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Neutral and threatening distracter word stimuli are unnecessarily stored in working memory but do not differ in their degree of working memory storage

Richard T. Ward [a], Salahadin Lotfi [a], Daniel M. Stout [b,c], Sofia Mattson [a], Han-Joo Lee [a], Christine L. Larson [a,*]

[a] Department of Psychology, University of Wisconsin – Milwaukee, United States
[b] Center of Excellence for Stress and Mental Health, VA San Diego Healthcare System, United States
[c] Department of Psychiatry, University of California San Diego, United States

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ABSTRACT

Evidence suggests that threatening stimuli induce attentional biases compared to neutral stimuli, leading to subsequent storage in working memory. The current study examined how threatening versus neutral word distracters influence attention, and how this affects the unnecessary storage of these task-irrelevant stimuli in working memory. We measured the N2pc and contralateral delay activity (CDA), two event-related potentials (ERPs) that index attentional selection and the number of items maintained in WM, respectively, as participants completed a lateralized change detection task using word stimuli. Our results replicated work demonstrating a CDA effect for word stimuli, and found that distracter words are unnecessarily stored in working memory. However, we observed non-significant differences in attentional bias and working memory storage between distracter word conditions, and individual variation in anxiety was not associated with these processes. Bayes Factor analyses supported these null effects, suggesting that differences between neutral and threatening distracter words are unlikely.

1. Introduction

We are presented with numerous stimuli in our daily lives, many of which hold little relevance to our ongoing goals. Because humans maintain a limited capacity of cognitive resources to efficiently processes this incoming information (Corbetta & Shulman, 2002; Desimone & Duncan, 1995), it is critical that individuals selectively attend to task-relevant stimuli in order to enhance processing of this information (Hillyard, Vogel, & Luck, 1998). This enhanced processing of goal-relevant stimuli is accomplished by the interplay between top-down and bottom-up processes, with top-down processes allowing us to attend our focus towards task-related stimuli while inhibiting task-irrelevant stimuli, and bottom-up processes causing us to attend to salient stimuli that may warrant our attention (Theeuwes, 2010; Yantis, 2000).

Enhanced attentional processing of stimuli, whether task-relevant or irrelevant, is likely to impact downstream cognitive systems, such as working memory (Awh, Vogel, & Oh, 2006; Ikkai & Curtis, 2011). Working memory is a limited-capacity system allowing for the representation and manipulation of information over a short period of time in order to carry out goal-oriented behavior (Baddeley, 2012; Cowan, 2001, 2010; Cowan, 2017). Disruption of these attentional and working memory systems resulting from enhanced attentional bias towards threatening stimuli has been proposed as a risk factor for the development of anxiety (Bar-Haim, Lamy, Pergamin, Bakermans-Kranenburg, & Van Ijzendoorn, 2007; Bishop, 2007; Cisler & Koster, 2010; Hamm, 2020; Heeren, De Raedt, Koster, & Philippot, 2013). Therefore, it is critical to further clarify the neurocognitive mechanisms supporting this attentional bias towards threat given that this risk factor serves as an etiological marker for the development of anxiety (Beck & Clark, 1997; Mathews & MacLeod, 2005; Ouimet, Gawronski, & Dozois, 2009).

An abundance of work has indicated that threatening stimuli, even if task-irrelevant, can capture our attentional focus (Anderson & Britton, 2019; Dowd, Mitroff, & LaBar, 2016; Hopkins, Helmstetter, & Hannula, 2016; Mulckhuyse, 2018; Schmidt, Belopolsky, & Theeuwes, 2015; Schupp et al., 2004), an effect often exacerbated in anxious individuals

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* Corresponding author at: Department of Psychology, University of Wisconsin-Milwaukee, Milwaukee, WI, 53201, United States.
E-mail address: larsoncl@uwm.edu (C.L. Larson).

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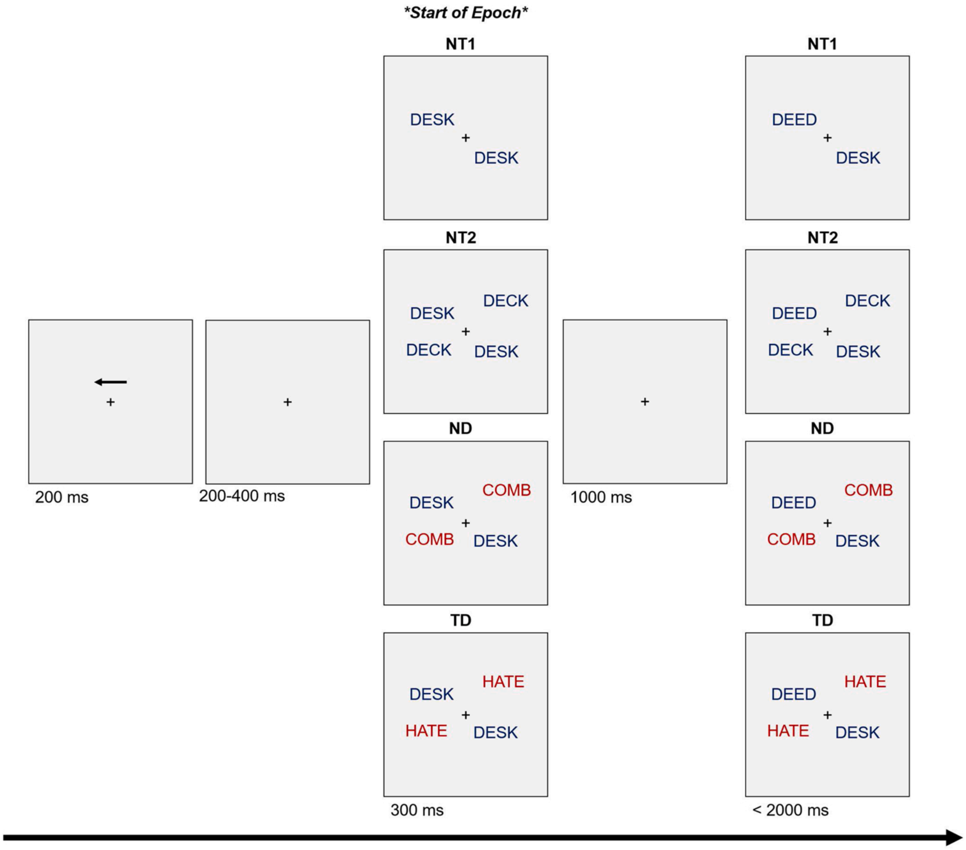

Fig. 1. Word Lateralized Change Detection Task.
Word lateralized change detection task requiring participants to attend to the target words in a particular color (blue in this example) in the cued hemifield while ignoring other colored distracter words (red in this example), which could be neutral (ND) or threatening (TD). Conditions consisted of one neutral target (NT1), two neutral targets (NT2), one neutral target and one neutral distracter (ND), and one neutral target and one threat distracter (TD). For visualization purposes, word stimuli are larger in this figure than they were in the experiment.

(Aftanas, Pavlov, Reva, & Varlamov, 2003; Fox, Russo, Bowles, & Dutton, 2001; Kim et al., 2018; Mogg & Bradley, 2016; Mogg, Bradley, De Bono, & Painter, 1997; Nelson, Purdon, Quigley, Carriere, & Smilek, 2015; Pacheco-Unguetti, Acosta, Callejas, & Lupiáñez, 2010; Quigley, Nelson, Carriere, Smilek, & Purdon, 2012; Raeder et al., 2019; Shah et al., 2018; Wieser, Hambach, & Weymar, 2018; Yao, Rodriguez, He, & Qian, 2019). This biased processing of threatening stimuli can be attributed to enhanced stimulus salience, leading to increased bottom-up attentional processes that override top-down processes dedicated toward inhibition of these stimuli and completion of task-relevant goals (Berggren & Derakshan, 2013; Eysenck, Derakshan, Santos, & Calvo, 2007; MacNamara, Kappenman, Black, Bress, & Hajcak, 2013; Sussman, Jin, & Mohanty, 2016). While this enhanced processing of threatening stimuli can be considered evolutionarily adaptive (Ekman, 1992; LeDoux, 2003; Öhman & Mineka, 2001; Öhman, Lundqvist, & Esteves, 2001), this process can become detrimental in circumstances in which an individual must attend to specific goal-related stimuli while effectively ignoring task-irrelevant stimuli, such as threatening distracters (Bishop, 2007; Devue, Belopolsky, & Theeuwes, 2011; MacNamara & Hajcak, 2009; Sussman, Heller, Miller, & Mohanty, 2013).

Preferential attentional processing of threat-related distracters is likely to impact other cognitive systems, such as working memory (Gazzaley & Nobre, 2012). For example, prior work has found that threat-related distracter stimuli are stored in working memory (Angelidis, Solis, Lautenbach, van der Does, & Putman, 2019; Stout, Shackman, & Larson, 2013; Stout, Shackman, Johnson, & Larson, 2015; Stout, Shackman, Pedersen, Miskovich, & Larson, 2017; Ye et al., 2018). These threatening stimuli are stored in working memory, resulting in competition for working memory resources between these distracters and ongoing task-relevant processes (Holmes, Mogg, de Fockert, Nielsen, & Bradley, 2014; Morey et al., 2009). However, much of this work has focused on threat-related distracters that hold biological relevance (e.g., threatening or emotional faces). Thus, it remains less clear if these findings generalize for other stimulus-modalities, such as words. This is critical given the abundance of written words encountered in our everyday lives, some of which may contain threatening meanings which can disrupt our emotional state (Lyubomirsky, Caldwell, & Nolen-Hoeksema, 1998; Tabibnia, Lieberman, & Craske, 2008; Weis & Herbert, 2017; Wormwood, Devlin, Lin, Barrett, & Quigley, 2018), and cognitive functioning (Algom, Chajut, & Lev, 2004; Carretié et al., 2008). Furthermore, anxious individuals may also be prone to engage in attentional bias towards non-biologically threatening words (Boehme et al., 2015; van Honk et al., 2001; Wabnitz, Martens, & Neuner, 2016; Yeung & Fernandes, 2019a), which may in turn impact their ability to filter such information from gaining access to working memory (Berggren, 2020; Eysenck et al., 2007; Qi, Ding, & Li, 2014). Furthermore, it should be noted that all stimuli forms (e.g., words, faces, etc.) have potential low-level confounds that may influence outcomes, making it necessary to demonstrate generalizability of attentional bias and working memory filtering effects across stimulus modalities to ensure that these effects are primarily related to emotional aspects, and not physical features associated with the stimulus category.

Prior work has found attentional bias towards emotional words (Algom et al., 2004; Boehme et al., 2015; Kousta, Vinson, & Vigliocco, 2009; Van den Heuvel et al., 2005; van Honk et al., 2001; Wabnitz et al., 2016; Yeung & Fernandes, 2019a). However, others have found a lack of attentional bias towards such emotionally-valenced words in anxious individuals (Moritz et al., 2008; Pishyar, Harris, & Menzies, 2004), even when those same individuals do show attentional biases toward negative faces (Pishyar et al., 2004). Thus, there is some question as to under what conditions anxious individuals do and do not show attentional bias to emotional words. In addition, much of this work has focused primarily on individuals displaying anxious traits or diagnosed with anxiety-related disorders, and thus it remains unclear if an attentional bias towards threatening words is present in healthy individuals. This is critical given that prior work has shown that other forms of threat-related stimuli attract attention in healthy individuals (Anderson & Britton, 2019; Dowd et al., 2016; Hopkins et al., 2016; Mulckhuyse, 2018; Schmidt et al., 2015; Schupp et al., 2004).

If threatening words induce attentional bias, this should also impact working memory processes (Gazzaley & Nobre, 2012). Indeed, previous studies have addressed this question by showing that emotionally charged distracter words interfere with working memory performance on higher working memory loads when individuals were in an induced state of anxiety (Angelidis et al., 2019). Others have also found greater working memory capacity for threatening words, suggesting that these words were stored in working memory to a greater degree than neutral words, albeit only for individuals diagnosed with generalized social phobia (Amir & Bomyea, 2011). However, others have failed to replicate this finding, showing that socially anxious individuals do not differ in their storage of threatening words compared to healthy controls (Waechter et al., 2018). Thus, findings regarding whether threatening words are stored in working memory preferentially over neutral words are mixed, and it is unknown if threat-related task-irrelevant distracter words are unnecessarily stored in working memory. Furthermore, it remains unclear if this effect is also present in healthy individuals.

Given that previous work from our laboratory (Stout et al., 2013, 2015; Stout et al., 2017) and others (Judah, Grant, & Carlisle, 2016; Meconi, Luria, & Sessa, 2014; Salahub & Emrich, 2020; Sessa, Luria, Gotler, Jolicœur, & Dell'Acqua, 2011; Ye et al., 2018) found enhanced unnecessary storage of threat-related compared to neutral distracter facial stimuli in working memory using a change detection task, we aimed to examine whether working memory storage for affective facial distracters generalizes to affective verbal stimuli, in this case written words. We incorporated the same design of lateralized change detection task used by Stout et al. (2013), but optimized it for the use of words as stimuli rather than faces. Specifically, we shortened the array presentation to 300 ms based on prior work showing ERP effects with similar durations (Cristescu & Nobre, 2008; Frühholz, Jellinghaus, & Herrmann, 2011; Kanske, Plitschka, & Kotz, 2011; Kanske & Kotz, 2007; Klumpp et al., 2010; Lavidor, Babkoff, & Faust, 2001; Schindler & Kissler, 2016), and shortened the number of trials to prevent fatigue based on our own previous work eliciting CDA effects from fewer trials (Ward, Lotfi, Sallmann, Lee, & Larson, 2020; Ward et al., 2019) than that used in Stout et al.' (2013).

The current study aimed to investigate the impact threat-related distracter words have on attentional selection bias and unnecessary storage in working memory compared to neutral distracter words by using a lateralized change detection task consisting of word stimuli (Fig. 1, see Appendix A for monochromatic figures). Specifically, this task presents word stimuli on one hemifield for a brief duration before disappearing. After a short interval delay period, the word stimuli are re-presented, and the participant must indicate whether the target words changed from their initial presentation. This design allows for the assessment of attentional selection of visual stimuli during their presentation, and their subsequent storage in working memory over the delay period. We used neutral valenced and negatively valenced words from the Affective Norms for English Words (Bradley & Lang, 1999) and an extended language database (Warriner, Kuperman, & Brysbaert, 2013) to serve as stimuli in a lateralized change detection task. The final words selected as threatening distracter words were examined to ensure they could be perceived as threatening versus simply negative. We recorded event-related potentials (ERPs) during this task to examine underlying electrophysiological signals reflecting attentional selection and working memory storage for threatening words. We examined the N2pc, an ERP component reflecting attentional selection (Eimer & Kiss, 2007; Luck, 2012; Mazza, Turatto, & Caramazza, 2009), and the contralateral delay activity (CDA), an ERP component that extends upon earlier identified ERP signals (see Klaver, Talsma, Wijers, Heinze, & Mulder, 1999) reflecting the number of visual items, including word stimuli (Rajsic, Burton, & Woodman, 2019), stored in working memory (Gao, Yin, Xu, Shui, & Shen, 2011; Ikkai, McCollough, & Vogel, 2010; Luria, Balaban, Awh, & Vogel, 2016; McCollough, Machizawa, & Vogel, 2007). The N2pc component has been used previously to assess attentional selection of emotional stimuli (Eimer & Kiss, 2007; Wieser et al., 2018), and whether task-irrelevant distracters are covertly attended to (Ikeda, Sugiura, & Hasegawa, 2013). The CDA has also been used as an electrophysiological marker to examine unnecessary storage in working memory by computing a filtering efficiency value based on the CDA obtained across conditions (Jost, Bryck, Vogel, & Mayr, 2011; Li, He, Wang, Hu, & Guo, 2017; Luria et al., 2016; Qi, Ding et al., 2014; Stout et al., 2013; Vogel, McCollough, & Machizawa, 2005; Ward et al., 2019, 2020; Ye et al., 2018). Using this computed CDA filtering efficiency value, others have shown that emotionally salient stimuli are unnecessarily stored in working memory (Stout et al., 2013; Ye et al., 2018).

Based on prior work showing attentional bias towards task-irrelevant threatening stimuli (Eimer & Kiss, 2007; Hopkins et al., 2016; Ikeda et al., 2013; Schmidt et al., 2015), we hypothesized that threat distracter words would elicit greater covert attention capture compared to neutral distracter words. This was calculated by examining the difference in N2pc between a condition containing a target word and a condition containing a target and distracter word. As such, this would suggest that the threat distracter condition would yield enhanced covert attentional selection over the single target word condition, and that this bias would be greater for the threat distracter condition compared to the neutral distracter condition. We further predicted that this enhanced attentional bias towards threatening distracter words would result in greater subsequent unnecessary storage in working memory, reflected by a decreased filtering efficiency value computed using the CDA across target and distracter conditions (Qi, Ding et al., 2014; Vogel et al., 2005) for neutral compared to threat distracter conditions. This hypothesis was also driven by prior work demonstrating that threat-related distracters are inefficiently gated from gaining access to working memory (Angelidis et al., 2019; Stout et al., 2013, 2015; Stout et al., 2017; Ye et al., 2018). If our predictions were upheld, these findings would support the notion that threat-related distracter words enhance bottom-up processes, overriding top-down cognitive control, and are thus preferentially attended to and stored in working memory compared to neutral distracter words.

Behaviorally, we predicted that participants would show a greater response time filtering cost for the threat compared to the neutral distracter words, as seen in prior work demonstrating enhanced response times for conditions including threat distracters (Schmidt et al., 2015). This is based on evidence that simple threatening stimuli have a potent attentional capture effect, leading to a prioritization in their processing and an overall decrease in processing time for goal-oriented targets (Bretherton, Eysenck, Richards, & Holmes, 2017; Öhman, Soares, Juth, Lindström, & Esteves, 2012; Soares, Lindström, Esteves, & Öhman, 2014).

In addition to our primary analyses, we also conducted exploratory analyses to examine whether trait anxiety (measured via the State-Trait Anxiety Inventory; Spielbeger & Gorsuch, 1983) was associated with enhanced attentional allocation towards threat compared to neutral distracter words via the N2pc, and impaired CDA filtering efficiency values for the threat compared to neutral distracter words. This is based on prior work indicating N2pc attentional biases towards emotional stimuli (Reutter, Hewig, Wieser, & Osinsky, 2017; Wieser et al., 2018) and the subsequent storage of threat distracters in working memory indexed by the CDA index (Stout et al., 2013) for threatening stimuli in anxious individuals. These correlational analyses were also conducted for response time filtering cost due to prior work has showing longer response times during the presence of threatening versus neutral distracters in anxious individuals (Fox et al., 2001; Mogg & Bradley, 2016; Pacheco-Unguetti et al., 2010). We predicted that trait anxiety would be associated with more pronounced response time filtering cost for threat relative to neutral distracters for response time.

2. Method

The study design and analyses pertaining to our CDA and behavioral measures were preregistered using aspredicted.org (aspredicted # 28059; https://aspredicted.org/32iz3.pdf) prior to data collection. In addition to our preregistered analyses, we also examined the N2pc to examine attentional processing of threat distracter words.

2.1. Power analysis

We conducted an initial power analysis using G*Power (Faul, Erdfelder, Lang, & Buchner, 2007; Faul, Erdfelder, Buchner, & Lang, 2009) to estimate an appropriate sample size to detect differences between our conditions. Our experimental design was a four condition (low target load, neutral distracter with low target load, threat distracter with low target load, and high target load) within-subject design, resulting in a repeated measures ANOVA as our primary inferential analytic analysis. We anticipated a main effect for condition across all our behavioral measures (accuracy, response time, Pashler's K score) and CDA, such that the high target load would significantly differ from the low target load. We used a conservative estimate and assumed a small effect size ($\eta_p^2 = 0.02$) for our power analyses. By using this effect size, a power of 0.8, and an α level of 0.05, our power analysis indicated a required sample size of 67 with usable EEG data.

2.2. Bayes factor analyses

Given the criticisms of traditional null hypothesis significance testing analyses, especially concerning non-significant results (Levine, Weber, Hullett, Park, & Lindsey, 2008), we also conducted Bayes Factor analyses for any null statistical outcomes to evaluate the degree of evidence for the null versus alternative hypothesis ([Dienes,2014], 2016; Jarosz & Wiley, 2014; Keysers, Gazzola, & Wagenmakers, 2020; Lakens, McLatchie, Isager, Scheel, & Dienes, 2020; Lee & Wagenmakers, 2014; van Doorn et al., 2020; Wagenmakers, Verhagen, & Ly, 2016, 2018a, 2018b). Specifically, we computed Bayes Factor 10, which indicates the likelihood ratio of evidence given both the null and alternative hypotheses (e.g., BF_{10} = (likelihood of data given H_1 / likelihood of data given H_0)). Thus, the outcome value for BF_{10} indicates the likelihood of the data to occur in the alternative compared to the null hypothesis. Importantly, the outcomes of Bayes Factor analyses are considered on a continuous scale reflecting the degree of evidence for the null versus alternative hypothesis (Dienes, 2014, 2016; Jarosz & Wiley, 2014; Keysers et al., 2020; Lakens et al., 2020; Lee & Wagenmakers, 2014; van Doorn et al., 2020; Wagenmakers et al., 2016, 2018a, 2018b). Therefore, unlike traditional inferential statistics in which a cut off score (e.g., $p < 0.05$) is incorporated, Bayes Factor analyses do not impose criterion estimates for the degree of evidence for one hypothesis over the other due to the use of this continuous scale (see Keysers et al., 2020; Lee & Wagenmakers, 2014; van Doorn et al., 2020; Wagenmakers et al., 2016; 2018a, 2018b). Despite this, some common guidelines for communicating Bayes Factor values have been proposed (see Dienes, 2014, 2016; Jarosz & Wiley, 2014; Jeffreys, 1939; Kass & Raftery, 1995; Lee & Wagenmakers, 2014; van Doorn et al., 2020), broadly indicating that Bayes Factor values closer to 0 reflect evidence for the null hypothesis, values far above 1 (e.g., > 3) indicate evidence in favor of the alternative hypothesis, and values around 1 reflecting inconclusive evidence for either hypothesis (Dienes, 2014, 2016; Lakens et al., 2020). While several others have provided more discrete categorical descriptions of the degrees of evidence for each hypothesis (see Jarosz & Wiley, 2014; Jeffreys, 1939; Kass & Raftery, 1995), we used the work of van Doorn et al. (2020) to help inform and guide our communication and interpretation of our Bayes Factor analyses outcomes. Specifically, BF_{10} values falling within the relative range of the following indicate: between 0 and 0.1 (strong evidence for the null hypothesis; between 0.1 and 0.33, moderate evidence for the null hypothesis; between 0.33 and 3, weak evidence for either the null or alternative hypothesis (values between 0.33–1 considered as weak evidence for the null and values between 1 and 3 as being weak evidence for the alternative hypothesis); between 3 and 10, moderate evidence for the alternative hypothesis; and greater than 30, strong evidence for the alternative hypothesis. Despite using these guidelines to inform our interpretation, we wish to express that these values do not serve as strict cut-off criterion, and that the degree of evidence for the null versus alternative hypothesis should be considered on a continuous scale, in which the specific interpretation for the relative strength of evidence for a given hypothesis differs across theories. Thus, we used this guideline as a formality for communicating our confidence in arriving at a null outcome (van Doorn et al., 2020).

Although Bayes Factor values serve as a primary measure of evidence in support of the null versus alternative hypothesis (Jeffreys, 1961; Morey, Rouder, Verhagen, & Wagenmakers, 2014, Simonsohn, 2015; Wagenmakers et al., 2018a), we have also included credible interval (CI) estimates of effect size (2016, Dienes, 2014; Keysers et al., 2020; Lakens et al., 2020; van Doorn et al., 2020; Wagenmakers et al., 2018a) for our primary analyses of interest (e.g., RT filtering cost, N2pc distracter attentional allocation, and CDA filtering efficiency). This was done to assess additional evidence for our null outcomes, and examine the minimal effect size value for each of our analyses. Specifically, CI estimates of effect size that cross "0" support the null hypothesis (Ferguson, 2016). In addition, by observing the minimal effect size estimate, we were able to determine whether or not these effect sizes would be too small to be considered as practical. While there is no consistent agreement on which effect sizes are "too small to be considered", many have proposed using arbitrary cutoffs (e.g., i.e., $d < 0.2$, Cohen, 1988), but such practice is cautioned against (Ferguson, 2016; Fritz, Morris, & Richler, 2012; Thompson, 2007) due to the impact that a small effect may have in one domain (e.g., life-saving treatment) versus another (e.g., slight increase in fatigue during a task). Therefore, we used the outcomes observed by recent work (Szucs & Ioannidis, 2017) to inform this judgment. Specifically, they reviewed effect sizes in over 3,800 cognitive neuroscience reports, and found a median effect size around of approximately $d = 0.237$ with an interquartile range of $0.106-0.421$ in non-significant result papers. Based on these outcomes, we have selected the arbitrary criterion of $d < +/- 0.1$ as an indicator of whether an effect size is considered too small to be worth future consideration.

2.3. Participants

Ethical considerations and study procedures, including the full list of word stimuli, were approved by our university's Institutional Review Board (IRB), and all participants were given informed consent prior to beginning the experiment. As part of the consent process, participants were fully informed that if they became upset during the experiment, or for any reason, that they could withdraw without any penalty. Post-experiment we also provide a debriefing form that includes resources for participants if they experienced adverse effects from the study.

Eighty-five undergraduates were recruited from the University of Wisconsin – Milwaukee to participate in the study in exchange for course credit or $40 in cash. Participants were at least 18 years of age, proficient in English, had fewer than two concussions or seizures (Only 7 participants, ~11 % of sample, indicated history of a concussion or head injury with none having more than one concussion/head injury in the past), and had no history of visual impairments. Twenty-five participants were excluded from data analysis due to having more than 20 % of ERP epochs rejected due to artifacts (n = 15), withdrawal from the study (n = 3), poor behavioral performance (i.e., less than 65 % accuracy) and reported lack of effort during the task (i.e., research assistant noted that participants were simply randomly answering and skipping break blocks; n = 5), having over two concussions (n = 1), and due to being an outlier for the computed CDA filtering efficiency values for both neutral and threat distracter word conditions (+/− 3 SDs; n = 1). This resulted in a total of 60 participants used for the final data analyses (44 Female;

Table 1
Word Stimuli.

Neutral Target		
ACRE	ARCH	AREA
AXLE	BACK	BALE
BEAK	BEAN	BOAR
BRAN	BROW	BULB
BUOY	BUSH	CARD
CART	CHAP	CHEF
CHIN	CLIP	COAT
COPY	CROP	CUBE
CURL	DECK	DEED
DESK	DISK	DOSE
DUNE	EASE	FARE
FOLD	FOOT	GEAR
GENT	GOAT	GRID
HARP	HAUL	HILL
HIND	HOLE	HOOF
HOST	HULL	INCH
ITON	ISLE	ITEM
KNOB	LEAF	LEND
LENS	LINE	LINK
LIST	LOAF	LOGO
LUNG	MAID	MASK
MEEK	MEMO	MILD
MINI	MINK	MITT
MONK	NOON	NOSE
PACE	PALM	PEAS
PERM	PLUM	POLE
POSE	POUR	PREP
PUTT	RAIL	RICE
PROBE	ROOM	SAKE
SEAL	SEAT	SEMI
SHOE	SIDE	SIGN
SIZE	SKIN	SLAB
SNUG	SOAK	SOIL
SPAN	SPOT	STEW
STIR	STOW	SUIT
SWAB	TAIL	TALE
TAPS	TEND	TILE
TUBE	TWIG	TYPE
WALL	WILL	WOMB
WOOL	YARN	YAWN

Neutral Distracter		Threat Distracter	
BASE	CODE	BOMB	FEAR
COMB	EXIT	GANG	HATE
FADE	FOAM	KILL	LIAR
MELT	MILL	PAIN	RAGE
PROP	SEEM	RAPE	SHOT

$M_{age} = 21.33$, $SE = 0.60$). However, an additional subject was removed from our exploratory correlational analyses for trait anxiety due to failure to complete the questionnaire, resulting in 59 participants for the exploratory correlational data analyses involving trait anxiety, and 60 participants for the remaining analyses concerning our primary dependent variables. The target sample size of 67 was not able to be reached as data collection was ended due to the coronavirus pandemic.

2.4. *Materials and procedure*

2.4.1. *Word stimuli*

Two sets of word stimuli were chosen for this experiment. The first set consisted of three letter words to be completed during a practice phase of our word lateralized change detection task. The second set included four letter words used in the test phase of the task. All words were taken from the Affective Norms for English Words (ANEW; Bradley & Lang, 1999) and an extended English language database (Warriner et al., 2013). Neutral and negative words were initially selected from the ANEW, using their reported normed valence values. Specifically, ANEW words with a valence between 4.52–5.72 were selected as neutral words, and ANEW words with a valence between 1.25 and 3.55 were selected as negative words (total scale of 1.25–8.82 for valence in the ANEW). Additional words not present in the ANEW stimuli were taken from Warriner et al' (2013) extension, and valence and arousal levels were used. Words with normed valence values between 4.65 and 6.16 were selected as neutral words, and words with valence values between 1.54 and 2.67 were selected as negative words from this dataset (total scale of 1.26–8.53 for valence in the Warriner and et al' (2013) inventory). Further examination of words by the researchers was conducted to select words that appeared as threatening. All word frequency values were calculated based on the SUBTLEXus (Brysbaert & New, 2009).

The practice session for the lateralized change detection task included 48 neutral three letter words. The test portion of our task consisted of 140 total words: 120 neutral target words, 10 neutral distracter words, which were randomly selected from a list of 130 neutral words (120 used as targets, 10 used as distracters), and 10 threat distracter words. (Table 1). Each word was presented 16 times throughout the task.

We examined normed valence arousal values from the ANEW (Bradley & Lang, 1999) and Warriner et al.' (2013) and extended English language database. We also examined normed values for word frequency using the SUBTLEXus database (Brysbaert & New, 2009). Three separate one-way ANOVAs, comparing target words, neutral distracter words and threat words. For valence, we found a main effect of word condition, $F(2, 137) = 261.899$. $p < 0.001$, $\eta_p^2 = 0.793$. Bonferroni post-hoc comparisons demonstrated that neutral target and neutral distracters did not differ in valence, $t(128) = 0.420$, $p > 0.99$, $d = 0.230$, $BF_{10} = 0.341$, but that threat distracter words were more negative in valence compared to neutral target, $t(128) = 22.850$, $p < 0.001$, $d = 7.521$, and neutral distracter, $t(18) = 15.244$, $p < 0.001$, $d = 6.808$, words. A similar pattern was observed for arousal, $F(2, 137) = 782.093$, $p < 0.001$, $\eta_p^2 = 0.919$, with post-hoc comparisons showing that neutral targets and neutral distracter words did not differ, $t(128) = 0.461$, $p > 0.99$, $d = 0.152$, $BF_{10} = 0.346$, but that threat distracter words had greater arousal values compared to neutral target, $t(128) = -40.048$, $p < 0.001$, $d = 13.181$, and neutral distracter, $t(18) = -20.345$, $p < 0.001$, $d = 9.090$, words. Thus, our neutral targets and neutral distracters were matched based on normative values for valence and arousal, and the threatening distracter words were more negative and arousing than neutral words. We also did not observe any differences in word frequency between the word conditions, $F(2, 137) = 0.377$, $p = 0.687$, $\eta_p^2 = 0.005$, $BF_{10} = 0.194$.

2.4.2. *Word lateralized change detection task*

Participants completed a lateralized change detection task following a design used previously in our laboratory (Stout et al., 2013) and others (Judah et al., 2016; Meconi et al., 2014; Salahub & Emrich, 2020; Sessa et al., 2011; Ye et al., 2018), but using word stimuli instead of faces, based on previous work demonstrating a robust CDA effect with words (Rajsic et al., 2019). This design allows us to examine the storage of words in working memory, and examine how task-irrelevant distracter words, both neutral and threatening, impacted are unnecessarily stored in working memory. This task is lateralized such that a set of stimuli appear in both left and right hemifields, but participants are instructed to attend to just one hemifield. This allows for proper measurement of the CDA, which is computed by taking the difference in contralateral and ipsilateral activity to the attended memoranda array.

Participants were presented a display containing two lateralized stimulus arrays (each 4.54° × 3.30°), each array being approximately 2.46° to the left and right of the central fixation point. A cue shown prior indicated which side of the array (i.e., left or right) participants must attend to. Participants were required to remember target colored words while ignoring any distracter colored words. Target and distracter words were either red or blue (luminance matched at ~30.42 cd/m2) and with the color counterbalanced across participants. Participants were instructed as to which color was associated with a target and distracter word. The total number of target and distracter words were always equal in both hemifield arrays, and the location of the word stimuli were

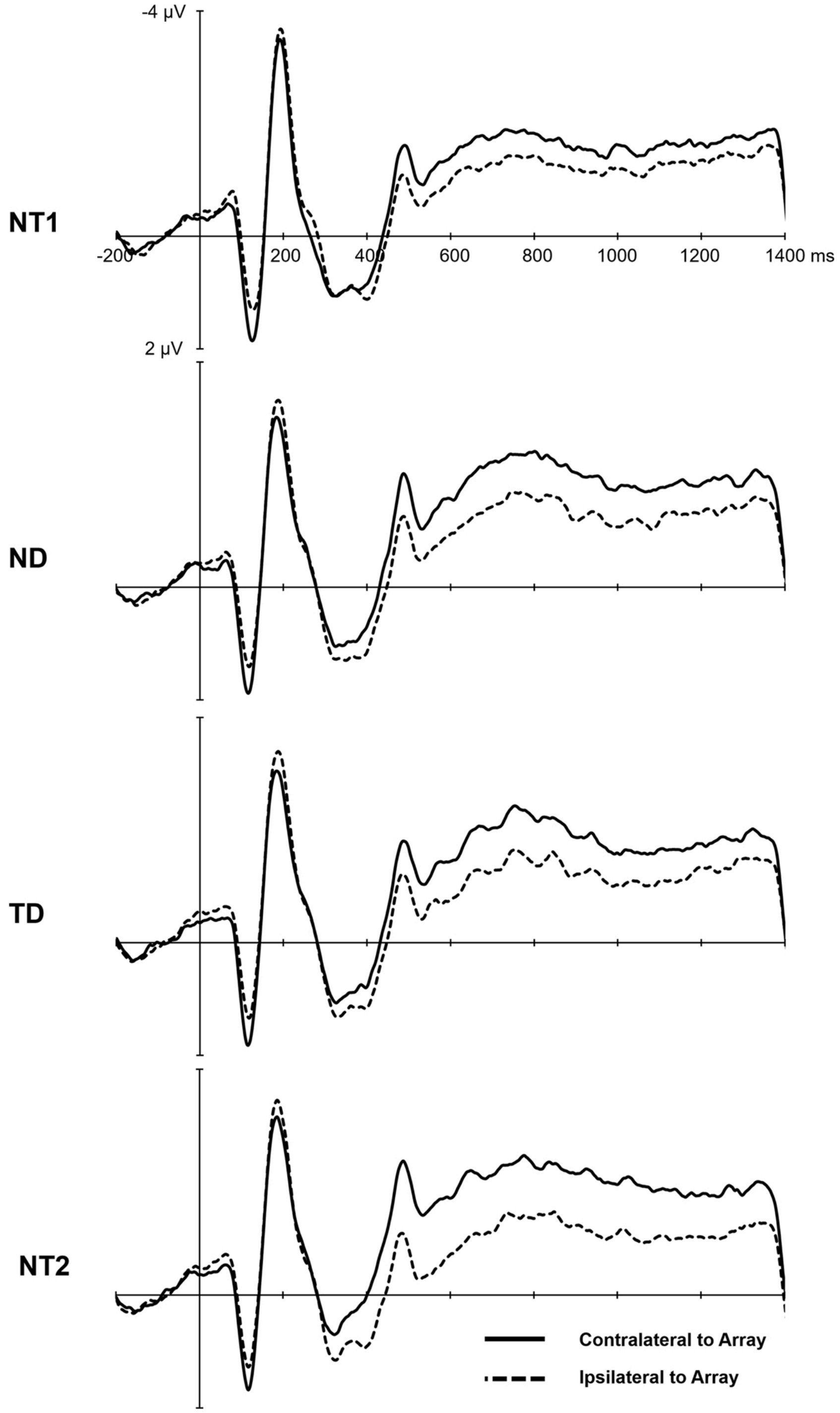

Fig. 2. Contralateral and Ipsilateral Waveforms.
Contralateral and ipsilateral waveforms across set-sizes for all word conditions.

randomized in their arrays. All words (neutral target, neutral distracter, and threat distracter) were randomly selected for each trial from their respective lists.

Each trial (Fig. 1) began with a fixation cross with an arrow indicating the side of the display to attend to (200 ms). Next, there was a brief presentation of a fixation cross (200−400 ms) followed by the word array (300 ms). After a brief delay (1000 ms), a probe display was shown for up to 2000 ms (or until response). Using the keyboard with their right hand, participants were required to indicate if any of the target words had changed in the probe in the hemifield they attended to. If the target word changed, they would press “2”. If there was no change, they would press “1”. Each trial was separated by a 1500 ms inter-trial interval. Importantly, participants were instructed to maintain their fixation on the centrally presented fixation cross throughout the task.

The task consisted of four conditions: one target word (NT1), one target word and one neutral distracter word (ND), one target word and one threat distracter word (TD), and two target words (NT2). The order of condition presentation and whether a change had occurred or not between the array and probe was randomized throughout the entire task. Participants first completed a practice session included 20 trials (5 trials for NT1, 5 trials for NT2, and 10 trials for ND to match the additional TD condition in the full task) consisting of three letter words.

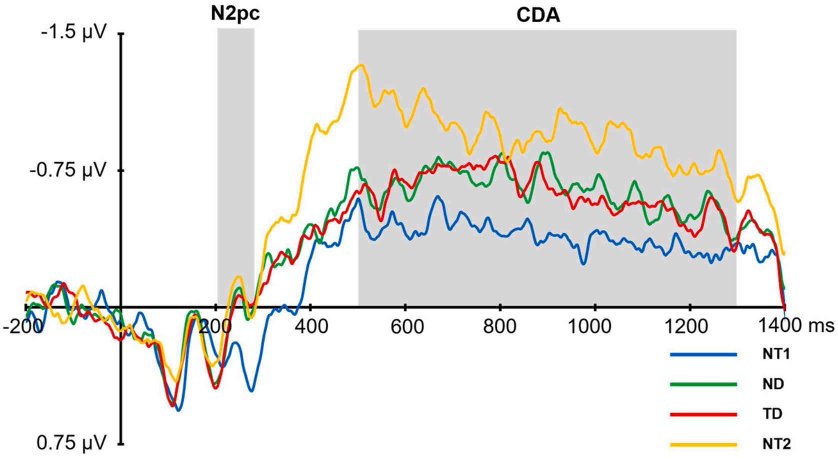

Fig. 3. Word Lateralized Change Detection Task Waveforms.

Participants were given feedback on their performance during this practice session. After completing the practice session, participants completed the test phase of the task. This consisted of 640 trials (160 trials per condition) across 10 blocks (64 trials per block). Half of the trials involved a target word change between the initial array and the probe, while the other half did not.

2.4.3. *Behavioral data*

Our behavioral variables included accuracy (% correct), response time (RT) in ms, and Pashler's K score. Pashler's K formula was used due to the use of a whole-probe display in our change detection task (see Pashler, 1988; Rouder, Morey, Morey, & Cowan, 2011). Using the following formula, we calculated a behavioral estimate of working memory capacity: K = N x (HR – FA)/(1 – FA). This formula considers the proportion of correct responses made if a target changes (i.e., HR or hit rate), and proportion of incorrect responses made if a target does not change (i.e., FA or false alarms). Trials with RTs under 150 ms were removed from analyses to remove any trials containing random responding and trials in which no response was made. In addition, only correct trials were used when calculating RT.

We also calculated filtering scores for RT to examine the impact of threatening compared to neutral distracters on behavioral performance. RT filtering cost was computed as NT1 - distracter (ND or TD) conditions. In this case, lower values indicated more RT filtering cost.

2.4.4. *Electroencephalography data acquisition and processing*

Electroencephalographic (EEG) data were recorded using an *asalab*™ EEG system with a 32 Ag-AgCl electrode fitted nylon cap (Advanced Neuro Technologies B.V., Netherlands) referenced to the left mastoid. Impedances were kept below 10 kΩ, and data were notch filtered (60 Hz). The antialiasing low pass filter was set at 102.4 Hz, with no high pass filter due to the system using a true DC amplifier. The online filtering slope was 24 dB/oct, with all signals digitized at 512 Hz. Horizontal and vertical electrooculogram (EOG) activity was recorded from electrodes placed on the left and right outer canthi and above and below the left eye, respectively. ERP analyses were conducted using EEGLAB (Delorme & Makeig, 2004) and ERPLAB (Lopez-Calderon & Luck, 2014). Non-task related data were removed from raw EEG data and channels containing excessive noise underwent spherical interpolation (3 or less channels per subject). Data were then re-referenced to the mean of the left and right mastoids and filtered with a Butterworth band-pass of 0.01–30 Hz (24 db/octave). Independent component analyses were run for each subject using EEGLAB's *runica* routine, and components reflecting blink artifacts were identified via visual inspection and removed from the EEG data. ERP data were segmented from −200 to 1700 ms at the onset of the target array, which allowed for a 200 ms baseline correction. Trials with residual eye blinks (VEOG exceeding +/− 75 µV), saccades (HEOG exceeding +/− 60 µV), or excessive movement (all channels exceeding +/− 75 µV) were identified as artifacts and removed from further processing. Following removal of participants exceeding artifact rejection threshold of 20 %, remaining participants had an average of 59.14 ($M = 9.54$ %, $SE = 0.77$) of the total 640 trials rejected prior to ERP computation. HEOG towards neutral and threat distracter conditions did not differ, $t(59) = -0.625$, $p = 0.535$, $d = 0.084$, $BF_{10} = 0.170$. In addition, neither the threat, $r(57) = -0.008$, $p = 0.952$, $BF_{10} = 0.163$, nor neutral, $r(57) = -0.146$, $p = 0.271$, $BF_{10} = 0.294$, distracter conditions' HEOGs correlated with trait anxiety scores. Additional residual EOG data is reported in Appendix B.

2.4.5. *N2pc quantification*

The N2pc component was calculated by taking the difference between contralateral and ipsilateral waveforms at parietal-occipital channel clusters (O1/O2, P3/P4, and P7/P8), as reported in previous studies (Luck, 2012; Qi, Ding et al., 2014; Störmer, Li, Heekeren, & Lindenberger, 2013). As such, the difference in waveforms contralateral to one display (e.g., right hemisphere waveforms to stimuli presented in left visual field) and waveforms ipsilateral to one display (e.g., left hemisphere waveforms to stimuli presented in the left visual field) are computed (Fig. 2). Next, contralateral – ipsilateral difference values were computed for each channel pair (e.g., O1/O2, P3/4, and P7/8), and then averaged across these parietal-occipital channel clusters to produce a final N2pc (Fig. 3). N2pc amplitude was then computed as the mean amplitude between 200–275 ms following the onset of the array. Only correct trials were used to calculate N2pc.

The N2pc distracter attentional allocation score was calculated as follows: Distracter (ND or TD) – NT1 conditions. More negative values indicate greater N2pc attentional allocation towards distracter stimuli, and thus greater attentional encoding of conditions containing this distracter type.

2.4.6. *CDA quantification*

The CDA component was also calculated by taking the difference between contralateral and ipsilateral waveforms at these parietal-occipital channel clusters, as done in prior work (McCollough et al., 2007; Qi, Chen et al., 2014; Qi, Ding et al., 2014; Rajsic et al., 2019; Vogel & Machizawa, 2004; Vogel et al., 2005). CDA amplitude was then computed as the mean amplitude between 500–1300 ms following the onset of the array. Only correct trials were used to calculate CDA.

CDA filtering efficiency was calculated as follows: FE = (F – D)/(F – T). In this formula FE represents filtering efficiency, F is the CDA amplitude for the condition containing the high target load (i.e., NT2), D

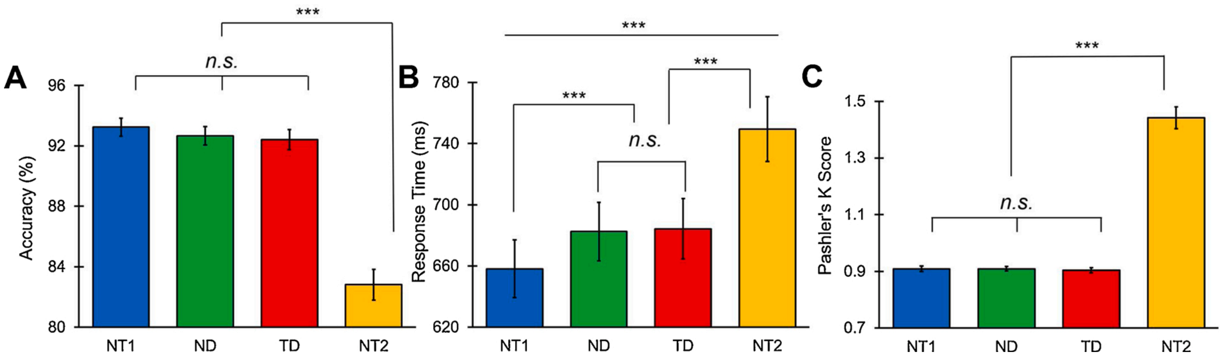

Fig. 4. Word Lateralized Change Detection Task Behavioral Results.
Word lateralized change detection task behavioral results. Error bars represent standard error. **A)** Accuracy was greater for NT1 than NT2, but did not differ from ND and TD. **B)** RT was faster for NT1 compared to ND, TD, and NT2. ND and TD were also faster than NT2. **C)** Pashler's K scores were greater for NT2 compared to NT1, ND, and TD. K scores did not differ between NT1, ND, and TD. * = $p < 0.05$, ** = $p < 0.01$, *** $p < 0.001$.

is the CDA amplitude for the distracter conditions (i.e., ND and TD), and T is the CDA amplitude for the condition containing the low target load (i.e., NT1; Vogel et al., 2005). Using this formula, efficiency scores reflect how similar the CDA for a distracter condition is to a low target load condition (i.e., NT1, values closer to 0) or a high target load condition (i.e., NT2, values closer to (1). Specifically, if a distracter condition had a CDA more similar to the high target load condition, one would expect this filtering efficiency value to be closer to 1. In contrast, if the distracter condition had a CDA more similar to the low target load condition, then this filtering efficiency value should be closer to 0. Therefore, a CDA filtering efficiency value closer to 1 would reflect less unnecessary storage of that distracter.

2.4.7. *Statistical analyses*

The dependent variables were accuracy, RT, RT filtering cost, Pashler's K scores, N2pc amplitude, N2pc distracter attentional allocation, CDA amplitude, and CDA filtering efficiency. A separate four-level one-way repeated measures ANOVA (NT1, ND, TD, and NT2 conditions) with Greenhouse-Geisser adjustment was conducted for accuracy, RT, Pashler's K scores, N2pc amplitude, and CDA amplitudes for our primary inferential statistical analyses. Significant main effects were decomposed using Bonferroni-corrected pairwise comparisons. Paired samples t-tests were conducted to analyze differences between ND and TD for RT filtering cost, N2pc distracter attentional allocation, and CDA filtering efficiency as follow-up inferential statistics to compare these conditions. We reported Bayes Factor outcomes for all non-significant results in our analyses.

In addition to our analytical methods, we also examined the N400 and Late Positive Potential (LPP) ERPs between the ND and TD conditions (Appendix C). This was done to examine potential differences in semantic processing between neutral and threatening distracter word conditions.

2.4.8. *Trait anxiety*

For our exploratory analyses, all subjects completed the trait subsection of the State-Trait Anxiety Inventory (STAI; Spielberger & Gorsuch, 1983). The distribution of scores in the current sample ranged from 21 to 73 ($M = 43.22$, $SE = 1.56$). There was strong internal consistency on this measure ($\alpha = 0.947$) in our sample, similar to other findings (Barnes, Harp, & Jung, 2002). Higher scores on this measure indicate greater trait anxiety.

After computing individual trait anxiety scores, we conducted Pearson's r correlational analyses between trait anxiety and the following variables: RT filtering cost, distracter attentional allocation indexed by the N2pc, and unnecessary storage of distracters in working memory indexed by the CDA filtering efficiency scores between neutral and threat distracter words. Multiple comparisons were corrected for using the Benjamini–Hochberg procedure to account for false-discovery rates, with a false discovery rate value of 0.05.

2.5. *Post-task distracter word semantic processing*

Participants completed a post-experimental questionnaire broadly assessing whether participants noticed any differences between neutral and target words, if any of the distracter words stood out to them, and whether any of the presented words appeared threatening (Appendix D, Figs. D1–D3). A second recognition task was also administered following the completion of the word lateralized change detection task and removal of EEG equipment. During this task, participants were presented with all distracter words and were required to indicate whether or not they remembered seeing each word and their level of confidence in their responses (Appendix D, Figs. D4 and D5).

3. Results

3.1. *Behavioral results*

3.1.1. *Accuracy*

The repeated measures ANOVA for accuracy revealed a significant main effect of Condition, $F(1.862, 109.886) = 131.166$, $p < 0.001$, $\eta_p^2 = 0.690$ (Fig. 4A). Follow-up comparisons showed that the accuracy for the NT1 condition was significantly greater than for NT2 condition ($t(59) = 13.015$, $p < 0.001$, $d = 1.680$), but did not differ from ND, $t(59) = 1.385$, $p > 0.99$, $d = 0.179$, $BF_{10} = 0.349$, and TD, $t(59) = 1.844$, $p = 0.421$, $d = 0.230$, $BF_{10} = 0.689$, conditions. In addition, performance for the NT2 condition was significantly worse than for the ND, $t(59) = 12.557, p < 0.001, d = 1.621$, and TD, $t(59) = 13.793, p < 0.001$, $d = 1.781$, conditions. Accuracy did not differ between the ND and TD conditions, $t(59) = 0.610$, $p > 0.99$, $d = 0.079$, $BF_{10} = 0.169$. Therefore, accuracy decreased for higher target loads, but was relatively unaffected by the presence of a distracter or by the valence of the distracter.

3.1.2. *Response time*

The repeated measures ANOVA for RT also yielded a main effect of Condition, $F(1.675, 98.826) = 90.685, p < 0.001, \eta_p^2 = 0.606$ (Fig. 4B). Follow-up comparisons demonstrated that RT was faster for the NT1 condition compared to the NT2, $t(59) = -12.435, p < 0.001, d = 1.605$, ND, $t(59) = -6.500, p < 0.001, d = 0.839$, and TD, $t(59) = -7.475, p < 0.001$, $d = 0.965$, conditions. RT for the NT2 condition was also slower than the ND, $t(59) = -9.076$, $p < 0.001$, $d = 1.172$, and TD, $t(59) = -8.691$, $p < 0.001$, $d = 1.122$, conditions. However, the ND and TD conditions did not significantly differ in RT, $t(59) = -0.524$, $p > 0.99$, $d = 0.068$, $BF_{10} = 0.161$. Therefore, RT increased as a function of load

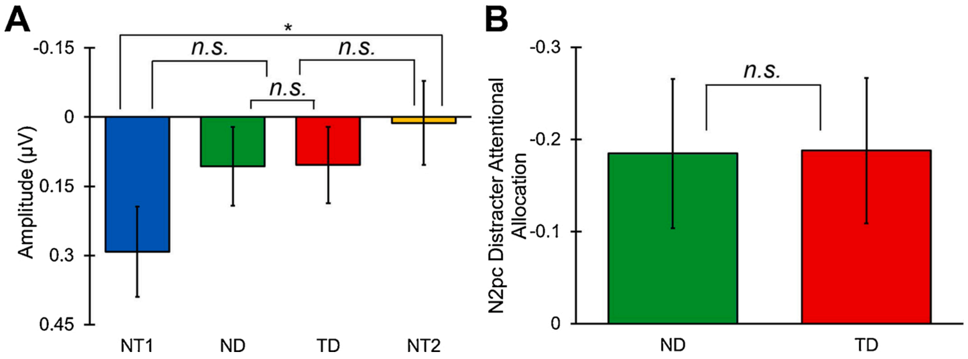

Fig. 5. Word Lateralized Change Detection Task N2pc Results.
Word lateralized change detection task N2pc results. Error bars represent standard error. **A)** N2pc amplitudes were more negative in NT2 compared to NT1, but did not differ from ND and TD. ND and TD N2pc amplitudes did not differ. **B)** N2pc distracter attentional allocation did not differ between ND and TD. * = $p < 0.05$, ** = $p < 0.01$, *** $p < 0.001$.

size and in the presence of distracters, but the valence of the distracter did not impact speed of response.

3.1.3. *Response time filtering cost*

Paired sample t-tests revealed that RT filtering cost (Distracter – NT1) did not differ between the ND and TD conditions, $t(59) = -0.524$, $p = 0.602$, $d = 0.068$. Follow-up Bayesian analyses ($BF_{10} = 0.161$, CI [-0.255, 0.429]) revealed moderate evidence for the null hypothesis. Thus, the presence of a threat relative to neutral distracter word has little impact on RT filtering cost.

3.1.4. *Pashler's K*

As with accuracy and RT, the repeated measures ANOVA for Pashler's K scores also yielded a significant main effect of Condition, $F(1.126, 66.432) = 241.012$, $p < 0.001$, $\eta_p^2 = 0.803$ (Fig. 4C). Follow-up comparisons demonstrated that K scores were greater in the NT2 condition compared to the NT1, $t(59) = -15.675$, $p < 0.001$, $d = 2.204$, ND, $t(59) = -15.569$, $p < 0.001$, $d = 2.201$, and TD, $t(59) = -16.445$, $p < 0.001$, $d = 2.123$, conditions. However, K scores did not differ between the NT1 condition and the ND, $t(59) = 0.073$, $p > 0.99$, $d = 0.009$, $BF_{10} = 0.142$, and TD, $t(59) = 0.759$, $p > 0.99$, $d = 0.098$, $BF_{10} = 0.186$, conditions. In addition, K scores did not differ between the ND and TD conditions, $t(59) = 0.694$, $p > 0.99$, $d = 0.090$, $BF_{10} = 0.178$. As expected, K scores, representing the amount of information stored in working memory, increased in the higher target load condition. However, this storage was not impacted by the presence of distracters, or the valence of the distracter.

3.2. *EEG results*

3.2.1. *N2pc amplitude*

The repeated measures ANOVA for N2pc amplitude yielded a main effect of Condition, $F(2.639, 155.695) = 4.575$, $p = 0.006$, $\eta_p^2 = 0.160$ (Fig. 5A). Follow-up comparisons demonstrated that N2pc amplitudes were more negative in the NT2 condition compared to the NT1 condition, $t(59) = 3.270$, $p = 0.011$, $d = 0.422$. However, the NT2 condition's N2pc did not differ from the ND, $t(59) = 1.128$, $p > 0.99$, $d = 0.146$, $BF_{10} = 0.258$, and TD, $t(59) = 1.177$, $p > 0.99$, $d = 0.152$, $BF_{10} = 0.272$, conditions. Furthermore, the NT1 condition's N2pc did not differ from the ND, $t(59) = 2.277$, $p = 0.159$, $d = 0.294$, $BF_{10} = 1.533$, and TD, $t(59) = 2.379$, $p = 0.124$, $d = 0.307$, $BF_{10} = 1.888$, conditions. The ND and TD conditions also did not differ in N2pc amplitude, $t(59) = 0.044$, $p > 0.99$, $d = 0.006$, $BF_{10} = 0.141$. Thus, higher target loads induced a greater N2pc, but the presence of distracters and the valence of the distracter did not influence this amplitude significantly.

3.2.2. *N2pc distracter attentional allocation*

Paired sample t-tests revealed that N2pc distracter attentional allocation (distracter – NT1) did not differ between the ND and TD conditions, $t(59) = 0.044$, $p = 0.965$, $d = 0.004$ (Fig. 5B). Follow-up Bayesian analyses ($BF_{10} = 0.141$, CI [−0.345, 0.326]) revealed moderate evidence for the null hypothesis. Thus, attentional allocation did not differ for trials containing threatening and neutral distracter words.

3.2.3. *CDA amplitude*

The repeated measures ANOVA for CDA amplitude yielded a main effect of Condition, $F(2.678, 157.991) = 16.303$, $p < 0.001$, $\eta_p^2 = 0.217$ (Fig. 6A). Follow-up comparisons demonstrated that CDA amplitudes were more negative in the NT2 condition compared to the NT1, $t(59) = 6.703$, $p < 0.001$, $d = 0.865$, ND, $t(59) = 3.705$, $p = 0.003$, $d = 0.478$, and TD, $t(59) = 3.992$, $p = 0.001$, $d = 0.515$, conditions. In addition, the CDA was more negative for the ND, $t(59) = 2.826$, $p = 0.038$, $d = 0.365$, and TD, $t(59) = 2.871$, $p = 0.034$, $d = 0.371$, conditions compared to the NT1 condition. However, the ND and TD conditions did not significantly differ in CDA amplitude, $t(59) = -0.223$, $p > 0.99$, $d = 0.029$, $BF_{10} = 0.145$. Thus, CDA amplitude became more negative for higher target loads and conditions containing the presence of distracters of both valences compared to the low target load.

A Pearson's r correlation demonstrated a negative association

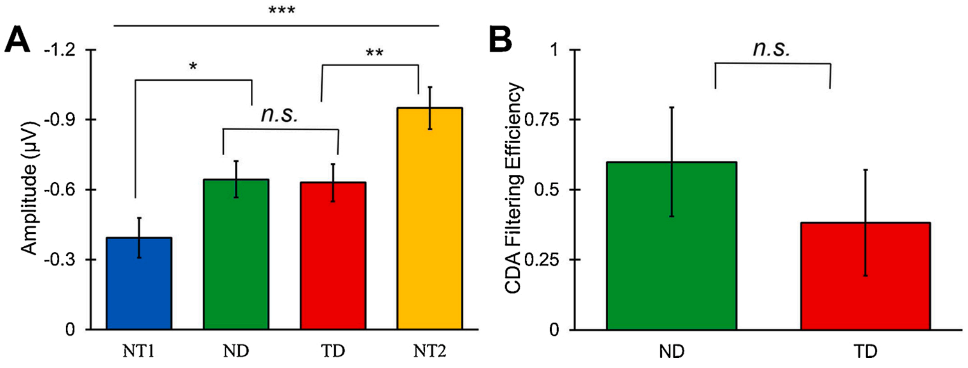

Fig. 6. Word Lateralized Change Detection Task CDA Results.
Word lateralized change detection task CDA results. Error bars represent standard error. **A)** CDA amplitudes were more negative in NT2 compared to NT1, ND, and TD. ND and TD also had more negative CDA amplitudes compared to NT1, but did not differ in CDA ampitude from one another. **B)** CDA filtering efficiency did not differ between ND and TD. * = $p < 0.05$, ** = $p < 0.01$, *** $p < 0.001$.

between K scores for the NT2 condition and changes in CDA amplitudes between the NT2 and NT1 conditions, $r(58) = -0.261$, $p = 0.044$, replicating common CDA finding for simple stimuli (Vogel & Machizawa, 2004). This indicates that individuals with greater working memory capacity yield greater changes in CDA amplitudes from low to high target loads.

3.2.4. *CDA filtering efficiency*

Paired sample t-tests revealed that CDA filtering efficiency ((NT2 - distracter)/(NT2 – NT1)) did not differ between the ND and TD conditions, $t(59) = 1.155$, $p = 0.253$, $d = 0.149$ (Fig. 6B). Bayesian analyses ($BF_{10} = 0.266$, CI [−0.151, 0.521]) revealed moderate evidence for the null hypothesis. Thus, unnecessary storage of distracters in working memory, represented by the CDA filtering efficiency index, did not significantly differ between threatening and neutral distracter words.

3.3. *Exploratory analyses of trait anxiety correlations*

3.3.1. *Behavioral results*

Pearson's *r* correlations demonstrated non-significant associations between trait anxiety and RT filtering cost for ND, $r(57) = 0.067$, $p = 0.613$, $BF_{10} = 0.184$, and TD, $r(57) = -0.097$, $p = 0.465$, $BF_{10} = 0.211$, conditions. Thus, trait anxiety was not related to behavioral outcomes reflecting the impact of either neutral or threat distracter words on response time for conditions containing distracters.

In addition to our hypothesized exploratory analyses of RT filtering cost, we conducted two Pearson's *r* correlations examining trait anxiety and accuracy filtering cost, calculated the same way as RT filtering cost (i.e., NT1 – distracter conditions). We obtained null results similar to with RT filtering cost for ND, $r(57) = -0.051$, $p = 0.702$, $BF_{10} = 0.175$, and TD, $r(57) = -0.188$, $p = 0.154$, $BF_{10} = 0.439$, conditions. These results indicate that trait anxiety is not associated with accuracy filtering cost. Bayes Factor analyses suggest moderate evidence for the null hypothesis in the model correlation trait anxiety and RT filtering cost for the ND condition.

3.3.2. *EEG results*

Pearson's *r* correlations demonstrated a significant negative correlation between trait anxiety and N2pc distracter attentional allocation for the ND condition, $r(57) = -0.263$, $p = 0.044$, $BF_{10} = 1.167$, suggesting that individuals higher in trait anxiety dedicated greater attentional processing towards neutral distracters. However, Benjamini-Hochberg corrections indicate that this value was no longer significant (i.e., corrected threshold for significance required was $p = 0.025$) after accounting for the 2 tests (i.e., ND and TD N2pc distracter allocation correlations). In addition, we observed a non-significant association between trait anxiety and N2pc distracter attentional allocation for the TD condition, $r(57) = -0.043$, $p = 0.744$, $BF_{10} = 0.171$.

Similar null effects were observed for the CDA filtering efficiency index for the ND, $r(57) = -0.065$, $p = 0.623$, $BF_{10} = 0.183$, and TD, $r(57) = 0.064$, $p = 0.632$, $BF_{10} = 0.182$, conditions. Our observed BayesTherefore, trait anxiety was not associated with ERP signals reflecting enhanced attentional allocation and unnecessary storage in working memory neutral and threat distracter words.

3.4. *Distracter word semantic processing*

A majority of participants (55.93 %) reported noticing differences between the target and distracter words in the word lateralized change detection task (Appendix D, Fig. D1). Furthermore, most participants (62.07 %) indicated that at least one of the distracter words stood out to them (Appendix D, Fig. D2), with most participants (64.41 %) stating that some of these distracter words appeared negative or threatening (Appendix D, Fig. D3). Furthermore, participants correctly indicated they remembered seeing these distracter words (Appendix D, Fig. D4) and were mostly confident in their responses to these prompts (Appendix D, Fig. D5). This suggests that the distracter words were semantically processed in our task design.

4. Discussion

Previous reports demonstrate that individuals show enhanced attention towards threat-related stimuli (Anderson & Britton, 2019; Dowd et al., 2016; Hopkins et al., 2016; Mulckhuyse, 2018; Schmidt et al., 2015; Schupp et al., 2004), including when emotional word stimuli are used (Algom et al., 2004; Boehme et al., 2015; Kousta et al., 2009; Van den Heuvel et al., 2005; van Honk et al., 2001; Wabnitz et al., 2016; Yeung & Fernandes, 2019a). In addition, although anxious individuals have been shown to demonstrate attentional bias towards threat-related stimuli (Aftanas et al., 2003; Fox et al., 2001; Kim et al., 2018; Mogg & Bradley, 2016; Mogg et al., 1997; Nelson et al., 2015; Pacheco-Unguetti et al., 2010; Quigley et al., 2012; Raeder et al., 2019; Shah et al., 2018; Wieser et al., 2018; Yao et al., 2019), the findings regarding this effect using emotional words is mixed, with some reporting a lack of this enhanced attentional bias effect (Moritz et al., 2008; Pishyar et al., 2004). Furthermore, while others have found that working memory is also influenced by the presence of emotional distracter words in anxious individuals (Amir & Bomyea, 2011; Angelidis et al., 2019), others have reported null effects when using word stimuli (Waechter et al., 2018). Thus, we aimed to investigate how threat-related distracter words influence attentional processing and unnecessary storage in working memory, and whether this effect is enhanced in individuals with higher levels of trait anxiety.

We observed an enhanced N2pc for the high target load condition compared to the low target load condition. This suggests that as more target words were presented, increased attentional selection was required to efficiently encode these stimuli. Others have also shown an enhanced N2pc based on the proportion of target presentations (Ester, Drew, Klee, Vogel, & Awh, 2012; Mazza & Caramazza, 2011; Pagano & Mazza, 2012; Pagano, Lombardi, & Mazza, 2014), supporting the notion that the N2pc is essential for attentional selection of stimuli for further cognitive functions. However, inconsistent with our hypotheses, we did not observe enhanced distracter attentional allocation for the threat compared to neutral words, reflected via the N2pc. This null difference in attentional allocation was further corroborated by our non-significant behavioral results for accuracy, RT, and Pashler's K scores between neutral and threat distracter words. In addition, we observed no correlations between trait anxiety and N2pc distracter attentional allocation for the neutral and threat-distracter conditions. Despite these results, our Bayes Factor analyses revealed moderate evidence for the null hypothesis concerning differences in N2pc distracter attentional allocation between the neutral and threat-distracter conditions. This suggests that there are unlikely to be differences in N2pc distracter attentional allocation between these distracter conditions. In addition, our Bayes Factor analyses indicated moderate evidence for the null hypothesis concerning the association between trait anxiety and threat-distracter condition N2pc distracter attentional allocation, further suggesting there is no association between these variables. However, our Bayes Factor results found anecdotal evidence for the alternative hypothesis for the association between N2pc distracter attentional allocation for the neutral distracter word condition and trait anxiety. Because the evidence for the alternative hypothesis was weak, we are hesitant to make a conclusive judgment regarding the outcome of this statistical test (Lakens et al., 2020). In addition, our Bayes Factor estimated effect size intervals were within the range of similar non-significant results published in other non-significant cognitive neuroscience papers (Szucs & Ioannidis, 2017), and our criterion of $d +/- 0.1$, suggesting that these effects are unlikely to be too small to be worth considering. Taken together, these results suggest that threat distracters did not preferentially capture covert attention relative to neutral distracter words, and that anxious individuals did not differ in their attentional allocation towards threat-distracter words.

This lack of attentional bias for threat-related distracter words is inconsistent with previous behavioral (Algom et al., 2004; Kousta et al., 2009; Van den Heuvel et al., 2005; van Honk et al., 2001), ERP (Grégoire, Caparos, Leblanc, Brisson, & Blanchette, 2018; Wabnitz et al., 2016), and neuroimaging (Boehme et al., 2015) reports. However, there are several important distinctions to consider between this prior work and our reported study. First, these prior studies assessed attention using an emotional Stroop (Algom et al., 2004; Boehme et al., 2015; Grégoire et al., 2018; Van den Heuvel et al., 2005; van Honk et al., 2001) or lexical decision making (Kousta et al., 2009) task, while we used a lateralized change detection task. While each of these tasks has been used to assess attention, the Stroop and lexical decision making tasks differ significantly from our lateralized change detection task in design. Specifically, the change detection task is often more appropriate for examination of working memory storage and maintenance features. Furthermore, to our knowledge, no other study has used emotional word stimuli with the lateralized change detection task to examine how threat-related distracter words influence attention in terms of both behavioral and neural outcomes. Thus, it is possible that the use of a lateralized change detection task consisting of threat-related distracter word stimuli does not yield attentional bias effects like that seen in other types of tasks (Algom et al., 2004; Boehme et al., 2015; Grégoire et al., 2018; Kousta et al., 2009; Van den Heuvel et al., 2005; van Honk et al., 2001; Wabnitz et al., 2016).

Second, it is possible that the threat-related word stimuli selected from the ANEW (Bradley & Lang, 1999) and extended English language database (Warriner et al., 2013) were not sufficiently strong enough to induce attentional bias effects. For instance, several studies finding such effects have used their own customized list of emotional or negative words (Algom et al., 2004; van Honk et al., 2001) or words that were specifically associated with a particular clinical anxiety disorder (Boehme et al., 2015; Grégoire et al., 2018; Van den Heuvel et al., 2005). However, others finding attentional bias effects have also used emotional words from the ANEW (Kousta et al., 2009), or from other standardized word databases, such as the Berlin Affective Word List Reloaded (Vo et al., 2009). Rather than the word stimuli in our study not being strong enough to induce a valence effect, it may be the case that the effects of our threat-related words on attentional bias were reduced due to habituation (i.e., reduced affective reactivity over time), given each threat word was repeated for a total of sixteen presentations. This is critical given that others have reported that attention towards negative distracter words only occurs during their initial presentation, and that this effect disappears after subsequent presentations of these stimuli (Aquino & Arnell, 2007; Harris & Pashler, 2004). In accordance with this, research reporting attentional bias effects in emotional words either did not repeat the presentation of their words (Algom et al., 2004; Kousta et al., 2009) or only repeated word presentations up to six times (Boehme et al., 2015; van Honk et al., 2001; Wabnitz et al., 2016). Despite finding an enhanced N2pc for their clinical sample group, Grégoire et al. (2018) did not find differences between neutral and trauma-related words, and repeated the presentation of their words up to 54 times. It is important to note that ERP studies often require a significant amount of trials in order to obtain adequate signal-to-noise ratio (Luck, 2014), likely contributing to possible habituation effects.

Third, many of the attentional bias effects were reported in individuals diagnosed with anxiety disorders (Boehme et al., 2015; Van den Heuvel et al., 2005; Wabnitz et al., 2016), those who recently experienced sexual trauma (Grégoire et al., 2018), or participants with elevated trait anxiety (van Honk et al., 2001), indicating that such effects are more likely to be seen in individuals with clinical anxiety disorders or extreme levels of anxiety. Contrasting this notion, others have also reported attentional bias effects towards negative words in healthy undergraduate samples (Algom et al., 2004; Kousta et al., 2009), suggesting that these effects may be generalizable to the population, and not exclusive to anxiety disorders. Finally, it is important to note that others have also reported null effects of attentional bias towards emotional words (Moritz et al., 2008; Pishyar et al., 2004). Specifically, Moritz et al. (2008) used an emotional Stroop task with two Obsessive Compulsive Disorder (OCD)-related word categories (e.g., washing and checking) to compare attentional bias between OCD patients and healthy controls, and found no differences in attentional bias between groups. As such, it remains unclear whether an attentional bias effect for threat-related words is primarily present in clinical samples, especially when these negative words have personal relevance to a given disorder, or if this effect is also observed in the general population. Instead, words in general may not produce as strong of an effect as other threat-related stimuli. For example, Pishyar et al. (2004) compared attentional bias between low and high socially anxious individuals using a dot probe task consisting of emotional words and faces. Their results revealed null effects for emotional words, but enhanced attentional bias towards threatening faces, suggesting that specific visual stimuli (e.g., faces) may be more likely to yield attentional biases than verbal stimuli. Taken together, we suspect that the lack of enhanced attentional processing for threat-related distracter words in our study is primarily the result of two factors: the type of task we used (i.e., lateralized change detection task), which may not induce the same attentional bias effects as seen in other types of tasks; and potential habituation due to the high presentation repetition for our word stimuli.

It's important to consider that words, whether threatening or neutral, are likely to be processed differently than other visual stimulus modalities (e.g., shapes, colors, faces, scenes, etc.; Sojka & Giese, 2006). For example, although threatening word stimuli have shown similar attentional capture effects as other stimulus modalities, the effect of this can be diminished based on the relative presentation time of these stimuli (Bar-Haim et al., 2007). This is because words use both sensory and semantic processing, requiring a longer presentation duration compared to simpler or biologically relevant stimuli. However, if words are presented briefly, as in our study, this attentional bias effect may diminish. Thus, because our stimuli were only presented for 300 ms, it may be argued that participants simply processed the perceptual properties of the words due to this short duration, and did not fully process their semantic meanings. However, previous work has identified ERPs reflective of semantic processing of words for 300 ms (Frühholz et al., 2011; Schindler & Kissler, 2016), 200 ms (Kanske & Kotz, 2007; Klumpp et al., 2010), 150 ms (Kanske et al., 2011; Lavidor et al., 2001), and even 100 ms Cristescu and Nobre (2008). Although some of these studies used central word fixations (Frühholz et al., 2011; Klumpp et al., 2010; Schindler & Kissler, 2016), others found effects for semantic processing when using lateralized word presentation designs (Cristescu & Nobre, 2008; Kanske & Kotz, 2007; Kanske et al., 2011; Lavidor et al., 2001). Moreover, participants in this study correctly remembered distracter words and were able to identify the distracter words as threatening (see Appendix D). Taken together, we believe these results suggest that these distracter words were semantically processed in the current study, and that participants were not simply storing perceptual features in working memory.

Biologically salient stimuli, such as faces, may be more likely to capture attention even when presented briefly compared to words (Bretherton et al., 2017; Öhman et al., 2012; Soares et al., 2014). For example, although prior reports have shown that distracter words can capture attention, this effect is reduced in comparison to other stimulus modalities, such as pictures (Carretié, 2014) and threatening faces (Pishyar et al., 2004). Furthermore, it is possible that the attentional bias effects observed in prior work reflect more of a familiarity processing of words than an actual valence effect (McNally, Riemann, & Kim, 1990). Our null findings may have also occurred due to the strong similarity in object properties between the target and distracter words, given that these stimuli were luminance matched to prevent any additional salience effects from occurring. Nonetheless, our results suggest that threat-distracter words from the ANEW (Bradley & Lang, 1999), when physically matched with neutral target and distracter words from the same stimulus database, do not capture attention in a lateralized change detection task when presented 16 times, and trait anxiety is not associated with such an attentional bias effect.

Similar to our N2pc hypotheses, we also failed to find enhanced unnecessary storage for threat compared to neutral distracter words in working memory, as indexed by the CDA filtering efficiency value, nor correlations between trait anxiety and these measures. Although inconsistent with our hypotheses, our results found that while threat and neutral distracter words are unnecessarily stored to a greater degree in working memory compared to a low target load condition, their storage does not differ based on valence, and this effect is unrelated to one's trait anxiety. Results from our Bayes Factor analyses indicated moderate evidence for our null outcomes, suggesting these data are more likely to occur under the null hypothesis versus the alternative hypothesis. Our Bayes Factor estimated effect sizes were also outside of our criterion of being too small to be considered, and were similar to those found in other cognitive neuroscience non-significant result studies (Szucs & Ioannidis, 2017). Ultimately, this suggests that there are unlikely any differences in CDA filtering efficiency between the neutral and threat-distracter conditions, and that trait anxiety was not associated with CDA filtering efficiency for either of these conditions. This contradicts prior behavioral studies that have found that threat-related distracter words impair working memory performance, and this effect is more pronounced in anxious individuals (Angelidis et al., 2019), and others reporting that individuals diagnosed with generalized social phobia preferentially store threat words in working memory compared to neutral words (Amir & Bomyea, 2011). However, Waechter et al. (2018) failed to replicate the findings of Amir and Bomyea (2011), and others have found that socially anxious individuals actually store threatening words less in working memory (Yeung & Fernandes, 2019b).

Several considerations regarding the differences between these prior reports and our own should be noted. First, these studies employed either an N-back (Angelidis et al., 2019), OSPAN (Amir & Bomyea, 2011; Waechter et al., 2018), or word digit span (Yeung & Fernandes, 2019b) task. While all of these tasks are considered working memory measures, they differ from one another in terms of design and the mechanism of interest that is measured. Specifically, the lateralized change detection task is often used to examine storage and maintenance features of working memory, whereas the other tasks may provide a measure of overall working memory ability and attentional control. Perhaps more importantly, our study is the first to use threat-related distracter words in a lateralized change detection task design. Therefore, it's possible that when using a lateralized change detection task, threat-related distracter words are not stored to a greater degree compared to neutral distracter words.

Most studies finding effects for altered working memory storage of threat-related words were isolated to individuals induced in a state of stress (Angelidis et al., 2019) or those with diagnosed social phobia (Amir & Bomyea, 2011) or elevated self-reported levels of social phobia (Yeung & Fernandes, 2019b). Importantly, others who also examined working memory storage of threat-related words in patients with social anxiety disorder (Waechter et al., 2018) failed to find any effects for the storage of threatening words. Therefore, it is possible that the altered working memory storage effects for threat-related words are not strong enough to be replicated across studies, even when examining this phenomenon in individuals diagnosed with clinical anxiety disorders.

The specific threat-related words that are used may have led to such inconsistencies in results across studies. For example, several of these studies used their own customized threat-related word lists (Amir & Bomyea, 2011; Angelidis et al., 2019; Waechter et al., 2018). Only Yeung and Fernandes (2019b) used words from the ANEW (Bradley & Lang, 1999) and instead found decreased storage of threat-related words in working memory. While the use of customized threat-related words may be more likely to induce working memory storage effects compared to a standardized word database, such as the ANEW, Waechter et al. (2018) used the same custom word list as Amir and Bomyea (2011) and failed to replicate these effects. Alternatively, the number of repeated presentations for these threat-related words may also influence the degree of strength for this effect. Unfortunately, studies showing such effects (Amir & Bomyea, 2011; Angelidis et al., 2019; Yeung & Fernandes, 2019b) and failing to find any effects (Waechter et al., 2018) for working memory storage of threat-related words did not report the total number of presentations for each word, making it difficult to determine if potential habituation effects from differing repetitions of threat-related words may have also contributed to the discrepancies in these findings (Aquino & Arnell, 2007; Harris & Pashler, 2004). Ultimately, this leads us to conclude that enhanced, or even decreased, working memory storage for threat-related words may not be an effect found in the general population, and one that is inconsistently found in individuals varying in anxiety disorders or elevated states of social anxiety. In addition, the words selected from the ANEW (Bradley & Lang, 1999) when used in a lateralized change detection task may not yield such storage effects of threat-related words in working memory. Given the age of this database (~20+ years), several of the words may not hold the same degree of aversion as when initially published. Alternatively, more personally-relevant threat-related words may be more likely to induce working memory storage effects compared to broad/common threatening words.

Previous work has found that other forms of threat-related stimuli, such as faces, yield enhanced storage in working memory (Judah et al., 2016; Meconi et al., 2014; Sessa et al., 2011; Stout et al., 2013, 2015; Stout et al., 2017; Ye et al., 2018). Although see Salahub and Emrich (2020) who found enhanced CDA for threat distracters, but did not find a relationship with the CDA and individual differences in anxiety. Specifically, we sought to conceptually replicate these findings of unnecessary storage of threat-related distracters using the same task design from our laboratory's previous report (Stout et al., 2013), but replacing the stimulus category with words instead of faces. Given our null findings for altered working memory storage of threat-related distracter words compared to neutral distracter words, this suggests that these effects may be more prominent in biologically salient stimulus categories, such as faces. Therefore, our results suggest that enhanced storage of threatening distracters compared to neutral distracters in working memory does not generalize to this stimulus modality, at least when using a lateralized change detection task design.

Given the novelty of the stimuli used in the lateralized change detection task we used to examine working memory capacity via the CDA, it is important to note several points. First, we found that CDA amplitude was greater for high compared to low target load conditions. In addition, the increase in CDA from low to high target load conditions was associated with Pashler's K scores, indicating that individuals with greater working memory capacity show larger changes in CDA amplitude. These findings replicate prior work showing similar effects for simple colored stimuli (Vogel & Machizawa, 2004), indicating increased working memory storage for greater target loads when using word stimuli. To our knowledge, only one study has examined the CDA load effect using word stimuli (Rajsic et al., 2019), and our results replicated their findings. Specifically, we demonstrated increased word storage in working memory via the CDA, and found a strong association between K scores and CDA amplitude for words. Our replication of Rajsic et al. (2019) work supports the validation of using word stimuli in the lateralized change detection task design, indicating that our task design was sound. Second, we extended the findings of Rajsic et al. (2019) by showing that distracter words, neutral or threat-related, are unnecessarily stored in working memory. Specifically, we found greater CDA amplitudes and longer RTs for the distracter conditions compared to the low target load condition. This suggests that distracter stimuli are unnecessarily stored in working memory and have potential behavioral costs, at least in terms of RT. However, the specific valence of these distracters does not seem to influence the degree of this storage or behavioral cost, given we observed no differences between neutral and threat distracter words. Thus, our results further support the notion that word stimuli induce a CDA reflective of overall working memory storage and maintenance, and provide a novel finding demonstrating that distracter words, regardless of valence, are unnecessarily stored in working memory and can lead to behavioral performance costs in terms of RT.

Unlike our main effect for N2pc, we found that CDA was enhanced for the distracter conditions compared to the low target condition. Given that attentional processing of stimuli and subsequent storage in working memory are interlinked (Awh et al., 2006; Ikkai & Curtis, 2011), one would suspect that the CDA findings would be similar to the N2pc, such that the distracter conditions do not differ from the low target load condition in CDA amplitude, or vice versa. It may be the case that despite preserved attentional selection of target stimuli in the distracter conditions, a separate downstream cognitive process is influenced by these distracters, resulting in enhanced maintenance of these distracters in working memory. For instance, prior work has also found discrepancies between N2pc and CDA amplitudes (Adam, Robison, & Vogel, 2018). Participants in this work showed no difference in N2pc on “good” (i.e., four or more targets correctly identified) or “poor” (i.e., two or less targets correctly identified) performance on trials, but showed enhanced CDA in “good” performance compared to “poor” performance trials. Thus, although attentional allocation and selection of stimuli did not differ as a function of performance, the encoding and maintenance of their stimuli were influenced. Others have also reported discrepancies between N2pc and CDA amplitude (Qi, Ding et al., 2014), with greater N2pc for distracter conditions despite showing a larger CDA for the high target load condition. These discrepancies may indicate that while selective attention promotes the storage of information in working memory, there is not necessarily a one-to-one relationship between how much attentional processing occurs and subsequent storage in WM. For example, it may be the case that our attentional processing is limited to a greater degree than or storage and maintenance capacity in working memory. In this case, individuals presented with numerous stimuli may reach their capacity limit for attentional processing, but still are capable of encoding visual stimuli in working memory. Alternatively, there may be a cognitive process that occurs between attentional selection and working memory encoding that actively encodes specific stimuli leading to greater storage of this information in working memory. Taken together, we suggest that word stimuli are effective in eliciting a CDA, as seen in prior work (Rajsic et al., 2019), and that cognitive processes occurring between attentional selection and working memory maintenance may contribute to working memory encoding, even if attentional selection isn’t influenced.

Contrary to our behavioral hypotheses, RT filtering cost did not differ between neutral and threat distracter word conditions, contradicting prior reports demonstrating enhanced RT for threat-related distracters (Schmidt et al., 2015). Furthermore, we found no relationship between RT filtering cost and trait anxiety. Our Bayes Factor analyses revealed moderate evidence for our non-significant association outcomes in RT filtering cost, which indicates that these data are more likely to occur under the null compared to alternative hypothesis. This suggests that it is unlikely that there are substantial differences in RT filtering cost between the neutral and threatening word distracter conditions, and that there is likely no association between trait anxiety and RT filtering cost in these conditions. Furthermore, estimated Bayes Factor effect sizes were similar to other non-significant work (Szucs & Ioannidis, 2017), and fell outside of our criterion for determining that these effect sizes were too small to be worth considering. This lack of differences between distracter conditions in RT contradicts prior theories positing that threatening stimuli automatically capture attention (Bretherton et al., 2017; Öhman et al., 2012; Soares et al., 2014). As described previously, it may be the case that this effect is only found in individuals with elevated levels of anxiety, specifically in individuals diagnosed with anxiety disorders, and in paradigms where words are presented for a longer duration. Nonetheless, the presentation of distracting stimuli did influence RT, suggesting that although processing of these distracter conditions did not vary by valence, their presence in addition to a single target word did require additional processing efficiency in order to make an appropriate response. Thus, it is likely that the duration of presentation in our study was sufficient to allow for additional processing of distracter word stimuli, whether threatening or neutral. Based on our results, we conclude that threatening distracter words do not influence RT filtering cost relative to neutral distracters in healthy or trait anxious individuals.

It is important to note several limitations of the current study. First, the threatening words we selected varied by topic, were not specific to one theme (e.g., physical, social, or emotional threat). It may be the case that the effects of threatening distracters are attenuated in a healthy sample when a wide range of threatening word stimuli are used, and attentional bias effects towards threatening stimuli in anxious individuals are more pronounced for specific categories of threat. For example, it is possible that individuals higher in trait anxiety are likely to dedicate more attention towards physically or emotionally threatening words. In contrast, individuals with elevated social anxiety may only show such effects in the presence of socially threatening words. Therefore, our null results in attentional processing and subsequent storage in working memory for threatening distracters may be due to the duration of our array, and the type of threatening words used in the study. Finally, it is important to note that many of our conditions (i.e., NT1, ND, and TD) had relatively high accuracy. Thus, it is possible that because this task was easy, and that subjects only had to monitor a single target word in the distracter conditions, the impact of threatening distracters on attentional selection and unnecessary storage in working were minimal. This would coincide with earlier work suggesting that increased working memory loads are more likely to elicit deficits in ignore task-irrelevant emotional distracters (Angelidis et al., 2019). Therefore, it may be the case that a more cognitively demanding task using word stimuli may result in attentional bias and storage of threat distracter words in working memory.

In conclusion, our results suggest that although the presentation of additional distracter word stimuli, both neutral and threatening, impact processing speed and are unnecessarily stored in working memory, these stimuli do not differ in terms of their degree of attentional allocation and subsequent working memory storage and behavioral performance. These null outcomes are further supported by our Bayes Factor analyses, suggesting that there are unlikely to be differences between neutral and threatening distracter word conditions in terms of behavioral and electrophysiological outcomes. These non-significant differences in attentional and working memory processes observed between these word conditions are likely due to low salience present in this stimulus modality compared to other more biologically relevant stimuli that have shown detrimental effects on attention and working memory processes (e.g., faces). Thus, threatening distracter words, at least as processed in our task, do not differ in their ability to capture attention or influence downstream working memory processes compared to neutral distracter words, and do not interfere with top-down processes that allow for individuals to attend towards and complete goal-oriented tasks (Theeuwes, 2010; Yantis, 2000).

Author note

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Declaration of Competing Interest

The authors report no declarations of interest.

Appendix A

Figs. A1–A6

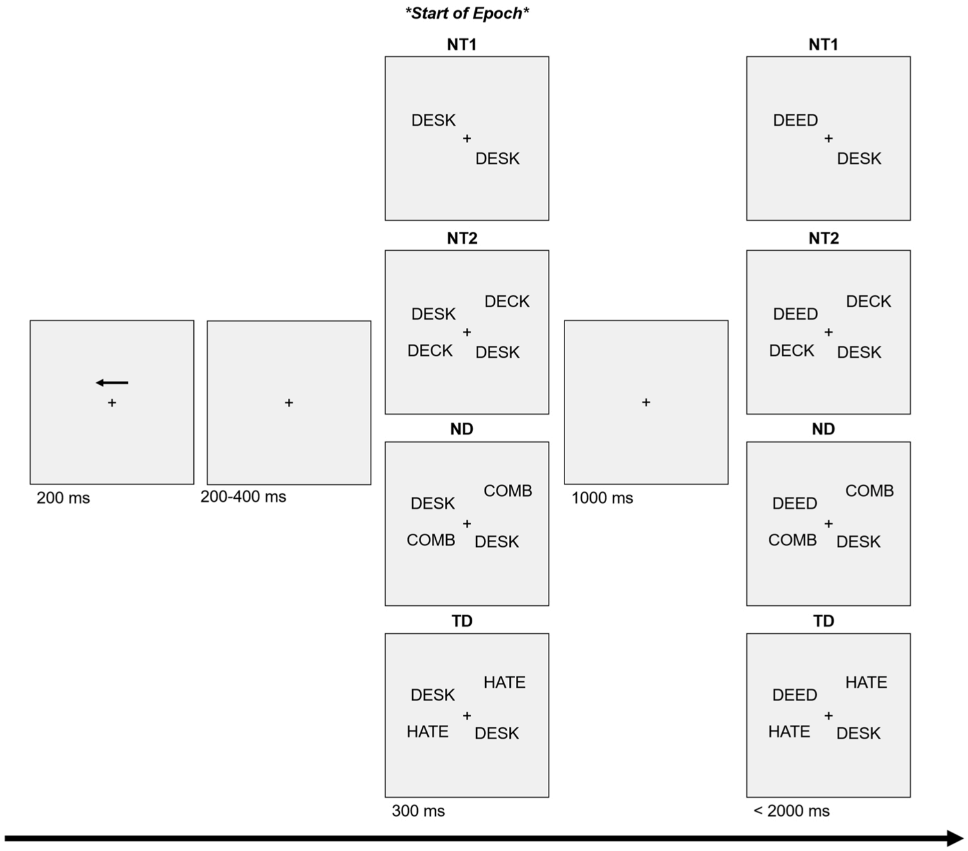

Fig. A1. Word Lateralized Change Detection Task (Monochromatic Version).
Word lateralized change detection task requiring participants to attend to the target words in a particular color (red or blue colors) in the cued hemifield while ignoring other colored distracter words (red or blue colors), which could be neutral (ND) or threatening (TD). Conditions consisted of one neutral target (NT1), two neutral targets (NT2), one neutral target and one neutral distracter (ND), and one neutral target and one threat distracter (TD). For visualization purposes, word stimuli are larger in this figure than they were in the experiment.

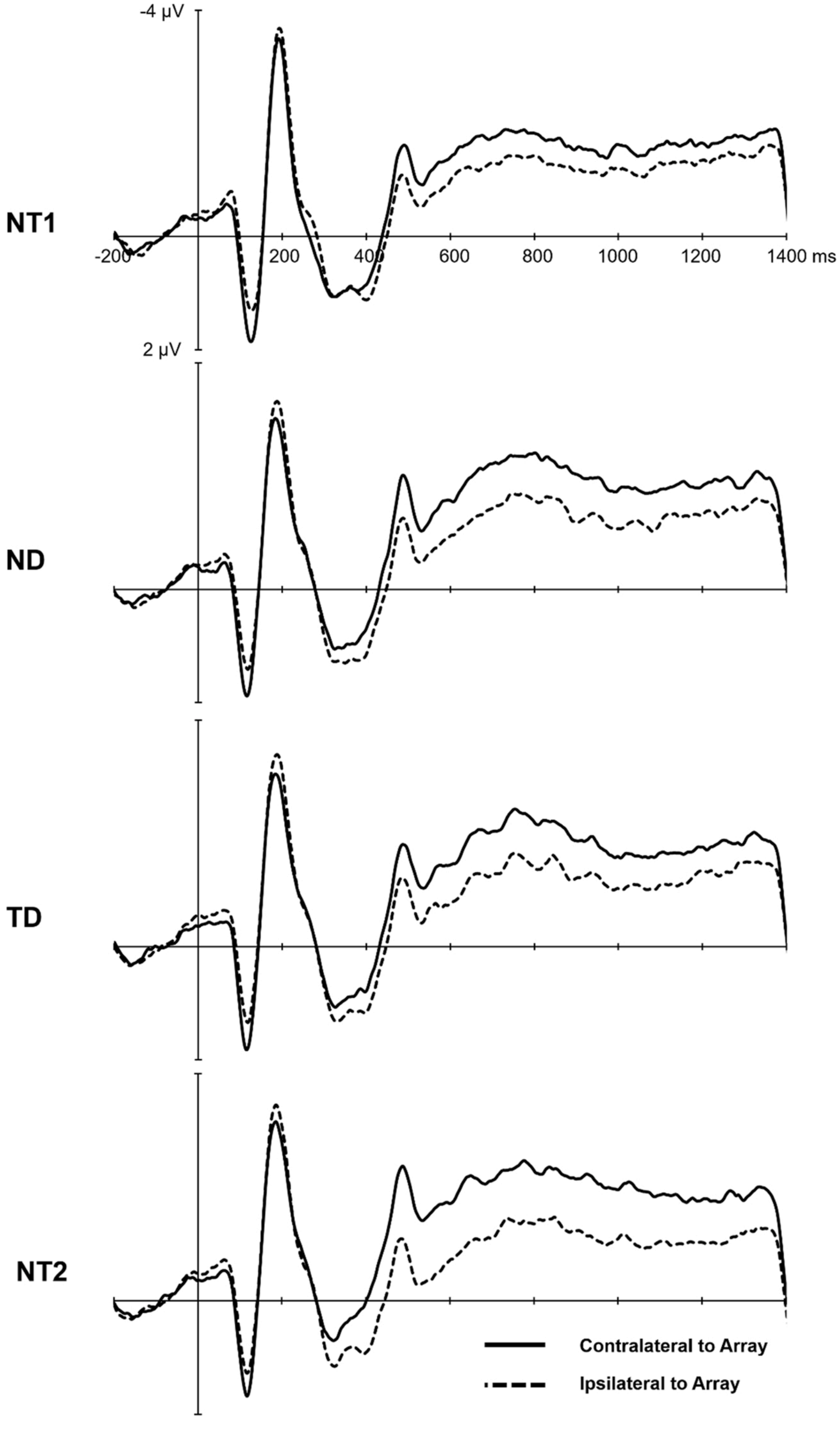

Fig. A2. Contralateral and Ipsilateral Waveforms.
Contralateral and ipsilateral waveforms across set-sizes for all word conditions.

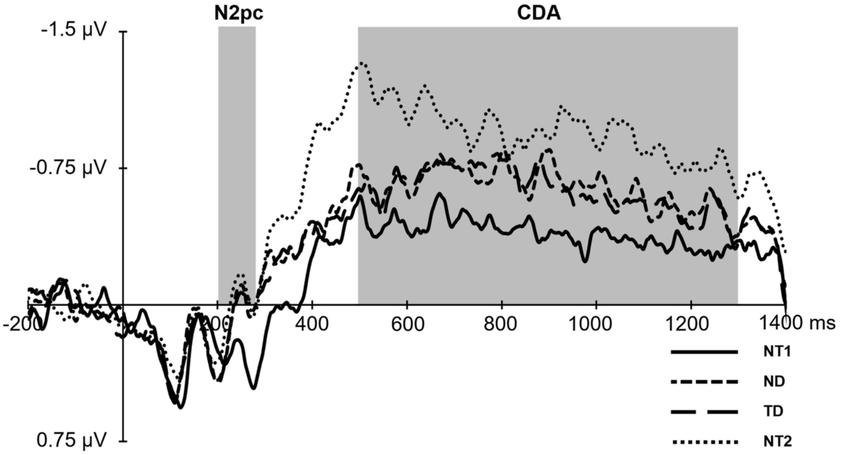

Fig. A3. Word Lateralized Change Detection Task Waveforms (Monochromatic Version).

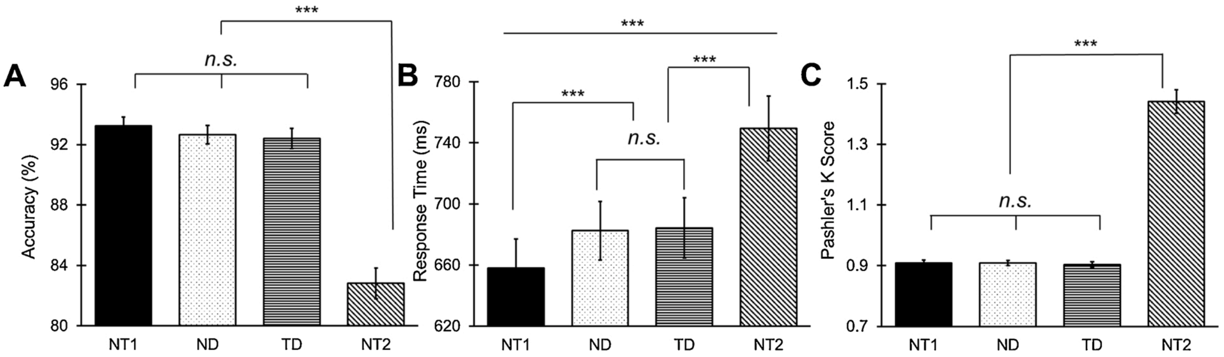

Fig. A4. Word Lateralized Change Detection Task Behavioral Results (Monochromatic Version).

Word lateralized change detection task behavioral results. Error bars represent standard error. **A)** Accuracy was greater for NT1 than NT2, but did not differ from ND and TD. **B)** RT was faster for NT1 compared to ND, TD, and NT2. ND and TD were also faster than NT2. **C)** Pashler's K scores were greater for NT2 compared to NT1, ND, and TD. K scores did not differ between NT1, ND, and TD. * = $p < 0.05$, ** = $p < 0.01$, *** $p < 0.001$.

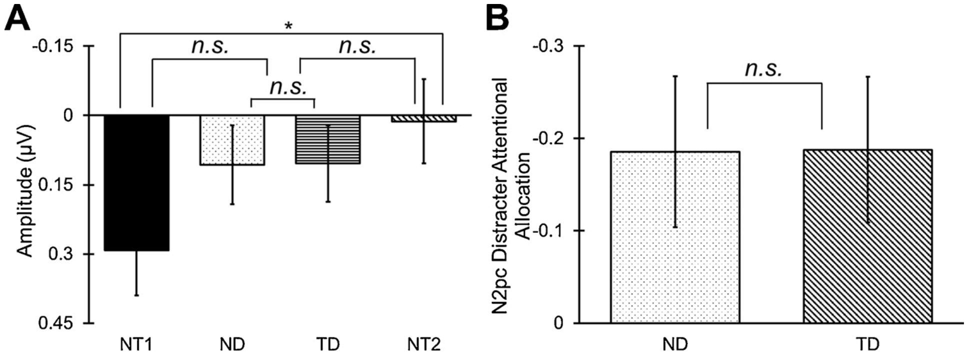

Fig. A5. Word Lateralized Change Detection Task N2pc Results (Monochromatic Version).

Word lateralized change detection task N2pc results. Error bars represent standard error. **A)** N2pc amplitudes were more negative in NT2 compared to NT1, but did not differ from ND and TD. ND and TD N2pc amplitudes did not differ. **B)** N2pc distracter attentional allocation did not differ between ND and TD. * = $p < 0.05$, ** = $p < 0.01$, *** $p < 0.001$.

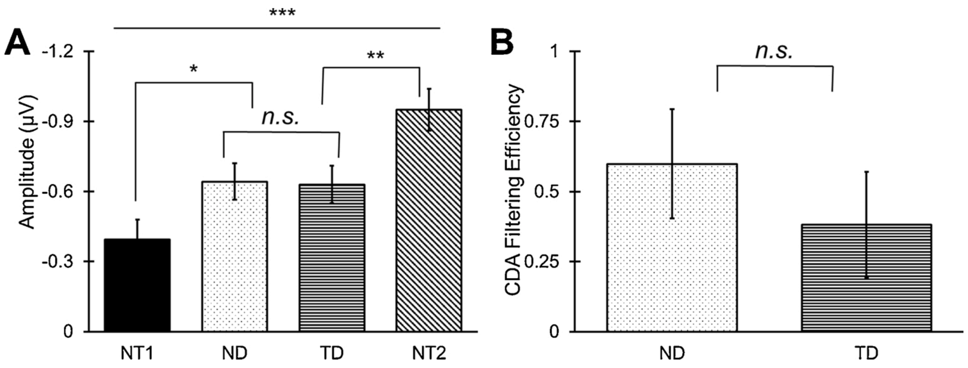

Fig. A6. Word Lateralized Change Detection Task CDA Results (Monochromatic Version). Word lateralized change detection task CDA results. Error bars represent standard error. **A)** CDA amplitudes were more negative in NT2 compared to NT1, ND, and TD. ND and TD also had more negative CDA amplitudes compared to NT1, but did not differ in CDA amplitude from one another. **B)** CDA filtering efficiency did not differ between ND and TD. * = $p < 0.05$, ** = $p < 0.01$, *** $p < 0.001$.

Appendix B

Tables B1 and B2

Table B1
Residual HEOG Values for the Pre-Trial Baseline Through the Entire Trial (−200–1300 ms).

Condition	Mean HEOG (μV)	Standard Error HEOG (μV)
NT1	0.373	0.602
ND	0.308	0.706
TD	0.450	0.677
NT2	−0.027	0.830
All Conditions	0.276	0.681

Residual HEOG values for the pre-trial baseline through the entire trial (−200–1300 ms). No significant differences in HEOG were observed between conditions, $F(2.389, 140.960) = 0.845$, $p = 0.449$, $\eta_p^2 = 0.014$, $BF_{10} = 0.059$. Average residual HEOG across conditions was 0.276 μV ($SE = 0.681$ μV). Because each degree of eye movement corresponds to 16 μV (Luck, 2014), our average residual eye movement was approximately 0.017°, which is less than the typical 0.2° degrees used in other processing pipelines (Ikkai et al., 2010; Luck, 2014; Rajsic et al., 2019; Salahub & Emrich, 2020; Vogel et al., 2005; Woodman & Luck, 2003).

Table B2
Residual HEOG Values for the Entire Trial (0–1300 ms).

Condition	Mean HEOG (μV)	Standard Error HEOG (μV)
NT1	0.439	0.694
ND	0.365	0.814
TD	0.529	0.781
NT2	−0.019	0.957
All Conditions	0.328	0.785

Residual HEOG values for the entire trial (0–1300 ms). No significant differences in HEOG were observed between conditions, $F(2.387, 140.825) = 0.840$, $p = 0.451$, $\eta_p^2 = 0.014$, $BF_{10} = 0.058$. Average residual HEOG across conditions was 0.328 μV ($SE = 0.785$ μV). Average residual eye movement was approximately 0.021° (Luck, 2014), which is less than the typical 0.2° degrees used in other processing pipelines (Ikkai et al., 2010; Luck, 2014; Rajsic et al., 2019; Salahub & Emrich, 2020; Vogel et al., 2005; Woodman & Luck, 2003).

Appendix C

Figs. C1 and C2
Table C1

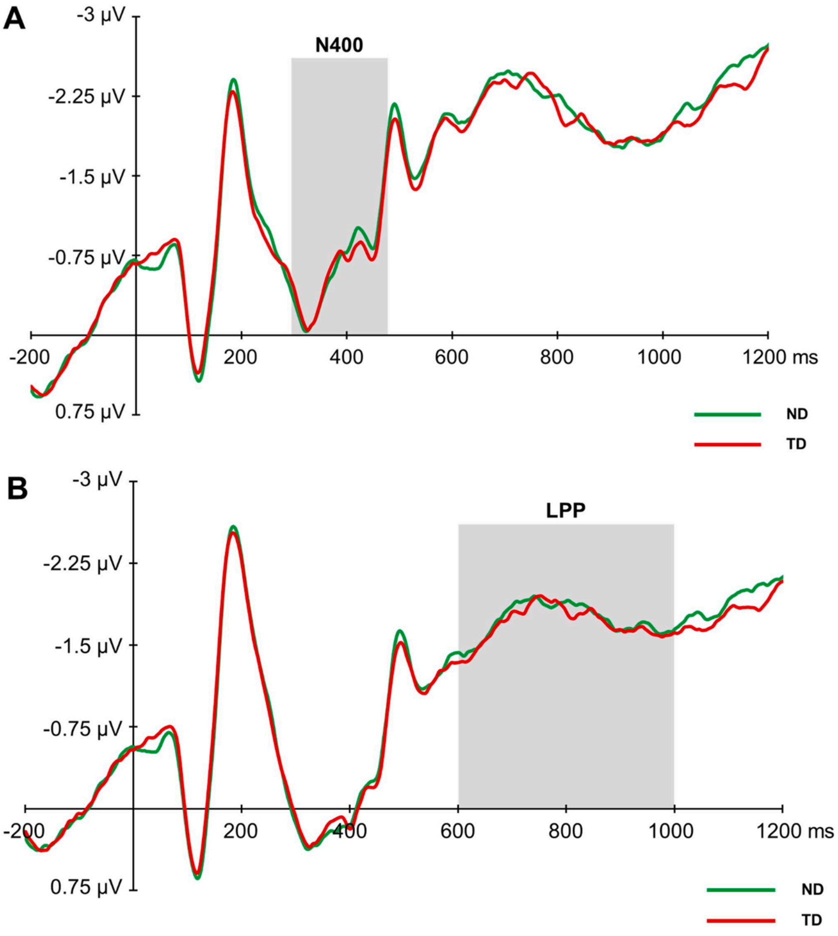

Fig. C1. Word lateralized change detection task waveforms for the N400 and LPP in the ND and TD conditions.
Word lateralized change detection task waveforms for the N400 and LPP in the ND and TD conditions. **A)** N400 waveforms were computed as the average amplitude between 300–500 ms at channels CP1/2 and P3/4 averaged together. **B)** LPP waveforms were calculated as mean amplitude between 500–1000 ms as CP1/2, CP5/6, P3/4, and P7/8 channels averaged together.

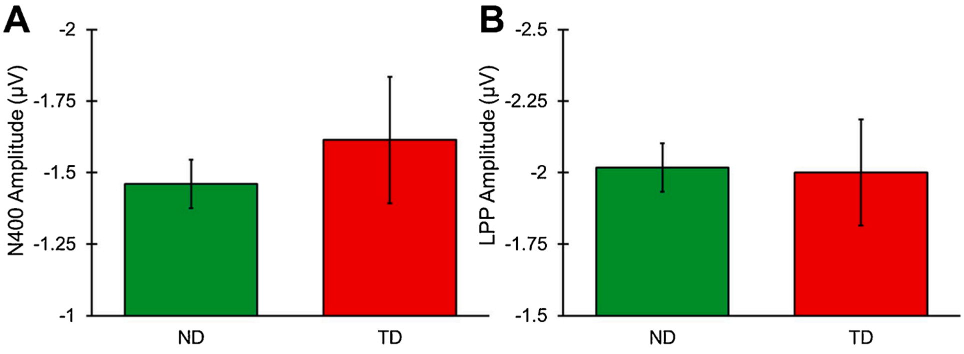

Fig. C2. Word Lateralized Change Detection Task N400 and LPP Results for the ND and TD Conditions.
Word lateralized change detection task N400 and LPP results for the ND and TD conditions. Error bars represent standard error. **A)** N400 amplitude did not significantly differ between the ND and TD conditions. **B)** No significant differences in LPP amplitude between the ND and TD conditions.

Table C1
Statistical Outcomes from N400 and LPP in ND and TD Conditions.

ERP Component	Time Window	Channel Cluster	Test Statistic	Significance Value	Effect Size	Bayes Factor 10
N400	300–500 ms	CP1/2, P3/4	$t(59) = 1.27$	$p = 0.208$	$d = 0.083$	$BF_{10} = 0.304$
LPP	600–1000 ms	CP1/2, CP5/6, P3/4, P7/8	$t(59) = -0.254$	$p = 0.800$	$d = 0.011$	$BF_{10} = 0.146$

No differences were observed for the N400 and LPP ERP between the ND and TD conditions. It should be noted that these analyses do not allow for a "pure" observation of semantic processing between neutral and threat-related distracter words. This is due to the simultaneous presentation of these distracter words with target words, and the list of words selected as neutral targets or neutral distracters were different. Therefore, we believe analyses of these conditions are confounded by the simultaneous presentation of a neutral target word, and using different neutral target and neutral distracter words, which may diminish potential differences in N400 and LPP effects between ND and TD conditions.

Appendix D

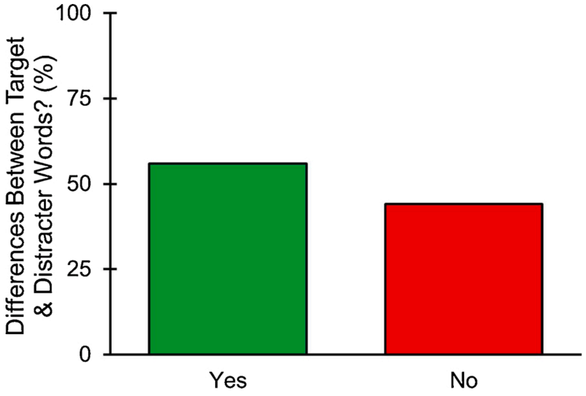

Fig. D1. Percentage of Participants Noticing Differences Between Target and Distracter Words.
Percentage of participants indicating whether they noticed any differences between the target and distracter words in the task. Approximately 55.93 % of participants indicated they noticed differences between the target and distracter words, while 44.07 % reported they did not.

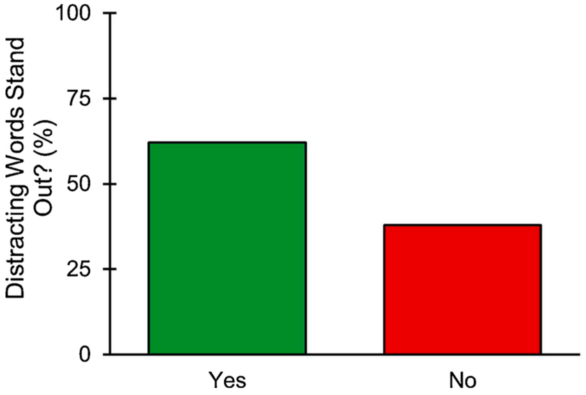

Fig. D2. Percentage of Participants Reporting Distracter Words Stood Out.
Percentage of participants indicating whether any of the distracting words stood out to them. Approximately 62.07 % of participants reported that at least one of the distracting words stood out and 37.93 % of the participants indicated that they did not.

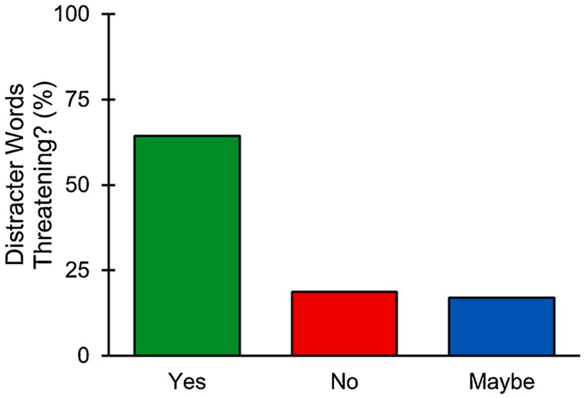

Fig. D3. Percentage of Participants Indicating Distracter Words Appeared negative or Threatening.
Percentage of participants indicating whether any of the distracter words appeared negative or threatening. Approximately 64.41 % of participants indicated that the distracter words appeared negative or threatening, 18.64 % reported they were not negative or threatening, and 16.95 % of participants stated "maybe" regarding whether or not the distracter words appeared negative or threatening.

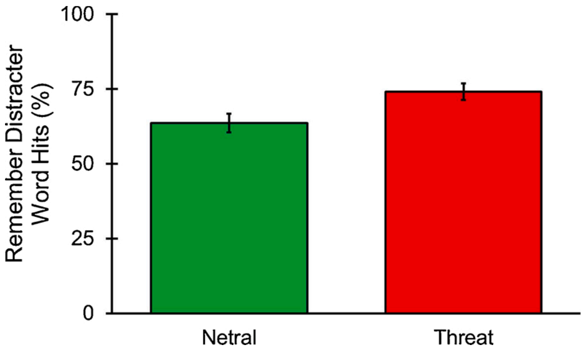

Fig. D4. Percentage of "Hits" for Correctly Remembering Distracter Words.
Percentage of "hits" for whether or not participants remembered seeing the presented neutral and threatening distracter words in the previous task. Specifically, participants were randomly presented all distracter words, and indicated if they remembered seeing the word or not (i.e., 1 = Yes, 2 = No). Total hits (correctly remembered) were calculated for each distracter word within each valence (neutral vs threatening) condition. Participants correctly remembered approximately 63.60 % of the neutral and 74.10 % of the threatening distracter words.

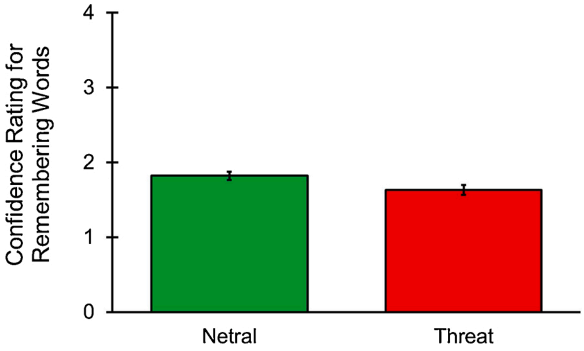

Fig. D5. Average Confidence Rating for Remembering Distracter Words. Average confidence rating for responses to whether or not participants remembered seeing the remembered seeing the presented neutral and threatening distracter words in the previous task. Specifically, participants indicated how confident they were in their response to whether or not they remembered seeing the presented word on a Likert scale from 1 to 4 (i.e., 1 = Very Confident, 2 = Somewhat Confident, 3 = Not Confident, 4 = Just Guessing). On average, participants demonstrated a high degree of confidence for their responses given to remembering the presented word for both neutral ($M = 1.82$, $SE = 0.06$) and threatening ($M = 1.63$, $SE = 0.07$) distracter words.

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