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ORIGINAL PAPER

The interference of negative emotional stimuli on semantic vigilance performance in a dual-task setting

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Abstract

A large body of previous research has shown that emotional stimuli have an advantage in a wide variety of cognitive processes. This was mainly observed in visual search and working memory tasks. Emotionally charged objects draw and hold attention, are remembered better, and interfere more with the completion of the primary task than neutral ones. Therefore, it seems reasonable to assume that emotional stimuli also greatly affect sustained attention and vigilance decrement. In the present research, we investigated whether emotional stimuli demand more attentional resources than neutral ones in a dual-task paradigm. We adopted the abbreviated semantic discrimination vigilance task and measured participants' (N = 49) performance in a single-task and two dual-task settings. In the dual-task conditions, the visual semantic vigilance paradigm was combined with an auditory word recall task (with neutral or emotional stimuli). We found reduced vigilance and improved word recall performance in the emotional dual-task condition compared to the neutral dual-task and single-task conditions. The reduced performance was apparent throughout the task, while in the neutral conditions, participants' performance first increased and then dropped as time progressed. To conclude, our results indicate that emotional stimuli not only have an advantage in cognitive processing but also demand more attentional resources continuously while it is present compared to neutral stimuli. These results are consistent with the emotionality effect theory and evolutionary accounts of the neural circuits underlying motivated behaviors associated with critical survival needs.

Keywords Sustained attention · Vigilance decrement · Signal detection theory · Emotionality effect · Word recall · Emotional valence

Introduction

Emotionally charged objects—those that evoke positive or negative feelings in the observer—typically hold vital cues regarding situations such as danger, feeding, or reproduction, that are of great importance to our survival (Bradley et al. 2001). It has been suggested that evolutionary evolved brain networks (i.e., survival circuits) involved in life-sustaining functions, such as thermoregulation, reproduction, and defense, are responsible for the processing of emotional stimuli (LeDoux 2000, 2012). In line with this, a large body of past research (Cacioppo et al. 1999; Niu et al. 2012; Pilarczyk and Kuniecki 2014; Vuilleumier 2015) have shown that emotionally charged objects have an advantage in attentional and memory processing over neutral ones. For instance, objects with an affective value are detected faster (Mulckhuyse 2018), draw and hold attention for longer (Richards et al. 2014), and are harder to ignore (Burra et al. 2019). These effects seem to be more pronounced for negative compared to positive emotional stimuli (Coelho et al. 2010; Humphrey et al. 2012; Niu et al. 2012; Zsido et al. 2018). In fact, the detection of cues that predict danger, harm, or the presence of threatening objects has been shown to be a part of an organism's defense system (Blanchard et al. 1990; Bolles 1970; Soares et al. 2017). As a consequence, negative stimuli tend to win the competition for attentional resources over neutral stimuli, potentially because negative valence activates brain regions (such as the superior colliculus, pulvinar, and amygdala) automatically and

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independently of attentional control (Lindström and Bohlin 2012; Pessoa et al. 2002). This automatic attentional grabbing character of negative valence stimuli is in line with past research (Gokce et al. 2021; Unsworth and Robison 2017; Zsido et al. 2022a, b) showing that the inhibition of negative emotional stimuli (presented as task-irrelevant distractors) is an active process requiring cognitive resources. Consequently, the performance of the task may deteriorate. Investigating the effect of negative affect on attentional performance is important as it may have implications for the aetiology and maintenance of anxiety disorders and can also help to understand another negative valence phenomenon, e.g., pain (Ádám 1978; Coelho et al. 2023; Cole et al. 2014; Hengen and Alpers 2019; Williams et al. 2020).

The disruptive effect of processing emotionally charged stimuli parallel to a vigilance task, despite the importance of the implications, has rarely been studied. The vast majority of previous studies investigated vigilance for task-relevant emotionally charged stimuli in simple task settings (Carretié et al. 2004; Estes and Adelman 2008; Kuperman et al. 2014; Mogg et al. 2000). Using emotional stimuli as task-relevant targets may be problematic because in such designs bottom-up and top-down processes are entangled. In contrast, the processing of task-irrelevant emotional distractors has to be actively inhibited by the observer and, thus, may provide a better and specific insight into the mechanisms of top-down processing (Calvo and Castillo 2005; Zinchenko et al. 2020; Zsido et al. 2022a, b). For example, if one thinks about an aching tooth, the cognitive processing involved in locating the source of pain is very much different than in suppressing the sensation in order to maintain focus on a given task. In fact, pain and anxiety may be interpreted as task-irrelevant distractors when one tries to perform a task while anxious or in pain. Past studies have shown (Anticevic et al. 2014; Cole et al. 2014; Duncan 2010) that the need to constantly regulate symptoms (e.g. anxiety, pain) and the accompanying negative affective state may cause disruption of the capacity of the working memory leading to a reduced capacity for other cognitive demands. Still, there are only a handful of exceptions (Flood et al. 2015; Helton and Russell 2011; Ossowski et al. 2011) that investigated the distractive effect of task-irrelevant emotional stimuli on vigilance. For instance, Flood and colleagues (2015) investigated the impact of task-irrelevant emotional stimuli on vigilance under dual-task conditions. Participants completed a signal detection task where the target (small oval shape) was presented at a slightly different spatial position than the other stimuli but otherwise was similar in appearance. Stimuli were presented in 11 equal-length experiment blocks. Between these blocks, participants either saw neutral or emotionally arousing pictures. The results showed that the performance decrement throughout the task was attenuated in the group that saw emotional pictures (compared to the neutral condition). These results are in line with the affective primacy hypothesis; i.e., affective information has processing priority over semantic information (Lai et al. 2012). However, past studies also showed that semantic categorization may precede affective evaluation (Nummenmaa et al. 2010), termed the cognitive primacy hypothesis. It has been argued that while one of the features (affective or semantic) of the stimuli presumably leads the processing (and, thus, will be prioritized over the other), which feature will that be is determined by the circumstances (Lai et al. 2012). Therefore, future studies should focus on identifying the circumstances that favor affective over semantic processing or vice versa. The studies mentioned before did not access this. However, in the studies, the emotional stimuli were task-irrelevant distractors to be ignored, and therefore, they did not measure the active processing of the affective content.

In scenarios when one needs to consciously focus on the processing of information coming from two different sources, an attentional prioritization favoring the source marked by negative stimuli could be expected. However, the reason for this bias is different in the active processing of negative stimuli compared to when they are to be suppressed. In dual task settings, when the primary task is non-emotional while the second task is an emotional one, then the allocation of attentional resources is known to be biased toward the secondary task (Gao et al. 2022; Kousta et al. 2009) leaving so fewer resources for the primary task. For instance, in a dual-task setting, Epling et al. (2016) examined the effect of memorizing words listened to (secondary task) on performance in a semantic vigilance task (primary task). They hypothesized that a vigilance decrement—the change in performance with time-on-task—will be apparent due to high cognitive resource demands. Participants either heard meaningless (single task condition) or meaningful (dual task condition) words while they performed the primary task. They were told in the dual task condition that when the primary task was over, they needed to recall the words they listened to. All conditions were broken down into three equal-length blocks during the analysis of the data to investigate the vigilance decrement. The authors found that participants' performance dropped in the dual task condition. However, while this study did not mention or purposefully study any emotional effects, the word list contained numerous words with negative emotional charge (e.g., bullet, hostage, morgue). It is, therefore, unclear how much the emotional content of these word stimuli influenced the results. One may plausibly assume that the emotional words biased the attentional resources toward the secondary task, further reducing the attentional capacity available for the primary vigilance task. That is, the impaired performance found in the dual task condition may have been caused merely by the presence of the emotionally negative words in the word list.

In the present study, to fill the gap of past research, we sought to test the effect of active processing of negatively valenced stimuli on sustained attentional performance. Using an adapted version of Epling et al's 2016 paradigm, we aimed to answer the question of whether the processing of negative emotions claims greater attentional resources than neutral stimuli in a dual task setting, and thus, decreases performance on the primary task. More specifically, we used a semantic vigilance task as the primary task where participants had to discriminate words that named living things from words naming non-living things. In the single task condition participants performed the semantic vigilance task, in the dual task condition they performed a word listening task parallel to the semantic vigilance task (and later a free recall task of the heard words). For the primary semantic vigilance task, we hypothesized that when participants perform a word recall task with negatively valenced compared to neutral words, their sensitivity to detect a visual signal will be lower, and they will also be more conservative[1] in responding. Consistently with the study of Epling et al. (2016) conditions were broken down into three equal-length blocks during the analysis of the data to investigate the vigilance decrement and the time-on-task effect. For the secondary listening task, we predicted that participants would recall more negative compared to neutral words because they will allocate more of their attentional capacity to these words.

Methods

Participants

We collected data from 49 Caucasian volunteers (41 women) who were undergraduate students. Their mean age was 20.8 (SD = 2.58, range: 18–30). An a priori power analysis using G*Power (Faul et al. 2007) was conducted to test for a repeated measures ANOVA (within-subject factors) with 9 (3×3) correlating repeated measures ($r = 0.35$). The required sample size for this experiment was determined by computing estimated statistical power based on the outcome of relevant previous studies (Epling et al. 2016; Head and Helton 2014). The analysis indicated a required minimum sample size of 31 with a conservative approach ($f = 0.25$, $1\text{-}\beta = 0.95$). However, our analysis included one more factor than that in the previous studies, therefore, we oversampled the minimum sample size suggested by G*Power.

All participants were right-handed and reported normal or corrected-to-normal vision. Data from two participants were excluded because of failure to follow instructions. The study protocol was approved by the Hungarian United Ethical Review Committee for Research in Psychology and was carried out in accordance with the Code of Ethics of the World Medical Association (Declaration of Helsinki). All participants provided written informed consent.

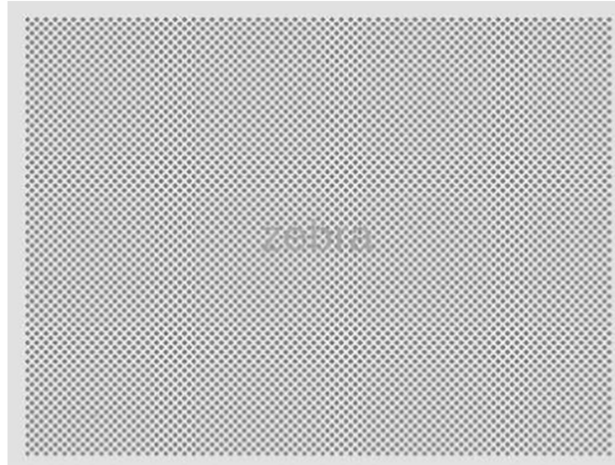

Fig. 1 An example of the visual stimuli used in the vigilance task

Experimental stimuli

We adopted the abbreviated semantic discrimination vigilance task (Epling et al. 2016), a Go-NoGo paradigm, where participants have to monitor the screen and respond if they saw a target ("living" words) by pressing a button and withhold a response when they see other ("non-living") words. Each word was presented for 250 ms in gray Arial size 20 fonts, centered on a gray noise field consisting of a grid of black circles. Figure 1 shows an example of what participants saw. We created a list of 48 living and 192 non-living words (240 in total). The words (all Hungarian) ranged from three to seven letters and we also aimed to use words that are relatively commonly used. The signal-to-noise ratio was 1:4 throughout the task.

We also pre-recorded three, 20-word lists[2]; two for the word recall task for the dual task conditions and one as a control for the single task condition. Across the two lists for the dual task condition, words were balanced for frequency, concreteness, imagery, and meaningfulness, each with two syllables and five to seven letters. The difference between

[1] A conservative criterion in responding within the framework provided by the signal detection theory minimizes false alarms but increases exposure to missed detections (Lynn and Barrett 2014). That is, the observer may be more likely to respond that a stimulus is not present.

[2] Neutral word list: ankle, load, flag, pepper, doorman, bustard, fridge, puppet, peanut, closet, move, ruler, matter, piano, pudding, salon, slipper, space, nozzle, bush. Negative word list: corpse, grief, sorrow, poison, guilty, gash, tumor, tombstone, death, prison, poverty, terror, ulcer, torture, accident, fear, funeral, murderer, nightmare, coffin.

the two lists was that one contained neutral words, while the other negatively valenced words[3] that were taken from the Affective Norms for English Words database (Bradley and Lang 1999). For the negative words list the inclusion criteria were a valence rating below 4 (on a scale of 1 to 9 where higher numbers indicate more positive valence), number of letters, and word frequency (greater than average, > 51). The list of meaningless words had the same average word length as the two other lists. This condition was included to control for the potential effect of audio stimulation and distraction present in the dual task conditions. The words were recorded by a male Hungarian speaker. All recordings were exactly 5 min long (one word every 15 s).

In the single task condition, participants heard the list of meaningless words while performing the semantic vigilance task. In the neutral dual task condition, they heard the 20-word list of neutral words, in the negative dual task condition they heard the 20-word list of negative words for the recall task.

Procedure

Data were collected individually, in a dim and quiet room. Participants were seated at a distance of approximately 60 cm from the monitor.[4] Participants were instructed to adjust the computer volume to a comfortable level before beginning; there were only minor differences. We used the PsychoPy Software v3.0 for Windows (Peirce 2007) to present the stimuli and to collect responses from participants. Behavioral responses were recorded via the keyboard of the computer. Participants received both oral and written task instructions and were assigned to one of three groups which counterbalanced the order of the three tasks. First, they completed a set of practice trials with 16 living and 64 non-living words that were not included in the list used for the experiment. After this, they were given an opportunity to ask questions. If they indicated that they understood the task fully, the experiment began.

The three vigilance tasks (single, neutral dual, and negative dual) were broken down into three, equal-length blocks. The order in which the tasks were presented was counterbalanced across participants. Living and non-living words were randomly sampled without replacement from the list of 240 words such that there were 16 living and 64 non-living words presented in each of three 100-s blocks in a 5-min task. During the single task, they heard the 5-min recording of meaningless words, while they listened to the recording of neutral and negative word lists in the neutral and negative dual-task conditions (respectively). At the end of one 5-min task, participants were instructed to write down as many words as they could recall from the recording. They had a minute for this.

Statistical analyses

Statistical analyses were performed using the JAMOVI Statistics Program version 2.0 for Windows (Jamovi Project 2022). For the reaction time (RT) data only RTs of correct reactions were used. First, we identified and removed outlier trials, defined as those greater than ± 2 standard deviations of the group mean (resulting in the removal of less than 1% of all the collected data) in each trial for each subject. This was necessary to remove implausibly fast and overly long RTs that may have indicated an error or lack of attention. Mean RTs in the different conditions were between 485 and 895 ms. We then checked to ensure that the distribution of the variables did not deviate significantly from a normal distribution (Shapiro-Wilk *p*s > 0.05).

First, we compared the difference in word recall performance between the neutral and negative dual task conditions with a paired t-test with Cohen's d as effect size. Then, we performed a 3 × 3 repeated-measures analysis of variances (rANOVA) with Task (single, neutral dual, negative dual) and Blocks of the vigilance task (i.e., the three blocks of the task) as within-subject factors. Blocks were entered in the analysis to follow the analysis plan of a previous study (Epling et al. 2016) that we sought to replicate and to allow a direct comparison of the results. We also entered the Order of the three vigilance tasks (as a between-subject factor) into the analyses to control for any confounding effect. The outcome variables included examining the number of positive answers on target-present trials (hit), d prime (d' = z(hit rate)—z(false alarm rate)), bias (c = —[z(hit rate) + z(false alarm rate)]/2), and RTs (in seconds). Main effects and interactions were supplemented with relevant follow-up ANOVAs to further investigate significant effects; in post hoc tests Tukey correction was used. Please note that the statistical results of the post hoc tests can be found in the *Appendix*. Effect sizes are presented as partial eta squared (η_p^2) for the ANOVAs.

Results

Word recall

Participants recalled significantly more words in the negative condition (M = 8.59, SD = 2.9) compared to the neutral condition (M = 7.29, SD = 3.35, $t(48) = 2.38$, $p = 0.021$,

[3] The mean valence rating was 2.08 (SD = .5) with the lowest and highest values being 1.39 and 3, respectively. The mean arousal rating was 5.75 (SD = 1.18) with the lowest and highest values being 4.13 and 7.59, respectively.

[4] A 23-inch TFT color monitor, with a resolution of 1920 × 1080, 16:9 aspect ratio, a refresh rate of 60 Hz, and color depth of 16.7 M.

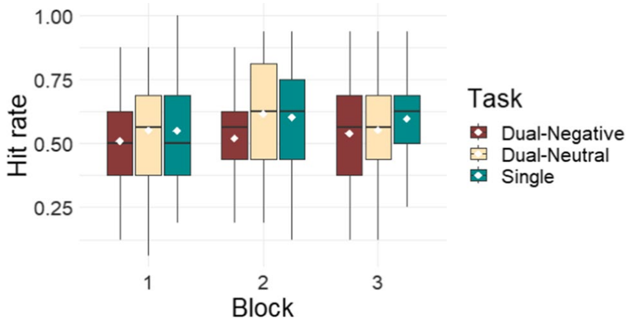

Fig. 2 Number of correct detections (hit rate) for the single, dual-neutral, and dual-negative tasks over the three experimental blocks. Error bars represent standard errors of the mean

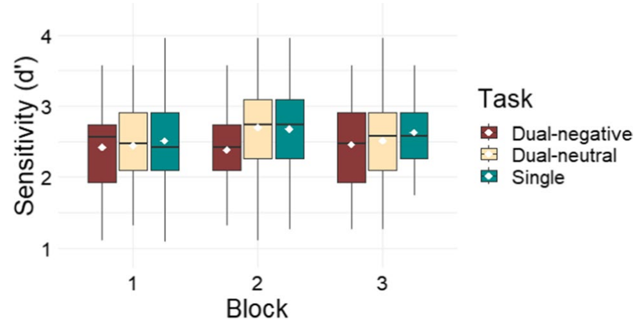

Fig. 3 Sensitivity, indicated by d' for the single, dual-neutral, and dual-negative tasks over the three experimental blocks. Error bars represent standard errors of the mean

Cohen's $d=0.34$, $M_{\text{difference}}=1.31$, 95%CI = −2.41 to −0.20).

Hit rate

Participants made significantly more correct detections in the single and dual-neutral tasks compared to the dual-negative task ($F(2,96)=4.49$, $p=0.014$, $\eta_p^2=0.085$). The performance was the worst in the first block, improved in the second block, and dropped back in the third block of trials ($F(2,96)=3.21$, $p=0.045$, $\eta_p^2=0.063$). See Appendix 2 for the descriptive statistics.

We also found a significant interaction between Task type and Block ($F(4,192)=2.60$, $p=0.037$, $\eta_p^2=0.051$) as shown in Fig. 2. Broken down for Task type, we found that in the single task ($F(2,96)=3.68$, $p=0.029$, $\eta_p^2=0.071$), the hit rate was higher in Block 2 and Block 3 compared to Block 1. For the dual-neutral task ($F(2,96)=6.05$, $p=0.003$, $\eta_p^2=0.112$), performance was better in Block 2 compared to Block 1 and Block 3. For the negative-dual task ($F(2,96)=0.315$, $p=0.730$, $\eta_p^2=0.007$), the performance did not change over blocks.

Broken down the significant interaction for Block, we found that in Block 1 ($F(2,96)=0.739$, $p=0.480$, $\eta_p^2=0.015$) and Block 3 ($F(2,96)=2.86$, $p=0.062$, $\eta_p^2=0.054$) the main effect of Task type was nonsignificant, while in Block 2 ($F(2,96)=8.03$, $p<0.001$, $\eta_p^2=0.138$) the performance was better in the single and dual neutral task to compare to the dual negative task.

D prime

We found a significant main effect for Task type ($F(2,96)=4.09$, $p=0.020$, $\eta_p^2=0.079$), participants had the highest sensitivity in the single task, lower in the dual-neutral, and lowest in the dual-negative task. Similarly to the hit rate, we found again an inverted V-shaped Block effect ($F(2,96)=3.39$, $p=0.038$, $\eta_p^2=0.066$), the sensitivity increased from Block 1 to Block 2 but dropped for Block 3. See Appendix 2 for the descriptive statistics.

The interaction between Task type and Block was also significant ($F(4,192)=2.50$, $p=0.044$, $\eta_p^2=0.049$), as shown in Fig. 3. Broken down for Task type, in the single task the Block effect reached only a marginal significance ($F(2,96)=2.83$, $p=0.064$, $\eta_p^2=0.056$), indicating that the sensitivity of participants was higher in Block 2 and Block 3 compared to Block 1. The Block effect was significant in the dual-neutral condition ($F(2,96)=6.93$, $p=0.002$, $\eta_p^2=0.126$): Performance was better in Block 2 compared to Block 1 and Block 3. In contrast, the sensitivity did not change over blocks in the negative-dual condition ($F(2,96)=0.338$, $p=0.714$, $\eta_p^2=0.007$).

Broken down the significant interaction for Block we found that in Block 1 ($F(2,96)=0.456$, $p=0.635$, $\eta_p^2=0.009$) and Block 3 ($F(2,96)=2.27$, $p=0.109$, $\eta_p^2=0.045$) the main effect of Task type was nonsignificant, while in Block 2 ($F(2,96)=8.04$, $p<0.001$, $\eta_p^2=0.143$) sensitivity was higher in the single and dual neutral task compare to the dual negative task.

Bias

We found a significant main effect for Task type ($F(2,96)=6.27$, $p=0.003$, $\eta_p^2=0.116$), participants were the least conservative in responding during the single task, more conservative during the dual-neutral, and the most conservative during the dual-negative task. In contrast, the Block main effect was nonsignificant ($F(2,96)=2.15$, $p=0.122$, $\eta_p^2=0.043$). See Appendix 2 for the descriptive statistics.

The interaction between Task type and Block was, again, significant ($F(4,192)=2.69$, $p=0.033$, $\eta_p^2=0.053$), as shown in Fig. 4. Broken down for Task type, in the single task the Block effect was nonsignificant ($F(2,96)=1.58$, $p=0.211$, $\eta_p^2=0.032$). There was a significant V-shaped

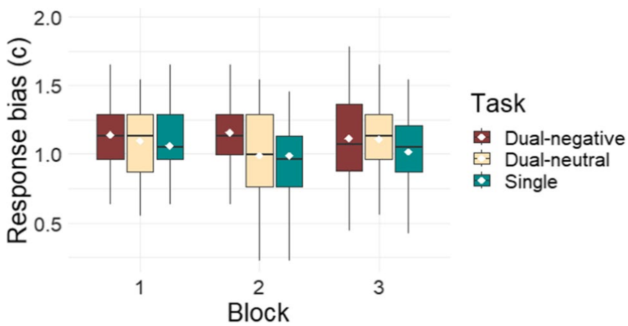

Fig. 4 Bias, indicated by c for the single, dual-neutral, and dual-negative tasks over the three experimental blocks. Error bars represent standard errors of the mean

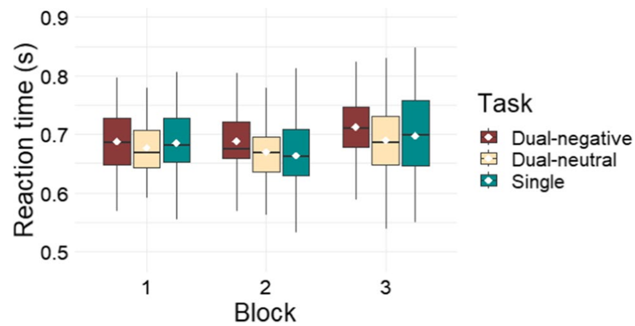

Fig. 5 Mean reaction time (in seconds) for the single, dual-neutral, and dual-negative tasks over the three experimental blocks. Error bars represent standard errors of the mean

Block effect in the dual-neutral condition ($F(2,96) = 5.64$, $p = 0.005$, $\eta_p^2 = 0.105$). That is, participants were less conservative in Block 2 compared to Block 1 and Block 3. There was no Block effect in the negative-dual condition ($F(2,96) = 0.572$, $p = 0.566$, $\eta_p^2 = 0.012$).

Broken down for Block we found that in Block 1 ($F(2,96) = 1.36$, $p = 0.261$, $\eta_p^2 = 0.028$) the main effect of Task type was nonsignificant. In Block 2 ($F(2,96) = 9.75$, $p < 0.001$, $\eta_p^2 = 0.169$) participants were significantly less conservative in the single and dual neutral task compared to the dual negative task. In Block 3 ($F(2,96) = 3.23$, $p = 0.044$, $\eta_p^2 = 0.063$) participants were significantly less conservative in the single compared to the dual neutral and task dual negative tasks.

Reaction time

Participants were significantly slower in responding during the dual-negative task compare to the dual-neutral and single conditions ($F(2,96) = 3.28$, $p = 0.044$, $\eta_p^2 = 0.063$). There was a V-shaped Block effect again, with participants responding slightly but not significantly faster in Block 2 compared to Block 1 but slowing down in Block 3 ($F(2,96) = 9.16$, $p < 0.001$, $\eta_p^2 = 0.160$). The interaction between Task type and Block was nonsignificant ($F(4,192) = 0.74$, $p = 0.567$, $\eta_p^2 = 0.015$). See Fig. 5 for the results and Appendix 2 for the descriptive statistics.

Discussion

It has long been posited that emotionally charged objects, especially those with negative valence, have an advantage in attentional and memory processing over neutral ones (Cacioppo et al. 1999; Niu et al. 2012; Pilarczyk and Kuniecki 2014; Vuilleumier 2015). As a consequence, the allocation of attentional resources is biased toward negative emotional stimuli (Gao et al. 2022; Kousta et al. 2009). Hence, in a dual task setting the availability of working memory resources is limited for the primary task that does not contain emotional information (Lindström and Bohlin 2012). Thus, in the present study, we examined the hypothesis that the processing of negative emotions in a word recall task claims greater attentional resources than neutral stimuli in a dual task setting and this results in a performance decrement on the primary semantic vigilance task. In line with our hypothesis, we found that the recall performance was better for emotional compared to neutral words. This corroborates with previous findings showing that negative emotional stimuli are remembered better compared to neutral ones (Reinecke et al. 2006; Zsido, Stecina, et al. 2022). In addition, our results showed that, as we predicted, the better memory for negative stimuli was accompanied by a decreased overall performance on the semantic vigilance task. The performance decrement was evidenced by lower sensitivity (i.e., *d*') and more conservative response (i.e., bias) to the target. In the neutral conditions, we also found a time-on-task effect (hit rate, *d*', and bias): participants' performance first increased (single, neutral dual task) and then dropped as they spent more time with the task (neutral dual task).

The initial improvement in performance was likely to be due to a learning (practice) effect observed frequently during a prolonged performance of a cognitive task (e.g., Csathó et al. 2012, Matuz et al. 2019). However, the decline in performance after two blocks of task completion in the neutral dual conditions implies that participants became fatigued by the third block of trials in line with many previous studies showing that high cognitive load (as e.g., a dual task performance) may have resulted in impaired performance (e.g., Flanagan and Nathan-Roberts 2019; Helton and Russell 2015; Ralph et al. 2017). The results for reaction time were different in that a linear, task-independent slowing was observed with increasing time-on-task. This result may suggest an overall decrease in participants' vigilance as they spent more time with the task.

The performance was not only worse in the negative duals task condition compared to the neutral ones, but it also remained unchanged over time. That is, we did not find a learning effect in this condition. These results favor the affective over the cognitive primacy hypothesis meaning the affective information is prioritized over semantic information in dual-task situations (Lai et al. 2012). Contradictory to previous results in a similar dual-task paradigm (Epling et al. 2016; Helton and Russell 2015), the performance did not change (i.e., no learning or fatigue effect was observed) in the dual-task condition. A possible explanation for this difference between the present study and the previous studies is that in the present study, negative and neutral words were included in separate task conditions, whereas in the previous studies, they were mixed. Our findings that performance in the negative emotional condition did not change over time and that only the negative dual-task condition was more difficult than the single task, suggest that emotional stimuli can attract a high level of attention. More specifically, our findings suggest that in the negative dual task, the processing of emotional stimuli claimed greater attentional capacity, which limited the availability of resources to other tasks. While this resulted in a better word recall performance, it impaired visual task performance. That is, the allocation of attentional resources was biased toward the task with negative emotional stimuli. Reaction times were in line with these findings; participants were slower to respond in the negative dual condition compared to the neutral ones. This is in line with past research (Gao et al. 2022; Gokce et al. 2021; Kousta et al. 2009; Unsworth and Robison 2017; Zsido et al. 2022a, b) showing that working memory resources are limited for the task that does not contain emotional stimuli. A task that contains negative emotional stimuli has an advantage in processing. This is also in line with previous results by Zsido et al. (2018, 2021) where it has been shown that at first, the negative emotional content has a negative effect on task performance due to its disruptive effect on attentional processes, but the increased arousal increases performance over time, and probably so it may compensate the detrimental effects of fatigue.

Limitations of the study include that we did not collect self-reported measures of perceived or induced stress or anxiety, although there might be connections between the present study and past stress research. Future studies should monitor stress in similar designs to observe its effects on executive functions, inhibition, working memory, and cognitive flexibility. The limitations of space and coherence did not allow us to delve deeper into the connection between anxiety and stress. Further, it shall also be noted that the present study used a relatively short behavioral-experimental paradigm that would not have been a good model of the stress response, and we did not record physiological indicators of stress and anxiety. Future research may do so in order to provide a better understanding of the relationship between stress, anxiety, and cognitive performance.

Conclusion for future biology

It has been argued (Anticevic et al. 2014; Cole et al. 2014; Duncan 2010) that the indirect disruption of the capacity of the working memory could be caused by the need to constantly regulate symptoms (e.g., anxiety, pain) and the accompanying negative affective state resulting in a reduced capacity for other cognitive demands. Thus, investigating the effect of negative affect on cognitive attentional performance is important as it may have implications for the aetiology and maintenance of anxiety disorders and understanding the psychology and physiology of pain. As a consequence, objects and bodily sensations with an emotional value (in particular those with a negative valence) could claim greater attentional resources overshadowing other processes (Buodo et al. 2002; Gokce et al. 2021), and may inhibit ongoing activities (e.g., movement, talking) in order to prepare the brain and the body for the appropriate reaction (LeDoux 2012). Both exogenous (e.g., seeing a dangerous animal) and endogenous (e.g., feeling pain) aversive stimuli share similar neurological and psychological functions, evoke highly similar physiological responses (Price 2000), and are part of the evolutionary developed defense system to avoid harmful stimuli (Butler and Finn 2009). Therefore, like in the present study, investigating the effects of negative exogenous emotional stimuli on performance on attentional tasks could serve to be a feasible way to model the effects of endogenous negative stimuli on attentional processes.

In conclusion, we found that negative emotional stimuli claim a large portion of the available cognitive capacity as evidenced by the better recall performance on the word recall task presenting negatively valenced words and the worse performance on the semantic vigilance task. This is in line with previous studies showing that stimuli with a negative emotional charge have an advantage in information processing and that such stimuli tend to overshadow the processing of other stimuli. The processing of exogenous negative stimuli (such as those used in the present study) and endogenous (such as a signal of pain or discomfort) evoke a highly similar physiological response (Price 2000) and are part of the evolutionary developed defense system to avoid harmful stimuli (Butler and Finn 2009). Therefore, studies such as ours might be good models to test how important bodily information, such as pain (Ádám 1978), marked with negative valence attract and maintain attention to facilitate processing and coping.

Appendix 1

See Table 1.

Table 1 Results of the post hoc tests with Tukey correction

				t	p_{tukey}
Hit rate					
	Block main effect				
	Block1	–	Block2	−2.845	0.018
		–	Block3	−1.939	0.140
	Block2	–	Block3	0.865	0.665
	Single task—Block main effect				
	Block1	–	Block2	−2.853	0.017
		–	Block3	−1.904	0.149
	Block2	–	Block3	0.675	0.779
	Dual neutral—Block main effect				
	Block1	–	Block2	−2.942	0.014
		–	Block3	−0.114	0.993
	Block2	–	Block3	2.847	0.017
	Block 2—Task type effect				
	Single	–	Neutral	−0.125	0.991
		–	Negative	3.179	0.007
	Neutral	–	Negative	3.245	0.006
D prime					
	Task type main effect				
	Single	–	Dual-neutral	17.jan	0.479
		–	Dual-negative	2.94	0.014
	Dual-neutral	–	Dual-negative	26.febr	0.073
	Block main effect				
	Block1	–	Block2	−2.834	0.019
		–	Block3	−1.565	0.272
	Block2	–	Block3	0.944	0.616
	Single task—Block main effect				
	Block1	–	Block2	−2.627	0.030
		–	Block3	−1.539	0.282
	Block2	–	Block3	0.643	0.797
	Dual neutral—Block main effect				
	Block1	–	Block2	−3.82	0.001
		–	Block3	−1.04	0.555
	Block2	–	Block3	2.40	0.053
	Block 2—Task type main effect				
	Single	–	Neutral	−0.313	0.947
		–	Negative	2.953	0.013
	Neutral	–	Negative	3.412	0.004
Bias					
	Dual neutral—Block main effect				
	Block1	–	Block2	2.371	0.056
		–	Block3	−0.387	0.921
	Block2	–	Block3	−3.239	0.006
	Block 2—Task type main effect				
	Single	–	Neutral	−0.0731	0.997
		–	Negative	−3.5724	0.002
	Neutral	–	Negative	−3.4544	0.003
	Block 3—Task type main effect				
	Single	–	Neutral	−2.3470	0.059
		–	Negative	−2.1088	0.099
	Neutral	–	Negative	−0.0916	0.995
Reaction time					
	Task type main effect				
	Single	–	Dual-neutral	0.433	0.902

Table 1 (continued)

				t	p_{tukey}
		–	Dual-negative	− 1.844	0.166
	Dual-neutral	–	Dual-negative	− 2.601	0.032
	Block main effect				
	Block1	–	Block2	1.82	0.175
		–	Block3	− 2.68	0.027
	Block2	–	Block3	− 3.75	0.001

Appendix 2

See Table 2.

Table 2 Descriptive data presented for reaction time (in seconds), hit rate, response bias (c), and sensitivity (d'), shown separately for each condition. Mean values and 95% confidence intervals (CI) values are presented

				95% Confidence Interval	
Task	Round	Mean	Std. Error	Lower	Upper
Reaction time					
Single	Block 1	0.685	0.01127	0.662	0.707
	Block 2	0.663	0.00931	0.645	0.682
	Block 3	0.698	0.01018	0.677	0.718
Dual-neutral	Block 1	0.677	0.00778	0.661	0.692
	Block 2	0.669	0.00905	0.651	0.687
	Block 3	0.690	0.00973	0.671	0.710
Dual-negative	Block 1	0.688	0.00860	0.671	0.705
	Block 2	0.688	0.00776	0.672	0.703
	Block 3	0.712	0.00935	0.693	0.731
Hit rate					
Single	Block 1	0.553	0.0289	0.495	0.611
	Block 2	0.607	0.0285	0.549	0.664
	Block 3	0.600	0.0232	0.554	0.647
Dual-neutral	Block 1	0.549	0.0259	0.497	0.601
	Block 2	0.620	0.0282	0.564	0.677
	Block 3	0.550	0.0281	0.494	0.607
Dual-negative	Block 1	0.517	0.0287	0.460	0.575
	Block 2	0.517	0.0286	0.460	0.575
	Block 3	0.542	0.0285	0.484	0.599
Response bias (c)					
Single	Block 1	1.061	0.0469	0.967	1.16
	Block 2	0.987	0.0439	0.899	1.08
	Block 3	1.016	0.0417	0.933	1.10
Dual-neutral	Block 1	1.096	0.0401	1.016	1.18
	Block 2	0.990	0.0445	0.900	1.08
	Block 3	1.110	0.0411	1.027	1.19
Dual-negative	Block 1	1.142	0.0379	1.065	1.22
	Block 2	1.158	0.0422	1.074	1.24
	Block 3	1.114	0.0419	1.030	1.20
Sensitivity (d')					
Single	Block 1	2.51	0.0923	2.32	2.70
	Block 2	2.68	0.0861	2.50	2.85
	Block 3	2.63	0.0674	2.49	2.76
Dual-neutral	Block 1	2.44	0.0777	2.28	2.60
	Block 2	2.70	0.0812	2.53	2.86
	Block 3	2.51	0.0849	2.34	2.68
Dual-negative	Block 1	2.42	0.0849	2.25	2.59
	Block 2	2.38	0.0880	2.21	2.56
	Block 3	2.46	0.0830	2.29	2.62

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