Research Article

The Blink and the Body

Cardiac Awareness Modulates the Perception of Emotionally Salient Words in an Attentional Blink Paradigm

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Abstract: We evaluated the interaction of emotion, interoceptive awareness (IA), and attention using an attentional blink (AB) task. Healthy undergraduates completed a cardiac awareness task and, based on previously validated cut scores, were classified as high or average perceivers (*n* = 19 in each group; matched on age and gender). Participants completed an AB task with counterbalanced emotional and/or neutral lexical stimuli as the first target (T1) and/or the second target (T2). Both high and average perceivers exhibited retroactive interference in conditions where T2 immediately followed T1. However, only the average perceivers exhibited a significant blink effect: They reported T2 inaccurately in trials in which one intervening stimulus occurred between T1 and T2. High perceivers exhibited their best performance in trials where both targets were emotional; average perceivers exhibited their worst performance in these trials. These results contribute to a small but growing literature that suggests IA and exteroceptive attention are related systems.

Keywords: interoception, emotion, attention, cognitive control, priming

OPEN DATA
OPEN MATERIALS

The perception of bodily signals is known as *interoception*, an experience that is proposed to be distinct from *exteroception*, or the awareness of external stimuli (Craig, 2003). The ability to perceive bodily signals is referred to as interoceptive awareness (IA; Murphy et al., 2019). IA is positively associated with sensitivity and reactivity to emotional stimuli (Pinna & Edwards, 2020). This sensitivity also corresponds to greater emotion recognition and regulation, and downstream benefits to mental health and well-being (Tsakiris & Critchley, 2016). One proposed mechanism for the link between emotion and IA is that high perceivers may find physiological sensations (e.g., increased heart rate) in certain situations (e.g., exposure to a phobic stimulus) to be more salient than those with lower IA, resulting in enhanced association and learning processes acquired passively (Paulus & Stein, 2010). However, the relation between interoception and general cognition, especially attention (clearly a related domain), has long been understudied (Tsakiris & Critchley, 2016).

There is a growing literature that has probed the link between objective IA and exteroceptive attention. However, the pattern of results in these studies has been mixed: Two studies found no significant associations of IA with behavioral data (Pollatos et al., 2007; Rae et al., 2018, 2020), and one found improved visual attention with better IA, although the results were complex (Matthias et al., 2009). Notably, although Pollatos et al. (2007) did not observe behavioral differences in the oddball task they used (likely due to ceiling effects), the researchers did observe greater P300 amplitudes for high perceivers than average perceivers, suggesting greater neural activation and working memory updating. Buldeo (2015) found that IA did not decrease under conditions of distraction, suggesting that it may be at least partially unique from exteroceptive attention. More research is needed to elucidate the relation between IA and attention, thus clarifying the relationship between interoceptive and exteroceptive attention.

The Attentional Blink

The attentional blink (AB; Raymond et al., 1992) is a popular paradigm used to assess the temporal dynamics and limits of attention (Dux & Marois, 2009). The AB is ideally suited to measure how attentional processes are influenced by bottom-up (stimuli driven) and top-down (individual differences) variables (Shapiro & Raymond, 2010). Thus, the AB allows the assessment of whether one group or another exhibits more efficient selective attention and with what types of stimuli (Mishra et al., 2017). In a typical AB paradigm, participants identify two targets from a stream of distractors presented via Rapid Serial Visual Presentation (RSVP). Targets are often simple

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symbols (e.g., letters) that are distinct from filler stimuli (e.g., numbers). At the end of a trial, the participant reports the count of targets and/or what those targets were. Following the first target (T1), the second target (T2) is presented at different locations in the stream: immediately after T1 (Lag1), one intervening stimulus (Lag2), two intervening stimuli (Lag3), and so on. The so-called *blink* occurs when the participant recalls the first but not the second target. Typical findings show that Lag1 tends to result in fewer blinks than Lag2 and Lag3 (within 200–500 ms after T1), but subsequent lags correspond to increasingly accurate T2 recall (Dux & Marois, 2009; Martens & Wyble, 2010).

The mechanism of the AB is a controversial topic, and numerous hypotheses have been proposed (for reviews, see Dux & Marois, 2009; Martens & Wyble, 2010; Shapiro & Raymond, 2010). One model argues that the depletion of attentional resources at the onset of T1 reduces available resources to encode T2 (Raymond et al., 1992). Alternatively, a modulation, but not depletion, of cognitive control during the encoding of T1 causes distraction preceding or succeeding T2 (Di Lollo et al., 2005). In short, these hypotheses differ on whether the AB occurs as a function of *filtering out* other information that are not targets, or *filtering in* information that are targets (Shapiro & Raymond, 2010). A third model, the *Boost and Bounce*, suggests that the AB occurs because T1 enhances (or boosts) attention to immediately subsequent stimuli, and the blink occurs when working memory sources are overfixated on filtering out other subsequent stimuli (Olivers, 2010).

The emotional content of stimuli is also an important factor in the AB. Much of the work investigating bottom-up and top-down processing related to emotions and the AB have used arousing, task-irrelevant distractors in and/or outside of the RSVP stream (Mishra et al., 2017). This method has elucidated the fragility of target encoding and temporal dynamics of working memory consolidation (e.g., Ní Choisdealbha et al., 2017), among other processes (McHugo et al., 2013; Mishra et al., 2017). In terms of target content, arousing T1 stimuli increase blinks whereas arousing T2 stimuli attenuate the blink regardless of T1 content (Schwabe et al., 2011; Schwabe & Wolf, 2010). The hypothesized mechanism for this effect, dubbed the emotional AB, is that the emotional and/or arousing features of T2 stimuli increase attentional capture and *break through* whatever filtering mechanism may underlie the AB, whereas emotional T1 enhances that filtering (McHugo et al., 2013). However, the content of targets, especially at T1, is infrequently assessed (Mishra et al., 2017).

Although most research into the AB centers on T2 recall accuracy only with correct T1 recall (and, thus, how T1 may cause proactive interference on T2), some work has probed how retroactive interference can impede encoding of T1 (Mishra et al., 2017). Sometimes referred to as a "backward blink," this phenomenon occurs most frequently in early lags (e.g., de Jong & Martens, 2007; Potter et al., 2005). Some argue that impaired T1 encoding is due to a failure to encode T1 due to interrupted working memory consolidation (Potter et al., 2002). Regarding the emotional AB, the backward blink is enhanced when T2 stimuli are emotional pictures (de Jong & Martens, 2007), although this phenomenon has not yet been established with lexical stimuli. Individual differences in the backward blink also have not yet been established.

Studies probing individual differences in the AB have found somewhat paradoxical results compared to conventional measurements of attention. Positive mood, hypervigilance, anxiety, and/or incentivized performance correspond to increased blinks, whereas negative mood, distraction, and no incentive to detect T1 decrease blinks (Biggs et al., 2015; Dux & Marois, 2009; Martens & Wyble, 2010; McHugo et al., 2013; Vermeulen, 2010). These authors suggest that those with greater engagement (e.g., due to positive mood or incentive) narrow their attentional focus and expend cognitive resources on T1, whereas the inverse is true with reduced engagement. Indeed, individuals who are less prone to blink at a trait level have a more diffuse attentional scope and greater working memory capacity allowing them to encode T1 efficiently, which, in turn, facilitates encoding T2 (e.g., Willems & Martens, 2015).

Current Research

The main goal of the present study is to elucidate how trait IA may impact the time course and intensity of attentional biases to emotional stimuli. More specifically, the primary aim of this study was to explore the influence of interoception on attention for emotional information in an AB paradigm. Only one previous study has used an AB to understand the relation of attention, emotion, and IA. In an emotional AB paradigm with positive, negative, and neutral words, Garfinkel et al. (2013) did not find an association of AB performance with IA overall but did find a significant, positive association between IA and accurate recall for positive and negative words when the participant's heart was in diastole but not systole. Based on the broader emotional AB literature, we hypothesized that within the crucial period of Lag1 and Lag2, those with average IA would demonstrate established blink effects when emotional stimuli are used: (a) Emotional T1 would result in increased recall of T1 and decreased recall of T2 regardless of T2 valence, and (b) emotional T2 would result in retroactive interference, resulting in reduced recall of neutral T1. Given the relatively novel research questions of the study and the mixed findings of Garfinkel et al. (2013), the hypotheses for the high perceivers are necessarily exploratory. We developed two alternative hypotheses regarding the high perceivers. First, at Lag1 and Lag2, since high perceivers are more sensitive to emotional stimuli, the refractory period following an emotional T1 may be extended compared to average perceivers, resulting in greater proactive interference (reduced T2 and improved T1 recall), whereas an emotional T2 may result in greater retroactive interference would impair encoding of T1 (i.e., backward blink). Alternatively, it is possible that high perceivers will exhibit more efficient attentional processes and working memory encoding, and, thus, would be less susceptible to impaired encoding of either T1 or T2, resulting in better performance overall.

Methods

Participants

Thirty-eight right-handed participants from the University of Kansas completed the study in exchange for course credit (n = 34) or US $20 payment ($n$ = 4). Participants were screened for eligibility and recruited from other studies within our laboratory over the course of three semesters and two summer sessions. As high perceivers were found, they were invited to complete this study for credit or return for payment. Three additional high perceivers did not wish to complete this study. For each included high perceiver, an average perceiver completed the study. Over 42 additional participants were screened, although a precise count is not possible as records of our screening procedures were lost to technical problems. All included participants scored below a clinical cut score of 14 on the Beck Depression Inventory-II (Beck et al., 1996). Participants were 17–31 years old (M = 19.0, SD = 2.32). By self-report, participants were native speakers of English, with no history of traumatic brain injury or learning disability and vision that was normal or corrected to normal. The two IA groups did not significantly differ in terms of gender, age, negative affect, emotion regulation, private body consciousness, or body competence[1] (ps > .212). Appendix A.1 to Appendix A.3, in the Electronic Supplementary Material (ESM 1), provide more information on these measures and descriptive information of the sample.

For a five-way repeated measures ANOVA with two groups (described below), an *a priori* power analysis suggested that a medium-to-large effect (f = 0.25; $\eta_p^2 \geq .059$) could be minimally attained with 11 participants in each group ($1 - \beta = 0.80$). A sensitivity analysis found that the present sample, with 19 participants in each group, was adequate to power ($1 - \beta = 0.80$) this model with small-to-medium effect sizes (f = 0.18; $\eta_p^2 \geq .031$).

Measures

Cardiac Awareness Task

The cardiac awareness task was based on Schandry (1981). In private, participants applied a heart rate monitor on their sternum. An experimenter then joined them in a quiet room while participants sat with their hands at their sides. The experimenter asked each participant to estimate the number of heartbeats they perceived in three trials each of 25, 35, and 45 s. Participants were not informed of the duration of each trial. Their spoken estimates were later compared to their recorded beats.

Cardiac data were collected using a Polar V800 heart rate monitor (Polar Electro Oy, Kempele, Finland), which has been previously validated to count peak-to-peak heartbeats (Giles et al., 2015). Cardiac awareness scores were calculated as $[1/3 \sum [1 - (|\text{recorded heartbeats} - \text{counted heartbeats}| / \text{recorded heartbeats})]$. Scores ≥ 0.85 were considered *high perceivers*, and all others were considered *average perceivers*. The well-established, taxometrically supported cut score of 0.85 has been used for nearly four decades (e.g., Schandry, 1981), where the demarcation of high and average perceivers continues to define two groups with distinct cognitive and emotional processing biases (e.g., Matthias et al., 2009; Werner et al., 2010). Given these prior demonstrations of validity, and to maintain consistency with this previous research, we used the established cut score while acknowledging the potential limits of doing so (discussed further below).

AB Task

A schematic of the task is presented in Figure 1. Participants were shown a stream of 15 stimuli, 5–8 characters in length, via RSVP. T1 was always the fifth item in the stream. In dual-target conditions, T2 was presented in one of three lags: Lag1 (immediately after the T1; stimulus onset asynchrony [SOA] = 100 ms), Lag2 (with one intervening distractor; SOA = 200 ms), and Lag8 (seven

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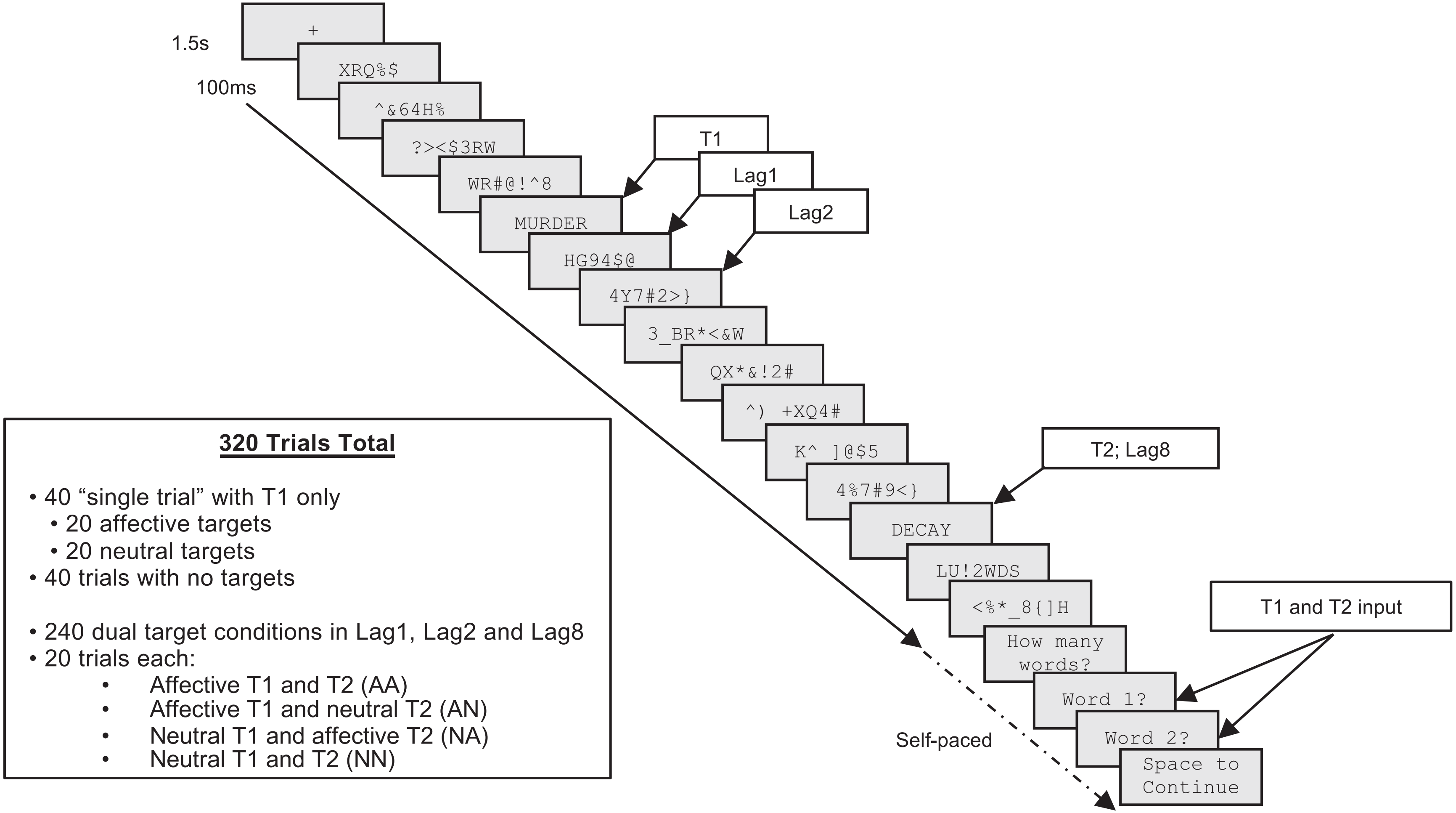
[1] High perceivers reported significantly higher public body consciousness than average perceivers, $t(35) = 1.45$, $p = .034$, $d = 0.22$. See Appendix A.3 in ESM 1.



320 Trials Total

- 40 “single trial” with T1 only
  - 20 affective targets
  - 20 neutral targets
- 40 trials with no targets

- 240 dual target conditions in Lag1, Lag2 and Lag8
- 20 trials each:
  - Affective T1 and T2 (AA)
  - Affective T1 and neutral T2 (AN)
  - Neutral T1 and affective T2 (NA)
  - Neutral T1 and T2 (NN)

Figure 1. Schematic of the AB task. Note the length of targets and distractor stimuli was 5–8 characters long; the T1 input screen only appeared if participant reported seeing one or two stimuli; T2 input screen only appeared if participant reported seeing two stimuli. AB = attentional blink.

intervening distractors; SOA = 700 ms). Of the dual-target conditions, there were 20 trials each for Lag1, Lag2, and Lag8: (negative) 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). There were also 40 single-target trials that contained only T1, half of which were neutral and the other half affective targets. Note that the stimulus category is labeled *affective*, but these stimuli were only in the negative valence (see below). Forty trials contained no targets. Thus, in total, there were 320 trials. Stimuli were randomized for each trial and each participant. Words did not repeat within the same trial. Repetition of any one word within the task was randomized per participant.[2]

At the end of each trial, the participant was asked how many words they saw (0, 1, or 2). If they indicated they saw one or two words, they were asked to recall each word or words in order (Vermeulen, 2010). Three times in the task, participants were made to pause for at least one minute during which they completed questionnaires. After one minute passed, the break screen became untimed. The task took about an hour to complete, and the whole study took about 1.5 hour.

Stimuli

Thirty unique affective (negative) and neutral stimuli were taken from the Affective Norms for English Words database (Bradley & Lang, 1999).[3] All words were 5-7 letters long. Affective words were rated as significantly more negative and arousing than neutral words ($ps < .001$, $d_{\text{valence}} = 9.42$, $d_{\text{arousal}} = 2.41$). Based on SUBTLEX-US data (Brysbaert & New, 2009), the two categories had comparable frequency (instances per million), $p = .878$, $d = 0.04$. Like previous work (e.g., Vermeulen, 2010), distractor stimuli were combinations of random letters, numbers, punctuation, and blank spaces that were five to seven characters long. Using random characters has been found to enhance the blink effect compared to distractor words or pseudowords (Maki et al., 1997, 2003) and can also reduce conceptual interference (Potter et al., 2005), which was a critical consideration in this study. All stimuli were presented using e-Prime Version 2.2 (Psychology Software Tools, Inc., Pittsburgh, PA) in upper case black Courier New font size 18 on gray background on an liquid crystal display (LCD).

Procedure

All procedures were approved by the Institutional Review Board at the University of Kansas. Upon arrival to the laboratory, participants completed informed consent procedures, demographic questionnaires, and the cardiac awareness task. After removing the heart rate monitor and confirming eligibility, participants then completed the AB task. When completed, participants were debriefed and compensated.

Data Analysis

To address the main goal of examining group differences in proactive and retroactive interference of emotional stimuli, we included both T1 and T2 recall accuracy in the model (de Jong & Martens, 2007; Vermeulen, 2010). Analyses of T2 accuracy as a function of T1 accuracy (T2|T1) are found in Appendix C of ESM 1. Although many of these results complement the ones presented here, some are discrepant, and it is not clear why. The count of accurately recalled words was entered into a 2 (*Group*: $_{\text{high vs. average perceivers}}$) × 2 (*T1 valence*: $_{\text{neutral vs. affect}}$) × 2 (*T2 valence*: $_{\text{neutral vs. affective}}$) × 2 (*Target*: $_{\text{T1 vs. T2}}$) × 3 (*Lag*: $_{1,\,2,\,8}$) mixed-model repeated measures ANOVA. Analyses of T2 recall accuracy as a function of T1 accuracy can be found in Appendix C of ESM 1. Word recall accuracy of single-target trials was analyzed with a 2 (*Group*: $_{\text{high vs. average perceivers}}$) × 2 (*Valence*: $_{\text{neutral vs. affect}}$) mixed-model repeated measures ANOVA. Misspellings and blanks were counted as errors (e.g., Vermeulen, 2010), although words out of order (i.e., reporting T1 as T2 and vice versa) were not.[4] Bonferroni correction was used for all post hoc analyses. Raw data are available at doi.org/10.17605/OSF.IO/45289 or upon request (Benau, 2021).

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[2] Any one word was repeated an average of 3.0 times (*Mdn* = 2.9, *SD* = 0.4) per participant. Frequency of repetition did not differ between groups in either affective or neutral words (*p*s > .08).

[3] *Affective (negative) words*: death, grief, afraid, abuse, slave, gloom, drown, cruel, upset, cancer, betray, corpse, killer, morgue, misery, hatred, poison, suicide, funeral, torture, sadness, poverty, failure, tragedy, agony, guilty, carcass, panic, sinful; *neutral words*: chair, trunk, elbow, clock, month, phase, paper, table, ankle, barrel, column, statue, locker, doctor, engine, kettle, pencil, street, office, hydrant, cabinet, machine, journal, utensil, context, history, sphere, basket, quarter (originally "quart"), detail.

[4] To anchor the present findings in previous work, we explored these reversals further. Of the 9,120 dual trials in the data set, reversals occurred on 92 (1%). Like previous work (e.g., Potter et al., 2005), most reversals occurred at Lag1 (*n* = 80), then Lag2 (*n* = 11), and Lag8 (*n* = 1). Results of a simple 2 (*Group*) × 3 (*Lag*) mixed-model repeated measures ANOVA confirmed that the variance across *Lag* was significant, $F(2, 72) = 28.19$, $p < .001$, $\eta_p^2 = .44$, and post hoc tests showed that the number of reversals in each lag significantly differed, (*p*s <.01). There was neither a significant main effect nor interaction of *Group* in the same model (*F*s < 0.4).

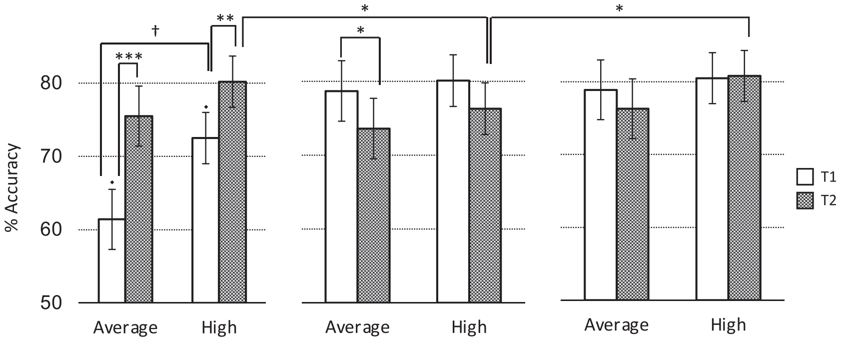

Figure 2. Results of the Lag × Target × Group interaction; ♦T1 recall at Lag1 was significantly worse than T1 recall at other lags for both groups (all *p*s < .05); †*p* < .10, **p* < .05, ***p* < .01, ****p* < .001.

Results

Overall Performance

Participants accurately recalled an average of 76.4% of stimuli (*SD* = 13.7%), which is similar to other studies using emotional words in an AB task (e.g., Vermeulen, 2010). Of the 80 words presented in single-target trials, participants correctly recalled 73.8% (*SD* = 14.4%). Accuracy on single-target trials did not significantly differ as a function of valence, group, or the interaction of the two (*p*s > .11). Thus, most participants were able to complete the task well, and there is no evidence of ceiling or floor effects.

Results of ANOVA

The main effect of *Group* was not significant, $F < 1.0$, $p = .337$. However, there was a significant main effect of *Lag*, $F\ (2, 72) = 60.46$, $p < .001$, $\eta_p^2 = .63$, a *Lag* × *Group* interaction $F\ (2, 72) = 4.84$, $p = .011$, $\eta_p^2 = .12$, a *Lag* × *Target* interaction, $F\ (2, 72) = 34.15$, $p < .001$, $\eta_p^2 = .49$, each of which can be explained within a significant *Lag* × *Target* × *Group* interaction, $F\ (2, 72) = 3.23$, $p = .045$, $\eta_p^2 = .08$. Post hoc tests showed that, at Lag1, both groups reported T2 more accurately than T1 (*p*s < .05). At Lag2, the average perceivers recalled T1 significantly better than T2 ($p = .042$), but this difference was not significant for high perceivers ($p = .13$). Both groups recalled T1 and T2 comparably at Lag8 (*p*s > .15). Across lags, both groups recalled T1 better at Lag2 and Lag8 than at Lag1 (*p*s < .05). At Lag2, high perceivers recalled T2 better than at Lag1, but worse than at Lag8 (*p*s < .05), whereas T2 recall did not significantly differ as a function of lag for average perceivers (*p*s > .39). Finally, at Lag1, high perceivers exhibited greater recall of T1 than average perceivers, although at a trend level ($p = .067$). No other pairwise comparisons approached significance in this interaction (*p*s > .34). Results of these analyses are depicted in Figure 2.

There were two additional significant interactions in the model. The first was a *T1 valence* × *T2 valence* × *Group* interaction, $F\ (1,36) = 5.23$, $p = .028$, $\eta_p^2 = .13$. Post hoc tests showed that average perceivers recalled both targets better in AA compared to NA conditions ($p = .021$), whereas the high perceivers recalled both targets better at AA compared to AN ($p = .044$). The high perceivers recalled AA conditions better overall than average perceivers, although at a trend level ($p = .061$). Figure 3 presents these results. Finally, there was a *T1 valence* × *T2 valence* × *Target* interaction $F\ (1,36) = 5.23$, $p = .028$, $\eta_p^2 = .13$. Post hoc tests showed that T2 was recalled better than T1 overall at AA ($p = .012$). For NN, T2 was recalled better than T1 ($p = .051$). There were no other significant post hoc tests in these interactions. No other significant main effects or interactions emerged in this model (*F*s < 2.9, *p*s > .066).

Discussion

The central finding of the present study is that high cardiac perceivers approached an emotional AB task in a different way from average perceivers, which is consistent with our predictions. Furthermore, we found evidence regarding mechanisms that influence recall results during the emotional AB paradigm. To illustrate our conclusions, we will consider each lag type separately starting with the data for Lag1.

Both groups exhibited evidence of retroactive interference at Lag1, consistent with previous work examining a *backwards blink* (e.g., Potter et al., 2002; 2005). More specifically, at Lag1, T2 was more likely to be recalled accurately than T1. We concur with Potter et al. (2002; 2005) who suggest that this backward blink at Lag1 is distinct from the blink phenomenon at later SOAs and is evidence of two-stage competition of attention. In the two-stage model, a stimulus needs at least 100 ms to transition from visual perception (Stage 1) into working memory

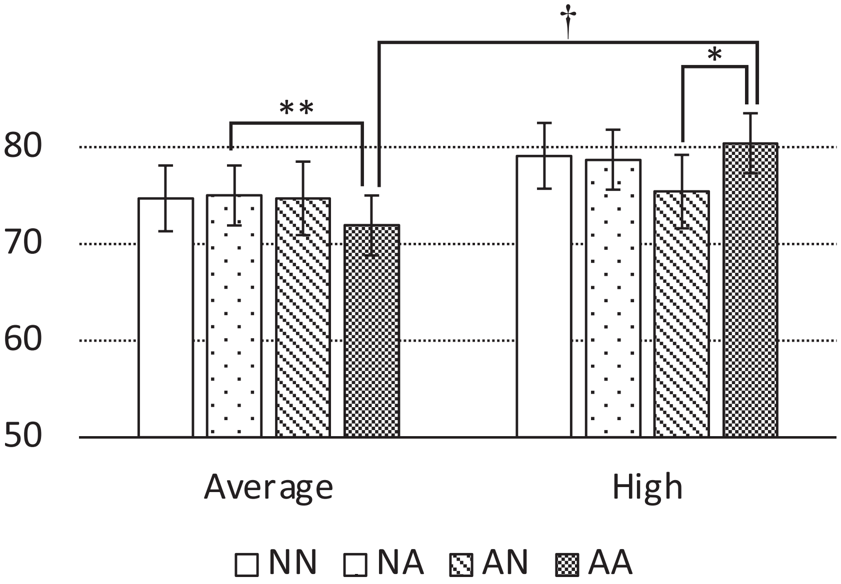

Figure 3. Results of the *Group × T1 Valence × T2 Valence* interaction; †$p < .10$, *$p < .05$, **$p < .01$.

(Stage 2), and both stages are necessary for accurate reporting. Interrupted transition to working memory increases the odds that the most recent stimulus (in this case, T2) will be the only one that is recalled. Additionally, we found that high perceivers were more likely to report T1 at Lag1 than were average perceivers. Although this finding was at a trend level, this provides tentative, partial support of our second exploratory hypothesis that high perceivers would perform better than average perceivers overall.

Accuracy data corresponding to the traditional blink window (Lag2) provide clearer evidence that high perceivers exhibited superior attentional abilities. Average perceivers exhibited significantly worse recall of T2 than T1 at Lag2, which is evidence of a traditional AB. In contrast, high perceivers did not exhibit this AB effect. The reduced susceptibility to the blink for high perceivers adds to a limited body of research suggesting improved visual attention is associated with performance on objective measures of IA (Matthias et al., 2009; Pollatos et al., 2007). A caveat to this finding is that the high perceivers recalled T2 at Lag2 worse than at Lag1 and Lag8; average perceivers recalled T2 at about the same accuracy across lags. Therefore, although high perceivers did not exhibit a traditional blink, it would be inaccurate to say that their encoding of T2 was impervious to interference that may occur in this time window.

Emotional content of stimuli played a surprisingly limited role in the present study. Valence did not influence either the backward blink seen at Lag1, nor the AB shown by average perceivers at Lag2. Davenport and Potter (2005) found that semantic content did not impact T1 recall in early lags. In contrast, de Jong and Martens (2007) found that an emotional T2 enhanced blinking of T1, especially (but not exclusively) at early lags. However, de Jong and Martens (2007) used facial stimuli for targets and participants completed a recognition task. It may be that the demands of encoding and recalling lexical stimuli trump any influence of emotional content at such brief SOAs.

We did find that T2 was recalled better than T1 in AA overall. However, group differences emerged in this condition that may better account for this finding: AA corresponded to the greatest recall for high perceivers and the lowest recall for average perceivers. Albeit at a trend level, the high perceivers exhibited superior recall of AA trials than average perceivers. This finding fits with previous work suggesting that high perceivers are simply better at recalling emotional words (as compared to neutral words) than average perceivers (Werner et al., 2010). When there are two emotional words to remember, this may play to high perceivers' strengths. A proposed mechanism for this improved recall is that these words increase physiological reactivity – for which high perceivers are, by definition, more sensitive – that enhances encoding and recalling of these words (Werner et al., 2010). Even briefly presented, backward masked words can increase physiological arousal (e.g., Hinojosa et al., 2010), so it is plausible that the mechanisms that enhance encoding during arousal were activated for high perceivers but not average perceivers.

In the case of average perceivers, the present findings are consistent with previous work that found the best recall to occur for the equivalent of the NA condition (Schwabe et al., 2011), presumably due to the affective features of words "breaking through" the attentional refractory period of encoding a neutral T1. It is less clear why the AA condition corresponded to the worst recall for average perceivers. On the one hand, it could be argued that an emotional T1 impedes encoding of any T2 as in previous work (Schwabe et al., 2011; Schwabe & Wolf, 2010). On the other hand, that would not explain why recall of AN was unimpaired for average perceivers in the present sample. Some work has shown that emotional stimuli can induce blindness to subsequent emotional stimuli in an RSVP stream (e.g., Most et al., 2005). It may be that the combined emotional content of two emotional targets resulted in doubled distraction and impaired encoding of both. Additional work is needed to better understand how the emotional content of T1 and T2 influences encoding.

This study provides important insights into the interaction of attention, emotion, and IA, although certain limitations should be noted. We did not investigate other elements of stimuli, such as arousal, nor did we examine positive valence. Positive words can influence performance in an AB similarly to negative (Vermeulen, 2010), and high perceivers have similarly improved recall of positive words compared to average perceivers (Werner et al., 2010). Therefore, future investigations of IA and/or the emotional AB should investigate both positive valence and negative valence as well potential modulations in performance as a function of arousal. Additionally, other measures of attention, including neuroimaging and psychophysiological measures, are certainly important to include to attain a full picture of the relation between IA and exteroceptive attention. Although the cardiac awareness task and cut score we used are both well-established and taxometrically supported (e.g., Schandry, 1981), these methods are not without limitations and criticism (Murphy et al., 2019). Future studies should include additional or alternative tasks and methods of quantifying IA. The present study was cross-sectional. Prospective studies (e.g., using interoceptive training) may elucidate causality of the relationships seen here. Finally, there are trade-offs to using the recall method used in the present study. We were interested in working memory consolidation and proactive and retroactive interference, for which free-recall, rather than recognition, is well-established to be a better index (e.g., Dillon & Thomas, 1975). However, with free-recall tasks, there are important variables we were not able to objectively measure. For example, it was impossible to determine if there was a bias in error regarding valence (e.g., what proportion of erroneously recalled words were affective vs. neutral). Similarly, it was impossible to define a typo versus other errors: Does typing "bloom" instead of "gloom" count as a typo or an intrusion of neutral stimuli? It was beyond the scope of the present study to pursue this line of inquiry, but this is an important avenue to consider for future research.

Summary and Conclusion

The present study is one of the first to demonstrate that IA, as measured by cardiac perception, distinguishes performance in an AB task. These findings support the increasing evidence that interoceptive attention, exteroceptive attention, and emotion all interact, although we are only beginning to understand the precise relation between these domains. Additional work is needed to better understand the mechanisms of cognition and interoceptive abilities.

Electronic Supplementary Material

The electronic supplementary material is available with the online version of the article at https://doi.org/10.1027/1618-3169/a000539

ESM 1. Appendix A: Description of self-report measures; Descriptive statistics of the sample and the two groups of demographic information, questionnaire data, and cardiac scores; Discussion on the significant differences on the Public Body Scale of the BCQ. Appendix B: Descriptive Statistics for behavioral variables. Appendix C: Supplementary traditional T1|T2 analyses. References.

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Conflict of Interest

The authors have no known conflicts of interest to declare.

Open Data

To the best of my ability and knowledge, I have provided all original materials and clear references to all other materials via a stable online repository. Raw data are available at https://doi.org/10.17605/OSF.IO/45289 (Benau, 2021). My article contains no experiment with a completely executed preregistration.

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