Changing emotional visual and auditory memories: Are modality-matched dual-tasks more effective?

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Abstract

Clinical and laboratory studies have demonstrated that executing a demanding dual-task while recollecting emotional memories weakens the emotional intensity and vividness of these memories. While this approach is generally effective, there is room for improvement. According to multi-component working memory theories, the effectiveness of dual-tasks may be improved by loading specifically the same sensory modality of the emotional memories. So far, however, the evidence for this idea is mixed. In the current report, this idea was tested in a pilot study (N = 36) and a pre-registered experiment (N = 60) by exposing participants to pictures of the International Affective Picture System database and to sounds of the International Affective Digital Sounds database, thus creating single-modality emotional memories. Using a within-subjects design, participants had to recollect their memories of the sounds and pictures while executing a visually-demanding task (i.e., identifying visual letters), an auditory-demanding task (i.e., identifying auditory letters), or no task. Across both studies, we only found limited evidence for modality-specific effects of dual-tasks on single-modality emotional memories. We discuss the relevance of our findings for working memory theories of memory change and therapeutic practices.

Keywords: Working memory; Modality; Cognitive load; Memories; EMDR therapy

Introduction

Memory provides us with the highly adaptive capacity to deal with situations based on our prior experience. However, vivid and emotional memories can also cause intense distress and interfere with daily functioning. This is most clearly demonstrated by the symptomatology of post-traumatic stress disorder (PTSD), which involves intrusive traumatic memories (American Psychiatric Association, 2013). Also in other psychological disorders, negative emotional memories are core components of the symptomatology, such as in obsessive-compulsive disorder, generalized anxiety disorder, and social phobia (Brewin, Gregory, Lipton, & Burgess, 2010).

One method to reduce the emotional intensity and vividness of emotional memories with proven effectiveness is to recall the memory while executing a demanding secondary task. This procedure is applied in Eye-Movement Desensitization and Reprocessing (EMDR) therapy. A core component of this therapy is that a patient retrieves a memory while making lateral eye-movements. Meta-analyses have found that EMDR is an effective therapy for PTSD (e.g., Bisson et al., 2007; Seidler & Wagner, 2006; Van Etten & Taylor, 1998). It is therefore recommended or suggested as treatment for PTSD by leading organizations (e.g., American Psychiatric Association, 2013; World Health Organization, 2013). Similarly, numerous laboratory studies have demonstrated that when healthy participants recall an emotional autobiographical memory while executing a demanding secondary task, compared to merely recalling such a memory, they report reduced memory emotionality and vividness when the memory is later recalled again (for recent reviews see Engelhard, McNally, & van Schie, 2019; Lee & Cuijpers, 2013). However, despite its effectiveness, there remains much room to improve the effect of dual-tasks on emotional memories. Particularly, for a substantial number of patients, PTSD symptoms persist after EMDR treatment (R. Bradley, Greene, Russ, Dutra, & Westen, 2005; Gauvreau & Bouchard, 2008). Likewise, dual-task interventions in laboratory studies often fail to substantially decrease the emotionality and vividness of autobiographical memories (i.e., post-intervention ratings of emotionality and vividness often remain in a range of 65-70 on a 0-100 point scale; Mertens et al., 2018; van Schie, van Veen, Engelhard, Klugkist, & van den Hout, 2016).

A key hypothesized mechanism of the effects of dual-tasks on emotional memories involved working memory (WM) (Andrade, Kavanagh, & Baddeley, 1997; Engelhard et al., 2019; van den Hout & Engelhard, 2012). According to this theory, executing a demanding task while remembering an emotional memory limits WM resources needed for memory retrieval, rendering the memory less vivid and emotional. That is, when people vividly recall a memory, it can become more distinctive (i.e., *imagination inflation*). However, when distraction diminishes the WM capacity for retrieval, imagination deflation typically occurs (van den Hout & Engelhard, 2012). The precise mechanism mediating the long-term effects of dual-tasks on memory remains unknown. Perhaps experiencing a weakened form of the aversive memory encourages reappraisal (see Engelhard et al., 2019) or the memory itself may be stored in a weakened form (Elsey, Van Ast, & Kindt, 2018).

Regardless of the exact mechanisms explaining the changes in long-term memory representations, WM theory provides two ways to improve the effects of dual-tasks. First, the dual-tasks can be made more demanding. This leaves fewer resources available for the recall of emotional memories. Indeed, several studies (Maxfield, Melnyk, & Hayman, 2008; van Veen et al., 2015), though not all (Mertens et al., 2018), have found that making the dual-task more difficult results in a greater decrease of the emotionality and vividness of negative memories.

Second, several WM theories propose that WM is composed of different subsystems (Baddeley, 2012). Particularly, an auditory-based and a visually-based subsystem are typically distinguished (in addition to an overarching executive system). According to these WM models, more interference with the recall of emotional memories can be achieved by matching the modality which the dual-task primarily taxes to the primary modality of the emotional memories.

So far, several studies have addressed the hypothesis that matching the modality of the dual-task to the modality of memories would increase the effects of the dual-task. The first set of studies was reported by Baddeley and Andrade (2000). In these studies, participants had to form images of pictures or sounds, or had to recollect primarily visual or auditory autobiographical memories while executing visual, auditory, and control tasks. Consistently across a set of six studies, a modality-specific effect was found, indicating greater interference between the images and the task when these were matched in modality. However, Baddeley and Andrade (2000) did not use emotional memories and therefore it is unclear whether their results apply to memories with emotional content, which is important for the clinical application of this procedure. Two other studies, which used negative autobiographical memories of students (Kemps & Tiggemann, 2007) and traumatic memories of patients with PTSD (Lilley, Andrade, Turpin, Sabin-Farrell, & Holmes, 2009), also found evidence for superior effects of modality-specific interference. Specifically, in the second experiment by Kemps and Tiggemann (2007), students were asked to form images of visual or auditory distressing and happy memories. They then had to recall these images while performing a visual task (making eye-movements), an auditory task (counting), or a control task (looking at a blank screen). There was an interaction between modality of the memory and modality of the task: vividness and emotionality of visual images were reduced more after executing a visual task than after executing an auditory task, and vice versa. Similarly, Lilley et al. (2009) found evidence for a beneficial effect of a visual task, relative to an auditory task and a control task, to reduce the rated vividness and emotionality of primarily visual traumatic memories.

However, not all experiments have found evidence for modality-specific interference with the recollection of emotional memories. Particularly, Kristjánsdóttir and Lee (2011) asked participants to recall primarily auditory and visual memories while executing a visual, auditory and control task. Unlike the previous studies of Kemps and Tiggemann (2007) and Lilley et al. (2009), they found that the visual and auditory task were comparably effective to reduce the emotionality and vividness of auditory and visual memories. Similarly, Pearson and Sawyer (2011; Experiment 2) manipulated both the modality and cognitive load of dual-tasks and found that only tasks high in cognitive load, regardless of their modality, were effective to reduce intrusion development related to negative emotional pictures. Finally, in a study by Matthijssen, Verhoeven, van den Hout, and Heitland (2017), patients with PTSD were asked to recall predominantly visual or auditory memories. While recalling these memories, patients had to perform a visual task, auditory task, or a control task. Matthijssen et al. (2017) also found that the different tasks were comparably effective, regardless of the modality of the memories.

There are three important limitations with regard to the previous studies investigating modality-specific interference. First, the content of the memories was not controlled in most of the studies. That is, in the studies of Kemps and Tiggemann (2007), Lilley et al. (2009), Kristjánsdóttir and Lee (2011), and Matthijssen et al. (2017), participants were asked to think of predominantly visual or auditory memories. However, it is unclear to what extent participants were able to do so (or whether their memories were influenced by components of other sensory modalities). Indeed, Lilley et al. (2009) asked participants to estimate the proportion to which the different sensory modalities (visual, auditory, olfactory, gustatory, somatic) were represented in their memories. Visual components were the most common (65.3-70.6%), but auditory components were also often reported (14.2-23.3%). Similarly, Matthijssen et al. (2017) asked participants to rate to what extent memories were visual or auditory. On a 100-point scale they applied a 50% cut-off to classify memories as visual or auditory. These results of Lilley et al. (2009) and this procedural aspect of the study of Matthijssen et al. (2017) indicates that there is a substantial overlap in the modality of the memories in these studies. This may have obscured evidence for modality-specific interference because the modality-unmatched task (in most cases an auditory task) may have interfered with those components of the memory that were not specifically visual (but were most often auditory in nature). Second, the evidence for modality-specific interference with *auditory* memories remains scarce (with the exception of the studies by Baddeley & Andrade, 2000; and Experiment 2 in Kemps & Tiggemann, 2007). This poses a problem for generalizing these findings to other types of memories. Particularly auditory intrusive memories are often also involved in psychopathology (Engelhard, van den Hout, Arntz, & McNally, 2002; Hackmann, Ehlers, Speckens, & Clark, 2004; Homer & Deeprose, 2017). Third and final, none of these prior studies except Pearson and Sawyer (2011) controlled for the general cognitive load of the dual-tasks. This is problematic because the previously observed modality-specific effects could be attributed to the greater general (i.e., modality a-specific) load of the modality-matched dual-task (Kvavilashvili, 2014; Tadmor, McNally, & Engelhard, 2016). Without measurement of the general load of the dual-tasks, such an explanation cannot be excluded.

With the current experiments, we aimed to test modality-specific interfering effects of dual-tasks on emotional memories. We designed our experiments to overcome the previously mentioned limitations of prior studies investigating modality-specific interference with emotional memories. Particularly, first, we installed unimodal unpleasant memories by exposing participants to pictures and sounds from the International Affective Picture System (IAPS) database and the International Affective Digital Sounds (IADS) database. Hence, unlike the memories recalled by participants in the previous experiments, which may contain both visual and auditory components, we ensured the modality-specificity of participants' memories by controlling the stimulus material the memories were based on. Second, we fully crossed the modality of the memories with the modalities of the different tasks in our experiments. This allowed us to investigate modality-specific effects for both visual and the auditory memories. Finally, we conducted a short preliminary study to determine the general cognitive load of the dual-tasks we used in our experiments (see Footnote 1 and the Supplementary Materials). Our main hypothesis was that, based on WM theory (Baddeley & Andrade, 2000), modality-matched dual-tasks would more effectively degrade emotional visual and auditory memories than unmatched dual-tasks.

Experiment 1

Participants

Thirty-seven female students participated in this experiment. Specifically females were selected due to the content of our stimulus material (e.g., a women attacked by a knife, domestic violence against a female spouse; see below). One participant dropped out because she felt uncomfortable with the pictures, leaving a final sample of 36 participants. The sample size was based on an a-priori power analysis in G*power 3.1 (Faul, Erdfelder, Lang, & Buchner, 2007). Based on the lowest effect size (f = 0.25) of the planned contrasts comparing emotionality ratings in Kemps and Tiggeman (2007), a sample of 28 participants was needed to reach a statistical power of .80 and an alpha level of .05 for a fully within-subject repeated measures ANOVA. Because the counterbalancing procedure required a sample size of divisible by 12, the sample size was increased to 36. Participants were recruited at Utrecht University and were excluded if they had vision or hearing problems, used medication, were diagnosed with a psychiatric disorder, or had received psychological treatment; these were assessed by a self-report screening questionnaire. The protocol of this specific study was approved by the Ethics Committee of the Social Sciences faculty of Utrecht University (FETC19-067). All participants provided informed consent and received study credits or €8,00 for their participation.

Materials

Software and hardware. The computer task was programmed using Inquisit 4.0 (https://www.millisecond.com/) and ran on an HP Elitedesk 600 G1 desktop with a 23-inch HP EliteDisplay E232 monitor.

Stimulus material.

Visual stimuli. The visual stimuli were emotional pictures selected from the International Affective Picture System (IAPS) (Lang, Bradley, & Cuthbert, 2008), with the criterium that all three pictures were sufficiently negative (i.e., valence rating < 2.5). The selected pictures were IAPS picture 6350 (a man attacking a woman with a knife; IAPS database rating: valence: M = 1.90, SD = 1.29; arousal: M = 7.29, SD = 1.87), 3400 (a severed hand; IAPS database rating: valence: M = 2.35, SD = 1.90; arousal: M = 6.91, SD = 2.22), and 9181 (dead cows; valence: IAPS database rating: M = 2.26, SD = 1.85; arousal: M = 5.39, SD = 2.41). Pictures were randomly allocated to the different tasks for each participant.

Auditory stimuli. Auditory stimuli were selected from the International Affective Digital Sounds (IADS) database (M. M. Bradley & Lang, 2007), also with the criterium that all three were sufficiently negative. These were IADS sounds 277 (human scream; IADS database rating: valence: *M* = 1.63, *SD* = 1.13; arousal: *M* = 7.79, *SD* = 1.63), 279 (domestic violence; IADS database rating: valence: *M* = 1.68, *SD* = 1.31; arousal: *M* = 7.95, *SD* = 2.22), and 286 (pleading and gunshot; IADS database rating: valence: *M* = 1.68, *SD* = 1.18; arousal: *M* = 7.88, *SD* = 1.72). Sounds were randomly allocated to the different tasks for each participant.

Dual-tasks.

Visuo-spatial task. The visuo-spatial task consisted of individual letters that repeatedly appeared on alternating sides of the computer screen, presented on a background of black and white stripes (Homer, Deeprose, & Andrade, 2016). Participants were asked to respond to the target letter when it appeared on either side of the screen by pressing the spacebar. One trial consisted of the presentation of 30 non-target letters (e.g., ‘p’) and two target letters (e.g., ‘q’). The letters were displayed for 300 ms, with a 450 ms inter-stimulus interval (ISI)[1], resulting in a total duration of each trial of 24s. The task consisted of four trials with a 10s break between the trials. Participants were instructed to focus on the letters using their eyes without moving their head.

[1]These stimulus times were based on a preliminary study (*N* = 24) in which different versions of the visuo-spatial task were compared to the auditory task and a control task using a random interval repetition task (van den Hout, Engelhard, Rijkeboer, et al., 2011). Specifically, the letter-presentation duration and inter-stimulus interval of the visuo-spatial task were set to either 220 + 330 ms, 250 + 375 ms, and 300 + 450 ms. While executing the different tasks, participants had to react to a tactile stimulus (50 ms, inter-stimulus interval 950-1550 ms) by saying “yes” as quickly as possible in a microphone. Surprisingly, the three different versions of the visuo-spatial did not differ significantly from each other (*M* = 538, *SD* = 68; *M* = 530, *SD* = 86; and *M* = 535, *SD* = 52, for the fast, intermediate, and slow version, respectively; $F < 1$), and all these tasks were significantly more difficult than the control task (*M* = 384, *SD* = 50) and the auditory task (*M* = 473, *SD* = 68), *F*-values > 30. We decided to use the slowest version of the visuo-spatial task for the main experiment. Please see the Supplementary Materials for a full description of this preliminary study. Note that participants from the preliminary study were excluded from participation in the main study.

Auditory task. The auditory task consisted of spoken individual letters that were provided through headphones (Homer et al., 2016). Participants had to listen to the letters while looking at a blank screen. Again, participants had to respond to a given target letter by pressing the spacebar. The letters were pronounced in English by a female (20 items) or a male voice (19 items). One trial consisted of 24s in which 39 non-target letters (e.g., ‘d’) and two target letters (e.g., ‘p’) were presented. The letters were presented to both ears simultaneously for 588 ms, with no ISI in-between. The task consisted of four trials with a 10s break between trials.

Control task. In the control task, participants were asked to look at a blank screen. The task consisted of four trials of 24s with a 10s break between trials.

Procedure

Participants were placed in a soundproofed room, 60cm from the computer monitor. All participants performed all three tasks twice: after a visual memory induction and after an auditory memory induction. Order of the tasks (visuo-spatial, auditory, and control) and order of the memory induction (visual and auditory) were counterbalanced over participants (resulting in 12 possible orders; see sample size determination). Before memory induction and each task type, a practice trial of the dual-task was provided. Thereafter, participants were presented with either a negative picture or a negative sound. Both types of stimuli were matched in duration (i.e., 6s). Following the memory induction, a one minute break allowed for memory formation. Next, participants were asked to recall the memory as vividly and detailed as possible for 10s and to rate vividness and emotionality of the memory on a Visual Analog Scale (VAS) from 0 (‘Not at all clear’/’Not at all unpleasant’) to 100 (‘Very clear’/’Very unpleasant’). These pre-ratings were followed by one of the three tasks. During the performance of the tasks, participants had to recall the memory as vividly and detailed as possible for the duration of the trial (i.e., dual-task), and they could let go of the memory during the 10s breaks. At the end of each task, post-ratings for vividness and emotionality were assessed, identical to the pre-rating (i.e., participants had to recall the memory for 10s and then rate vividness and emotionality). Finally, participants were asked how well they were able to keep the visual/auditory memory in mind during the visuo-spatial/auditory/control task. These ease of memory retrieval ratings were answered on VASs from 0 ('Not at all well') to 100 ('Very well').

Data Analysis

To assess the difference between modality-matched and unmatched dual-tasks, two separate 2 (Memory: visual, auditory) by 3 (Task: visuo-spatial, auditory, control) by 2 (Time: pre vs post task) within-subjects repeated measures analysis of variances (ANOVAs) with emotionality ratings and vividness ratings as dependent variables were performed. Ease of memory retrieval ratings for the different tasks were analyzed using a 2 (Memory: visual, auditory) by 3 (Task: visuo-spatial, auditory, control) within-subjects repeated measures ANOVA. When the assumption of sphericity was violated, the Greenhouse-Geisser corrections are reported. The alpha-level was set at .05 for all analyses. Data analyses were executed in RStudio (version 1.1.453).

Results

Emotionality ratings. The ANOVA with emotionality ratings as dependent variable (see Figure 1) showed a main effect of Memory with higher ratings for the auditory memories (M = 66.18, SD = 18.96) than for the visual memories (M = 58.74, SD = 18.01), $F(1, 35) = 17.26$, $p < .001$, $\eta^2_p = .33$, 90% CI [0.12, 0.49]. Furthermore, a significant main effect of Time was observed, with higher emotionality ratings before than after the task (see Figure 1), $F(1, 35) = 57.43$, $p < .001$, $\eta^2_p = .62$, 90% CI [0.43, 0.72]. A significant interaction effect between Memory and Task was also found, $F(2, 70) = 3.31$, $p = .042$, $\eta^2_p = .09$, 90% CI [0.00, 0.19]. This interaction was due to higher emotionality ratings for the auditory memories, particularly in the condition with the control task (see Figure 1). Also a significant interaction between Task and Time was observed, $F(2, 70) = 5.63$, $p = .005$, $\eta^2_p = .14$, 90% CI [0.03, 0.25]. This interaction was due to stronger decreases in emotionality ratings after the auditory task ($M_{diff} = 11.64$, $SD = 11.44$) and the visuo-spatial task ($M_{diff} = 10.86$, $SD = 9.40$) than after the control task ($M_{diff} = 6.10$, $SD = 8.17$). Finally, the crucial three-way interaction between Memory, Task, and Time was not significant, $F(2, 70) = 2.16$, $p = .123$, $\eta^2_p = .06$, 90% CI [0.00, 0.15].

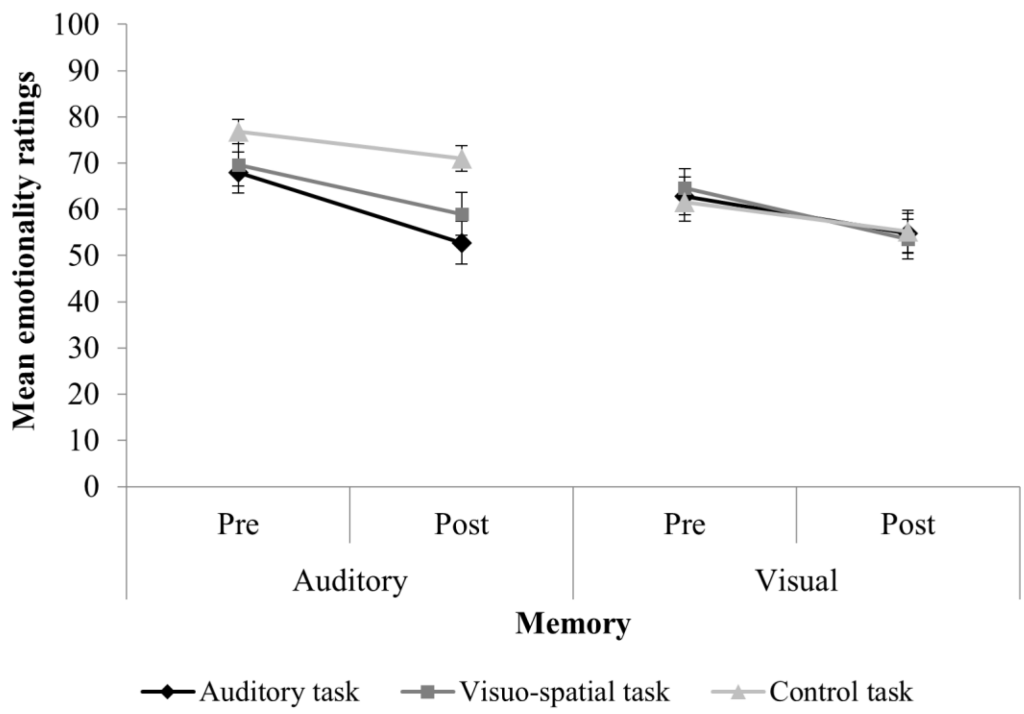

Figure 1. Mean emotionality ratings in Experiment 1 for the auditory and visual memory, pre and post executing the auditory, visual, and control task. Error bars reflect standard error of the mean.

Vividness ratings. The ANOVA with vividness ratings as dependent variable showed a significant main effect for Task, $F(2, 70) = 8.17$, $p < .001$, $\eta^2_p = .19$, 90% CI [0.06, 0.31], and Time, $F(1, 35) = 85.42$, $p < .001$, $\eta^2_p = .71$, 90% CI [0.55, 0.79]. Furthermore, significant interactions between Task and Time, $F(2, 70) = 11.05$, $p < .001$, $\eta^2_p = .24$, 90% CI [0.10, 0.36], and between Memory and Time, $F(1, 35) = 4.14$, $p = .049$, $\eta^2_p = .11$, 90% CI [0.00, 0.27], were found. Importantly, a significant three-way interaction between Memory, Task, and Time was found, $F(2, 70) = 6.08$, $p = .004$, $\eta^2_p = .15$, 90% CI [0.03, 0.26]. This interaction was due to larger reductions in vividness ratings for auditory memories after the auditory task ($M_{diff} = 26.08$, $SD = 22.07$) than after the visuo-spatial task ($M_{diff} = 15.19$, $SD = 14.12$) or the control task ($M_{diff} = 10.36$, $SD = 11.04$). Likewise, reductions in vividness ratings for visual memories were slightly larger after the visuo-spatial task ($M_{diff} = 16.17$, $SD = 16.81$) than after the auditory task ($M_{diff} = 13.64$, $SD = 12.37$) or the control task ($M_{diff} = 11.17$, $SD = 12.01$; see Figure 2).

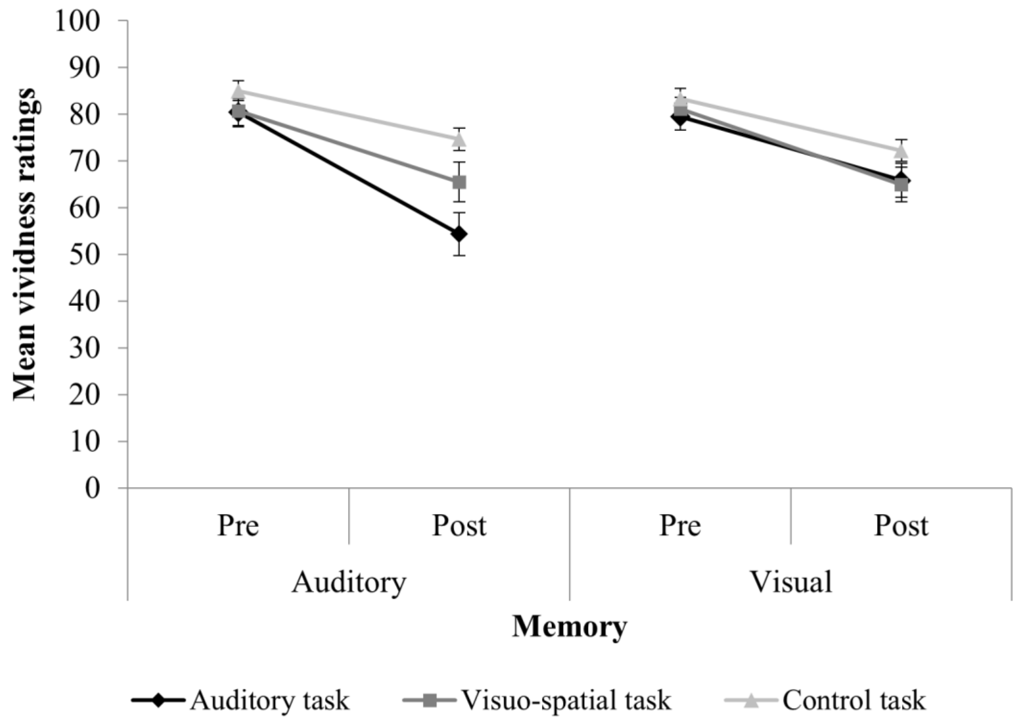

Figure 2. Mean vividness ratings in Experiment 1 for the auditory and visual memory, pre and post executing the auditory, visual, and control task. Error bards reflect standard error of the mean.

Ease of memory retrieval ratings. The ANOVA with memory retrieval easiness ratings as dependent variable showed a significant main effect of Task, $F(1.72, 60.21) = 46.34$, $p < .001$, $\eta^2_p = .57$, 90% CI [0.42, 0.66], and a significant interaction between Memory and Task, $F(1.31, 45.98) = 13.61$, $p < .001$, $\eta^2_p = .28$, 90% CI [0.10, 0.42]. The main effect of Task was due to the fact that participants found it easier to recollect memories when they performed the control task ($M = 79.13$, $SD = 15.26$) than when they performed the visuo-spatial task ($M = 56.35$, $SD = 17.07$) or the auditory task ($M = 56.06$, $SD = 15.99$). Importantly, the interaction between Task and Memory was due to the fact that participants found it easier to recollect the auditory memory when they performed the visuo-spatial task ($M = 62.14$, $SD = 22.43$) than when they performed the auditory task (*M* = 50.50, *SD* = 22.31), and vice versa (visual memory and auditory task: *M* = 61.61, *SD* = 18.27; visual memory and visuo-spatial task: *M* = 50.56, *SD* = 20.46).

Discussion

The results of this first study provide evidence for modality-specific interference with emotional memories using vividness self-report ratings. Furthermore, we found that participants consistently reported that retrieving the memories was more difficult while executing a modality-matched dual-task than an unmatched task or the control task. However, no modality-specific interference effect was found for emotionality ratings of the memories. This is a limitation of this first study, because for clinical purposes it is important to also obtain effects on the experienced emotional intensity of memories. In addition, this first study consisted primarily of students enrolled in the Research Master program in Psychology at Utrecht University. Such a specific sample may have potentially influenced the results because participants may have been aware of multiple-component working memory models and the effects of dual-tasks on emotional memories.

To address the lack of evidence for modality-specific effects for memory emotionality and potential sample bias, we conducted a second pre-registered study (Experiment 2) with a larger sample size and screened participants for their prior knowledge of multiple-component WM models and EMDR therapy.

Experiment 2

Pre-registration

The power calculation, sample size, design, procedure, and data analyses steps for this experiment were pre-registered on the Open Science Framework (OSF) prior to the data collection (https://osf.io/dc2u3/). Furthermore, the experiment code, data files, and data analyses scripts for both experiments can be obtained via this OSF project.

Participants

Sixty female participants with a mean age of 22.73 (*SD* = 2.32) participated in this second experiment. The sample size was determined on the basis of the data of Experiment 1. Particularly, emotionality data were restructured into two variables: congruent modality and incongruent modality and an effect size of $d_z = 0.31$ was found. An a-priori sample size calculation using a dependent t-test in G*power with an alpha-level of .05 and statistical power of .80 indicated a required sample of 66 participants. Because of the counterbalancing procedure (the sample size needs to be divisible by 12) and feasibility, the target sample size was set at 60 participants. The exclusion criteria, prescreening questionnaire, and reimbursement were identical to Experiment 1.

Materials and Procedure

The materials and procedure of this second study were identical to Experiment 1. In addition, at the end of the experiment, participants were asked about their prior knowledge about Baddeley's working memory model and EMDR therapy to explore whether prior knowledge impacts the results. Six participants had prior knowledge of Baddeley's working memory model and 16 participants had prior knowledge of EMDR (two participants had both)[2].

Data reduction and analysis

Data preparation and statistical analyses were identical to Experiment 1.

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[2] Analyses including only participants who had no prior knowledge of EMDR and WM theory showed the same results on all outcome measures as the analyses with the full sample. For brevity we only report the results with the full sample here. Please see the provided data files and syntax (https://osf.io/dc2u3/) for the analyses with the restricted sample.

Results

Emotionality ratings. The ANOVA with emotionality ratings as dependent variable (see Figure 3) showed a main effect of Memory, $F(1, 59) = 4.76$, $p = .033$, $\eta^2_p = .08$, 90% CI [0.00, 0.20], with higher ratings for the auditory memories ($M = 65.52$, $SD = 15.94$) than visual memories ($M = 61.71$, $SD = 17.08$). A main effect of Time was also found with higher ratings before compared to after the task, $F(1, 59) = 141.79$, $p < .001$, $\eta^2_p = .71$, 90% CI [0.59, 0.77]. A significant interaction between Memory and Time was found, $F(1, 59) = 18.49$, $p < .001$, $\eta^2_p = .24$, 90% CI [0.09, 0.38], due to a stronger decrease of emotionality ratings for auditory memories than for visual memories (see Figure 3). No other effects were found, F-values < 1.

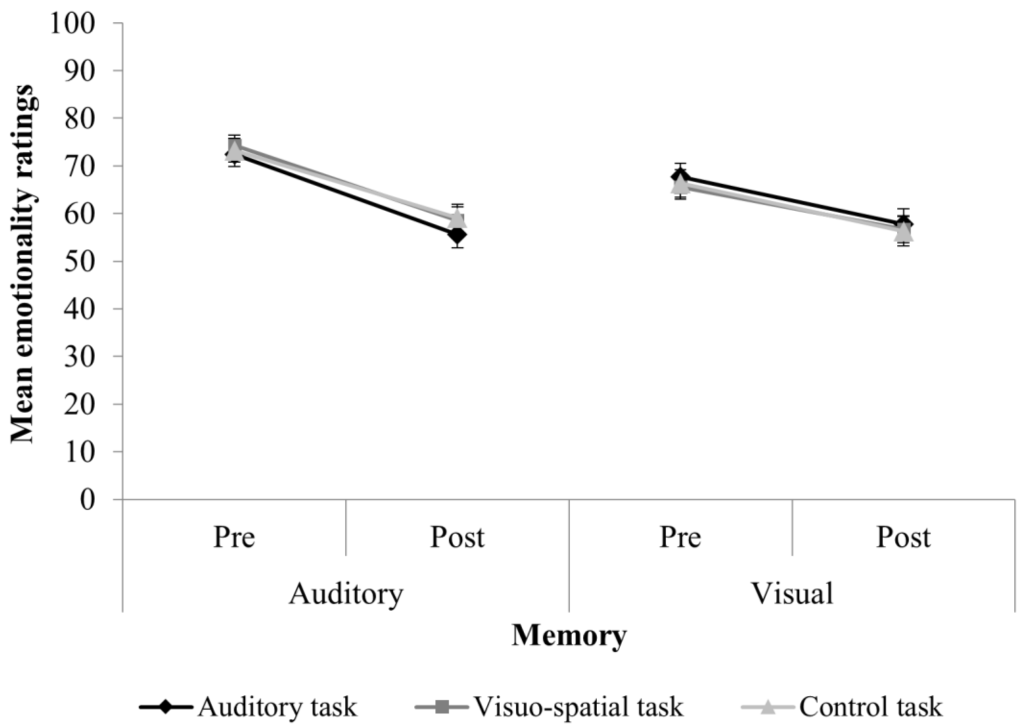

Figure 3. Mean emotionality ratings in Experiment 2 for the auditory and visual memory, pre and post executing the auditory, visual, and control task. Error bars reflect standard error of the mean.

Vividness ratings. The ANOVA with vividness ratings as dependent variable (see Figure 4) showed a main effect of Time, $F(1, 59) = 209.58$, $p < .001$, $\eta^2_p = .78$, 90% CI [0.69, 0.83], an interaction effect between Memory and Task, $F(2, 118) = 3.81$, $p = .003$, $\eta^2_p = .06$, 90% CI [0.00, 0.13], and an interaction effect between Memory and Time, $F(1, 59) = 28.62$, $p < .001$, $\eta^2_p = .33$, 90% CI [0.17, 0.46]. Importantly, a significant three-way interaction was found between Memory, Task, and Time, $F(2, 118) = 6.89$, $p = .001$, $\eta^2_p = .11$, 90% CI [0.03, 0.19]. The reason for this three-way interaction was slightly different than in Experiment 1. Particularly, reductions in vividness ratings for auditory memories were larger after the auditory task ($M_{diff} = 23.85$, $SD = 16.55$) and the visuo-spatial task ($M_{diff} = 22.32$, $SD = 16.91$), than after the control task ($M_{diff} = 17.40$, $SD = 16.63$). However, reductions in the vividness ratings for visual memories were larger after the control task ($M_{diff} = 16.78$, $SD = 17.09$) than with the visuo-spatial task ($M_{diff} = 11.82$, $SD = 12.23$) or the auditory task ($M_{diff} = 12.93$, $SD = 11.94$; see Figure 4).

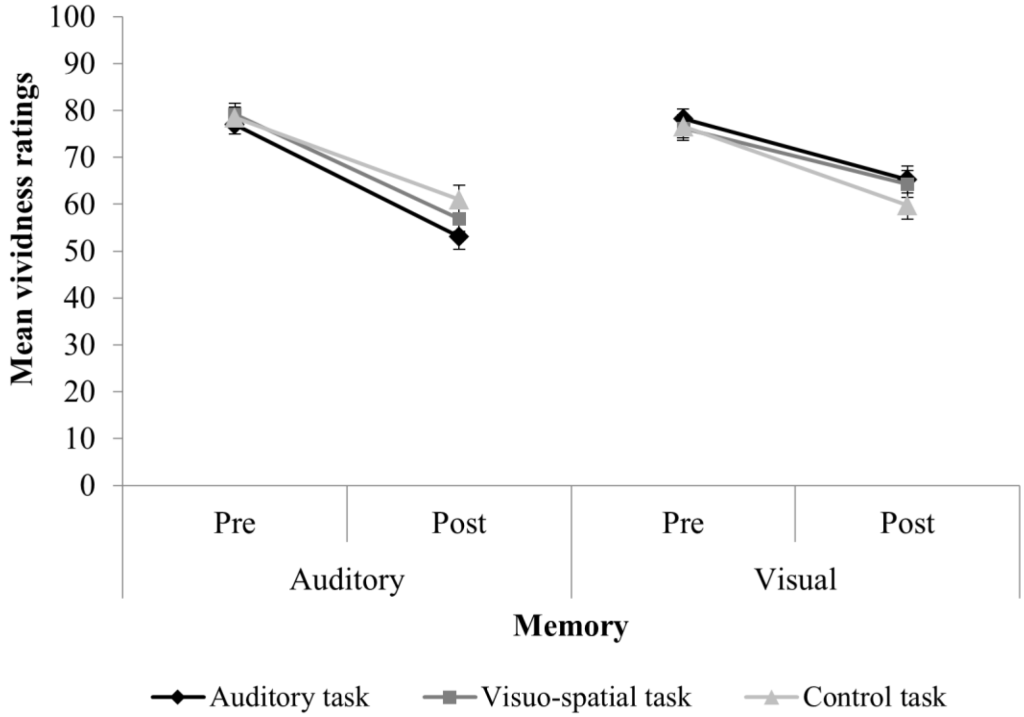

Figure 4. Mean vividness ratings in Experiment 2 for the auditory and visual memory, pre and post executing the auditory, visual, and control task. Error bars reflect standard error of the mean.

Memory retrieval easiness. The ANOVA with ease of memory retrieval as dependent variable showed a significant main effect of Task, $F(1.70, 100.18) = 39.83$, $p < .001$, $\eta^2_p = .40$, 90% CI [0.28, 0.50], and a significant interaction between Task and Memory, $F(1.39, 82.27) = 34.66$, $p < .001$, $\eta^2_p = .37$, 90% CI [0.23, 0.48]. As in Experiment 1, participants found it easier to recollect the memories during the control task ($M = 71.92$, $SD = 19.63$) than during the visuo-spatial task ($M = 55.18$, $SD = 20.57$) or the auditory task ($M = 49.63$, $SD = 22.13$). Importantly, they found it easier to recollect the auditory memory during the visuo-spatial task ($M = 61.25$, $SD = 23.59$) than during the auditory task ($M = 41.87$, $SD = 23.57$), and vice versa (visual memory and auditory task: $M = 57.38$, $SD = 25.69$; visual memory and visuo-spatial task: $M = 49.10$, $SD = 22.76$).

Discussion

In this second experiment we set out to replicate the results obtained in our first experiment also for emotionality ratings and to control for potential bias in our results due to prior knowledge by participants. The results of Experiment 1 were partially replicated in this second experiment. Particularly, we found a similar interaction between task and memory modality for vividness ratings and memory retrieval easiness ratings. The pattern of results for memory retrieval easiness ratings was in fact identical to the results in Experiment 1, with memory retrieval being more difficult when the modality of the memory and the task overlapped than when these did not overlap. The interaction observed for memory vividness ratings in Experiment 2 was partly due to the control task: Reductions in memory vividness were more outspoken for auditory memories after the auditory and visuo-spatial tasks than after the control task, and the reverse was true for visual memories. Most importantly, as in Experiment 1, we did not obtain any evidence for modality-specific effects on memory emotionality ratings.

Combined Bayesian Analyses

The results of Experiment 1 and 2 only provide mixed evidence for the hypothesis that modality-specific tasks are more effective to change the vividness and emotionality of negative emotional memories than nonspecific tasks. In order to obtain more definitive evidence for the advantage of modality-specific interference, we decided to perform Bayesian analyses on the combined data of Experiment 1 and 2. There are several advantages to using Bayesian analyses that are relevant for our research. First, Bayesian analysis does not depend on the sampling plan of studies. This differs from Null Hypothesis Significance Testing (NHST) in which the probability of the data given the null hypothesis is quantified (expressed as the *p*-value) and where the goal is to keep the false-positive rate under a certain threshold (usually 5%).

Combining the data of two independent samples using NHST to test the same hypothesis would inflate the false-positive rate and thus requires a correction of the alpha-value (which in turn results in a loss of statistical power). In contrast, Bayesian analysis does not inflate the false-positive rate because it does not rely on significance testing, but rather quantifies the support for competing hypotheses. Thus, Bayesian analysis provides an efficient way to evaluate our hypotheses on the basis of the combined data of both experiments (Dienes, 2011; Krypotos, Blanken, Arnaudova, Matzke, & Beckers, 2017). Second, Bayesian analysis can provide a quantification of the support for the null hypothesis (Dienes, 2014; Krypotos et al., 2017). For our purposes (i.e., establishing whether modality-specific interference is more effective to change negative emotional memories) it is useful to know whether or not the null hypothesis is supported.

For these reasons, we combined the data of Experiment 1 and 2 and analyzed the results using Bayesian repeated measures ANOVA with JASP (v0.8.1.2), using default priors (Rouder, Morey, Speckman, & Province, 2012). Similar to Experiment 1 and 2, memory emotionality and vividness ratings were analyzed with a 2 (Memory: visual, auditory) by 3 (Task: visuo-spatial, auditory, control) by 2 (Time: pre vs post task) Bayesian repeated measures ANOVA. Memory retrieval ease ratings were analyzed using a 2 (Memory: visual, auditory) by 3 (Task: visuo-spatial, auditory, control) Bayesian repeated measures ANOVA. The statistic of interest was the Bayes Factor (BF) for the three-way interaction between Memory, Task, and Time for memory emotionality and vividness ratings, and the two-way interaction between Memory and Task for memory retrieval easiness ratings. BF_{10} provides a quantification of the relative support of the alternative hypothesis over the null hypothesis, whereas BF_{01} provides a quantification of the relative support of the null hypothesis over the alternative hypothesis. Descriptive statistics for the combined data of Experiment 1 and 2 are provided in Tables S1, S2, and S3 of the Supplementary Materials.

Results

Emotionality ratings. Bayesian analysis of the emotionality ratings did not provide support for an interaction between Memory, Task, and Time. Instead, the results of the Bayesian repeated measures ANOVA strongly favored the null hypothesis: BF_{01} for the three-way interaction between Memory, Task, and Time = 500.

Vividness ratings. Bayesian analysis of the vividness ratings did not provide convincing evidence for the null or the alternative hypothesis: BF_{01} for the three-way interaction between Memory, Task, and Time = 1.05.

Memory retrieval ease ratings. The Bayesian repeated measures ANOVA for the memory retrieval easiness ratings provides overwhelming support for the interaction between Memory and Task, $BF_{10} > 10000$.

General Discussion

In two studies, we addressed the hypothesis that executing a modality-matched dual-task while recalling a modality-specific emotional memory would show stronger degrading effects on the memories than executing a modality-unmatched dual-task. Our studies improved on previous work by creating modality-specific memories by using pictures and sounds from the IAPS and IADS databases, respectively, by using a within-subjects design including both visual and auditory memories, and by measuring the general cognitive load of the used tasks. In contrast to our expectations, we did not consistently observe a substantial advantage of modality-matched dual-tasks in our two studies. Particularly, some evidence for superior effects of modality-matching was found for memory vividness ratings in Experiment 1 and for retrieval ease ratings in both experiments. However, in neither experiment, nor in the combined analyses of the two experiments, did we find evidence for modality-specific interference on memory emotionality ratings.

The results of our studies add to the limited set of experiments investigating the role of modality-specific interference with emotional memories. Particularly, our experiments confirm the conclusions of Kristjánsdóttir and Lee (2011) and Matthijsen et al. (2017) that modality-matched dual-tasks do not seem to outperform modality-unmatched dual-tasks to decrease the emotionality and vividness of emotional visual or auditory memories. Furthermore, our findings are not entirely in contrast with the earlier findings by Kemps and Tiggemann (2007) and Lilley et al. (2009) either. These studies did indeed provide evidence for an advantage of modality-matched dual-tasks. However, a closer look at the findings of these studies reveals that they are quite consistent with our own observations. First, both studies indicated that also tasks which do not match the modality of the emotional memory can effectively decrease reported emotionality and vividness of these memories. Hence, regardless of any modality-specific effects, both studies indicated that dual-tasks which impose a cognitive load can impact emotional memories, similar to what was observed in the studies which did not find a modality specific advantage. Notably, in the second experiment reported by Kemps and Tiggemann, the general effect of conducting a dual-task was relatively more outspoken (f = .73 and .86 for vividness and emotionality ratings, respectively) than the modality-specific effects of the dual-tasks (f = .32 and .36 for vividness and emotionality ratings, respectively). Second, the results of Lilley et al. (2009) indicated that the advantage of modality-specific interference was specifically outspoken *during* the execution of the task, but this advantage was not maintained at a one-week follow-up test. This finding corresponds with our own observation that participants judged recollecting a memory as more difficult *while* conducting the dual-task that matched the modality of the memory. However, this modality-specific advantage was not observed anymore when participants' rated the vividness and emotionality of the memory *after* the task was concluded. Hence, taken together, both the current experiments and earlier studies indicate that there may be a slight advantage for modality-matched dual-tasks to interfere with emotional memories, but this advantage may be limited to within-task recollection.

With regard to practical implications, two observations from our experiments merit some further consideration. First, as mentioned, participants consistently reported that it was more difficult to recollect a memory when conducting a modality-matched dual-task. Hence, our manipulation worked and this pattern of results is consistent with observations from the WM literature that there is more interference between material processed by the same subsystem of WM than material processed by different subsystems (Andrade et al., 1997; Baddeley, 2012). Surprisingly, this greater difficulty of recollecting the memories did not translate into greater reductions of the emotionality of the memory when there was modality overlap between the memory and the task. This suggests that recollection difficulty during recall is not necessarily translated into reduced emotionality of the long-term memory, as we will discuss further below. Second, in both experiments we found some evidence for modality-specific effects on memory vividness ratings, and these were more outspoken for auditory memories than for visual memories. In particular, reductions in memory vividness of auditory memories were substantially larger when executing the auditory dual-task (Experiment 1: M_{diff} = 26.08, SD = 22.07; Experiment 2: M_{diff} = 23.85, SD = 16.55) than when executing the visuo-spatial dual-task (Experiment 1: M_{diff} = 15.19, SD = 14.12; Experiment 2: M_{diff} = 22.32, SD = 16.91). In contrast, there was only a small advantage to reduce memory vividness of visual memories by executing the visuo-spatial dual-task (Experiment 1: M_{diff} = 16.17, *SD* = 16.81; Experiment 2: M_{diff} = 11.82, *SD* = 12.23) compared to executing the auditory dual-task (Experiment 1: M_{diff} = 13.64, *SD* = 12.37; Experiment 2: M_{diff} = 12.93, *SD* = 11.94). These larger modality-specific effects for the auditory tasks than for the visuo-spatial task cannot be explained by a difference in general difficulty of the two tasks because the results of a preliminary study indicated that the auditory task was easier to execute than the visuo-spatial task (see Footnote 1). Hence, it may potentially be the case that auditory memories are more sensitive to modality-specific interference than visual memories. This could be a relevant observation for clinical practice given that trauma-exposed individuals and patients often also report to suffer from auditory memories (Hackmann et al., 2004). Hence, when patients report to suffer from auditory intrusive memories, it may be worthwhile to consider including an auditory task in EMDR treatment. However, this suggestion should be taken with care given the inconclusive results from our two experiments. Further research (possibly with our material provided through OSF; see above) is required to establish whether auditory memories are sensitive to modality-specific interference.

With regard to theoretical implications, the findings of our experiments are relevant for the WM theory of EMDR therapy and laboratory analogues. WM theory provides a useful framework to organize existing knowledge and to generate novel hypotheses regarding EMDR therapy (van den Hout & Engelhard, 2012). However, several crucial predictions of WM theory have not received unequivocal support. In particular, some prior studies have found that more difficult tasks (which should tax WM more) do not necessarily outperform easier tasks (Engelhard, van Uijen, & van den Hout, 2010; Mertens et al., 2018; van den Hout et al., 2010). Furthermore, WM taxation is not consistently correlated with the effectiveness of dual-tasks (Engelhard et al., 2010; Mertens et al., 2018; van den Hout, Engelhard, Beetsma, et al., 2011).

The current experiments add to this set of unconfirmed predictions of WM theory by demonstrating that matching the modality of the dual-task does not necessarily improve the memory degrading effects of the dual-task. These results suggest that the WM theory for EMDR therapy may be too simplified. Most likely other factors are at play that mediate the effectiveness of EMDR therapy, besides WM interference, such as changed memory appraisals (e.g., changed meaning or negativity of the memory; see Gunter & Bodner, 2008) and positive expectancies of patients and students in the laboratory (Gunter & Bodner, 2008; Shapiro & Forrest, 2016). Future studies should take these factors into account and investigate whether and how they are related to the effectiveness of EMDR therapy and its laboratory analogue.

Finally, several limitations of our experiments should be acknowledged. First, they were conducted in the lab with students. Hence, it is unsure whether the results from our experiments generalize to treatment setting involving patients diagnosed with PTSD or other anxiety disorders. Relatedly, the memories we have investigated in our experiments were induced using emotional pictures and sounds that are only mildly emotional and which were only presented to participants for 6 seconds just before conducting the dual-tasks. This differs considerably from emotional autobiographical memories of patients diagnosed with PTSD or students in terms of memory complexity, intensity, age, and personal-relevance. Second, the visual and auditory dual-tasks were not matched in general cognitive load (see Footnote 1 and the Supplementary Material). Though our preliminary study to assess the cognitive load improves on prior studies in which no information of the cognitive load about the tasks was available, the observed difference in cognitive load complicates the interpretation of our findings. Future studies should extend efforts to equate the difficulty of the dual-tasks. A related issue is that during the auditory task, letters were presented simultaneously to both ears. Future studies may consider adapting the auditory task by alternating presentation of letters to each ear in order to further investigate the hypothesis that EMDR-related interventions work through bilateral hemispheric activation (Propper & Christman, 2008). Finally, we investigated the effects of a brief intervention (four times 24s) and did not assess long-term effects. To establish whether conclusions also hold in a therapy setting, translational research should be conducted using clinical protocols (i.e., using more extended interventions), effects should be assessed over longer durations (i.e., multiple days, weeks, or months), and should include the target populations (i.e., sub-clinical populations or anxiety-disorder patients).

Author Contribution Statement

GM, JFA, and IME conceptualized the design of the experiments. JFA and VB collected the data of Experiment 1 and 2, respectively. GM and VB analyzed the results. GM drafted the manuscript. IME, VB, and JFA critically revised the manuscript and have approved the final version of the manuscript.

Conflict of Interest Statement

The author(s) declared no conflicts of interest with respect to the authorship or the publication of this article.

Data and Material Availability Statement

The data, analyses syntax, and material of the experiments reported in this article are available at https://osf.io/zgw3r/.

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