



Contents lists available at ScienceDirect

Behaviour Research and Therapy

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

EMDR: Eye movements superior to beeps in taxing working memory and reducing vividness of recollections

Marcel A. van den Hout^{a,*}, Iris M. Engelhard^a, Marleen M. Rijkeboer^a, Jutte Koekebakker^b, Hellen Hornsveld^a, Arne Leer^a, Marieke B.J. Toffolo^a, Nienke Akse^a

^aClinical and Health Psychology, Utrecht University, PO Box 80140, 3508 TC Utrecht, The Netherlands

^bAltrecht Mental Health Centre, Utrecht, The Netherlands

ARTICLE INFO

Article history:

Received 6 July 2010

Received in revised form

28 October 2010

Accepted 15 November 2010

Keywords:

EMDR

Eye movements

Working memory

Binaural stimulation

ABSTRACT

Posttraumatic stress disorder (PTSD) is effectively treated with eye movement desensitization and reprocessing (EMDR) with patients making eye movements during recall of traumatic memories. Many therapists have replaced eye movements with bilateral beeps, but there are no data on the effects of beeps. Experimental studies suggest that eye movements may be beneficial because they tax working memory, especially the central executive component, but the presence/degree of taxation has not been assessed directly. Using discrimination Reaction Time (RT) tasks, we found that eye movements slow down RTs to auditory cues (experiment I), but binaural beeps do not slow down RTs to visual cues (experiment II). In an arguably more sensitive “Random Interval Repetition” task using tactile stimulation, working memory taxation of beeps and eye movements were directly compared. RTs slowed down during beeps, but the effects were much stronger for eye movements (experiment III). The same pattern was observed in a memory experiment with healthy volunteers (experiment IV): vividness of negative memories was reduced after both beeps and eye movements, but effects were larger for eye movements. Findings support a working memory account of EMDR and suggest that effects of beeps on negative memories are inferior to those of eye movements.

© 2010 Elsevier Ltd. Open access under the [Elsevier OA license](http://creativecommons.org/licenses/by/3.0/).

Introduction

About 20 years ago, eye movement desensitization and reprocessing (EMDR) was introduced as a treatment for posttraumatic stress disorder (PTSD; APA, 2004), and it has met with considerable skepticism (e.g., Herbert et al., 2000). However, methodologically strict and rigorous meta-analyses of clinical trials have indicated that EMDR is an effective treatment for PTSD, and is equally effective as cognitive behavior therapy (Bisson et al., 2007; Bradley, Greene, Russ, Dutra, & Westen, 2005; Seidler & Wagner, 2006).

It has been questioned whether the eye movements involved in EMDR add anything to its effects (e.g., MacCulloch, 2006). An early meta-analysis concluded that the eye movement component does not contribute to EMDR effects (Davidson & Parker, 2001), but the study has been criticized on methodological grounds (Lee & Cuijpers, submitted for publication). A more recent and encompassing meta-analysis did find significant additive effects for eye movements in clinical trials (Lee & Cuijpers, submitted for publication).

These clinical data are corroborated by analogue studies showing that eye movements during recall of aversive memories reduce their vividness and emotionality (Andrade, Kavanagh, & Baddeley, 1997; Barrowcliff, Gray, Freeman, & MacCulloch, 2004; Engelhard, van Uijen, & van den Hout, 2010; Gunter & Bodner, 2008; van den Hout, Muris, Salemink, & Kindt, 2001; Kavanagh, Freese, Andrade, & May, 2001; Kemps & Tiggemann, 2007; Maxfield, Melynck, & Hayman, 2008). The analogue studies also suggest how EMDR affects emotional memories. During recall, emotional memories become ‘labile’, and their reconsolidation is affected by experiences during recall (Baddeley, 1998). Recalling an episode depends on working memory (WM) resources that are limited. If a secondary task is executed during recall that shares this dependence, fewer resources will be available for recalling an episode and the memory will be experienced as less vivid and emotional. Eye movements are held to serve as such a ‘secondary’ task that taxes WM (Andrade et al., 1997; Barrowcliff et al., 2004; Gunter & Bodner, 2008; van den Hout et al., 2001; Kavanagh et al., 2001; Kemps & Tiggemann, 2007; Maxfield et al., 2008). Interestingly, memories are not only blurred *during* the eye movements (e.g., Kavanagh et al., 2001), but also during recollections immediately *after* the eye movements session (e.g., van den Hout et al., 2001; Gunter & Bodner, 2008,

* Corresponding author. Tel.: +31 30 253 9216; fax: +31 30 253 7482.

E-mail address: m.vandenhout@uu.nl (M.A. van den Hout).

experiments 1 and 3; Engelhard, van den Hout, Janssen, & van der Beek, 2010; Engelhard, van Uijen, et al., 2010) or one week later (Gunter & Bodner, 2008, experiment 2). The observation that the vividness of future recollections can be affected by the nature of earlier recollections is not new. If individuals engage in concentrated mental imagery, the vividness of future recollections increases substantially (e.g., Hyman & Pentland, 1996). While such concentrated mental imagery creates “imagination inflation”, cognitive taxing during recall seems to do the opposite and *deflates* the vividness and emotionality of future recollections. EMDR seems to therapeutically exploit the fact that memories become labile during recall and that reconsolidation is affected by the nature of the recall (Baddeley, 1998).

This WM account of EMDR fits comfortably with experimental data. Traditionally, during EMDR, eyes are moved horizontally. In line with the WM account, but in contrast to original explanations, moving eyes vertically is equally effective (Gunter & Bodner, 2008). Crucially, the same effects occur if WM is taxed during recall with non-eye-movement secondary tasks, like listening to a series of non-words (auditory shadowing; Gunter & Bodner, 2008), drawing a complex figure (Gunter & Bodner, 2008), or counting (Engelhard, van den Hout, & Smeets, 2011; van den Hout et al., 2010; Kemps & Tiggemann, 2007). Tasks that are presumably hardly taxing, like simple finger tapping, do not have beneficial effects (van den Hout et al., 2001), while more complex tapping does (Andrade et al., 1997). Likewise, activating memories about a previously seen trauma film while playing taxing computer game reduced flashbacks in the week afterwards (Holmes, James, Coode-Bate, & Deeprose, 2009). Whereas EMDR has been advocated as treatment for past trauma, the WM theory implies that negative images about future events (‘flashforwards’) can be treated as well. Experimental evidence confirms this (Engelhard, van den Hout, et al., 2010). Finally, WM rightly predicts that individuals who are bad at multi-tasking derive more benefit from eye movements, counting et cetera during recall of negative memories (Gunter & Bodner, 2008; van den Hout et al., 2010).

WM is typically held to consist of three subsystems (Baddeley, 1998). The “central executive” (CE) allocates and divides attention between tasks, selects retrieval strategies, activates memories, and inhibits distracters. Furthermore, two “slave systems” are postulated: the visuospatial sketchpad (VSSP), involved in the processing of visuospatial information, and the phonological loop (PL) that processes verbal information. The question then ensues what component(s) of WM is (are) affected by the tasks mentioned above.

The dominant theoretical perspective on this issue suggests modality specificity (Baddeley, 1986). Eye movements should load the VSSP and verbal tasks should load the PL. In line with the modality specificity view, it has been found that eye movements strongly interfere with WM for (sequences of) locations and much more than equivalent limb movement or covert attention shifts without eye movements (Pearson & Sahraie, 2003).

With regards to autobiographical memory, Lilley, Andrade, Turpin, Sabin-Farell, and Holmes (2009) asked 25 PTSD patients who awaited treatment to recall elements of the trauma under three conditions: recall + eye movements, recall + counting or recall only with all treatments lasting 8 × 8 s. Trauma memories became (temporarily) less vivid and less emotional during recall + eye movements but not during the other treatments, and the authors interpret their findings “as showing that the eye-movements task reduced image vividness by temporarily disrupting active maintenance and manipulation of traumatic images in the VSSP of working memory” (p. 317). There is no reason to doubt that eye movements load the VSSP, but they also load the CE (see below) and it is unclear to what degree the effects reported by Lilley et al. (2009) were due to CE effects or VSSP effects. That is, the verbal condition (counting aloud from one upward) may have required

less overall cognitive load than making the eye movements. If so, results may also be explained by more CE effects by eye movements. Gunter and Bodner (2008; experiment 3) reported that effects of auditory shadowing were as strong as effects of eye movements on reductions of vividness/emotionality. While, obviously, this argues for a general, or CE, account, Gunter and Bodner add that their findings do “not completely rule out the possibility that some of the benefit is due to taxing the VSSP” (Gunter & Bodner, 2008, p. 927). Finally, Kemps and Tiggemann (2007) found that, compared to recall + counting, recall + eye movements reduced vividness and emotionality of *visual* images to a greater degree than vividness/emotionality of *auditory* images, whereas recall + counting had larger effects on auditory images. The authors suggest that memory disruption by dual tasking during recall is modality specific. Still, inspection of their data (experiment II) shows that the largest effect was a general one. Compared to recall-only, recall + eye movements and recall + counting each reduced vividness/emotionality of both visual and auditory memories. Modality-specific effects were present, but they were superimposed on a much larger general, non-specific effect.

In sum then, laboratory data suggest that EMDR and related procedures derive their effects from the taxing of WM during recall of aversive memories (Engelhard, van Uijen, et al., 2010; Engelhard et al., 2011; Gunter & Bodner, 2008; Holmes et al., 2009; van den Hout et al., 2010; Maxfield et al., 2008). The data suggest that procedures like eye movements and counting have memory effects that are general, affecting the CE component of WM, as well as modality specific, affecting visuospatial or phonological aspects of memory.

EMDR therapists have started to use ‘binaural stimulation’ as an alternative to eye movements (Maxfield, 2008). During ‘binaural stimulation’, the patient wears a headphone and hears beeps alternating Left-Right beeps, typically one per s. During the 10th EMDR European conference held in Amsterdam in 2009, participants were asked if they used binaural stimulation during their EMDR sessions and, if so, how often. Out of 414 respondents, 299 (73%) said they used binaural stimulation in, on average, 69% of the sessions. A first rough estimate is therefore that about half (73% × 69%) of the EMDR treatments consist of binaural stimulation sessions. Despite its apparent popularity, no controlled outcome data for this technique have been published (Maxfield, 2008). Unlike eye movements, mental arithmetic, and other interventions that proved to be effective in reducing vividness and emotional intensity of upsetting memories, binaural stimulation does not require the person to actively engage in cognitive or motor operations. This raises the question whether binaural stimulation taxes WM, and how this compares to the effect of, for example, eye movements.

Eye movements load the VSSP (Postle, Idzwickowski, Sala, Logi & Baddeley, 2006) Although it has been suggested that eye movements of the type used in EMDR (also) have more general, central executive, WM effects (Gunter & Bodner, 2008; van den Hout et al., 2010) no *direct* evidence is available. Testing whether eye movements tax the CE as indexed by slowing down of Reaction Times (RTs) to *auditory* cues, was the aim of experiment I. In experiment II, we tested if RTs increase when participants simultaneously listen to bilateral beeps. Here, participants were asked to discriminate *visual* cues. In experiment III, eye movements and beeps were directly compared on the degree to which they taxed the CE. Using auditory cues (cf. experiment I) during binaural stimulation would be as problematic as providing visual cues (cf. experiment II) during eye movements. Therefore, a tactile cue was used in experiment III. RTs were recorded under three conditions: no dual-task, binaural stimulation, and eye movements.

The WM/CE account of the eye movements component of EMDR implies that therapeutic changes in memories are due to the degree of CE taxation during recall. Thus, the pattern to be found in study III

should be reflected in changes in negative memories. If binaural stimulation would not tax the CE, no effect on memory should be expected, if eye movements and binaural stimulation would affect RTs to the same degree, effects on memory should be comparable, et cetera. The aim of experiment IV was to examine the degree to which memories are affected if participants make eye movements or listen to binaural tones during recall. We examined whether the pattern of results found in study III was reflected in the results of study IV.

Experiment I

Introduction

A valid way to assess the presence and severity of cognitive taxing by task \times is to have it carried out while the individual is simultaneously carrying out an RT task. The more task \times taxes WM, the more it should result in a slowing down on the RT task (Bower & Clapper, 1989). Using a discrimination RT, in which participants had to discriminate simple visual displays, it was found earlier that counting during the RT task induced slowing of RTs. The same type of counting during retrieval reduced vividness and emotionality of the retrieved memory (Engelhard et al., 2011; van den Hout et al., 2010). There is sound evidence that eye movements tax VSSP resources (Pearson & Sahraie, 2003; Postle et al., 2006). While it has been assumed that eye movements of the type made in EMDR tax the CE component of WM (Gunter & Bodner, 2008; van den Hout et al., 2001) this assumption has never been tested by e.g., slowing down of RTs to non-visuospatial cues. The aim of the first experiment was to test whether eye movements tax the CE as indexed by slowing down of RTs to auditory cues. The visual RT task used earlier (cf. van den Hout et al., 2010) was replaced by an auditory RT task.

Method

Participants

Fifteen undergraduates (mean age 24 years, $SD = 2.6$; 10 females) participated in exchange for remuneration.

Procedure and assessments

Degree of CE taxing was assessed with a stimulus discrimination RT task using auditory cues. Participants sat in front of a computer screen, which displayed the instructions, and wore headphones. They were asked to respond as fast as possible by saying "high" into a microphone when they heard a high-pitched tone, and saying "low" when they heard a low-pitched tone. Participants started with a practice task. Then the RT task was carried out under two conditions of 3 min each: 1) baseline and 2) eye movements. During baseline, participants performed the RT task without any secondary task. During the eye movement task, participants performed the same RT task, but had to make eye movements simultaneously. The experimenter induced the eye movements, approximately 1 cycle per s, by sitting in front of the participant, and moving her hand across the participant's visual field, approximately 30 cm from the face, with a distance between the right and left of about 40 cm. Each tone in the RT task was presented for 500 ms, and the inter-stimulus interval ranged between 2.2 s and 3 s (2.6 s average), leaving 69 RTs to be recorded in each of the two conditions. The order of the conditions was counterbalanced: eight participants started with the baseline condition, seven participants started with the eye movements condition.

Results

Fig. 1 shows that RTs during eye movements ($M = 701$; $SD = 190$) were longer than RTs during baseline ($M = 602$;

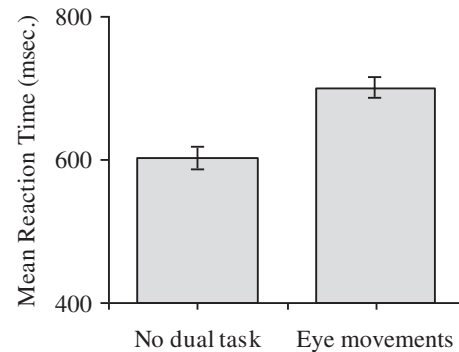


Fig. 1. Reaction Times for discriminating auditory cues during no dual-task and eye movements: means and SEMs (adjusted for within-group comparison).

$SD = 154$). A paired t -test showed that the difference between the conditions was significant, $t(15) = 3.27$; $p = .006$, $r = .66$.

Discussion experiment I and introduction experiment II

Eye movements induced a substantial slowing down of RTs to auditory cues, which implies that eye movements tax the CE. While several authors have anticipated this observation (Gunter & Bodner, 2008; van den Hout et al., 2001; Maxfield et al., 2008), this is the first experiment that directly shows that the CE is taxed during eye movements. The question whether, and to what degree, binaural stimulation taxes the CE was addressed in experiment II. To allow for conclusions about CE taxing vs. loading the phonological loop, the auditory stimulation in the RT task could not be used here. It was replaced by a visual RT discrimination task, in which participants discriminated between two circles with different colors without a secondary task or while receiving binaural stimulation. Earlier, it was shown that during mental arithmetic, visual stimulus discrimination RTs slow down (van den Hout et al., 2010; Engelhard et al., 2011). As a validity check, the RT task in experiment II also including a dual-task counting condition.

Experiment II

Method

Participants

Eighteen undergraduates (mean age 25.2, $SD = 2.7$; 13 females) participated in exchange for remuneration. None of them participated in experiment I.

Procedure and assessments

Degree of WM taxing was assessed with a discrimination RT task to visual cues. Participants were asked to press the "Q" key of the keyboard as soon as a green circle appeared on the screen and the "P" key if a yellow one appeared. The circles were presented quasi-randomly, with no more than four consecutive circles of the same color. Participants did the RT task under 3 conditions of 3 min each: 1) no dual-task, 2) binaural stimulation, and 3) mental arithmetic. In the no dual-task condition, participants only performed the RT task. During binaural stimulation, the same RT task was performed, but participants simultaneously wore headphones that presented 1 beep per s in alternating ears. During the mental arithmetic condition, participants were asked to subtract 10 from 3000 downwards (2990, 2980, et cetera). Each circle was presented for 500 ms, and the inter-stimulus interval for the RT task ranged between 2.2 s and 3 s (2.6 s average), leaving 69 RTs to be recorded in each of the three conditions (cf. van den Hout et al., 2010).

The order of the conditions was counterbalanced with 3 individuals for each of the 6 order conditions. Testing took place in soundproof laboratory cabins.

Results

Fig. 2 indicates that RTs during arithmetic were longer, and there was no difference between no dual-task and binaural stimulation. One way repeated measures ANOVA shows the conditions differed, $F(2,34) = 20.01$; $p < .0001$; $\eta_p^2 = .54$, and paired t -tests revealed that RTs were significantly slower during mental arithmetic compared to the no dual-task, $t(18) = 4.75$; $p = .0002$, $r = .76$, and during mental arithmetic compared to binaural stimulation, $t(18) = 4.39$; $p = .0004$, $r = .73$. RTs during binaural stimulation and the no dual-task condition did not differ, $t(18) = .54$, and were nearly identical (Fig. 2).

Discussion experiment II and introduction to experiment III

The slowing of RTs to visual cues during arithmetic replicated earlier findings (van den Hout et al., 2010; Engelhard et al., 2011), and shows that it taxed the CE. During binaural stimulation, however, there was no trace of increased RTs compared to no dual-task. The findings contrast with the data displayed in Fig. 1. This suggests that, compared to eye movements, unattended binaural stimulation does not require CE capacity. If binaural stimulation would have beneficial clinical effects, this would not be readily explicable in terms of WM theory.

However, the RT tasks required participants to discriminate between two stimuli. Vandierendonck, De Vooght, and Van der Goten (1998) showed that RTs to auditory cues presented at random intervals (without the requirement to discriminate; a Random Interval Repetition (RIR) task), provides a valid and highly sensitive measure of CE taxation. RTs in such an RIR task are substantially shorter compared to discrimination tasks, which leaves more room for slowing down due to subtle CE taxing. Therefore, in experiment III, an RIR task instead of a stimulus discrimination RT task was used. We wanted to directly compare the taxing effects of beeps and eye movements. Using auditory cues (cf. experiment I) for the RIR task with a binaural dual-task would be as problematic as providing visual cues (cf. Experiment II) during eye movements. Therefore, a tactile cue was used. RTs were recorded under three conditions: no dual-task, binaural stimulation, and eye movements.

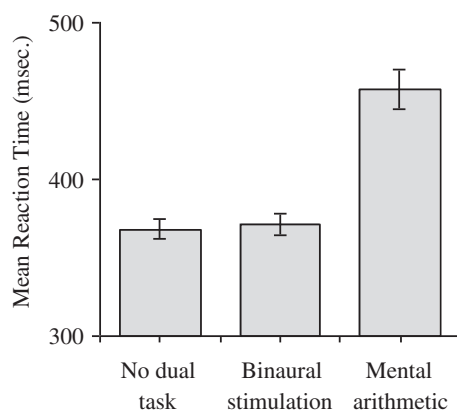


Fig. 2. Reaction Times for discriminating visual cues during no dual-task, binaural stimulation, and mental arithmetic: means and SEMs (adjusted for within-group comparison).

Experiment III

Method

Participants

Eighteen undergraduates (mean age 25.6, $SD = 3.7$; 13 females) participated in exchange for remuneration. None of them participated in experiment I or II.

Materials and procedure

Participants performed an RIR task, in which mild electrical stimuli were administered to the index and middle finger of the non-dominant hand. Intensity of stimulation was determined by a work-up procedure starting with .2 mA. The stimulus level could be increased to .4, .6, .8, 1.1, 1.4, 1.7, 2.0, 2.3, and 4.0 mA. Participants were asked to indicate at what level the stimulus was clearly discernable but not painful. Duration of the electrical pulse was 50 ms, and it was generated by a battery powered Coulbourn Transcutaneous Aversive Finger Stimulator (E13-22).

Participants were asked to press the '0' key with the index finger of the dominant hand as soon as they felt the electrical stimulus. Half of the inter-stimulus intervals (ISIs) were 900 ms and the other half were 1500 ms. The order of the ISIs varied quasi-randomly with no more than four consecutive identical ISIs. The RIR task took 3 min, in which 148 stimuli were administered, and was carried out in three conditions: no dual-task, eye movements, and binaural stimulation. All participants completed all three conditions, each lasting 3 min. The order of conditions was counterbalanced with 3 participants in each of the 6 orders. In all conditions, participants wore a headphone, but it only produced sound in the binaural stimulation condition. The eye movements condition was identical to experiment I, the binaural stimulation condition was identical to experiment II. In the no dual-task condition, only the RIR task was carried out.

Results experiment III

Mean RTs for the three conditions are depicted in Fig. 3. During eye movements and binaural stimulation, RTs slowed down relative to the no secondary stimulation condition, while this slowing down was about 4 times as large in the eye movement condition. One way repeated measures ANOVA was significant, $F(2, 34) = 20.99$; $p < .0001$; $\eta_p^2 = .55$. RTs during binaural stimulation were significantly slower compared to the no dual-task condition, $t(17) = 2.78$; $p = .01$, $r = .56$, but faster compared to eye movements, $t(17) = 4.07$;

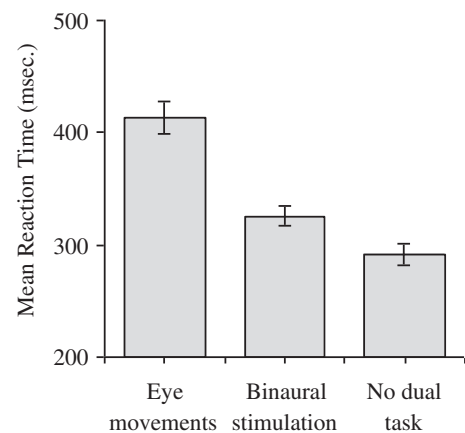


Fig. 3. Reaction Times to tactile cues during eye movements, binaural stimulation, and no dual-task in a Random Interval Repetition (RIR) task: means and SEMs (adjusted for within-group comparison).

$p = .0008$, $r = .70$. The difference between eye movements and no dual-task was likewise significant, $t(17) = 5.37$; $p < .0001$, $r = .79$.

Discussion experiment III and introduction experiment IV

The pattern provided by the data (Fig. 3) seems unambiguous. First, RTs were substantially faster compared to the discrimination tasks of experiment I and II. In the no dual-task condition, participants were approximately 100 Ms faster compared to the visual discrimination task without dual task (Fig. 2), and about 300 Ms faster than in the auditory discrimination task without dual task (Fig. 1). Presumably, this faster baseline made the task more sensitive to CE taxing by dual-tasks. The data show that, relative to the no dual-task condition, eye movements produced a substantial interference with the RIR task, which replicates the effect found in experiment I. Making eye movements is an active task that requires concentration and motor operations. Although this does not hold for binaural stimulation, the latter also interfered with the RIR performance. This contrasts with the absence of an effect of binaural stimulation on the discrimination task of experiment II. It seems plausible that the task difference (RIR task vs. discrimination RT task) was responsible for these difference effects. Taken together, the data from experiment II and III suggest that binaural stimulation requires CE resources, but the effect is subtle and small compared to eye movements.

WM theory suggests that the RT tasks used in experiments I–III tap the same process that is responsible for the beneficial effects of EMDR and related interventions. It follows from WM theory that the effects of eye movements on memory are larger than those of binaural stimulation, while the binaural stimulation should have no or little effect. Testing these predictions was the aim of experiment IV.

Experiment IV

Method

Participants

Prior to the experiment 6 or 7 individuals indicated that they had heard of 'EMDR' or 'Eye Movement Desensitization and Reprocessing', and were excluded. Fifty-four undergraduates (mean age = 21.0, $SD = 3.1$; 43 females) were included in exchange for remuneration. None of them participated in experiments I–III.

Materials and procedure

There were three task conditions during which negative memories were recalled: no dual-task, eye movements, and binaural stimulation. Vividness and emotional intensity of the memories were assessed before and after recall. The procedure was adapted from the eye movements procedure described by van den Hout et al. (2001), and Gunter and Bodner (2008). The experiment consisted of four phases.

During phase 1, participants were asked to recall three negative autobiographical memories that made them fearful or sad and had still emotional impact on them, for example 'being unprepared for an exam' or 'witnessing an accident'. Participants were asked to form an image of the three memories and to describe them to the experimenter, who wrote down a label and some keywords for each memory to refer to during the experiment. Participants ranked the memories in terms of adversity, and the ranked memories were balanced over the three task conditions, with order being balanced as well.

During phase 2, the experimenter asked the participant to retrieve one of the memories by referring to the keywords, and to form an image of that memory in the following way: 'Form an image of ... now, and keep your eyes open.' Remember where it happened,

who was present, and anything else you can think of. Bring it to mind vividly, as if it were happening right now. After holding this image in mind for 10 s, participants rated two 10 cm visual analogue scales (VAS) for the emotional intensity and vividness of the image. These scales run from 'extremely unpleasant/not clear at all' (extreme left) to 'extremely pleasant/very clear' (extreme right).

During phase 3, participants took part in all three conditions in a balanced order. In the eye movements condition, participants were asked to imagine one of the negative memories and simultaneously follow a 1 cm white circle that blinked from one side of a computer screen 21.5 cm across to the other side for four periods of 24 s each. Between these periods there was a 10-s rest. Eye movements were carried out at a rate of 1 cycle per s.

In the binaural stimulation condition, participants recalled a negative memory while listening to alternating sounds ('beeps') offered by an audio headphone for four periods of 24 s each, with a 10-s rest between periods. The sounds occurred at a rate of 1 beep per s and alternated from the left to the right ear. In the no dual-task control condition, participants were asked to imagine one of the negative memories for four periods of 24 s with 10-s rest in between. After each condition (phase 4), participants imagined the memory again, and rated it in the same way as in phase 2.

Results

Table 1 shows emotionality and vividness scores. Data were tested with 2×3 ANOVA with Time (pre-test vs. post-test) and Task (no dual-task vs. binaural stimulation vs. eye movements) as within-group factors. For emotionality ratings, there was a main effect of Time, $F(1, 53) = 8.68$; $p = .005$, $\eta_p^2 = .14$, reflecting the fact that, overall, memories were less negative at post-test relative to pre-test. There was no main effect of Task, $F(2, 106) = .75$; NS, and the crucial Time \times Task interaction was not significant either, $F(2, 106) = .23$; NS.

For vividness ratings, there was again a main effect for Time, showing that, overall, memories were less vivid after the tasks than before, $F(1, 53) = 15.57$; $p = .0002$, $\eta_p^2 = .23$. The Task main effect, $F(2, 106) = 5.39$; $p = .006$, $\eta_p^2 = .09$, and the crucial Time \times Task interaction, $F(2, 106) = 7.50$; $p = .002$, $\eta_p^2 = .12$, were also significant. To decompose the interaction, we examined which of the conditions differed in terms of pre-test minus post-test changes (Fig. 4). Changes during eye movements were larger than the no dual-task, $t(53) = 3.33$, $p = .002$, $r = .42$, and the binaural stimulation, $t(53) = 2.03$, $p = .047$, $r = .27$. The binaural stimulation task showed larger changes than the no dual-task, $t(53) = 2.28$, $p = .026$, $r = .30$.

Discussion experiment IV

In earlier studies, making eye movements during recall of aversive memories rendered the memories less emotional and vivid. In experiment IV, the effect on vividness was replicated, but there was no superior effect of eye movements on emotionality. Erroneously, emotionality of aversive memories was measured on a VAS ranging from extremely pleasant to extremely unpleasant (cf. van den Hout et al., 2001). The first pole should have read 'not

Table 1

Scores on emotionality and vividness of aversive memories, before and after recall during eye movements, binaural stimulation, and no dual-task.

	Emotionality		Vividness	
	Pre	Post	Pre	Post
No dual-task	2.3 (1.6)	2.6 (1.9)	8.0 (1.6)	8.1 (1.5)
Binaural stimulation	2.1 (1.3)	2.3 (1.5)	7.9 (1.6)	7.4 (2.0)
Eye movements	2.4 (1.7)	2.7 (1.8)	7.8 (1.8)	6.5 (2.6)

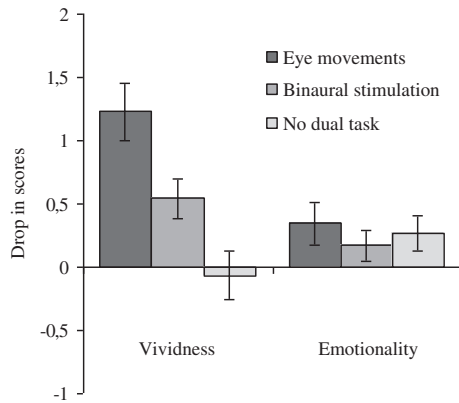


Fig. 4. Reductions in emotionality and vividness of negative memories after recall during eye movements, binaural stimulation, and no dual-task: means and SEMs (adjusted for within-group comparison).

unpleasant' and the scale used may have lacked sensitivity. Eye movements and related WM taxing procedures typically induce reductions in vividness as well as emotionality, and the effect is fairly robust. There are exceptions though, where effects were only found for vividness but not for emotionality (Maxfield et al., 2008) or the other way round (Lee & Drummond, 2008). With regard to vividness, the data reflect the pattern found in experiment III: binaural stimulation taxed the CE a little in experiment III, and had relatively small effects on vividness in experiment IV. Eye movements taxed the CE considerably more than binaural stimulation (Fig. 3), and had substantially larger effects on vividness (Fig. 4).

General discussion

It is estimated that about 50% of EMDR sessions are carried out using binaural stimulation rather than eye movements. It is assumed, apparently, binaural stimulation is equally or more effective than eye movements. Data from the discrimination task of experiment I and the simple RT task of experiment III suggest that eye movements affect memory by taxing the CE during recall. In experiment II (discrimination task), we found that binaural stimulation did not slow down RTs, but in the allegedly more sensitive RIR task of experiment III, RTs during binaural stimulation were slower than the no dual-task condition. Apparently, binaural stimulation taxes the CE to some degree. However, the slowing down due to binaural stimulation was about one-fourth of the effect achieved by eye movements (Fig. 3). WM theory implies that the RIR task used in experiment III taps the same process that is responsible for the beneficial effects of eye movements and related interventions used in EMDR. Hence, we predicted that, in terms of reduced vividness and emotionality of negative memories, eye movements would outperform binaural stimulation, while the latter would have no or small effects. Eye movements had no stronger effects than the other conditions on emotionality. As discussed in the discussion of experiment IV, an error in defining the extremes of the VAS scale used may have been responsible here (see above). For vividness, the effects for eye movements were evident. Binaural stimulation had effects as well, but they were about one-third of the effects of eye movements. Indeed, the pattern provided by Fig. 3 is highly similar to the pattern on the left part of Fig. 4. The authors used the protocol that was successfully used earlier (van den Hout et al., 2001; Gunter & Bodner, 2008) and that uses, per condition (e.g., eye movements) 4 periods of 24 s. In clinical EMDR sessions, the duration is typically much longer and it seems likely that the effects can be enlarged by longer durations of multi-tasking. Meanwhile, there is no reason to believe that

the difference between the effects of eye movements and binaural stimulation would become less with longer task durations.

It is unlikely that the auditory RT task from experiment I may (also) have required VSSP resources, while it is unlikely that the visual RT task used in experiment II taxed the phonological loop. Experiment III indicates that both interventions required CE resources. The RIR task was an adaptation of the task introduced by Vandierendonck et al. (1998) as a specific measure of CE taxation. In the present version of this task, the cues were tactile rather than auditory. There is no reason to believe that motor responses to simple auditory cues require different cognitive processes than responding to tactile cues. Furthermore, it would be hard to argue that the responding to tactile cues taxes either the phonological loop or the VSSP, so it appears that binaural stimulation and eye movements taxed the CE. The data from the experiments support a CE explanation of the eye movement component of EMDR and related procedures. They do not support the widespread substitution of binaural stimulation for eye movements in the clinical application of EMDR.

There are several limitations of the present experiments. First, proponents of binaural stimulation may object that the present study did not test the clinical effects of binaural stimulation relative to eye movements. Obviously this is true, 'not proven effective' does not mean 'proven ineffective'. The present findings may serve to illustrate that the need for such trials is unusually urgent. Furthermore, like earlier analogue studies using a comparable paradigm, changes in the quality of negative memories (experiment IV) were assessed by self-reports. Although it is not evident why experimental demand would explain the differences between eye movements and beeps in experiment IV, future studies may assess changes in the affective quality of memories by, e.g., startle probe methods (cf. Engelhard, van Uijen, et al., 2010) or affective priming. Furthermore, the longer-term effects of the interventions in experiment IV were not studied. Future experiments may do so.

The history of EMDR and its relationship with academic psychology is curious, if not ironic. The early clinical claims and proposed explanations met with skepticism (see Gunter & Bodner, 2008). However, controlled clinical trials showed the eye movement procedure yields good effects, which are as good as various types of Cognitive Behavior Therapy (Bisson et al., 2007; Davidson & Parker, 2001; APA, 2004). An explanation for the EMDR effects in terms of WM taxing by eye movements emerged and has been supported by a series of critical experimental studies from various laboratories (Andrade et al., 1997; Barrowcliff et al., 2004; Engelhard et al., 2010; Engelhard, van den Hout, et al., 2010; Engelhard, van Uijen, et al., 2010; Gunter & Bodner, 2008; van den Hout et al., 2001, 2010; Kavanagh et al., 2001; Kemps & Tiggemann, 2007; Maxfield et al., 2008). Over the past decade, EMDR therapists have started to replace eye movements with other types of bilateral stimulation, most notably binaural stimulation. However, there were no controlled clinical data, no coherent theoretical arguments, and no laboratory studies suggesting that binaural stimulation is effective. Data from the present studies, in conjunction with WM theory, suggest that, and why, binaural stimulation is inferior to eye movements in the reduction of vividness of memories.

References

- American Psychiatric Association. (2004). *Practice guideline for the treatment of patients with acute stress disorder and post traumatic stress disorder*. Arlington, VA: American Psychiatric Association Practice Guidelines.
- Andrade, J., Kavanagh, D., & Baddeley, A. (1997). Eye-movements and visual imagery: a working memory approach to the treatment of post-traumatic stress disorder. *British Journal of Clinical Psychology*, 36, 209–223.
- Baddeley, A. D. (1986). *Working memory*. London: Oxford University Press.
- Baddeley, A. D. (1998). *Human memory: Theory and practice*. Needham Heights, MA: Allyn & Bacon.

- Barrowcliff, A. L., Gray, N. S., Freeman, T. C. A., & MacCulloch, M. J. (2004). Eye movements reduce the vividness, emotional valence and electrodermal arousal associated with negative autobiographical memories. *Journal of Forensic Psychiatry and Psychology, 15*, 325–345.
- Bisson, J. I., Ehlers, A., Mathews, A., Pilling, S., Richards, D., & Turner, S. (2007). Psychological treatments for chronic post-traumatic stress disorder: systematic review and meta-analysis. *British Journal of Psychiatry, 190*, 97–104.
- Bower, G. H., & Clapper, J. P. (1989). Experimental methods in cognitive science. In M. I. Posner (Ed.), *Foundations of cognitive science* (pp. 245–300).
- Bradley, R., Greene, J., Russ, E., Dutra, L., & Westen, D. (2005). A multidimensional meta-analysis of psychotherapy for PTSD. *American Journal of Psychiatry, 162*, 214–227.
- Davidson, P. R., & Parker, K. C. H. (2001). Eye movement desensitization and reprocessing (EMDR): a meta-analysis. *Journal of Consulting and Clinical Psychology, 69*, 305–316.
- Engelhard, I. M., van den Hout, M. A., Janssen, W. C., & van der Beek, J. (2010). Eye movements reduce vividness and emotionality of images about “flashforwards”. *Behaviour Research and Therapy, 48*, 442–447.
- Engelhard, I. M., van den Hout, M. A., & Smeets, M. A. M. (2011). Taxing working memory reduces vividness and emotionality of images about the Queen's Day tragedy. *Journal of Behavior Therapy and Experimental Psychiatry, 42*, 32–37.
- Engelhard, I. M., van Uijen, S. L., & van den Hout, M. A. (2010). The impact of taxing working memory on negative and positive memories. *European Journal of Psychotraumatology*, doi:10.3402/ejpt.v1i0.5623.
- Gunter, R. W., & Bodner, G. E. (2008). How eye movements affect unpleasant memories: support for a working-memory account. *Behaviour Research and Therapy, 46*, 913–931.
- Holmes, E. A., James, E. L., Coode-Bate, T., & Deeprouse, C. (2009). Can playing the computer game “Tetris” reduce the build-up of flashbacks for trauma? A proposal from cognitive science. *PLoS One, 4*, e4153. doi:10.1371/journal.pone.0004153.
- Herbert, J. D., Lilienfeld, S. O., Lohr, J. M., Montgomery, R. W., O'Donohue, W. T., Rosen, G. M., et al. (2000). Science and pseudoscience in the development of eye movement desensitization and reprocessing: implications for clinical psychology. *Clinical Psychology Review, 20*, 945–971.
- van den Hout, M., Muris, P., Salemink, E., & Kindt, M. (2001). Autobiographical memories become less vivid and emotional after eye movements. *British Journal of Clinical Psychology, 40*, 121–130.
- van den Hout, M., Engelhard, I. M., Smeets, M. A. M., Horsnfeld, H., Hoogeveen, E., de Heer, E., et al. (2010). Counting during recall: taxing of working memory and reduced vividness and emotionality of negative memories. *Applied Cognitive Psychology, 24*, 1–9.
- Hyman, I. E., & Pentland, J. (1996). The role of mental imagery in the reaction of false childhood memories. *Journal of Memory and Language, 35*, 101–117.
- Kavanagh, D. J., Freese, S., Andrade, J., & May, J. (2001). Effects of visuospatial tasks on desensitization to emotive memories. *British Journal of Clinical Psychology, 40*, 267–280.
- Kemps, E., & Tiggemann, M. (2007). Reducing the vividness and emotional impact of distressing autobiographical memories: the importance of modality specific interference. *Memory, 15*, 412–422.
- Lee, C. W., & Drummond, P. D. (2008). Effects of eye movement versus therapist instructions on the processing of distressing memories. *Journal of Anxiety Disorders, 22*, 801–808.
- Lee, C. W., & Cuijpers, P. A. (2008). A meta-analysis of the contribution of eye movements in processing emotional memories, submitted for publication.
- Lilley, S. A., Andrade, J., Turpin, G., Sabin-Farell, R., & Holmes, E. (2009). Visuospatial working memory interference with recollections of trauma. *British Journal of Clinical Psychology, 48*, 309–321.
- Maxfield, L. (2008). Considering mechanisms of action in EMDR. *Journal of EMDR Practice and Research, 2*, 234–238.
- MacCulloch, M. (2006). Effects of EMDR on previously abused child molesters: theoretical reviews and preliminary findings from Ricci, Clayton, and Shapiro. *Journal of Forensic Psychiatry & Psychology, 17*, 531–537.
- Maxfield, L., Melnyk, W. T., & Hayman, C. A. G. (2008). A working memory explanation for the effects of eye movements in EMDR. *Journal of EMDR Practice and Research, 2*, 247–261.
- Pearson, D. G., & Sahraie, A. (2003). Oculomotor control and the maintenance of spatially and temporally distributed events in visuo-spatial working memory. *The Quarterly Journal of Experimental Psychology, 56A*, 1089–1111.
- Postle, B. R., Idzikowski, C., Della Salla, S., Logie, R. H., & Baddely, A. D. (2006). The selective disruption of working memory by eye movements. *The Quarterly Journal of Experimental Psychology, 59*, 100–120.
- Seidler, G. H., & Wagner, F. E. (2006). Comparing the efficacy of EMDR and trauma-focused cognitive-behavioral therapy in the treatment of PTSD: a meta-analytic study. *Psychological Medicine, 36*, 1515–1522.
- Vandierendonck, A., De Vooght, G., & Van der Goten, K. (1998). Interfering with the central executive by means of a random interval repetition task. *Quarterly Journal of Experimental Psychology, 51A*, 197–218.