cardiac awareness task. Participants were told to keep their hands by their sides and not take their pulse and to inform the researcher when they were ready

¹ 17 of the average perceivers, and 12 of the high perceivers were recruited in Fall of 2016 and the remainder were recruited in Spring of 2017 (described below). After attaining 19 average perceivers, we proceeded to screen for high perceivers. Approximately 20 additional participants completed the cardiac awareness task and were identified as average perceivers and, thus, were excluded from this study and completed an unrelated task. High perceivers were given an opportunity to complete an unrelated task for credit and then return to the lab for payment, or to complete the present task only for credit. This method was approved by the Institutional Review Board.

to begin. Participants were asked to count their heartbeats for three rounds of 25s, 35s, and 45s. At the end of each round, they were asked how many heartbeats occurred. This number was compared to their actual heart rate. After the cardiac awareness task, participants removed the heart rate monitor and were offered privacy to do so. Cardiac awareness scores are calculated as the average of the error in perceiving heartbeats over three trials of the three intervals $[1/3 \sum [1 - (|\text{recorded heartbeats} - \text{counted heartbeats}| / \text{recorded heart - beats})]]$, and scores ≥ 0.85 (i.e., 85% accurate) are considered “high perceivers” while all others are considered “average perceivers.” The test and its requisite cut score has been validated numerous times to classify high IA and average IA (Herbert et al., 2010; Herbert et al., 2007; Matthias et al., 2009; Pollatos et al., 2005; Schandry, 1981). Importantly, the group of “average” perceivers should not be confused with “poor” perceivers, who have been identified as being notably poor at the task, which may be predictive of alexithymia and depression (Furman, Waugh, Bhattacharjee, Thompson, & Gotlib, 2013). The present “average” perceivers, on the other hand, have a wide distribution of scores (see Figure 1).

AB task. After the heart rate monitor was removed, participants moved to the EEG lab and sat in a comfortable chair while being fitted with an EEG cap. Once the EEG was set up, participants were provided AB task instructions. Participants were shown a rapid stream of stimuli that were 5-8 characters in length. Each trial began with a fixation cross that is presented for 1500ms. Each stimulus in the stream was presented for 100ms. Filler, non-word, non-target stimuli were a mix of letters, numbers, blank spaces, and symbols. Within a dual-target condition, the participant saw an initial target word (T1) as the fifth item in the stream. Followed by a second target (T2) at one of three “lags”: Lag1 (immediately after the T1; no inter-stimulus

interval), Lag 2 (with one intervening distractor stimulus; 100ms delay), and Lag 8 (seven intervening stimuli; 700ms delay).

Forty trials contained a T1 but no T2 (i.e. single-target condition). Half of the single-target trials had a neutral target and the other half had an affective target. Forty of the trials contained no targets. No trial contained a T2 without a T1. Of the dual-target trials, there were 20 trials per lag of: affective T1 and T2 (AA), an affective T1 and neutral T2 (AN), a neutral T1 and affective T2 (NA), a neutral T1 and T2 (NN). Thus, in total, there were 60 trials each of AA, AN, NA, and NN across each of the three lags (20 trials per condition per lag), 40 single-target trials (20 neutral, 20 affective), and 40 no-target conditions for a total of 320 trials.

At the end of each trial, the participant was asked how many words they saw. They were only able to press 0, 1, or 2 followed by the Enter key. If they indicated they saw at least one word, they were asked to recall the word or words (in order) by typing it into the program, followed by Enter. They were then presented with an indication that the next trial is to begin. The screen between trials was untimed, allowing for the participant to have a self-paced break if. Three times in the task, participants were made to pause for one minute to complete questionnaires and to prevent fatigue and disengagement from the task. Figure 2 presents a schematic and overview of the task. The task took about an hour.

Stimuli. Thirty unique affective and neutral stimuli, respectively, were taken from the Affective Norms for English Words (ANEW) database (Bradley & Lang, 1999)². All words were between five and seven characters in length. Based on the ANEW ratings, affective words were rated as significantly more negative [$t(32.33) = 35.82, p < .001$] and more arousing [$t(45.59) = 9.42, p < .001$] than neutral words. Neutral words were ranked as somewhat more frequent ($M =$

² Affective words: 100, 195, 8, 1, 398, 188, 591, 92, 465, 60, 37, 188, 244, 285, 879, 202, 319, 8, 419, 178, 445, 368, 322, 156, 447, 10, 197, 679, 601, 392; Neutral words: 66, 1020, 737, 688, 283, 936, 303, 426, 638, 651, 695, 995, 850, 129, 148, 832, 309, 412, 568, 564, 675, 855, 828, 1024, 84, 208, 991, 547, 951, 724.

68.0, SD = 82.39) than affective stimuli [$M = 30.7$, $SD = 50.41$, $t(48.05) = 2.12$, $p = .040$, $d = 0.61$]. Previous research has found that minor fluctuations in word frequency likely makes little impact in an emotional AB (Anderson, 2005). All stimuli were presented in upper case black Courier New size 18 font on gray background on an LCD screen. Stimuli were presented using e-Prime Version 2.2 (Psychology Software Tools, Inc., Pittsburgh, PA).

Apparatus and data preparation

Cardiac Data. Cardiac data was collected using Polar V800 heart rate monitor (Polar Electro Oy, Kempele, Finland). The sum of inter-beat intervals (i.e. R-R intervals) was compared to the participant's estimation of the number of beats that were measured. The use of a Polar V800 heart rate monitor for peak-to-peak counts of heartbeats and beats per minute, in lieu of a comprehensive electrocardiogram, has been validated in previous studies in humans (Board, Ispoglous, & Ingle, 2016; Giles, Draper, & Neil, 2015).

Electroencephalography. All EEG equipment and software was developed and manufactured by Compumedics Neuroscan (Charlotte, NC). EEG was collected via 36 electrodes mounted in an elastic cap (QuikCap 40) according to the International 10-20 system. Data was recorded using a NuAmps40 amplifier. Additional electrodes were placed above and below the left eye to record vertical artifact and two additional electrodes were placed next to the outer canthi (outer part of the eye) to monitor ocular movement. All impedances were kept below $10k\Omega$. Data was digitized at 1kHz. Offline, EEG data were filtered using a .01-30hz bandpass filter and were re-re-referenced to linked mastoid electrodes. Data were collected and analyzed using Curry 7.0.10 software. Artifacts were corrected using the proprietary covariance procedure within our software based on the methods of Gratton, Coles, and Donchin (1983). Trials containing artifact that exceeded $\pm 70 \mu V$ after correction were automatically removed. As a final

step, each trial containing excess artifact that was not corrected or removed in the previous steps (e.g., Alpha-wave intrusion) was removed. The waveforms included a 400ms pre-T1 baseline and were extended for 1.6s after T1 (Keil, Ihssen, & Heim, 2006; Martens, Elmallah, London, & Johnson, 2006a). There were ≥ 15 usable trials in each condition for each participant in the included dataset.

Data reduction and analysis

The number of blinks (i.e., there were two stimuli presented but the participant reported seeing just one) were entered into a 2 (group: high vs. average perceivers) X 2 (T1 Valence: neutral vs. affect) X 2 (T2 Valence: neutral vs. affective) X 3 (lags 1, 2, and 8) mixed-model repeated measures ANOVA. Single-target conditions, containing a T1 but no T2, were entered into a 2 (group: high vs. average perceivers) X 2 (Valence: neutral vs. affect) mixed-model repeated measures ANOVA. The temporal proximity of T1 and T2 in Lag1 make it nearly impossible to distinguish EEG data from the targets and, therefore, P300 amplitude was assessed only at Lags 2 and 8. All P300 maximal peak amplitude was analyzed from electrode Cz. P300 amplitude for T1 was scored at 360 – 520ms for both lags. P300 amplitude was extracted from 700 – 830ms for Lag2 and 1200 – 1330ms for Lag8. Amplitude data were then analyzed using a 2 (group: high vs. average perceivers) X 2 (Target Position: T1 vs. T2) X 2 (T1 Valence: neutral vs. affect) X 2 (T2 Valence: neutral vs. affective) X 2 (Lag Lag2 vs. Lag8).

Results

Cardiac awareness groups

The sample consisted of 19 high perceivers (i.e., average scores $\geq .85$ on the cardiac awareness task; $n = 10$ women) and 19 average perceivers (scores $< .85$; $n = 11$ women). The average score of the BDI for the whole group 5.27 (SD = 4.20). The scores on the BDI-II did not

significantly differ between high ($M = 5.57$, $SD = 4.54$) and low ($M = 4.57$, $SD = 3.74$) perceivers ($p = .50$). The mean score on the task for the whole group was $.78$ ($SD = .16$). As would be expected, the high perceivers scored significantly higher ($M = .91$, $SD = .05$) than did the average perceivers [$M = .66$, $SD = .15$; $t(23) = 8.17$, $p < .001$, $d = 2.23$] on the cardiac awareness task. These scores were comparable to that of the samples of Herbert et al. (2007), Herbert et al. (2010), and Pollatos et al. (2005) ($ts < 1.2$). Both groups had a normal distribution of scores as indicated by non-significant Shapiro-Wilks and Kolmogorov-Smirnov tests ($ps > .18$). The mean age of high perceivers was 19.40 ($SD = 3.2$) and the mean age for average perceivers was 19.63 ($SD = 0.96$). The two groups did not significantly differ in terms of age or sex (both $ps > .1$). Men and women in the study did not significantly differ in their cardiac perception ($p = .3$), and there was no correlation between age and cardiac perception ($r = .064$, $p = .64$). Again, Figure 2 presents a histogram of the distribution of cardiac awareness scores for both groups.

Blinks

Descriptive statistics for blinks and percent accuracy are found in Table 1. The median number of blinks across all participants was 38 ($M = 49.84$; $SD = 33.40$; range: 14 – 143). Results of the omnibus ANOVA showed that there was an expected main effect of Lag [$F(2, 72) = 32.72$, $p < .001$, $\eta_p^2 = .48$] such that there were fewer blinks at Lag8 ($M = 1.88$, $SE = .21$) than Lag1 and Lag2 ($ps < .001$), likely due to increased time between targets. It was unexpected that there were somewhat more blinks at Lag1 ($M = 5.74$, $SE = .69$) than Lag 2 ($M = 5.07$, $SE = .60$; $p = .060$) as greater numbers of blinks at Lag2 than Lag 1 are typically observed (e.g., Martens & Wyble, 2010). There was no main effect of group on the number of blinks ($F < 0.1$, $p = .46$). However, there was a significant Group X T1 Valence X T2 Valence interaction [$F(1, 36) =$

14.41, $p = .001$, $\eta_p^2 = .29$]. Follow-up pairwise comparisons revealed that average perceivers blinked significantly more at NN than NA ($p = .001$) and at AN, though at a trend-level ($p = .082$). Average perceivers also blinked more at AA than NA ($p = .005$). High perceivers, however, blinked less at AA than NA ($p = .042$) and AN, though this was a trend-level difference ($p = .096$). No other pairwise comparison approached significance ($ps > .19$). Figure 3 presents results of pairwise comparisons.

As an exploratory measure, semantic categories were tested as a potential explanation for our findings. To do this, trial conditions were collapsed into congruent (sum of blinks at AA and NN) vs. incongruent (sum of blinks at NA and NA). These blink totals were then analyzed with 2 (group: high vs. average perceivers) X 2 (congruence: incongruous vs. congruous trials) mixed-model repeated measures ANOVA. Results showed neither a significant main effect of group nor congruence ($ps > .2$), though there was a significant Group X Congruence interaction: [$F(1, 36) = 15.42$, $p < .001$, $\eta_p^2 = .30$], such that average perceivers blinked more when the valence of T1 and T2 were congruent ($M = 29.32$, $SE = 3.73$) than the valence of T1 and T2 were incongruent ($M = 25.47$, $SE = 4.04$, $p = .003$). Conversely, high perceivers blinked *more* when the T1 and T2 valences were incongruent ($M = 24.74$, $SE = 4.05$) than when they were congruent ($M = 22.00$, $SE = 3.77$, $p = .027$).

Percent Accuracy. Generally, the percent accuracy reflected the pattern of results seen in the elicitation of blinks. There was a significant main effect of Lag [$F(2, 74) = 34.54$, $p < .001$, $\eta_p^2 = .48$], such that performance at Lag8 ($M = .89$, $SE = .01$) was better than at Lag1 ($M = .69$, $SE = .04$) and Lag2 ($M = .72$, $SE = .03$; $ps < .001$), as expected. Accuracy at Lag1 and Lag2 did not significantly differ ($p = .16$). There was also a significant interaction of T1 Valence, T2 Valence, and Group [$F(1, 36) = 14.49$, $p = .001$, $\eta_p^2 = .29$]. Follow-up pairwise comparisons

showed that average perceivers were significantly more accurate at NA than at AA and NN ($ps < .01$). Conversely, high perceivers were less accurate at AN than at AA ($p = .027$) and marginally to NN ($p = .096$). Thus, overall, average perceivers were most accurate with a neutral T1 and affective T2 (NA). High perceivers were most accurate when both targets were affective (AA). Notably, there was no interaction of lag, indicating that these effects were consistent regardless of the position of the second target in the stream. Figure 3 presents a graphical representation of this interaction.

In the single-target conditions, there was a significant main effect of valence [$F(1, 36) = 13.17, p = .001, \eta_p^2 = .27$] such that neutral targets were identified with greater accuracy ($M = .95, SE = .01$) than affective targets ($M = .91, SE = .01$). There was no significant main effect of group nor did group significantly interact with target valence ($F_s < 0.6, ps > .5$).

P300

Descriptive statistics for P300 amplitudes are presented in Table 2. Results of the omnibus ANOVA revealed an expected and typical main effect of Target Position such that the amplitude for the P300 for T1 was significantly larger than for T2 [$F(1, 36) = 12.54, p = .001, \eta_p^2 = .26$]. There was a significant interaction of Lag and T2 Valence [$F(1, 36) = 4.64, p = .038, \eta_p^2 = .11$]. The only follow-up pairwise comparison that approached significance for the interaction showed that neutral T2 generated a smaller P300 amplitude at Lag2 than at Lag8 ($p = .13$). The remaining pairwise comparisons did not approach significance ($ps > .27$). Given that the higher-level interaction was significant while the post-hoc pairwise comparisons were not, these results should be interpreted cautiously.

There was a significant interaction of Group, Target Position, T1 Valence and T2 Valence [$F(1, 36) = 10.85, p = .010, \eta_p^2 = .17$]. For average perceivers, the P300 to T2 stimuli

was significantly smaller than T1 in the AN and NA conditions ($p < .05$). Thus, the P300 was significantly reduced for the second target when the targets' valences were incongruent. Finally, for average perceivers, the P300 amplitude to T2 in the AN condition was significantly smaller than the P300 amplitude to T2 in AA and NA conditions ($p < .05$). Thus, the AN condition generated a significantly smaller P300 amplitude to the second, neutral target than to its first, affective target, which was also significantly smaller than the P300 to the second target in either condition with an affective second target. In short, the average perceivers generally exhibited the expected interactions of affect and target position, broadly replicating effects that were found in previous literature (Yiend, 2010).

No pairwise comparison approached a level of significance for the high perceivers. There was a trend-level attenuation of T2 in the AA condition ($p = .10$). Figure 4 presents the waveforms of both the average and high perceivers. Figure 5 presents the results of these analyses for both groups as a bar graph. Thus, counter to hypotheses, high perceivers, did not exhibit modulated P300 amplitudes as a function of valence or valence congruence of targets. Further, their amplitudes did not significantly differ from those of the average perceivers. Waveforms for Lag2 and Lag8 for both high and low perceivers are shown in Figures 4 and 5, respectively. These data are presented as a bar graph in Figure 6.

Relation of P300 amplitudes to blink magnitude. At Lag2, for average perceivers, no correlation of blink magnitude — either the sum number of blinks or the number of blinks within each category — approached significance as a correlate to P300 amplitudes ($p > .5$). However, for the high perceivers, greater P300 amplitude at T2 corresponded with greater number of blinks in the NN condition ($r = .66, p = .002$), as was the total number of blinks in the whole task ($r =$

.48, $p = .039$). These positive correlations are counter to expectations where a larger P300 amplitude at T2 is generally associated with fewer blinks.

At Lag 8, for average perceivers, in the NN condition, P300 amplitudes at T1 significantly correlated with number of blinks in that condition ($r = -.46, p = .049$). For the high perceivers, T2 amplitude was negatively correlated with the number of blinks in the NN condition ($r = -.57, p = .010$) and the NA condition ($r = -.52, p = .022$). Total number of blinks in the study was negatively correlated with the T1 amplitude in the AA condition ($r = -.69, p = .001$) for high perceivers.

No other correlation in any other condition approached statistical significance for either group.

Discussion

The main goal of the present study was to explore the relation of the perception of emotional stimuli, attention and interoceptive abilities (IA). This study had two related aims regarding the emotional AB: (a) to replicate and extend AB methods by using emotional and neutral words (rather than the more typical use of symbols and pictures) while using EEG to identify neuroelectrical correlates to the task; and (b) to explore the role of IA in AB task performance and EEG correlates of an emotional AB. To accomplish these aims, participants were recruited who were rated to be high or average in IA based on previously-established cut-scores from a cardiac awareness task. Participants then completed an attentional blink task while EEG was recorded. I had two hypotheses regarding those with average IA. First, electrophysiological (i.e., P300 amplitudes) and behavioral (e.g., behavioral accuracy and fewer blinks) indices of the AB would reduce when the second target was emotional, regardless of the first target. Second, when the first target was affective, I hypothesized that average perceivers

would show an enhanced blink effect. In contrast to those with average IA, I hypothesized that those with high IA would be less susceptible to the blink effect, but would show a relatively enhanced blink when presented with an emotional stimulus at T1. Results provided mixed support for these hypotheses. These results nonetheless have important implications for the interaction of attention, emotion, and IA.

Results for average perceivers

Behavioral Data. Reflective of previous work with random samples of healthy participants (McHugo et al., 2013; Yiend, 2010), average perceivers exhibited altered behavioral performance and electrophysiological indices of a blink as a function of the valence of targets in the stream. More specifically, average perceivers were most accurate when presented with a neutral (vs. emotional) stimulus at T1 followed by an affective stimulus at T2. Also consistent with previous literature and with hypotheses, average perceivers were most likely to “blink” (i.e., report that they had seen one stimulus when two had been presented) when an affective stimulus was followed by a neutral stimulus. In short, average perceivers had worsened AB performance when stimuli were matched on valence (i.e. AA and NN conditions) and best when valence was incongruent (i.e. NA and AN). This pattern of performance was further confirmed in an exploratory analysis comparing number of blinks in congruent and incongruent trial types.

There are several explanations for the pattern of behavioral response. Congruent stimuli may be perceived and processed, to some degree, as members of a similar semantic category (De Houwer, Hermans, Rothermund, & Wentura, 2002). Previous research suggests that targets belonging to the same semantic category enhance the blink compared to targets that are semantically distinct (Tibboel et al., 2011). Thus, the affective valence of the targets may not have been as important in the performance of the task as the broader semantic network or

category they belong to (e.g., “negative words”). This phenomenon has been previously observed in random samples, and it has been suggested that the presence of an emotional word heightens sensitivity to search for another negative word (Yiend, 2010). In the case of affective words following neutral words, the heightened salience may simultaneously increase attention to the second target and, depending on the timing and arousal of the stimulus, create a type of retrograde interference with T1 (Asplund et al., 2010; Kennedy & Most, 2015; Most & Jungé, 2008; Zakay & Block, 2004).

The results of the average perceivers’ behavioral data reflect several other findings in previous studies. The NN condition in the present study is likely the closest analog to previous tasks that used non-affective, non-lexical stimuli (Kawahara et al., 2006; Martens & Wyble, 2010; McHugo et al., 2013; Wyble, Bowman, & Nieuwenstein, 2009). Therefore, it is not surprising that NN was the condition that resulted in the lowest accuracy and most blinks. Consistent with previous research (Schwabe et al., 2011; Schwabe & Wolf, 2010), the NA condition resulted in the fewest blinks and highest accuracy. The attenuated blink may have resulted from attentional orienting and other processes being directed toward a T1 target that is overridden when the T2 is arousing, potentially threatening, or otherwise notable (McHugo et al., 2013). The AA condition enhanced the blink effect, consistent with previous work (Schwabe et al., 2011; Schwabe & Wolf, 2010). Schwabe and colleagues suggest that affective T2 stimuli typically “break through” the mechanisms responsible for the blink, however, when preceded by an affective stimulus, the attentional resources are already dedicated over-allocated to T1. Another possibility is downstream “bottlenecking,” wherein the second aversive target prevents the successful encoding of both targets (Yiend, 2010). This result challenges the “Boost and Bounce” hypothesis of the AB, as the presence of an aversive stimulus at T1 thwarted the

“boost” (Lunau & Olivers, 2010; Olivers, 2010). To better understand the mechanisms for the observed effects, future studies could consider including affective stimuli in streams that contain more than two targets.

P300. In addition to the behavioral responses, average perceivers’ EEG was modulated robustly as a function of the affective content of stimuli. The P300 amplitude to T2 was significantly reduced compared to that of T1 when the valence of the two targets were incongruent. The greatest attenuation of the P300 occurred for T2 in the AN, was significantly smaller than the P300 to both T1 in that condition and to the T2 in the AA and NA conditions. Notably, these incongruent valence conditions were also the conditions to result in the fewest blinks and the highest accuracy for this group. There are several explanations for the behavioral and EEG data in the present study.

The P300 amplitude to the second target in the AN and NA condition was significantly attenuated compared to their T1. In other words, the two conditions with incongruent T1 and T2 valences resulted in a significant decrement in the P300 to T2. Further, in the AN condition, the P300 amplitude to T2 was significantly smaller than that of the AA and the NA condition. This reduction in P300 amplitude would indicate an increased likelihood of a blink (Martens et al., 2006b; Martens & Wyble, 2010; Shapiro et al., 2006; Willems & Martens, 2015), yet NA resulted in the fewest blinks overall while AA and NN resulted in the most. It may be that, while the P300 was attenuated for a T2 in an incongruent valence from T1, these P300 amplitudes did generally exceed a threshold to result in encoding and attentional orientation. This finding generally supports previous work that that found performance in the AB task may not be fully accounted by ERP components related to higher-level linguistic processes and memory encoding. The blink may, therefore, occur because of post-perceptual processes. The present data

further support this postulation. The post-perceptual impairment was initially suggested in a set of classic studies wherein electrophysiological indices of perception and semantic processing (e.g., the P300 and N400) were predictably impacted by semantic relatedness (i.e. larger amplitudes for less related content), yet the behavioral expression of the attentional blink was not impacted by content (Luck et al., 1996; Rolke et al., 2001; Vogel et al., 1998). Additionally, irrelevant distractors that occurred outside after T2 in a stream did not impact target-related P300 amplitudes, but did correspond to increased blinks (Dux & Marois, 2008; Lunau & Olivers, 2010; Most et al., 2007). Therefore, modulation of the blink effect may be due to any number of stimulus-driven variables in the general population.

It is notable that the correlation of blinks to P300 amplitudes was less robust for average perceivers than for high perceivers. No significant correlations occurred at Lag2. At Lag8, increased T1 amplitudes corresponded to fewer blinks overall, but only in the NN condition. This is consistent with previous work (Shapiro et al., 2006), which posited that over-allocation of cognitive resources to T1 impedes the ability to encode T2. However, it is not clear why the P300 amplitudes for average perceivers were not more robustly associated with behavioral responses. The correlation between T1 and behavioral accuracy may have been impeded in the use of affective stimuli at T2, which “breaks through” the over-allocation to neutral stimuli and, thus, reduces the blink (Most & Jungé, 2008), particularly if attention spread is boosted at T1 (Olivers, 2007, 2010). Affective T1 may provide no additional boost than neutral T1 and, instead, “capture” some component of attention related to emotion and affect that is not observed in the P300, which then results in an enhanced blink effects if T2 is neutral, but not if it is affective (Most & Jungé, 2008).

Results for high perceivers. Novel to the present study was the examination of individual differences in interoceptive abilities, as measured by cardiac awareness, in the performance in, and EEG response to, the AB. The behavioral and EEG data for the high perceivers stands in contrast to the average perceivers. I hypothesized that high perceivers would have greater vigilance and sensitivity to emotional stimuli than average perceivers, as demonstrated by decreased blinks and increased P300 amplitudes, particularly to emotional T2 stimuli. I also hypothesized that P300 amplitudes in high perceivers would be larger than those generated by average perceivers. My hypotheses for high perceivers were not supported. In fact, behaviorally, average perceivers performed best at AA, with the fewest blinks and greatest accuracy, followed closely by NN. In terms of EEG, high perceivers elicited statistically comparable P300 amplitudes between all conditions and target positions. Despite these hypotheses not being supported, results further our understanding of the role of trait-level IA in cognitive and affective stimulus processing.

My hypotheses were derived from previous literature that indicated that individuals with high IA show attentional bias to emotional stimuli — especially negative — measured by behavioral and/or electrophysiological methodologies (Critchley et al., 2013; Garfinkel et al., 2013; Herbert et al., 2010; Pollatos et al., 2005; Werner, Mannhart, Reyes Del Paso, & Duschek, 2014; Werner et al., 2010). In turn, extant literature suggests that high IA is positively associated with neuroticism, anxiety, and other pathologies (Barrett et al., 2004; Paulus & Stein, 2006, 2010; Wiens, 2005). The present results support a more optimistic view of those with trait-level high IA. One interpretation of the data is that high perceivers reoriented their attentional – and therefore emotional – functioning to complete the task. There is some evidence that high perceivers have improved executive control of attention (Matthias et al., 2009), general learning

abilities (Katkin, Wiens, & Öhman, 2001), and adaptive decision making abilities (Werner et al., 2009) particularly when emotions are invoked (Sutterlin, Schulz, Stumpf, Pauli, & Voegelé, 2013b). Perhaps as a result, high perceivers have been found to exhibit improved trait-level emotion regulation (Kever et al., 2015b) and are better at utilizing top-down mechanisms to control emotion such as through instruction for reappraisal (Fustos et al., 2013).

These laboratory-based findings have real-world implications and may illustrate the adaptiveness of high IA. Both adults (Matthias & Pollatos, 2014; Pollatos, Matthias, & Keller, 2015) and children (De Witte, Sutterlin, Braet, & Mueller, 2016; Koch & Pollatos, 2014) with high IA are more likely to be resilient in the face of social exclusion and social pain. High IA may be protective against eating disorders (Ainley & Tsakiris, 2013; Lattimore et al., 2017), alexithymia (Herbert et al., 2011), depression (Paulus & Stein, 2010), and is associated with fewer and less severe symptoms of psychosis (Ardizzi et al., 2016) and autism (Garfinkel et al., 2016). In addition, persons with high IA more frequently show empathy, which is considered to be an adaptive emotional expression (Ernst, Northoff, Boker, Seifritz, & Grimm, 2013; Fukushima, Terasawa, & Umeda, 2011). Finally, those with high IA show better responses to psychological interventions. For example, individuals with high IA show increased benefits from mindfulness-based interventions (Farb et al., 2013; Kirk, Downar, & Montague, 2011; Parkin et al., 2013) and respond better to psychotherapy (Masdrakis et al., 2013). Thus, high IA does not exclusively reflect and predict an increase in neuroticism, emotional lability, or over-allocation of attention to threat; instead, it represents an increased ability to have efficacy during emotional experience to maintain goal-directed behavior.

The use of a cognitively challenging AB task may be another explanation for the divergence of the present findings with those of previous studies. Previous studies that

established attentional bias for affective stimuli for those with high IA often used tasks that involved minimal strategy or challenge. These tasks have included passive viewing (e.g., Herbert et al., 2010; Herbert et al., 2007), word stem completion with subsequent recall assessment (Werner et al., 2010), and a Stroop paradigm (Werner et al., 2014). While those with high IA may, in fact, have a bias to negative information, when asked to strategize or complete a challenging task, these individuals are more adept at top-down regulation of attention for the purposes of task completion than were average perceivers. In the case of the present task, high perceivers may have been better able to regulate their emotional reactivity as a function of improved top-down cognitive control and spread of attention compared to average perceivers (Matthias et al., 2009). It is well-established that the blink effect is attenuated by online regulation of emotion, motivation, and affect (Dijksterhuis & Aarts, 2010; Raymond & O'Brien, 2009). Therefore, the high perceivers in the present study may not have viewed each stimulus as equally threatening — as hypothesized— but were able to better regulate their attention and affect to view all stimuli as equally neutral. As a result, the present data suggest that high perceivers likely approached the task in a two-step process: first, through down-regulated emotional reactivity (most clearly seen in P300 data that did not significantly vary as a function of valence), which then allowed for an approach to the task and second through semantic categorization processes.

P300. Evidence for the postulation that high perceivers elicited down-regulated emotional reactivity through a spread of attentional resources to stimuli is provided by P300 data. In no condition did the P300 amplitude significantly change at T2 compared to T1, nor did any P300 amplitude significantly differ between any condition. Previous work indicated that the blink occurs because of an over-allocation of resources to T1 (Shapiro et al., 2006). One could

interpret the present findings as high perceivers being more adept at reducing over-focus to T1 (even aversive T1) to better accomplish the task. In other words, this study serves as an extension of previous work (Matthias et al., 2009) and shows that high perceivers were better able to distribute their attention more evenly across stimuli, even overriding the otherwise reflexive emotional capture of the affective qualities of the targets. This would have allowed them to reorient their cognitive control strategies in such a way that the expected reactivity was not reflected in modulated brain electrophysiological reactivity.

Behavioral data. While the P300 amplitudes reflect the down-regulation of affective response to stimuli, the behavioral data may reflect post-perceptual processes putatively associated with the AB. For high perceivers, congruent affective categories of targets (AA and NN) resulted in the fewest blinks and best behavioral accuracy while incongruent categories of targets (AN and NA) resulted in the lowest behavioral accuracy and greatest number of blinks. If the affective responses to stimuli becomes muted, as reflected in the P300, it is possible that the high perceivers would then view these words as belonging to a semantic category (e.g., *neutral* versus *emotional*). Thus, what may be driving the behavioral results is a process related to semantic categorization rather than emotional reactivity. Spreading activation hypotheses posit that within-category members are easier to detect when primed (Collins & Loftus, 1975). It is adaptive, though more difficult, to maintain awareness of categorically or aesthetically similar objects under cognitive strain (Kennedy & Most, 2015; Most et al., 2005a; Most et al., 2001; Tibboel et al., 2011). High-perceivers evidenced no emotional interference and a benefit of congruent semantic categories in a manner like spread of activation. The spread of activation may have been enhanced by the so-called boost and bounce model of the AB (Olivers, 2010). For high perceivers, the semantic category of T1 (affective/neutral) may be a prime for a

subsequent member of that semantic category at T2. IN this model, when the high perceiver views a T2 from a different category, it becomes more difficult to encode it.

The second model is that of a “bottleneck” or “rubberneck” of attention (Kawahara et al., 2006; Most et al., 2005a). In this model, attention is not depleted, but is temporarily impeded from spreading to T2 (Martens et al., 2006b; Martens & Valchev, 2009; Most et al., 2005a; Shapiro et al., 2006). Notably, at Lag2, the average perceivers’ P300 amplitude at T1 positively correlated to blinks in the NN condition while the high perceivers did not. Instead, in the same condition, high perceivers P300 amplitudes to T2 positively corresponded to blinks. This result may be due to the “rubberneck” aspect of these models in which interference is caused by either the second target or some process that occurs after T2 offset (Asplund et al., 2010; Most & Jungé, 2008; Most et al., 2007). High perceivers were seemingly more susceptible to over-allocation of cognitive resources to T2 while average perceivers were more sensitive to over-allocation to resources at T1.

Conversely, at Lag8 for the NN and NA conditions, T2 amplitudes negatively correlated with blink frequencies. This increased P300 may no longer indicate interference due to the extended time from T1, but would indicate a more expected pattern of encoding which is seemingly a more consistent process for high perceivers than for average perceiver. Notably, the high perceivers demonstrated this pattern while the average perceivers did not.

Broader Implications and Applications

The results of the present study can inform our understanding of the mechanisms of the AB, attention, and emotional experience, and how interoception may interact with these processes. Within this study are several important replications and extensions of previous research. For example, there are a limited number of studies including an emotional AB using

lexical stimuli. To date, only a few studies have counterbalanced emotional stimuli for either/both T1 and T2 (Most et al., 2005a; Most & Jungé, 2008; Most, Scholl, Clifford, & Simons, 2005b; Yiend, 2010). To my knowledge, this is the first study to utilize EEG to explore the individual differences in interoception in neural activation during an emotional attentional blink task. Taken together, the results of the present study have important implications for the role of the body in emotional experience.

Implications for the AB. There is limited consensus on the mechanisms of the AB (Dux & Marois, 2009; Martens & Wyble, 2010). Using emotional lexical stimuli in an AB task is a necessary step to understand the mechanisms and limitations of the phenomenon and, by extension, attention itself. It was initially proposed that the AB indexes depletion of limited attentional resources during T1, but clearly this cannot be the case if the emotional stimuli so consistently “break through” the supposed attentional depletion (McHugo et al., 2013; Yiend, 2010). The present study provides further evidence of the complicated nature of the AB regarding valence of stimuli. The traditional window of the “blink” was not clearly observed in the present study: regardless of valence of stimuli, Lag1 resulted in more blinks than Lag2, though Lag8 resulted in the fewest. While this effect was marginal, Lag2 typically results in the most blinks. This may have been due to the use of lexical stimuli as they are more feature-rich than individual symbols such as letters, shapes, and numbers. Luck, Vogel, and colleagues (1996; 1998) also used words as targets, but their distractors were all letters while the present study was a mix of letters and symbols. Perhaps the mix of symbols and letters provided sufficient distinctiveness to prevent the typical blink pattern from emerging. Regardless of the content of the words themselves, the orthography of a word compared to a string of non-words likely provided sufficient distinctiveness to otherwise undo the typical pattern of blinks being

maximal at Lag2 (Wyble et al., 2009). The words used were all high frequency, and high frequency words at T1 have been found to reduce the blink while increasing blinks when at T2 (Wierda, Taatgen, van Rijn, & Martens, 2013).

Beyond surface features of the stimuli, the present study supports previous research that content of stimuli, specifically the semantics of targets, play a key role in attention as measured by the AB (Kennedy & Most, 2015; Rolke et al., 2001; Tibboel et al., 2011). In a set of classic AB studies, words that were embedded in the RSVP stream that were unrelated (*nurse – thunder*) were reported with comparable accuracy than related pairs (*nurse – doctor*), even though the N400 component was elicited as expected with greater amplitudes for unrelated targets (Luck et al., 1996; Rolke et al., 2001; Vogel et al., 1998). The authors argue that the stimuli and their features were seen but not encoded accurately, therefore, some element of the blink effect is due to post-perceptual processing. The present study supports this finding, but suggests that it is modulated as a function of IA. The high perceivers may have been able to down-regulate the affective response to words and treat stimuli as a prime for members of the same category while average perceivers were more susceptible to emotional features of the words that prevented these processes from occurring.

Positive valence was not examined in the present study. The present study leaves unanswered whether attention is biased selectively to negative information or to emotional information in general. It has been proposed that there are separate systems for evaluating negative, threatening, or otherwise aversive stimuli than there is for evaluating approachable, appetitive, or otherwise pleasant stimuli (Carretie et al., 2009). It may also be that emotional stimuli, in general, capture attention comparably regardless of valence, with, perhaps, a slight preference or automatic processing for positive stimuli (Benau et al., In Press; Citron, Abugaber,

& Herbert, 2015; Vanlessen, De Raedt, Koster, & Pourtois, 2016; Yang et al., 2013). Preliminary work in our lab suggests that individuals with high IA are biased to positive stimuli referring to physical attributes (Benau & Atchley, Under Review).

In addition to bottom-up, stimulus driven influences in the AB, the present study underscores that the AB is also driven by participant characteristics. There is a notable dearth of research examining individual differences in the AB. While some research has investigated trait-level imperviousness to the blink (Martens et al., 2006b; Martens & Valchev, 2009; Taatgen et al., 2009; Willems & Martens, 2015; Willems et al., 2013), these investigations have focused on neurocognitive functioning. The present study contributes to the limited previous work that found individual differences such as state and trait emotion, cognitive abilities, and motivation influence the AB (McHugo et al., 2013; Yiend, 2010). Namely, heightened motivation and positive affect tend increase blink susceptibility while negative affect and distractibility reduce the blink effect (Dijksterhuis & Aarts, 2010; Dux & Marois, 2009; Martens & Wyble, 2010; MCHugo et al., 2013; Yiend, 2010). The present study adds to the literature examining IA and attention as measured by the AB (Garfinkel et al., 2013; Garfinkel et al., 2014). It is important to continue examining the interaction of individual differences and cognitive functions — particularly attention — to better the composition and function of both. The present study contributes to the growing literature that suggests that, attention, particularly as measured in the AB, is more flexible, adaptive, and individually-variant than initially proposed (Dux & Marois, 2009; Martens & Wyble, 2010; Petersen & Posner, 2012), and provides further evidence that IA influences, or is influenced by, attention (Matthias et al., 2009).

Implications for Interoception, Attention, and Emotion. The present findings contribute to our understanding of the relation between sensitivity to bodily sensations and attention and

attentional biases. One question the present study sought to address is: do people with heightened IA have increased attention selectively to emotional stimuli, increased attentional skills more generally, or some combination of both? The present study provides support for previous work that showed that high perceivers exhibit generally superior attention ability compared to average or low perceivers (Matthias et al., 2009), though it is unclear if this was cause or consequence of improved emotional down-regulation compared to average perceivers. Previous work showed that affective stimuli either impede encoding of upstream and downstream neutral stimuli (Most & Jungé, 2008; Yiend, 2010). The present results indicate that this effect may be limited to average perceivers. The results of the present study showed that high perceivers elicited P300 amplitudes that did not modulate as a function stimulus valence at any target position and showed no effect of valence other than as a semantic category in behavioral response. This finding provides further evidence that those with high IA have improved top-down control of attention, perhaps allowing for enhanced or speeded reappraisal and attentional reorientation (Fustos et al., 2013; Kever et al., 2015b). Future research would do well to explore this aspect further.

Applications. There are several applications for these findings. First, it provides a target for cognition-oriented treatments. Emphasizing visceral or somatic control (e.g., meditation, relaxed breathing) rather than solely focus on cognitive distortions has also shown efficacy in improving cognition and emotional distress (Farb et al., 2013; Kirk et al., 2011; Parkin et al., 2013; Sedlmeier et al., 2012). Research suggests that modifying visceral reactions to emotional stimuli (e.g., deliberate modification of these reactions through exercise, meditation, or focused and relaxed breathing) also reduces and enhances emotional responses when engaged routinely (e.g., Goyal et al., 2014); effects of which are seen as quickly as a single session (Fennell, Benau,

& Atchley, 2016). These findings highlight the importance of physiological changes in addition to cognitive reappraisal. Hyperarousal enhances attention to threat-related, but not neutral stimuli, as evidenced by results of an AB task (Kever et al., 2015a; Kever et al., 2015b). Promoting relaxation and control of arousal may, in turn, reduce biased attention to emotional stimuli and, therefore, reduce its deleterious effects.

Interestingly, individuals with pathology wherein the body is a source of distress (e.g., chronic pain, fibromyalgia, panic disorder), tend to use denial and ignoring bodily signals as a coping mechanism; however, this technique exacerbates symptoms (McCracken & Eccleston, 2003). Conversely, increasing IA (including emphasis on pain) has been found to decrease symptoms and distress (Bakal, Coll, & Schaefer, 2008), especially when paired with elements of acceptance and other adaptive coping skills (Veehof, Oskam, Schreurs, & Bohlmeijer, 2011). Similar to the high perceivers in the present task, increased awareness of bodily signals allows an individual to regulate, contextualize, and utilize these signals more adaptively (Bakal et al., 2008). In addition to the physical distress described above, increasing evidence suggests that interoceptive training improves cognition, social skills, and both physical and psychological wellbeing in both healthy individuals and those with medical and/or psychological pathology (Bornemann, Herbert, Mehling, & Singer, 2014; Bornemann & Singer, 2017; Farb et al., 2015; Farb & Mehling, 2016; Farb et al., 2013; Schaefer, Egloff, Gerlach, & Witthoft, 2014; Shah, Catmur, & Bird, 2017). The benefits of increased IA are also seen across the lifespan (Koch & Pollatos, 2014; Murphy, Brewer, Catmur, & Bird, 2017). The benefits of increased IA are also seen across the lifespan (Koch & Pollatos, 2014; Murphy et al., 2017). The present study supports IA to be an adaptive function. Clinicians should consider integrating interoceptive awareness into their treatment plans and case conceptualizations.

Limitations and Future Directions

This study provides an important insight into the mechanisms of attention, the attentional blink, and interoceptive awareness, but it is not without limitations. The sample was comprised of otherwise healthy, self-selected undergraduates at one Midwestern university. Interoception has been found to modulate as a function of culture and age (Khalsa & Lapidus 2016; Khalsa, Rudrauf, & Tranel, 2009; Ma-Kellams, 2014). Therefore, additional samples are needed to generalize and replicate the present findings. The present study was cross-sectional, and, therefore, causation of these associations cannot be determined. As discussed above, experimental investigations of interoceptive training may elucidate causality of the relationships seen here. It was beyond the scope to investigate other aspects of valence and arousal of stimuli and this is certainly an avenue for future studies to explore (e.g., positive valence, high vs. low arousal, personally-relevant stimuli). Similar to previous research, the arousing words were somewhat less frequent than the neutral words; however, similar to previous research, this should have resulted in a pattern opposite of what was seen (Anderson, 2005). Lastly, although the present cardiac awareness task is well-established, there are limitations to it that have been discussed elsewhere (Khalsa & Lapidus 2016; Kleckner, Wormwood, Simmons, Barrett, & Quigley, 2015). Therefore, future studies could consider additional or alternative tasks and/or modifications to the present one (e.g., additional trials; different measures IA such as challenge tasks).

Conclusion

In sum, this study has broad implications for improving our knowledge of the interactions and relations between attention, emotion, and interoception. The AB is not only influenced by state-level motivation, but trait-level IA. The findings also show that those with high IA are not

simply more attuned to spreading attentional resources to both interoceptive and exteroceptive stimuli, but that they are likely more in control of the ability to monitor and control the resources needed to accomplish the task. Future research should further investigate the role of IA in the perception of emotional stimuli using other tasks involving cognitive control, attention, and other executive functions to further clarify the present findings.

Table 1: Descriptive statistics [M (SE)] for behavioral data.

| Lag | T1 Valence | T2 Valence | Average | High |
|------|------------|------------|-------------------------|-------------|
| | | | <u>Blinks</u> | |
| Lag1 | Affective | Affective | 6.95 (0.94) | 4.68 (0.94) |
| | | Neutral | 5.90 (1.01) | 5.21 (1.02) |
| | Neutral | Affective | 5.68 (1.07) | 5.37 (1.07) |
| | | Neutral | 7.11 (1.05) | 5.05 (1.06) |
| Lag2 | Affective | Affective | 5.05 (0.92) | 4.79 (0.91) |
| | | Neutral | 5.42 (1.00) | 5.00 (1.02) |
| | Neutral | Affective | 4.58 (0.90) | 5.34 (0.90) |
| | | Neutral | 6.05 (0.83) | 4.37 (0.84) |
| Lag8 | Affective | Affective | 2.26 (0.34) | 1.32 (0.34) |
| | | Neutral | 2.21 (0.51) | 2.05 (0.51) |
| | Neutral | Affective | 1.68 (0.30) | 1.74 (0.30) |
| | | Neutral | 1.90 (0.41) | 1.84 (0.41) |
| | | | <u>Percent Accuracy</u> | |
| Lag1 | Affective | Affective | 0.62 (0.05) | 0.75 (0.05) |
| | | Neutral | 0.68 (0.05) | 0.71 (0.05) |
| | Neutral | Affective | 0.69 (0.06) | 0.72 (0.06) |
| | | Neutral | 0.63 (0.06) | 0.74 (0.05) |
| Lag2 | Affective | Affective | 0.72 (0.05) | 0.74 (0.05) |
| | | Neutral | 0.69 (0.06) | 0.71 (0.06) |
| | Neutral | Affective | 0.74 (0.05) | 0.72 (0.05) |
| | | Neutral | 0.68 (0.04) | 0.76 (0.04) |
| Lag8 | Affective | Affective | 0.87 (0.02) | 0.92 (0.02) |
| | | Neutral | 0.87 (0.03) | 0.89 (0.03) |
| | Neutral | Affective | 0.89 (0.02) | 0.90 (0.02) |
| | | Neutral | 0.89 (0.03) | 0.90 (0.03) |

Note: Values are rounded and represent estimated marginal means.

Table 2: Descriptive statistics [M (SE)] for P300 amplitudes.

| Position | Lag | T1 Valence | T2 Valence | Average | High |
|----------|------|------------|------------|-------------|-------------|
| T1 | Lag2 | Affective | Affective | 3.40 (0.32) | 3.27 (0.32) |
| | | | Neutral | 4.33 (0.45) | 3.22 (0.45) |
| | | Neutral | Affective | 3.78 (0.48) | 3.66 (0.48) |
| | | | Neutral | 3.57 (0.47) | 3.33 (0.47) |
| | Lag8 | Affective | Affective | 3.44 (0.49) | 2.77 (0.49) |
| | | | Neutral | 2.33 (0.46) | 2.66 (0.46) |
| | | Neutral | Affective | 3.10 (0.41) | 3.22 (0.41) |
| | | | Neutral | 3.08 (0.40) | 2.77 (0.39) |
| T2 | Lag2 | Affective | Affective | 3.71 (0.45) | 3.45 (0.45) |
| | | | Neutral | 3.88 (0.48) | 3.13 (0.48) |
| | | Neutral | Affective | 4.01 (0.50) | 3.28 (0.50) |
| | | | Neutral | 4.21 (0.45) | 3.74 (0.45) |
| | Lag8 | Affective | Affective | 2.96 (0.38) | 2.91 (0.38) |
| | | | Neutral | 2.73 (0.41) | 3.46 (0.42) |
| | | Neutral | Affective | 2.80 (0.42) | 2.90 (0.43) |
| | | | Neutral | 3.38 (0.43) | 3.01 (0.43) |

Note: Values are rounded and represent estimated marginal means.

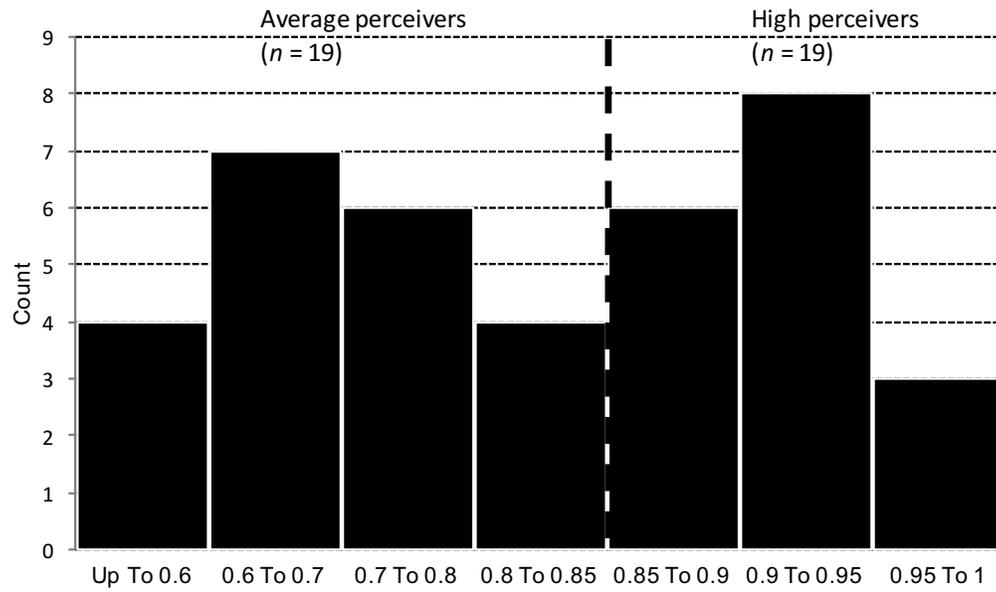


Fig. 1: Histogram of cardiac scores for average and high perceivers in the task

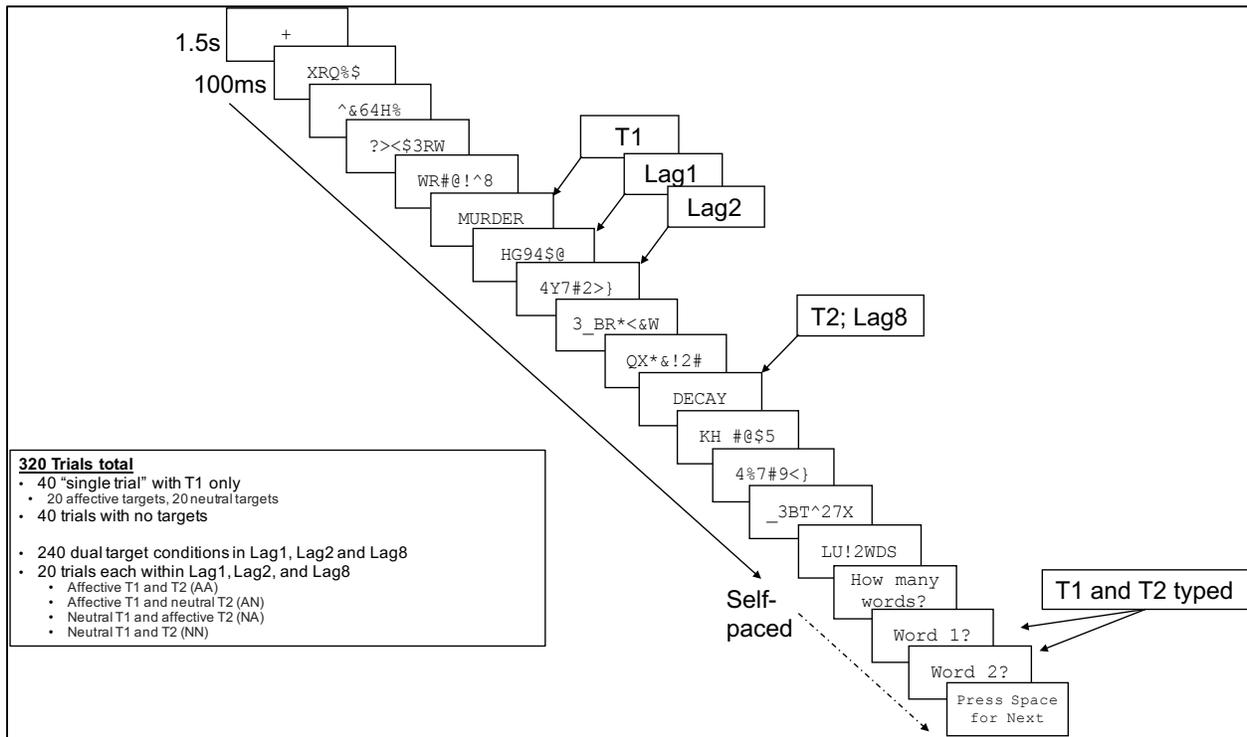


Fig. 2: Schematic of the AB task used in the present study illustrating the location of the target stimuli in each lag. Note that the sample trial here is an AA trial at Lag8. Sample distractor stimuli are abbreviated.

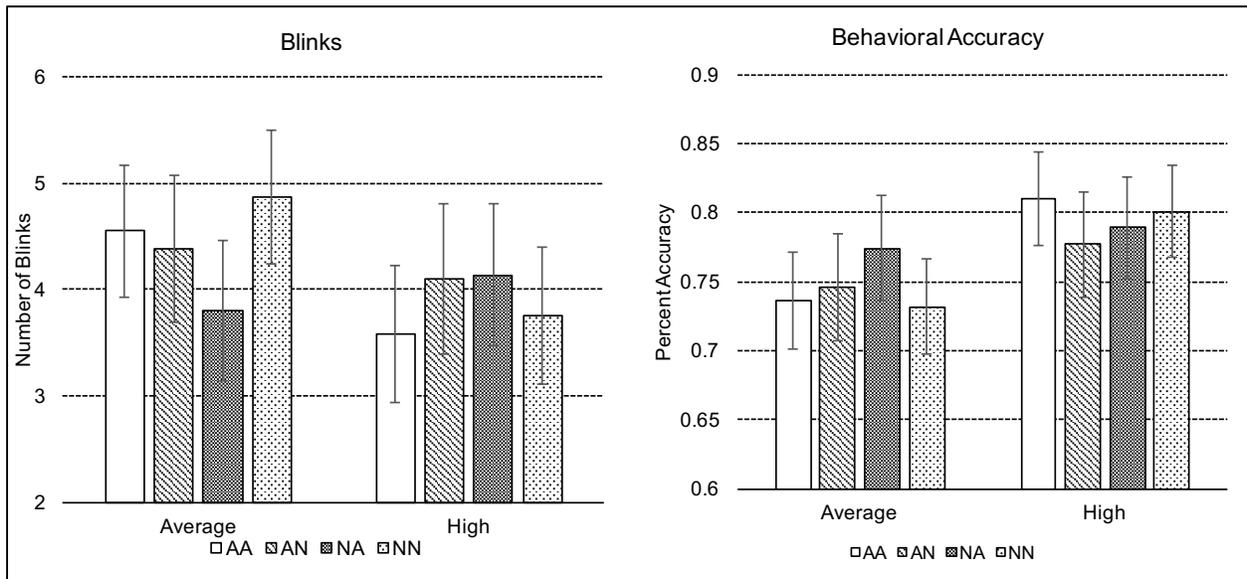


Fig. 3: Results of behavioral data showing blinks (left) and behavioral accuracy (right). Low perceiver data are shown on the left portion of the graphs while high perceiver data are shown on the right portion. Error bars represent one standard error of the mean. Arrows point indicate significant and trend-level differences.

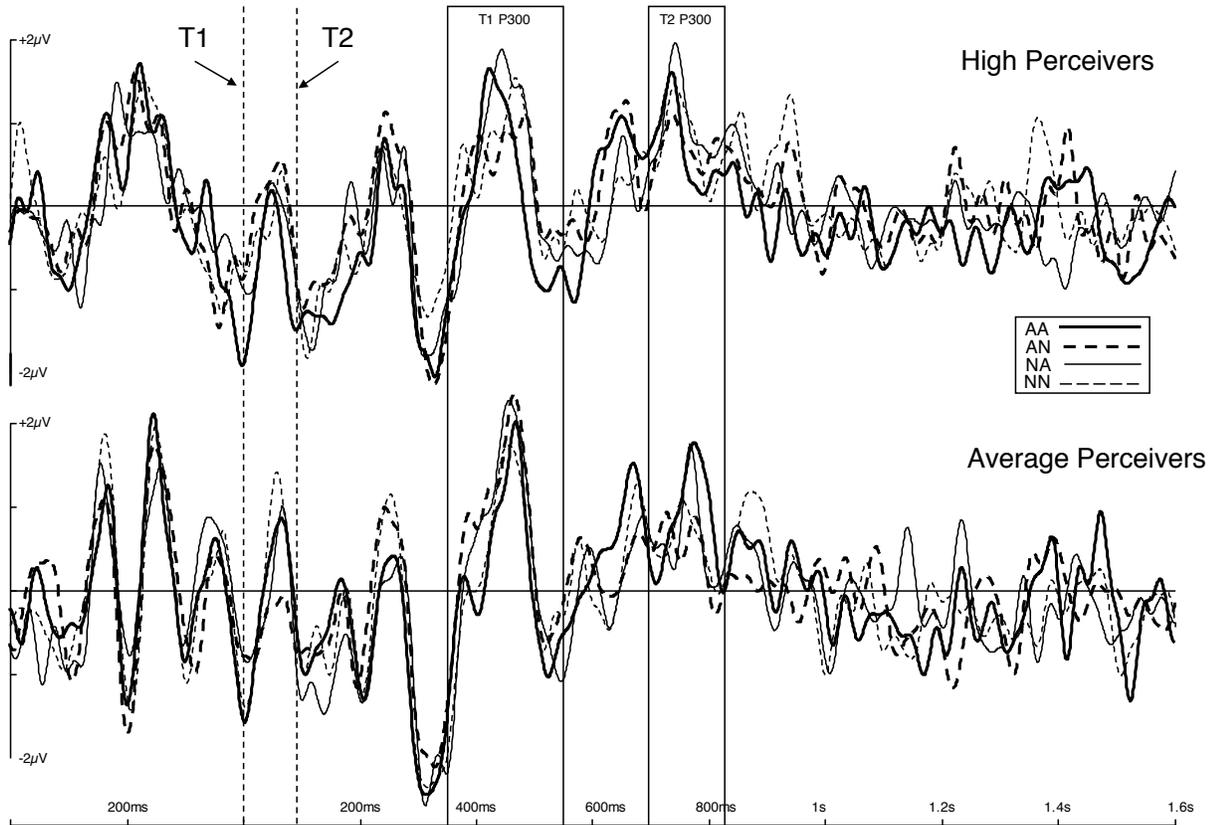


Fig. 4: Waveforms for Lag2 for high perceivers (upper panel) and average perceivers (lower panel). Target onset is highlighted by vertical dashed lines. P300 windows for T1 and T2 are outlined in solid lines.

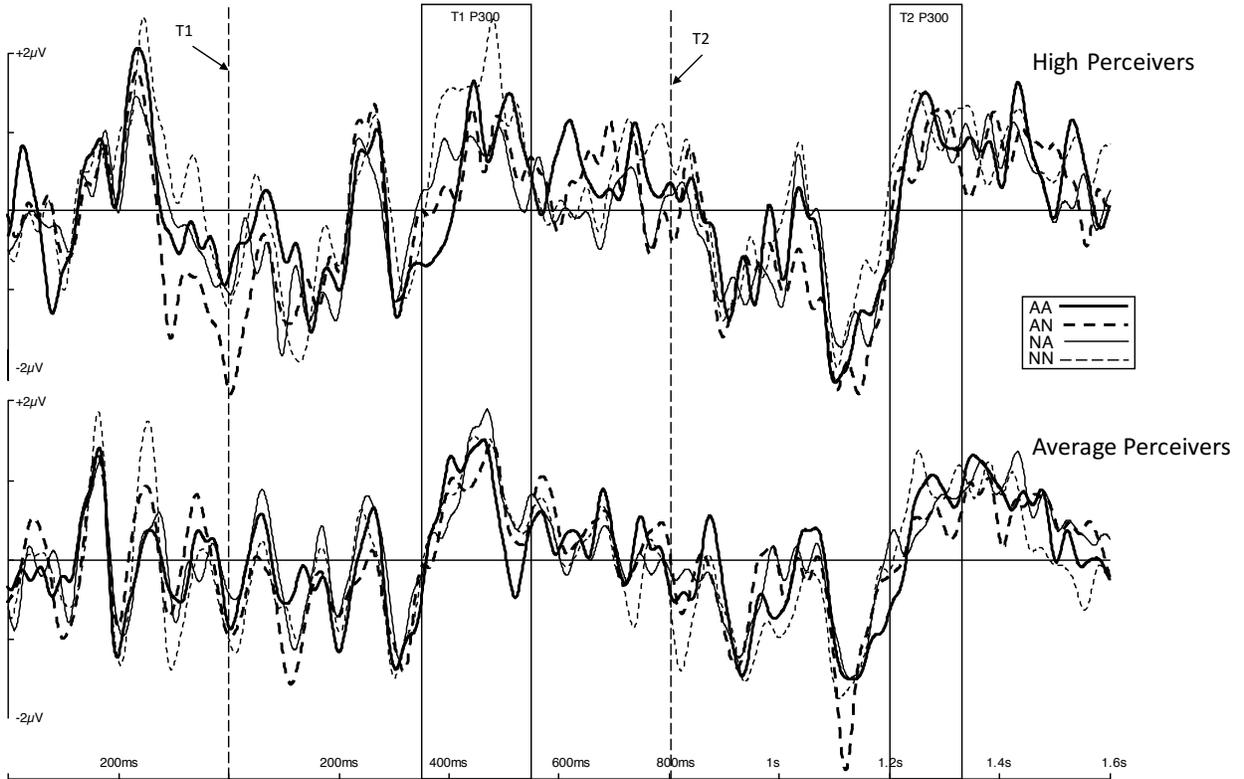


Fig. 5: Waveforms for Lag8 for high perceivers (upper panel) and average perceivers (lower panel). Target onset is highlighted by vertical dashed lines. P300 windows for T1 and T2 are outlined in solid lines.

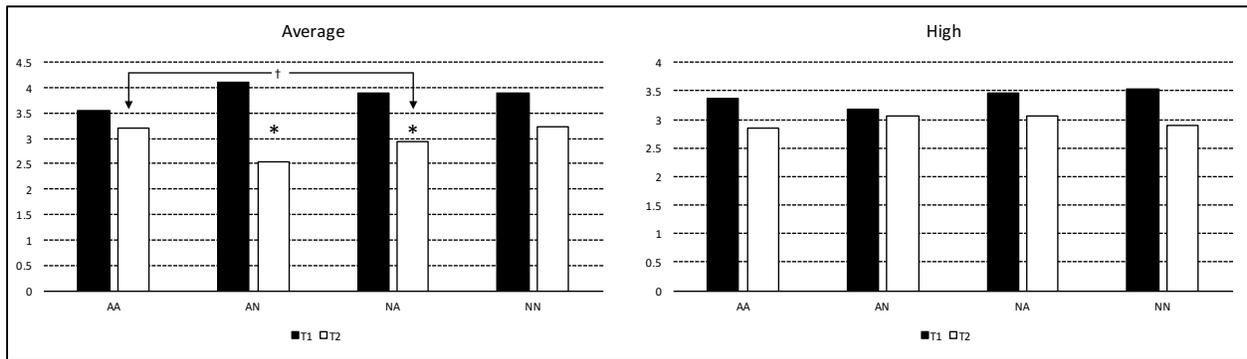


Fig. 6: Bar graph depicting average peak P300 amplitudes for both targets at each condition for average perceivers (left) and high perceivers (right).

* T2 significantly smaller than T1 in AN and NA.

† T2 of AN significantly smaller than at NA and AA

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