Exploring the Interactions Between Affective Auditory Distractions and Working Memory

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ABSTRACT

In our daily lives, the ability to focus on tasks while filtering out distractions is crucial. Attention and working memory play pivotal roles in this process, but distractions, particularly emotional stimuli, can still interfere. Working memory is susceptible to impairments when dealing with emotional distractions, which can have implications for emotional regulation and overall well-being. Negative emotional distractions, in particular, have been shown to interfere with cognitive task performance. However, the impact of affective distractions lacks a consensus in terms of how they interact with working memory performance. Further, the range of acoustic stimuli used as affective distractors is limited, often confined to brief, task-irrelevant sounds, which may not always be applicable to real-world scenarios. In the current study, participants were asked to reproduce the colors of three images presented to them in order of their confidence in their ability to successfully reproduce the correct color. Additionally, the research incorporated prolonged exposure to distraction with the presentation of emotional auditory distractions in the form of news reports. Results showed that the presence of auditory distractions increased participant reports of being off-task. Further, memory errors were higher in the distraction conditions when compared to the no distraction conditions during the last response, when participant confidence was low. The findings suggest that there is a relationship between participant confidence and the interference of emotional auditory distractions. This study underscores the need to consider emotional distractions, particularly auditory stimuli, in real-world scenarios to better comprehend their effects on working memory and cognitive functioning.

INTRODUCTION

I. Attention and working memory

We are constantly exposed to distractions in our everyday lives. Whether it be filtering out other conversations while on the phone, trying to study while a roommate is blasting music, or trying to concentrate on an exam while someone keeps coughing loudly, the ability to filter out distractions and focus on the task at hand is an important skill. An integral part of this information selection process is attention (Oberauer, 2019). Attention encapsulates our ability to concentrate on specific information while effectively ignoring all that is irrelevant (Oberauer, 2019). While taking an exam, for instance, one might block out sounds to focus on the task at hand. Despite the role of attention in filtering information, however, it is not always sufficient to prevent distractions from affecting working memory.

Occasionally, distractors get processed in working memory (Lewis-Peacock et al., 2018). Working memory serves a multifaceted role in cognitive processes by both maintaining and processing information necessary for various tasks, and one of its roles is to remove irrelevant information that could potentially distract from the primary cognitive objective (Oberauer, 2019; Oberauer & Lewandowsky, 2016). Although our working memory has important functions, there is a limit to the amount of information that can be stored in working memory at a time (Miller, 1956; van Dillen & Hofmann, 2023).

For example, an individual may be unable to study and retain new content if they are overloaded with their roommate's music. Because working memory has a limited capacity, there can be competition between which information is maintained in working memory and which information is filtered out (Miller, 1956; van Dillen & Hofmann, 2023). A student would want, for instance, to retain information on what they are studying and remove information about the music in the background. This highlights the importance of why we need to be able to keep the important information and discard irrelevant information.

Although we have multiple processes in place to prevent irrelevant stimuli from interfering with cognitive tasks, our working memory occasionally fails to remove distractions (Lewis-Peacock et al., 2018). Emotional information, in particular, has been shown to interfere with working memory performance (van Dillen & Hofmann, 2023). Impairments in the ability to filter out and remove irrelevant information have been associated with anxiety and depression (Everaert et al., 2023; Berggren et al., 2017). However, we are rarely in a state where we are experiencing no emotion whatsoever (Engelmann & Hare, 2019). Therefore, the ability to filter irrelevant emotional stimuli out of working memory when we are trying to complete a task is important for our day to day lives.

II. Emotional information, attention, and memory

Research suggests that emotional stimuli take precedence in attentional processing when compared to more neutral stimuli (Öhman et al., 2001; van Dillen & Hofmann, 2023). From an evolutionary perspective, affective information can be expected to have significant motivational relevance due to holding important information regarding survival, such as danger, safety, and nourishment. Öhman et al. showed that individuals tend to detect threatening targets more quickly and accurately when compared to friendly or neutral targets, providing support for the idea of the threat advantage, which suggests that humans unconsciously allocate attentional resources towards threatening stimuli (2001). What constitutes as threatening stimuli can be highly dependent on the individual based on past experiences such as early life stress (van Dillen & Hofmann, 2023). Despite the influence of individual experiences, there are also universally shared notions regarding the relevance of certain affective information, such as the common perception of snakes and guns as threatening stimuli (van Dillen & Hofmann, 2023; Öhman & Soares, 1998; Brosch & Sharma, 2005).

In addition to the recruitment of attentional resources, affective information has associations with working memory. Working memory has been shown to be involved in the regulation of emotions, both in encoding newly presented emotional information and managing the current attentional representation of emotions (Rutherford et al., 2015). Emotional information is not always relevant to the task at hand, which is why the ability to regulate emotions is an important process. Working memory capacity has been directly correlated with emotional regulation abilities such as suppression and managing emotional expression (Schmeichel & Demaree, 2010). For example, negative information has been shown to have less of an effect among individuals with greater working memory capacity (Schmeichel & Demaree, 2010). While working memory is involved in emotional regulation, emotions can also impact working memory. Affective information has been shown to both impede and enhance working memory performance in different situations, depending on factors such as task-relevance (Kensinger & Corkin, 2003; Schweizer et al., 2019). It is important to consider the benefits and detriments of the effects of emotions on working memory to understand the relationship.

A common effect of task-irrelevant emotional stimuli is that they tend to impair working memory performance (Wingert et al., 2018; Pereira et al., 2006). Previous research has suggested that emotional information consumes more resources than neutral information, which results in both transient and sustained memory impairments (Pereira et al., 2006). Furthermore, it has been demonstrated that negative emotional distractions tend to have larger effect on working memory performance when compared with emotionally neutral or positively valenced distractions (Anticevic et al., 2010; Schweizer et al., 2019; Wingert et al., 2018). Task-irrelevant negative information seems to be associated with higher amygdala activity and lower activity in prefrontal regions, suggesting that it interferes with the processing of information in working memory (Anticevic et al., 2010). The ability to experience and overcome emotional intrusive thoughts is an integral part of daily life, and difficulties with controlling these types of thoughts could have long-term consequences.

III. Distractions and working memory

It is important to study the effects of task-irrelevant negative stimuli to further our understanding of how this information impairs working memory. Although there has been much research centering around emotional information and working memory, more manipulations can be done to further generalize it to real situations. For example, a student attempting to study in a coffee shop may be exposed to loud music, other people's conversations, or several other interruptions that may interfere with the task they are working on. In a situation such as this, the individual is being subjected to auditory distractions as they try to complete an unrelated task. Research looking at the effects of auditory distractions on working memory performance have shown impaired cognitive performance (Max et al., 2015). However, the conditions of these experiments are not fully applicable to the real world. Many of these studies are designed so that the participant must complete some kind of working memory task with auditory distractions interspersed between the target stimuli.

Stimuli used for auditory distractions are commonly loud and purposefully interruptive, such as annoying tones or blaring alarms (Kolbeinsson et al., 2022; Max et al., 2015; Stewart et al., 2023). While this may apply to certain situations, individuals are commonly presented with more constant distractions. Going back to the previous example, let us assume that a student is trying to read a textbook while in a coffee shop and the people sitting next to them are engaged in an emotional conversation. In this case, the neighboring conversation may distract the student from their task. This distraction is more constant than an alarm blaring for a brief time. Furthermore, it occurs simultaneously with the student's task.

Looking more specifically into auditory distractions, current studies have inconsistent results in terms of how they impact working memory (Stewart et al., 2023). While the general consensus among studies looking at the impact of affective stimuli is that negative distractions impair working memory performance, some studies using affective auditory stimuli have opposing views (Kolbeinsson et al., 2022). Negative stimuli has long been thought to incite more arousal than neutral or even positive stimuli (LeDoux, 1996; Öhman et al., 2001). Negative task-irrelevant sounds have been shown to impair working memory performance less than neutral sounds (Asutay & Västfjäll, 2015; Max et al., 2015). This has been attributed to the idea that negative stimuli increases arousal, causing participants to become more vigilant and therefore be less impacted by negative distractors than neutral distractors (Asutay & Västfjäll, 2015; Kolbeinsson et al., 2022). Despite certain studies supporting this theory, other studies have shown that negative auditory distractors impair working memory more than neutral or positive distractors (Marsh et al., 2018; Hjärtström et al., 2019). This could occur because negative stimuli make us more vulnerable to distractors. Parmentier suggests that negative stimuli make it difficult to disengage from distracting stimuli by overusing cognitive resources (Pacheco-Unguetti & Parmentier, 2014; Parmentier, 2013). On the other hand, others suggest that negative stimuli could be processed more vigilantly than neutral or positive stimuli (Gross, 1998; Lazarus, 1991; Bodenhausen et al., 2000; Parmentier, 2013). In any case, studies have disagreed over the effects of auditory stimuli on working memory, highlighting a gap to be addressed.

IV. The current study

This study compares the effects of negative and positive auditory distractions on working memory performance. Specifically, I aim to expand on prior research through two important questions. First, I studied the effect of auditory distraction on working memory. While aforementioned studies used brief distractions such as alarm sounds, the current study uses a prolonged exposure to distraction throughout the entire working memory task with the auditory presentation of news reports. A meta-analysis of research looking at distractions and working memory showed minimal effects of affective stimuli (Schweizer et al., 2019). Schweizer et al. attributed this to the idea that stimuli typically used in experiments are not affectively significant enough to incite a distracted response (2019). Using stimuli more appropriate for real scenarios – more consistent distractions unlike brief sounds or pictures – could address this weakness. Although working memory studies have previously used several types of distractions, using emotional news reports is a novel concept. Through this, I aim to understand if these stimuli act as distractions and significantly impair task performance. This can address the inconsistencies seen in previous studies in regards to the effects of auditory distractions. I expect that the administration of these auditory distractions during a working memory task will impair performance.

Second, I plan to compare the effect of valence on the impact of distractions. Previous studies using auditory distractions have inconsistencies regarding the effect of negative distractions. For instance, Hjärtström et al. showed that negative auditory distractions impair working memory performance, while Max et al. described how they are less detrimental than neutral distractors (Hjärtström et al., 2019; Max et al., 2015). These inconsistencies could be due to the effect highlighted by Schweizer et al., with affective stimuli not being relevant enough to incite a realistic response (2019). The news reports used in this study, having been previously rated and validated in terms of valence, could help investigate this inconsistency (Samide et al., 2020). This study observes the differences in working memory performance in the presence of negative and positive distractions. Although there has been some variability regarding the effect of affective auditory distractions, most studies on the effects of affective distractions agree that negative affect tends to play a larger role (van Dillen & Hofmann, 2023). I expect that participants will perform worse on tasks when they are presented with a negative auditory distraction than when presented with a positive auditory distraction.

The information gained from this study can help identify another point of consideration when studying emotional distractions. Developing a better understanding of the interference of emotional stimuli during cognitive tasks could have future implications regarding identifying the mechanisms and providing solutions for impaired cognitive control processes involved in working memory. Excessive bias towards emotional information has been associated with lower well-being, as well as mood disorders (Grafton & MacLeod, 2019; Gotlib & Joorman, 2010; van Dillen & Hofmann, 2023). Understanding how affective information impacts working memory could contribute to developing future therapies for individuals diagnosed with anxiety or depression.

METHODS

I. Participants

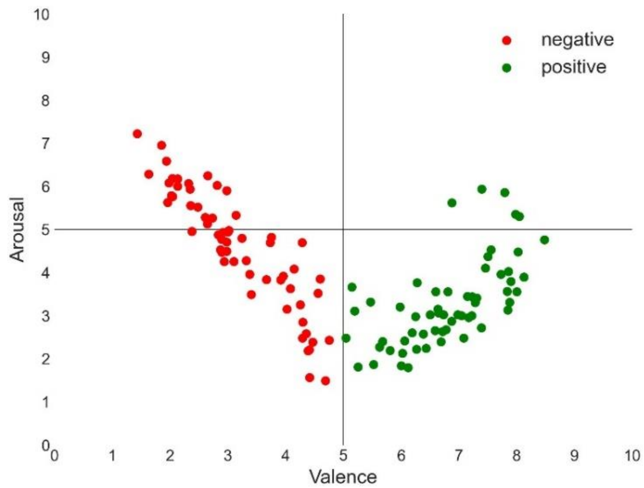
Participants were recruited through Redcap, an online platform for subject recruitment. A total of 30 adult subjects participated in the study (Age: $M = 20.7$, $SD = 1.3$; 25 women, 5 men). Participants provided informed consent and received compensation of $12 per hour, with the experiment lasting approximately 90 minutes.

II. Stimuli

The experiment was conducted in-person for all participants through Psychopy. The stimuli were presented on a gray background. The items for the memory task were object stimuli that are color-manipulable, similar to stimuli used in previous studies (Brady et al., 2013). The stimuli were randomly selected from a collection of 200 images, with 360 color variations of each image. The audio stimuli used for the distraction element were collected from a database of previously validated news videos rated on a scale of 1-10 on valence and arousal (Samide et al., 2020). Videos with a mean valence score of less than 5 were categorized as negative videos, while those with a score above 5 were categorized as positive (Figure 1). Some videos were removed due to no longer being publicly available. In total, the audio from 59 negative videos and 59 positive videos were isolated for the study.

Figure 1

Valence and Arousal Ratings for Stimuli Used as Emotional Distractions



Note. News reports with a valence rating below 5 were used as negative distractions, and those with a valence rating above 5 were used as positive distractions.

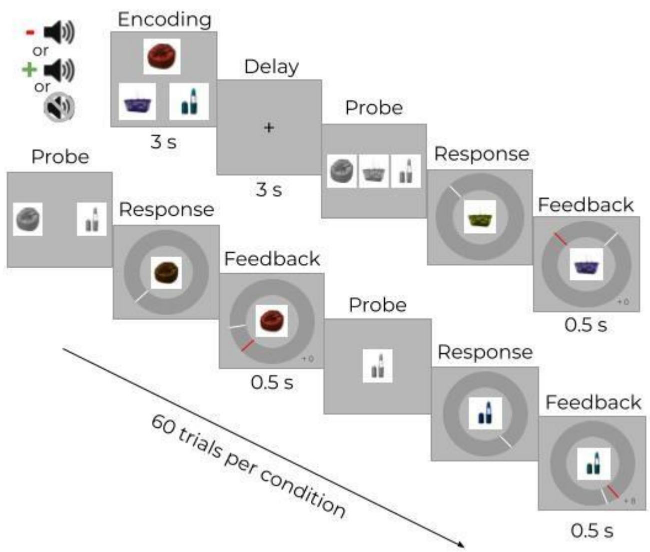
III. Procedure

The study was designed as a delayed estimation working memory paradigm with four experimental blocks and two control blocks. Each block consisted of 30 trials, with a total of 180 trials. The order of the blocks was randomized for each participant. Each trial began with a central fixation (0.5 s). Participants were then asked to study a set of three images equidistant from the fixation point and remember the color of the images (3 s). After a short delay (0.5 s), they were presented with the three images in grayscale in the center of the screen. Participants were instructed to click on the image that they feel most confident reproducing the color of. They were then asked to reproduce the color of the image on a response wheel. After their selection, they were presented with a feedback screen displaying the correct answer (0.5 s). If their answer was less than 24 degrees from the correct answer, the screen displayed that they received 8 points. Any answer that was greater than 24 degrees away from the correct answer received 0 points. They were then taken back to the screen with the grayscale images to choose one of the two remaining images and repeat the process. Again, they were told to pick the image they were most confident about reproducing the color of. For each trial, they were required to reproduce the color of all three images in order of most confident to least confident. The controls had no distraction present, while two of the experimental blocks had negative distractions and two of the experimental blocks had positive distractions. In the distraction trials, the audio from the negative or positive news videos were played in the background while the participant completed the task. Participants were told that the audio was irrelevant to the completion of the task and to simply focus on completing the task. There was a short delay at the end of each trial (1 s).

At the end of each trial, participants were asked to rate how well they were paying attention to the task. They were presented with a probe asking what they were focusing on during the last trial and asked to rate their focus on a scale of 1 (*completely focusing on the news*) to 5 (*completely focusing on the task*). Furthermore, one-third of the trials from each condition included a probe asking participants to rate their emotion and arousal levels. They were told to rate their level of pleasure on a scale of 1 (*sad*) to 5 (*happy*) and their level of arousal from 1 (*bored*) to 5 (*aroused*). All responses were self-paced.

Figure 2

Experimental Design



Note. Participants completed 180 trials total. Each block either had negative auditory distraction, positive auditory distraction, or no distraction.

IV. Analysis

Memory errors were calculated using the absolute value of the difference between the participant response and the correct answer for each trial. These errors were averaged for each of the three conditions (positive, negative, no distraction) for each participant. Further, attention was categorized as "off-task" when the participants rated their focus between 1 and 3, and was categorized as "off-task" when the participants rated their focus as a 4 or 5. A repeated-measures analysis of variance (ANOVA) was used to evaluate the differences between the conditions.

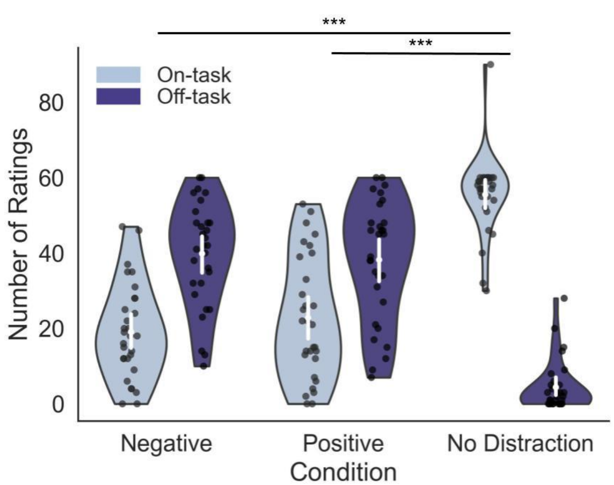
RESULTS

I. Attention and Emotion Ratings

The number of “on-task” and “off-task” ratings given by participants for each distraction condition is shown in Figure 3. There was a significant main effect for the interaction between condition and attention state ($F(2, 58) = 146.260$, $p < 0.001$, $\eta^2 = 0.618$). Follow-up t-tests revealed significantly more off-task ratings for negative ($t(29) = 13.907$, $p < 0.001$) and positive distraction conditions ($t(29) = -11.721$, $p < 0.001$) than the no distraction condition. There were more on-task ratings for the no distraction condition than negative ($t(29) = -13.338$, $p < 0.001$) and positive conditions ($t(29) = 10.485$, $p < 0.001$).

Figure 3

Number of On-task and Off-task Ratings by Distraction Condition



Note. Responses indicate significantly more on-task ratings and less off-task ratings for no distraction condition compared to distraction conditions.

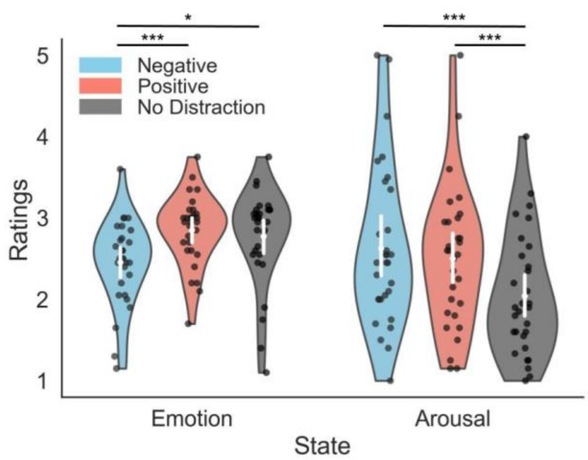
Violin plots display individual mean data distributions.

*** indicates that $p < 0.001$.

Figure 4 shows the emotion and arousal ratings given by participants at the end of the trials for each distraction condition. Main effects were found for condition for both emotion ($F(2, 58) = 10.116$, $p < 0.001$, $\eta^2 = 0.103$) and arousal ($F(2, 58) = 11.652$, $p < 0.001$, $\eta^2 = 0.079$). Follow-up t-tests show lower emotion ratings for the negative condition than the positive ($t(29) = -5.309$, $p < 0.001$) or no distraction conditions ($t(29) = -2.895$, $p = 0.007$). Looking at arousal ratings, they are significantly higher for the negative condition than the no distraction condition ($t(29) = 4.108$, $p = 0.001$), and higher for the no distraction condition than the positive condition ($t(29) = -4.165$, $p = 0.001$).

Figure 4

Emotion and Arousal Ratings by Distraction Condition



Note. Results show lower (more negative) emotion ratings for negative distraction condition than positive or no distraction conditions and higher arousal ratings for distractions conditions than no distraction condition.

Violin plots display individual mean data distributions.

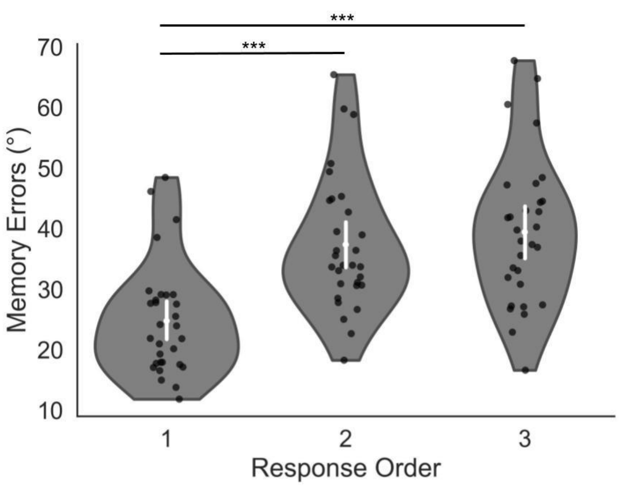
* indicates that $p < 0.5$. *** indicates that $p < 0.001$.

II. Memory errors

The absolute memory errors across all trials and all subjects are shown in Figure 5. A repeated measures ANOVA comparing the effect of response order on memory errors revealed a significant effect ($F(2, 58) = 72.312$, $p < 0.001$, $\eta^2 = 0.267$). There was a significant difference in the scores for response 1 and response 2 ($t(29) = -9.761$, $p < 0.001$) and response 1 and response 3 ($t(29) = -8.763$, $p < 0.001$).

Figure 5

Absolute Memory Errors Across All Trials



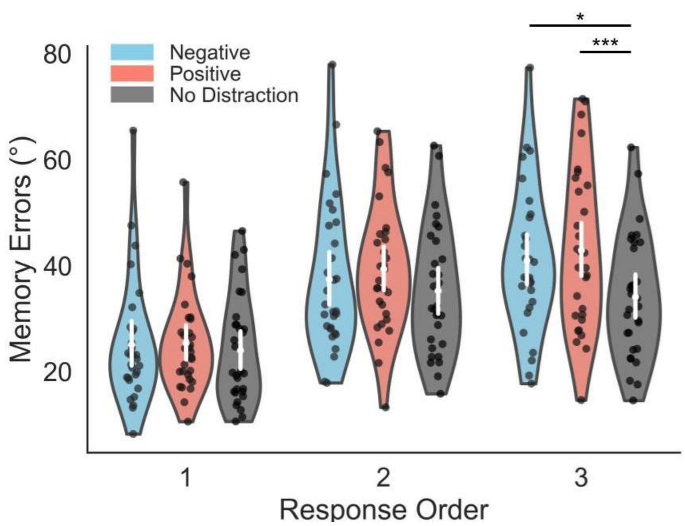
Note. Responses show more memory errors for response orders 2 and 3 than response order 1. Violin plots display individual mean data distributions.

*** indicates that $p < 0.001$.

The interactions between condition (negative, positive, no distraction) and response order (Figure 6) revealed a main effect of condition ($F(2, 58) = 5.787$, $p = 0.007$, $\eta^2 = 0.027$), response order ($F(2, 58) = 70.891$, $p < 0.001$, $\eta^2 = 0.219$), and the interaction ($F(4, 116) = 4.806$, $p = 0.010$, $\eta^2 = 0.012$). A follow-up ANOVA showed a significant difference between conditions in response 3 ($F(2, 58) = 12.196$, $p < 0.001$, $\eta^2 = 0.074$). Paired t-tests revealed a higher number of memory errors for the negative ($t(29) = 3.550$, $p = 0.012$) and positive conditions ($t(29) = -5.737$, $p < 0.001$) than the no distraction condition in response 3.

Figure 6

Memory Errors Across Distraction Condition



Note. Findings indicate significantly more memory errors during distraction conditions compared to no distraction condition for response order 3.

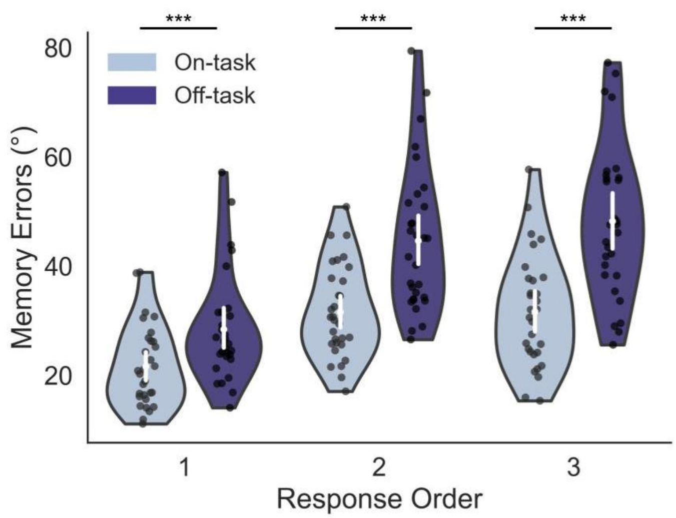
Violin plots display individual mean data distributions.

* indicates that $p < 0.5$. *** indicates that $p < 0.001$.

When analyzing the interactions between attention state (on-task or off-task) and response order (Figure 7), main effects were found for both mental state ($F(1, 29) = 55.394$, $p < 0.001$, $\eta^2 = 0.247$), response order ($F(2, 58) = 76.632$, $p < 0.001$, $\eta^2 = 0.282$), and the interaction ($F(2, 58) = 18.073$, $p < 0.001$, $\eta^2 = 0.035$). Memory errors were higher for off-task ($M = 40.43$, $SD = 15.08$) than on-task trials ($M = 28.27$, $SD = 9.93$) for all response orders.

Figure 7

Memory Errors Across Attention State



Note. Responses indicate significantly more memory errors for off-task trials than on-task trials for all three response orders.

Violin plots display individual mean data distributions.

*** indicates that $p < 0.001$.

DISCUSSION

This study compared the effects of emotional auditory content on the ability to encode and maintain information and recall the information after a delay by changing the emotional content of stimuli used in a working memory task. The findings report more on-task ratings for the no distraction condition and more off-task ratings for the distraction condition, suggesting that the distraction impacted participant focus. The predictions of this study expected that the presence of constant auditory distraction would increase memory errors. In line with this prediction, participants showed worse working memory performance for the distraction conditions than the no distraction condition in the last response order.

Looking at the effects of valence, participants had lower emotion ratings for the negative condition, implying that they were aware of the content of the auditory distractions. Contrary to the predictions of the study, no significant difference was found in task performance between the negative distraction and positive distraction conditions. Although there was no significant effect of valence, there was a large effect of attention state on memory errors. Participants performed worse on the working memory task in trials where they reported that they were paying attention to the distraction (off-task trials) compared to trials where they reported that they were paying attention to the task (on-task trials). This suggests that participants perform worse when they perceive a higher amount of interference from distractions.

These findings bring up several interesting considerations in terms of the hypotheses of this study. Based on the results of previous studies, it was expected that auditory distractions will impair working memory performance. During response order 3, the participants performed as expected, displaying worse accuracy in the trials with distractions, suggesting that the auditory distractions interfered with working memory. Finding significant results only for the last response was unexpected. Despite participants reporting that they were off-task significantly more in the distraction conditions, the impairment caused by the distractions was not seen in the first two responses. This suggests that there might be a relationship with participant confidence and the interference of the distraction.

The second hypothesis, that negative auditory distractions will impair working memory more than positive auditory distractions, was not supported by the data. There were no significant differences between the negative and positive distraction trials with any interaction. These findings do not address the inconsistencies revealed in previous studies in regards to the impacts of negative and positive task-irrelevant auditory stimuli. There was no support in these findings that negative auditory distractions are less impactful because they cause participants to be more vigilant, as suggested by some studies showing worse working memory performance in the presence of positive and neutral auditory distractions (Max et al., 2015; Kolbeinsson et al., 2022). However, there was similarly no support for the idea that negative distractions interfere more with working memory performance than positive distractions.

Although there was minimal evidence supporting the impact of valence of auditory distractions on working memory performance, the results highlighted an unexpected relationship between response order and distraction condition on memory error. The results could have implications in terms of the ability to maintain information in working memory in the presence of constant auditory distractors. Participants had to maintain the information for the last response for a longer period of time, leaving more time for the distraction to interfere with the maintenance process. When participant confidence for the task was lowest in the maintenance phase, distractions could have interfered more with their performance. In contrast, the findings could suggest an effect of the distraction during the encoding phase. Participants were given 3 seconds to encode the colors of all three images. The distraction could have interfered with the encoding of the last image, leading participants to be less confident and perform worse. In a different lens, the results could underscore the relationship between confidence and working memory, suggesting that memory recall is impaired by auditory distractions when participants are less confident. Participants may be able to more effectively ignore or remove irrelevant auditory information when they are more self-assured in the task.

This study used news reports as the auditory stimuli to increase the affective significance of the distraction, since a previous meta-analysis suggested that many affective stimuli are not emotionally significant enough to interfere with working memory processes (Schweizer et al., 2019). The news reports were previously validated in a study of 100 participants in both valence and arousal (Samide et al., 2019). To understand whether the distractions were inciting the intended emotional response, participants were asked to rate their emotional state in 33% of the trials from each condition (1 = very sad, 3= neutral, 5 = very happy). The results showed an average rating of 2.46 in the negative distraction trials and 2.85 in the positive distraction trials. The no distraction trials had an average emotion rating of 2.78. Although ratings for the negative condition were significantly lower than the ratings for the positive and no distraction conditions, the means are still different than expected. This data suggests that the auditory distractions, specifically the positive distractions, did not affect the response of the participants in the intended manner. Ratings for the positive distraction condition were expected to have a mean above 3, but the mean was under 3, meaning that participants reported being more sad than happy or neutral during the positive distraction conditions. This could explain the low effect of distraction valence on working memory performance.

In order to address the issue of creating an effective emotional response, future studies should validate the affective stimuli among the participants before conducting the study in order to confirm the valence ratings. Due to time constraints, this study had to rely on prior validation, which did not correspond with the participant ratings. Validating the stimuli could have produced more effective distractors, so that the effects of the auditory distractions would be more significant. Further, this study used a no distraction condition as a control. Future iterations could replace this condition with a neutral auditory distraction condition to more precisely observe the effect of valence.

In summary, the current study identified an effect of distraction on working memory performance, suggesting an impact of constant auditory distraction when confidence is low.

Moreover, participants were accurate at identifying when distractions interfered with their focus, showing worse performance when individuals reported being less focused on a task.

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