J. Behav. Ther. & Exp. Psychiat. 52 (2016) 45–50

Contents lists available at ScienceDirect

Journal of Behavior Therapy and Experimental Psychiatry

journal homepage: www.elsevier.com/locate/jbtep

Degrading emotional memories induced by a virtual reality paradigm

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A R T I C L E I N F O

Article history:
Received 5 November 2015
Received in revised form
1 March 2016
Accepted 7 March 2016
Available online 10 March 2016

Keywords:
Virtual reality
Trauma film paradigm
EMDR
Working memory
Shape sorter
PTSD

A B S T R A C T

Background and objectives: In Eye Movement and Desensitization and Reprocessing (EMDR) therapy, a dual-task approach is used: patients make horizontal eye movements while they recall aversive memories. Studies showed that this reduces memory vividness and/or emotionality. A strong explanation is provided by working memory theory, which suggests that other taxing dual-tasks are also effective. Experiment 1 tested whether a visuospatial task which was carried out while participants were blindfolded taxes working memory. Experiment 2 tested whether this task degrades negative memories induced by a virtual reality (VR) paradigm.
Methods: In experiment 1, participants responded to auditory cues with or without simultaneously carrying out the visuospatial task. In experiment 2, participants recalled negative memories induced by a VR paradigm. The experimental group simultaneously carried out the visuospatial task, and a control group merely recalled the memories. Changes in self-rated memory vividness and emotionality were measured.
Results: The slowing down of reaction times due to the visuospatial task indicated that its cognitive load was greater than the load of the eye movements task in previous studies. The task also led to reductions in emotionality (but not vividness) of memories induced by the VR paradigm.
Limitations: Weaknesses are that only males were tested in experiment 1, and the effectiveness of the VR fear/trauma induction was not assessed with ratings of mood or intrusions in experiment 2.
Conclusions: The results suggest that the visuospatial task may be applicable in clinical settings, and the VR paradigm may provide a useful method of inducing negative memories.

1. Introduction

In the late eighties, Francine Shapiro introduced a new therapy for post-traumatic stress disorder (PTSD) called eye movement desensitization and reprocessing (EMDR; Shapiro, 1989a, 1989b). One of the key components of the protocol, which is unique to EMDR, is a dual-task approach: the patient holds the traumatic memory in mind while making eye movements by simultaneously tracking the therapist's finger as it moves horizontally across the patient's visual field (Shapiro, 2001). Because EMDR also shares many components with well-established interventions, and there was no strong rationale for using eye movements, skeptics suggested that the eye movements component was unnecessary (see Engelhard, 2012). However, a recent meta-analysis has shown that the addition of eye movements leads to superior results (Lee & Cuijpers, 2013).

Various theories were put forward to explain the effects of eye movements in EMDR. For instance, Christman, Garvey, Propper, and Phaneuf (2003) proposed that horizontal eye movements enhance the ability to retrieve memories of traumatic events due to increased interhemispheric interaction, which may enhance effects of techniques such as exposure. A growing body of research, however, indicates that horizontal eye movements do not improve free recall performance (Matzke et al., 2015). Moreover, Gunter and Bodner (2008) found that vertical eye movements were as effective as horizontal eye movements; both led to an equal decrease in vividness and emotionality of memories. Another theory came from Stickgold (2002), who argued that the repetitive redirecting of attention in EMDR induces a neurobiological state that is similar to that of rapid eye movement (REM) sleep. REM sleep seems to be optimally configured to support the integration of traumatic memories into general semantic networks (Stickgold, 2002, 2008). However, as Pitman et al. (1996) mentioned, there is a lack of phenomenological correspondence between the rhythmic eye movements induced by EMDR and the spontaneous, arrhythmic, non-saccadic eye movements that occur during REM sleep.

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http://dx.doi.org/10.1016/j.jbtep.2016.03.004
0005-7916/

Gunter and Bodner (2008) also put another hypothesis to the test derived from working memory (WM) theory. Andrade, Kavanagh, and Baddeley (1997) hypothesized that both making eye movements and keeping a visual image in mind tax the visuospatial sketchpad (VSSP) of WM, which leads to a reduction of the vividness and emotionality of the image. In contrast to this VSSP version of the WM account, Gunter and Bodner (2008) argued that eye movements are effective because they tax the limited capacity of the central executive (CE). These two WM accounts are not incompatible. Research showed that eye movements work better for visual emotional memories and an auditory dual-task works better for auditory memories; yet these modality-specific effects of dual-tasks are superimposed on general effects (Kemps & Tiggemann, 2007; but see Tadmor, McNally, & Engelhard, 2015). The WM account is substantiated by studies that showed that tasks other than eye movements, such as copying the Rey complex figure (Gunter & Bodner, 2008), attentional breathing (van den Hout et al., 2011a) and playing the computergame Tetris (Engelhard, van Uijen, & van den Hout, 2010) are effective as well. Although multiple mechanisms may underlie the effects of eye movements in EMDR (Leeds & Korn, 2012), the WM account provides a solid explanation of the effectiveness of other tasks.

The experiments in which effects of 'recall with dual-tasking' are compared with 'recall only', serve as laboratory models of therapy procedures like EMDR. The recalled memories in these experiments are typically aversive and autobiographical (van den Hout & Engelhard, 2012). The use of autobiographical memories may enhance the ecological validity of inferences, but an obvious disadvantage is that the nature of the recalled memories is not under experimental control and may differ substantially between participants. The use of 'trauma films' relating to e.g. traffic accidents (Holmes & Bourne, 2008) may provide an alternative, but a drawback seems to be that watching film clips is a somewhat passive endeavor and lacks active behavioral engagement. Therefore, in the present study, we explored the utility of a VR paradigm in which participants had to navigate through an immersive VR environment by using a button hand controller. This environment was interactive, as it responded to both the participants' viewing directions and their button input.

In recall with dual-tasking vs. recall only studies, the dual-task most often used consists of eye movements (van den Hout & Engelhard, 2012). Here, we explored the utility of using a non-visual task on VR-induced memories instead of eye movements for two reasons. First, given that the recall with dual-task paradigm serves as an experimental model, it would be worthwhile to have a task that could be used not only during memory recall, but also during exposure to visual reminders of the memorized events. Furthermore, adding non-visual tasks to the library of suitable tasks allows patients with limited or no eyesight to benefit from EMDR therapy as well; the commonly used auditory task in EMDR is far less effective than eye movements, as it requires less concentration and no motor operations (van den Hout & Engelhard, 2012; van den Hout et al., 2011b). We expected that the non-visual task would tax WM, making it useful for the practice of EMDR. Experiment 1 tested whether the task indeed taxes WM. Experiment 2 tested whether the task also reduces vividness and emotionality of emotional memories. We used a VR paradigm to induce negative memories in healthy participants, and compared the influence of the dual-task intervention on the vividness and emotionality of these negative memories to that of recall only.

2. Experiment 1

2.1. Introduction

The non-visual task was a shape sorter task that had to be carried out while being blindfolded. A very similar visuospatial task – shaping plasticine into small cubes and pyramids as fast as possible while the hands are covered with a box – reduced memory vividness and emotionality, as well as intrusion frequency in a previous study (Krans, Näring, Holmes, & Becker, 2010). We tested whether the shape sorter task taxes WM by means of a Reaction Time (RT) task in which participants had to respond to auditory cues. The performance on this task alone was compared to the performance on both tasks simultaneously (WM taxing: single-task vs. dual-task). A slowing down of RTs due to dual-task processing indicates the presence and severity of WM taxing by the shape sorter task (Bower & Clapper, 1989; see also van den Hout & Engelhard, 2012). Because haptic processing of peripersonal space comprises several attention-demanding components, such as identifying the nature of objects (Baddeley, 2001; 2012; Postma, Zuidhoek, Noordzij, & Kappers, 2007), we expected dual-task processing to result in higher RTs.

2.2. Method

2.2.1. Participants

Twenty male coworkers of a Dutch company (Triple IT) participated. One participant's data were excluded from the analysis, because he finished the shape sorter task before the RT task was over. The mean age of the remaining 19 participants was 28.8 years (range 22–45; $SD = 6.5$).

2.2.2. Tasks

2.2.2.1. Random interval repetition (RIR) task. Participants were blindfolded and wearing headphones, and received auditory cues (beeps; 200 Hz) with varying intervals (850 and 1450 ms). They were asked to respond as fast as possible when they heard a beep, by pressing a foot pedal with their right foot. The task contained 20 practice trials followed by 40 experimental trials. RTs below 200 ms were not registered, and responses exceeding 2000 ms were recorded as misses. The RIR provides a valid measure of WM taxation (Vandierendonck, De Vooght, & Van der Goten, 1998; see also van den Hout & Engelhard, 2012).

2.2.2.2. Shape sorter task. A shape box was positioned in front of the participants. The box (150 × 150 × 150 mm) had holes on 4 sides, of which only the front-(4 holes) and topside (3 holes) were used in the experiment. Seven different figures lied in front of the box, and each matched a different hole in the box. Participants were instructed to try to put these figures into the matching holes with their hands. The experimenter stressed that it was important to carefully explore the holes and figures before trying to match them, instead of trying to push the figures through every hole until a match is found. We expected this to lead to greater VSSP taxing, because participants had to identify the nature of the figures and create a conscious image of where objects were.

2.2.3. Procedure

After receiving the task instructions and signing the consent form, participants sat down behind a desk. They were asked to take off their right shoe and place their foot on the foot pedal underneath the desk. When a comfortable position was found, they were blindfolded by a head-mounted display (HMD), so that they would keep their eyes open, and were given headphones to put over their ears. Next, half of the participants (randomly assigned) first carried out the RIR task without the shape sorter task and then carried out both tasks simultaneously. The other half did this in reverse order. After these tasks, participants were debriefed.

2.2.4. Materials

A Lenovo ThinkPad E540 laptop was used. The foot pedal was made out of a Logitech Media Keyboard 600 by the removal of all buttons except the L-button. Participants wore Sennheiser HD 449 headphones and were blindfolded with an unconnected Oculus Rift Development Kit 2 made by Oculus VR. The RIR task was run in OpenSesame version 2.9.5 *Hesitant Heisenberg*, developed by Mathôt, Schreij, and Theeuwes (2012). The shape sorter was made by Jouéco.

2.3. Results

No misses were recorded in the single-task condition. In the dual-task condition however, participants missed 2.32 out of 40 trials (range 0–7; $SD = 2.14$) on average, which resulted in a slightly smaller dataset.

Because the data were skewed for the dual-task condition, a Wilcoxon Signed-Ranks Test was run. The reaction times of the dual-task condition ($M = 594.61$; $SD = 117.07$) were significantly higher than the reaction times of the single-task condition ($M = 350.24$; $SD = 35.91$), $Z = -3.82$, $p < .01$.

2.4. Discussion experiment 1

Several studies found a 100 ms difference for eye movements, compared to a single-task RT task (e.g., van den Hout & Engelhard, 2012; van den Hout, Bartelski, & Engelhard, 2013; van den Hout et al., 2011b). Although the results have to be interpreted with caution as RTs were measured in a slightly different way in those studies, the shape sorter task seems to be at least as taxing on WM as eye movements.

A limitation of our findings is that only males were included in the experiment. As they generally outperform females on spatial tasks (Voyer, Voyer, & Bryden, 1995), the task might be more taxing on WM for females. Also, participants sometimes missed trials in the dual-task condition, indicating that at those moments it was too difficult for them to focus on both tasks simultaneously. Of course, the shape sorter task is not equally taxing on WM over time as, unlike in case of eye movements, the pace is determined by participants themselves instead of an external stimulus. Furthermore, the shape sorter task comprises multiple different components, such as identifying the nature of objects, and constructing a conscious image of where things are within one's reach (see Postma et al., 2007), which are not equally relevant during each phase of the task. This is however not a problem per se, as the same applies to games such as Tetris that proved to be useful (e.g., Engelhard et al., 2010).

3. Experiment 2

3.1. Introduction

In this experiment, we tested the effects of the visuospatial task on emotional memories induced by a VR paradigm, by having participants play a VR game that is designed to induce fear. We refer to this VR paradigm as a game, because it was designed to be challenging. It does not involve getting scores or competition, but it is considered to be a challenge to complete the game by reaching the end of the Manor (see below) while experiencing fear. We compared the influence of a dual-task intervention (Recall + DT condition) on the vividness and emotionality of the negative memories to that of recall only (Recall no DT condition). This was done in a group of healthy participants, as was done in previous experiments (for an overview of studies, see van den Hout & Engelhard, 2012).

The VR paradigm is similar to the trauma film paradigm, which was introduced by Horowitz (1969), and is a well-established method used as an analogue model of psychological trauma (Bourne, Mackay, & Holmes, 2013). Although it is useful, a drawback of the trauma film paradigm is that the participant remains an outsider who does not immerse in the film scenes (Dibbets & Schulte-Ostermann, 2015). Previous research suggests that the use of a VR paradigm should result in stronger emotions, because it induces a feeling of presence (Riva et al., 2007). Dibbets and Schulte-Ostermann (2015) recently published the first study in which a VR paradigm was used to induce negative memories. They compared the effectiveness of a short trauma film scene in inducing negative mood and distressful intrusions to that of an interactive VR scene with similar content; a woman being physically assaulted by her lover. The results suggested that the trauma film paradigm was more effective than the VR paradigm. According to the authors, this may be explained by the experimental setup, because the VR scene was less intense than the film scene. However, another explanation is the lack of an interpersonal relationship between participant and victim (Pfefferbaum, Pfefferbaum, North, & Neas, 2002): the victim was a stranger to participants, and the interactive features of a VR scene are limited to the ability to determine one's distance to the event as a passive observer of the scene. We decided to use a VR game, in which participants take on a more active role, because distressing events in the game are directed at themselves, and are triggered by their actions and decisions. Furthermore, this game contains several randomly generated jump scares. Such unpredictability may increase anxious responses (Grillon et al., 2008).

In the Recall + DT condition, participants' WM was taxed while focusing on their negative memories of the VR game. We expected that Recall + DT would lead to greater reductions in memory vividness and emotionality compared to 'Recall no DT'.

3.2. Method

3.2.1. Participants

Participants were recruited via the website proefbunny.nl, a Facebook recruitment page for experiments at Utrecht University ("Universiteit Utrecht Betaalde Experimenten"), and flyers that were spread at Utrecht University's Faculty of Social Sciences. To be eligible, participants had to be at least 18 years old, and have no known medical history of heart disease or epilepsy. This was made clear through the acquisition text, and participants were asked about their medical history with regard to aforementioned diseases before the start of the experiment. Thirty-four participants (20 male, 14 female; equally distributed across both conditions), most were students at Utrecht University, participated in exchange for remuneration or course credits. Their mean age was 23.5 years (range 18–28; $SD = 3.4$); 22.6 years in Recall + DT ($SD = 2.8$), and 24.3 years ($SD = 3.8$) in Recall no DT.

3.2.2. Ethical considerations

The study was approved by the Ethical Committee of the Faculty of Social and Behavioral Sciences of Utrecht University (FETC15-040). Our study was one of the first to use this specific VR paradigm to induce negative memories. More specifically, the emotional response to the VR game we used was largely unpredictable. Therefore, several safety strategies had to be adopted. First, participants were informed about the nature of the VR content (horror) in both the acquisition text and an information letter. Second, participants with a known medical history of heart disease or epilepsy were excluded from participation. Third, we offered participants a short mindfulness session at the end of the experiment. Finally, a therapist was part of the research team and was available

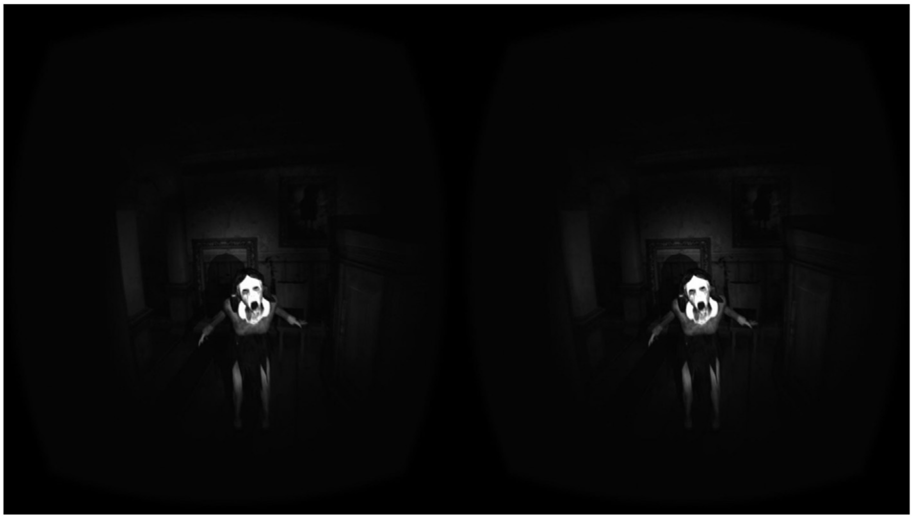

Fig. 1. Screenshot of unpleasant moment in the game.

for consultation by the participants. This was mentioned in both the informed consent procedure and the debriefing.

3.2.3. Procedure

After reading the information sheet, participants signed the consent form. They were then instructed to put on a HMD and headphones, and to take a button hand controller in their hands. The experimenter then started the VR game "Affected", a game that is designed to induce fear. The game starts in a small room with an elevator, which can be freely explored. When participants felt comfortable with the VR environment, they were instructed to select the 'Manor' stage by looking at the corresponding button next to the elevator. Upon entering the elevator, they were taken there. The environment of the manor is generally scary and contains several jump scares, such as a slamming door, a cabinet falling over, and a poltergeist that spawns near you. The goal was to reach the other end of the manor by crossing each section and jump scare once. Upon reaching the end, participants re-appeared in the elevator room following a loading screen.

After finishing the game, participants were asked about the most unpleasant moment of the game. Fig. 1 shows a screenshot of a moment that was frequently selected. A distractor task was then carried out for the removal of gameplay visuals from the VSSP. It was a paper-and-pencil Sudoku puzzle, taken from an online database and ranked level 'easy' (cf. Tadmor et al., 2015). Participants were asked to complete as much of the puzzle as possible within 90 s. This was followed by the memory pre-test, in which participants were asked to recall the moment from the VR game that they considered most unpleasant. They were instructed to visualize this moment and keep an image of it in mind for 10 s, and then rate its vividness and emotionality on two 100 mm visual analogue scales (VAS) that ranged from 0 (not vivid/unpleasant) at all to 100 (extremely vivid/unpleasant; cf. Engelhard, van den Hout, & Smeets, 2011).

Next, participants were asked to wear the HMD while keeping their eyes open; the HMD was turned off and merely served as a blindfold. Participants in the dual-task condition (Recall + DT) were instructed to retrieve and visualize the selected negative memory while carrying out the shape sorter task from experiment 1. They were asked to do this for 24 s, 4 times in a row, with 10 s intervals (cf. van den Hout, Muris, Salemink, & Kindt, 2001). The Recall no DT condition consisted of the same procedure, without the dual-task.

After this, the distractor task continued, and the memory post-test was carried out. Apart from the instruction to recall the exact same moment from the pre-test, the post-test was identical to the pre-test. Finally, participants were debriefed and were offered a mindfulness session of approximately 5 min. The duration of the experiment strongly depended on the time it took participants to finish the game, which was generally about 15 min.

3.2.4. Materials

We used a PC compiled by VR Powerhouse (model VRP-M1), equipped with a NVIDEA GTX980 graphics card, and an Intel i5-4690 processor. This allowed VR games to run at the suggested framerate (75 FPS) for the HMD we used, namely the Oculus Rift Development Kit 2 made by Oculus VR. The VR game was "Affected" version 1.55 developed by Fallen Planet Studios (fallenplanetstudios.com). In this game, participants moved through the virtual environment using a Microsoft Xbox 360 controller, while wearing Sennheiser HD 449 headphones. The shape sorter was made by Jouéco, and the Sudoku's used as distractors were extracted from 1sudoku.net.

3.2.5. Data analyses

Changes in ratings for both measures (memory vividness; and memory emotionality) were analyzed by repeated measures ANOVAs with Time (pre-test vs. post-test) as within-subjects factor and Condition (Recall + DT vs. Recall no DT) as between-subjects factor.

3.3. Results and discussion experiment 2

Table 1 shows mean scores before and after the two interventions, and Fig. 2 illustrates changes in memory vividness and emotionality.

Table 1
Mean scores (SD) on memory vividness and emotionality before (pre-test) and after (post-test) the intervention (Recall + DT; and Recall no DT).

	Recall + DT		Recall no DT	
	Vividness	Emotionality	Vividness	Emotionality
Pre-test	75.7 (15.2)	52.4 (29.3)	51.4 (24.8)	41.9 (29.6)
Post-test	69 (14.8)	41.9 (28.1)	52.7 (30.5)	45.3 (33.4)

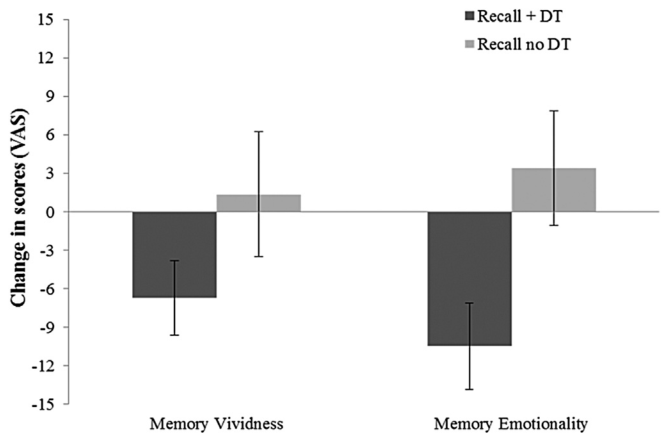

Fig. 2. Changes in memory vividness and emotionality after intervention (Recall + DT; and Recall no DT). Error bars represent standard errors of difference scores.

With regard to memory vividness, there was no significant main effect for Time, $F(1,32) < 1$, but there was a significant main effect for Condition, $F(1,32) = 8.20$, $p < .01$, $\eta_p^2 = .20$. However, the crucial Time × Condition interaction did not reach significance, $F(1,32) = 2.02$, $p = .17$, $\eta_p^2 = .06$.[1]

With regard to memory emotionality, there were no significant main effects for Time, $F(1,32) = 1.60$, $p = .22$, $\eta_p^2 = .05$, and Condition, $F(1,32) < 1$. Fig. 2 indicates a drop in memory emotionality in the Recall + DT condition and an increase in the Recall no DT condition. This was statistically reflected in the crucial Time × Condition interaction, $F(1,32) = 6.16$, $p < .05$, $\eta_p^2 = .16$. Pairwise comparisons showed a significant decrease in memory emotionality for the Recall + DT condition, $t(16) = 3.09$, $p < .01$, but no significant increase for the Recall no DT condition, $t(16) < 1$.

The results were largely consistent with the hypothesis: the dual-task intervention yielded superior results compared to recall only in terms of reductions in memory emotionality. The decrease in the Recall + DT condition resulted in equal scores as the initial scores for the Recall no DT condition. However, it should be noted that there were no significant differences in the pre-test emotionality scores between the conditions. It seems that using the VR game was an effective method to induce negative memories.

4. General discussion

4.1. Implications for the WM account

The finding that the emotionality of the recalled memory dropped due to the dual-task intervention supports the WM account of EMDR. The intervention however did not lead to reductions in memory vividness. It is unclear how this can be explained, but it should be noted that several studies found effects just for memory emotionality (Andrade et al., 1997, experiment 2; Engelhard et al., 2010; Kavanagh, Freese, Andrade, & May, 2001; Schubert, Lee, & Drummond, 2011) or vividness (Andrade et al., 1997, experiment 1; Maxfield, Melnyk, & Hayman, 2008, experiment 1; van den Hout et al., 2011a, experiment 2; van den Hout et al., 2011b, experiment 4; Leer, Engelhard, & Van Den Hout, 2014), and not for both. Gunter and Bodner (2008) hypothesized that decreased emotionality is a consequence of decreased vividness. The present results do not support this hypothesis, but do fit nicely within the contrasting view that decreased emotionality results directly from cognitive load modulating emotional responses in the brain; VanDillen, Heslenfeld, and Koole (2009) found that increased task load increases activation in cognitive regions and decreases activity in emotional regions, and that these changes in activity are related. As noted by Kearns and Engelhard (2015), investigating the underlying mechanisms linking dual-tasks to effects on memory emotionality is an important direction for future research. We think it would be interesting to compare the effects on memory of a 'classic' dual-task intervention with a dual-task intervention in which recall is visually supported. This can be examined using the VR paradigm from the present study, as (3D) screenshots from the moments selected as most unpleasant can be recorded and displayed as visual reminders during recall moments. Such an experiment could tell us whether this would prevent a decrease in vividness, and whether this has consequences for emotionality.

Our study and the study by Krans et al. (2010), were not the first to use a visuospatial dual-task intervention that requires haptic processing of peripersonal space. Andrade et al. (1997, experiment 4) compared the effects of a spatial task (tapping a complex boustrophedon pattern on a keypad) on mental images of personal recollections to that of eye movements and a recall only control condition. Vividness and emotionality ratings were given during the interventions. Both dual-task conditions were more effective than the control condition, although the effect of tapping was weaker than that of eye movements. Similarly, van den Hout et al. (2001) compared the effects of a simpler spatial task (rhythmically tapping the table top with index and middle finger together every second) on emotional memories to that of eye movements and a recall only control condition. Only the eye movements condition affected memory vividness and emotionality; negative memories became less negative, and positive memories became less positive. This discrepancy is well-accounted for by WM theory. The link between taxing WM and the effect on memory seems to have the form of an inverted U; too little and too much taxing both having little or no effect (Engelhard et al., 2011). A spatial task may only be effective when it is complex enough.

4.2. The use of a VR paradigm to induce negative memories

With the exception of studies using the trauma film paradigm, the effects of dual-task interventions on healthy participants are usually studied using autobiographical memories. One problem of this is that the nature and age of the event underlying the memory differs between participants. Studies have shown that older and stronger memories are less susceptible to modification than younger and weaker ones (see Schwabe, Nader, & Pruessner, 2014). Like the trauma film paradigm, the VR paradigm solves these problems, because it allows control over the nature, intensity and duration of exposure to distressful events. Unlike the trauma film paradigm, however, playing a first person game while being immersed in a VR environment comes considerably closer to a real-life experience. A small downside that comes with the autobiographical element is that participants are exposed slightly differently from one another due to differences in playstyle (e.g., pace and viewing direction). Still, the VR paradigm seems to combine the best elements of both other methods into one.

The results of the present study suggest that the VR paradigm may provide a useful method of inducing negative memories, as the memories induced by playing the game were strong enough to be affected by the dual-task intervention, but not by recall only. This is however only a first step towards validating the utility of the VR paradigm, and based on the present study we cannot draw

[1] The pre-scores for memory vividness differed between conditions. However, with Time defined as pre-test vs. relative decrease the Time × Condition interaction did not reach significance either, $F(1,32) < 1$.

conclusions regarding its utility as an analogue to real-life trauma. A future study should include pre- and post-game mood ratings (i.e., happy, anxious, depressed and angry; cf. Davies & Clark, 1998), and test PTSD-like symptoms such as intrusion frequency and distress in the week after (for an elaborate review of studies investigating PTSD-like symptomology, see Holmes & Bourne, 2008). Furthermore, these effects should be directly compared to those of the trauma film paradigm, as was done by Dibbets and Schulte-Ostermann (2015). This will allow us to draw conclusions about the presumed advantages of the VR paradigm.

Acknowledgments

This study was conducted in collaboration with the Concept & Creation department of Triple IT, a Dutch company based in Alkmaar, the Netherlands. Marcel A. van den Hout is supported by a TOP grant (dossier number: 40-00812-98-12030) from the Netherlands Organization for Health Research and Development (ZonMw). Iris M. Engelhard is supported with a Vidi grant (452-08-015) from the Netherlands Organization for Scientific Research (NWO).

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