



Virtual reality eye movements are not inferior to computerized eye movements and exposure in ameliorating aversive memories

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ABSTRACT

Background and objectives: Lab studies show that the emotionality and vividness of aversive memories decrease as a result of engaging in a working memory task during the recall of that memory. Translation of the dual tasking working mechanism to a VR program would allow for future VR-EMDR clinical and dissemination trials. The current study took the first step towards that goal by assessing the non-inferiority of a Virtual Reality (VR) eye movement task compared to computerized eye movements in amelioration of aversive autobiographical memory in a student sample.

Methods: In a cross-over design, university students ($N = 195$) recalled three aversive autobiographical memories and received VR Eye Movements (VR EM), Computerized Eye Movements (EM), and Exposure Only (EO). Emotionality and vividness of the memories were assessed before and after each condition.

Results: We found VR EM to be non-inferior to Computerized EM and EO in reducing emotionality and vividness. Both EM conditions outperformed the EO condition. Against our expectations, we found steeper declines of emotionality scores in the VR EM condition compared to the Computerized EM. Lastly, we found a sensitization effect in our EO condition: emotionality and vividness increased due to this procedure.

Limitations: Despite our efforts in standardizing working memory taxation between the dual tasking conditions (such as viewing angle and speed of eye movements), characteristics of the VR eye movements task might have unintentionally loaded additional working memory.

Conclusions: These findings show that VR eye movements could be a viable dual task and might serve as the first step to research VR eye movements in clinical practice.

1. Introduction

The World Health Organization (WHO) survey indicates that 70.4% of people experience potentially traumatizing events (Kessler et al., 2017) and 4% develop a subsequent Post-Traumatic Stress Disorder (PTSD; Liu et al., 2017). Patients suffering from PTSD experience intrusions related to the traumatic event and show avoidance behaviors. In addition, negative cognitions and mood related to the event as well as marked alterations in reactivity and arousal are part of the symptoms (American Psychiatric Association, 2013). Patients with PTSD show severe impairments in quality of life (Baranyi et al., 2010; Monson et al., 2015; Rapaport et al., 2005) and high comorbidity with other

(psychological) disorders (Gradus, 2017). These symptoms can result in not being able to attain or sustain life opportunities, for example in the areas of education, employment, and marriage (Kessler, 2000). It seems that the disorder is not only costly to the patient, but to society as well in the form of the cost of treatment and loss of productivity (Ferry et al., 2015; Marciniak et al., 2005).

There are a couple of effective evidence-based psychological treatments for PTSD. Eye Movement Desensitization and Reprocessing (EMDR) and trauma focused Cognitive Behavioral therapy (TF-CBT) are regarded as the most effective treatments for PTSD (Lewis, Roberts, Andrew, et al., 2020). As such, both are recommended in clinical guidelines for PTSD (National Institute for Health and Care Excellence

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[NICE], 2018). Even though these treatments are recommended, there is still room for improvements since high drop-out (Imel et al., 2013; Lewis, Roberts, Gibson, & Bisson, 2020; Schottenbauer et al., 2008) and non-responders (Schottenbauer et al., 2008; Sripada et al., 2019; Steenkamp et al., 2015) are not uncommon. In addition, not everyone who is referred for PTSD treatment receives evidence-based (PTSD) treatment (Becker-Haimes et al., 2017; McLean & Foa, 2011; van Minnen et al., 2010; Wolitzky-Taylor et al., 2015). Additionally, there is also a subgroup who does not receive treatment at all and suffers from the consequences of untreated PTSD (Priebe et al., 2009). It is therefore important to find novel ways to make PTSD treatment widely accessible.

There are several barriers known to dissemination, such as novelty resistance of therapists or costs of training the therapists (for an extensive list see Foa et al., 2013). Dissemination strategies mainly concern themselves with overcoming these barriers, so that more eligible patients can receive evidence-based treatments (EBT) (Foa et al., 2013; Wolitzky-Taylor et al., 2018). In this light, e-health has been recognized as an important innovation that could play a role in future dissemination protocols (Fairburn & Patel, 2017; Foa et al., 2013). Several advantages of this are that a wider audience can be reached and, when used in conjunction with regular therapist practice, it could enhance therapist efficiency which in turn lightens the load on waiting lists. Seeing that most patients face significant waiting lists (Beck et al., 2015; Deutsche Welle, 2021; Iqbal et al., 2021; Kazlauskas et al., 2016), and there is evidence that being on the waiting list worsens the clinical status of patients (Beck et al., 2015; Rozental et al., 2017) every initiative that enables therapists to help more patients in less time (while conforming to evidence based practice) should be embraced.

A relatively new development within e-health is Virtual Reality (VR), in which an alternative reality is projected using a head mounted display (HMD). The use of this technology has potential for new applications in clinical psychology such as assessment, understanding and most importantly, treatment of mental health disorders (Freeman et al., 2017). While a variety of VR applications has been researched in the context of psychological treatment, the majority has focused on exposure therapy in anxiety (see the reviews by Carl et al., 2019; Deng et al., 2019; Fernández-Álvarez et al., 2020; Freeman et al., 2017; Geraets et al., 2021; Kothgassner et al., 2019). The last couple of years are characterized by an increase in higher quality, clinically relevant VR studies (Lindner, 2021), which may be fueled by the availability of these technologies to a broader public. In addition, first evidence of cost-effectivity with VR technology has appeared in psychosis research (Pot-Kolder et al., 2020) and preliminary evidence suggests that therapists are increasingly ready to adopt the technology in practice (Lindner et al., 2019).

To date, there has been no VR research concerning EMDR or its working mechanism (dual tasking). This is a missed opportunity for several reasons. Firstly, it would offer clinicians and patients more flexibility regarding the array of offered treatments or personalized treatment trajectories (Norcross & Wampold, 2018). Secondly, because the most probable working mechanism of EMDR – overloading working memory with a dual task (Houben et al., 2020; Landin-Romero et al., 2018; Lee & Cuijpers, 2013; Mertens et al., 2021) – lends itself for translation to a digital medium because of its highly mechanical nature. Overloading the working memory with a dual task works as follows: by simultaneously recalling the most aversive moment in an aversive or a traumatic memory and engaging in a secondary task (such as eye movements in the classic EMDR model), competition for the limited resources of the working memory is created (Andrade et al., 1997; van den Hout & Engelhard, 2012). The result of this competition for resources in the working memory is that the (traumatic) memory becomes less emotional and less vivid (van den Hout & Engelhard, 2012). Recent meta-analyses indicate that the dual tasking effect is robust and that the effect extends to other tasks other than eye movements as long as the task loads sufficient working memory (Houben et al., 2020; Mertens et al., 2021). A third reason is related to the second argument and lies in

the broader scope of treatment and possible research avenues. Usually in TF-CBT vs EMDR Randomized Controlled Trials (RCT), one can argue that the time that the patient is exposed to the trauma in therapy (in other words: the amount of dose that they receive) is different between the interventions, since homework is part of the TF-CBT protocol. However, effects seem comparable (de Jongh et al., 2019) despite the absence of homework in EMDR (Ho & Lee, 2012). The highly controlled nature of a projected VR environment allows for structured homework assignments (Geraets et al., 2021) that are personalized to the patient's individual working memory taxation needs (e.g. control over the speed and pattern of the eye movements, but also standardization with regard to viewing distance to the target (often in the form of a 'ball') that is projected in the VR HMD for the eye movements). The question is what could be achieved in outcomes if the dose of TF-CBT and EMDR would be equalized. In this sense, more dissemination might also mean more effectivity, but empirical support for this supposition is lacking. Lastly, and related to VR technology in general, it allows the user to fully immerse oneself into the program, meaning that they experience less distraction.

However, before further VR research in clinical populations and dissemination can take place, several matters need to be addressed. First, it needs to be shown that the working mechanism of dual tasking translates to VR, by assessing non-inferiority of the VR procedure compared to the standard lab EMDR paradigm (eye movements) with regard to emotionality and vividness. A non-inferiority analysis is indicated when there is an advantage of the new method over the traditional method and the research question is not about whether the treatment is effective or not (Greene et al., 2008). In non-inferiority studies, a minimal acceptable margin is formulated from which the original therapy may deviate from the standard: if the lower tail of the 95% confidence interval overlaps with that boundary, non-inferiority may not be assessed. As such, a non-inferiority analysis may be more adequate to help move the field forward and should be a necessary first step before converting a treatment to a new modality, such as is the case in the current VR study. Because analogue populations have proven to be a good vehicle for researching the working mechanisms of EMDR (van den Hout et al., 2017), we assess these matters in a non-clinical population as a first step towards more research and dissemination.

The current study looked at the potential of a VR dual tasking method in ameliorating aversive autobiographical memories in a student sample. Specifically, we wanted to assess whether VR dual tasking was not inferior compared to computerized dual tasking (i.e. a non-inferiority analysis). Participants received three conditions: VR Eye Movements (VR EM), computerized Eye Movements (EM) or Exposure only (EO). Adding the exposure only condition as a control condition is common practice in dual tasking research (Mertens et al., 2021). The rationale for adding this condition is to assess whether the intervention is effective in reducing emotionality and vividness compared to solely recalling memory. We equalized the characteristics between the VR EM and computerized EM as much as possible by taking viewing angle and speed of eye movements into account. We expected the VR condition to perform within the bound of non-inferiority, and that both dual tasking conditions would outperform the exposure only condition with regard to decreasing emotionality and vividness of aversive memories.

2. Methods

2.1. Subjects

We included 201 psychology undergraduate students from two Dutch Universities (Tilburg University: $n = 192$) and Maastricht University: $n = 9$) for course credits. We excluded 4 participant that did not meet the inclusion criteria (not able to formulate an appropriate memory, see section 2.4), and 2 participants because of missing scores due to a procedural error (experimenter forgetting the baseline measurement; $n = 1$) or a technical error (depleted battery; $n = 1$), resulting in a final

sample of 195 participants (186 from Tilburg University and 9 from Maastricht University). We received ethical consent from the Ethical Review Board at Tilburg University. The sample of participants consisted of 41 males and 154 females (79%), with a mean age of 19.96 years ($SD = 2.17$). Most were first year students ($n = 188$: 96.4%). Reported nationality was mainly Dutch ($n = 110$: 56.4%), followed by 'other' ($n = 50$: 25.6%) and German ($n = 35$: 17.9%).

For the power analysis we based our calculations on the meta-analysis that was available at the time of setting up the study by Lee and Cuijpers (2013). The confidence interval for emotionality states that the true value will likely lie between 0.47 and 0.85 (95% CI: Lee & Cuijpers, 2013). We aimed for a conservative estimate using $d = 0.30$ and desired power = 0.95 to ascertain our sample size. Then, using the spreadsheet for performing power analyses for equivalency testing (Lakens, 2017), we performed a conservative power-analysis with the above parameters. This amounted to a sample size of $N = 145$. We aimed to recruit 200 to counter for attrition.

2.2. Design

The study consisted of a 3 (conditions) \times 2 (time points) within-subjects design. The three conditions were: VR Eye Movements (VR EM), Computerized Eye Movements (EM), and Exposure Only (EO). Each participant received all three conditions (order counterbalanced). The two time measurements took place before and after each condition.

2.3. Materials

2.3.1. Demographics and control questions

Questions about age, sex, years of attending university, nationality, and familiarity with EMDR were included. After the experimental procedures several control questions gauged how these procedures were experienced by the participants. For the VR EM condition the questions were: 'How well were you able to follow the instructions in the VR environment?' (0 – not well to 100 – very well), 'How well were you able to hold onto the image while moving your eyes during the VR task?' (0 – not well to 100 – very well). For the Computerized EM the questions were: 'How well were you able to hold onto the image while moving your eyes during the computer task?' (0 – not well to 100 – very well). For the EO condition these were: 'How well were you able to hold onto the image while looking at the blank screen?' (0 – not well to 100 – very well).

2.3.2. Emotionality and vividness

The VR application displayed Visual Analogue Scales (VAS) to obtain scores for the emotionality and vividness of the aversive memories. In the other conditions experimenters presented pen and paper VAS. The scales went from 0 (not unpleasant/vivid at all) to 100 (extremely unpleasant/vivid).

2.3.3. Nausea and comfort of the VR glasses

In addition, participants were asked to what extent they agreed with statements about the comfort of wearing the VR headset and the VR headset causing nausea, both on a scale from 1 (not at all) to 5 (very well).

2.3.4. Computerized eye movements and exposure only tasks

We used a commonly used E-prime eye movement task (Engelhard et al., 2010; van den Hout et al., 2011), which projected a white ball that moved from one side of the screen to the other side in about 1 s (1Hz). The exposure only task mirrored the exposure times of the eye movement conditions but displayed a black screen instead of a moving ball. The positioning of the participants was aimed at equalizing the viewing angle of the participants and thus working memory taxation as much as possible between conditions (see 2.3.5 and Fig. 1). This amounted to participant sitting approximately 26 cm from the computer screen.

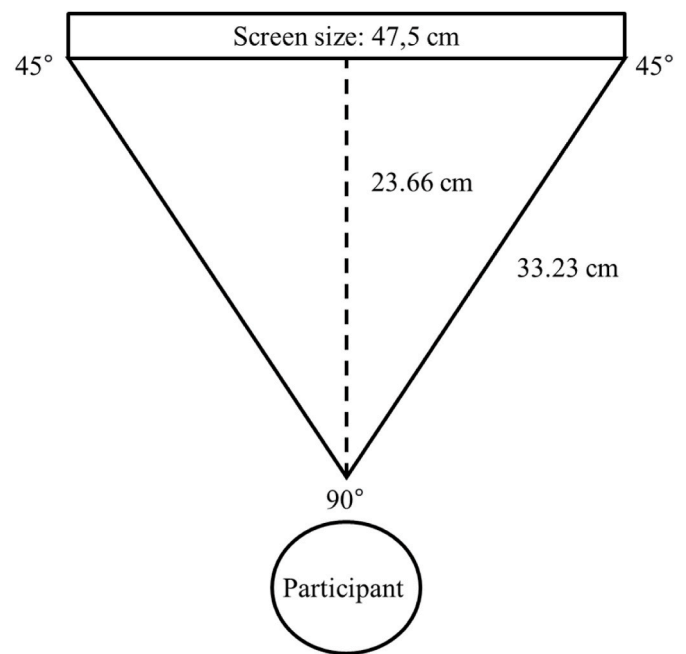


Fig. 1. Positioning of the participants in the eye movements and exposure only conditions.

Note. To add leeway to the above calculations, we added 2 cm to the rounded off number of 24, resulting in participants being seated 26 cm in front of the computer screen.

2.3.5. Psylaris® VR application

The VR dual tasking application was developed by Psylaris® (<https://www.psylaris.com/en/>). The company develops commercially available health solutions, including Virtual Reality EMDR. All the task characteristics (such as speed of the ball and exposure times) were matched with the regular eye movement task and the exposure only conditions (see 2.3.4). The Oculus Go (<https://www.oculus.com/go/>) was used and we used a viewing angle of 90° to base our calculation of the distance to the screen (89 ± 2.5 , see <https://www.infinite.cz/projects/HMD-tester-virtual-reality-headset-database-utility>). The participants found themselves immersed in a modern apartment (see Fig. 2).

2.4. Procedure

An often-used dual tasking lab protocol was followed (van Veen et al., 2020; van den Hout et al., 2001). Students could sign up online for the study and were invited to the lab. After receiving information and giving informed consent, participants were asked to recall an aversive autobiographical memory 'that still makes you feel bad or distressed right now, at this moment'. The event should have happened longer than one week ago. Participants then summarized their memory in keywords and subsequently gave unpleasantness and vividness scores. To ensure the balance of triggering discomfort but not to include a too emotional memory, memories were required to have a subjectively rated unpleasantness score between 60 and 90. We let the participants select another memory if the memory rating was below 60 or above 90. No boundaries were set for vividness. In the case that participants were not able to come up with an aversive autobiographical memory fitting these criteria by themselves, we provided a list of examples of commonly experienced aversive memories (e.g., seeing/being involved in an accident, the death of a friend/relative/acquaintance) to help them identify an eligible personal memory.

Participants then explained their memory in general terms, while being encouraged to stick to events that happened the same day of the event. Then, the most unpleasant image was distilled from this broad



Fig. 2. A screenshot from the Psylaris® VR EMDR app.

outline (the ‘hotspot’). We then asked the participants to formulate a ‘working title’, which described the memory in general, non-emotional terms. Examples from the study are: ‘hospital’, ‘fight’, ‘seeing accident’. Then, the participants ranked their memories from most to least aversive. After this procedure, they received all three conditions in randomized order, starting with the worst memory. In all conditions, participants first recalled their aversive autobiographic memory and gave ratings on emotionality and vividness (pre-measurement).

In the *EO* condition, participants recalled their memory while looking at a blank screen, for four blocks of 24 s, with 10 s rest breaks (126 s total).

In the *EM* condition, participants tracked a white ball moving from left to right and back once a second while thinking of their aversive memory (Engelhard et al., 2010; van den Hout et al., 2011) again for four 24 s blocks, with 10 s rest breaks (126 s total).

The *VR EM* condition, was identical to the *EM* condition except that the white ball was replaced by a moving 3D ball. The participants found themselves in a virtual modern apartment in which they could look around (see Fig. 2).

After receiving all three tasks (order depended on random allocation), participants rated emotionality and vividness (post measurement). Thereafter, they completed a questionnaire with control questions that checked for the transparency and credibility of our manipulations (see 2.3.1) and received a debriefing.

2.5. Data analysis

The choice of the non-inferiority margin is a crucial decision. Unfortunately, there is no clear-cut standard, but there is a consistent recommendation. In mental health research the margin should not be greater than the smallest effect size the active intervention would be reliably expected to have compared to a control condition (Greene et al., 2008). Translating this principle to the current study meant that we used the data on the basis of difference scores (dual tasking vs exposure only) reported by the most recent meta-analysis (Mertens et al., 2021) to formulate the non-inferiority margin. For emotionality the 95%

confidence intervals were [4.50, 7.94] and for vividness these were [7.06, 11.29]. We selected the lower bounds of these reported confidence intervals as our non-inferiority margins (4.50 for emotionality and 7.06 for vividness). For the non-inferiority analyses, the difference scores and their respective 95% CIs were plotted in a graph together with the pre-set boundaries described above. Secondly, to paint the complete picture, we report superiority analyses as well (Dunn et al., 2018). This amounted to two separate repeated measures ANOVAs for emotionality and vividness, which we followed up with additional t-tests in the case of significant differences and used a Bonferroni corrected p -value threshold of $\alpha = .017$ (0.05/3 comparisons) to interpret our p -values. We reported the uncorrected p -values. Lastly, we performed a post hoc tests in the case of unexpected results. This pertained to possible sensitization effects within one condition on which we conducted paired sample t-tests. All the data and used scripts are available at Open Science Framework (https://osf.io/jq7tk/?view_only=2976f9b01cff421897342d180daf47d3).

3. Results

3.1. Preliminary analyses

Descriptive data with regard to the outcome measures can be found in Table 1.

3.1.1. Control questions and randomization check

We included several control questions in the study. Firstly, the majority of the participant indicated they knew what the hypothesis of the study was ($n = 148$: 77.5%) and the majority of the participants indicated that they never heard of EMDR ($n = 141$: 72.3%). Secondly, we assessed whether participants were able to follow instructions in the different conditions: In both the *VR EM* ($M = 86.37$, $SD = 14.54$) and *Computerized EM* ($M = 85.45$, $SD = 14.03$) conditions participants indicated that they were able to follow instructions well. Thirdly, a repeated measures ANOVA indicated a significant difference between conditions in the ability to hold on to their image $F(1.61, 316.64) =$

Table 1

Means and standard deviations in the *VR EM*, *Computerized EM* and *EO* conditions for the emotionality and vividness outcome measures.

| | | VR Eye Movements | Computerized Eye movements | Exposure Only |
|--------------|------|------------------|----------------------------|---------------|
| Emotionality | Pre | 75.60 (14.82) | 69.92 (12.08) | 70.29 (11.68) |
| | Post | 68.22 (19.75) | 65.50 (16.55) | 74.14 (14.90) |
| Vividness | Pre | 77.15 (18.66) | 73.02 (16.47) | 73.68 (15.97) |
| | Post | 68.92 (23.75) | 66.33 (20.47) | 77.78 (16.84) |

112.67, $p < .001$, $\eta_p^2 = 0.37$. Follow-up paired samples t -tests with a Bonferroni corrected p -value threshold (required $\alpha = 0.017$) showed that the scores in the VR EM ($M = 62.21$, $SD = 23.62$) and Computerized EM ($M = 60.10$, $SD = 22.45$) conditions did not differ significantly ($t(193) = 1.72$, $p = .087$, $d = 0.12$), but in the EO condition participants were better able to hold on to their image ($M = 82.30$, $SD = 16.91$) compared to the Computerized EM ($t(193) = 13.12$, $p < .001$, $d = 0.94$) or the VR EM condition ($t(193) = 10.54$, $p < .001$, $d = 0.76$). Lastly, participants indicated the VR HMD was comfortable ($M = 3.94$, $SD = 0.79$) and the procedure did not cause nausea ($M = 1.26$, $SD = 0.58$).

Additionally, we implemented several analyses to check the validity of our randomization procedure. Firstly, we checked for differences between our six randomization orders with regard to sex and nationality. These analyses showed no evidence for a difference with regard to sex ($\chi^2(5, N = 195) = 0.43$, $p = .995$), but did indicate a difference for nationality ($\chi^2(50, N = 195) = 71.02$, $p = .027$). A post hoc analysis failed to identify which cells differed. Secondly, we checked for baseline differences (first score in the experiment of emotionality and vividness) between the six different randomization orders. This resulted in finding evidence for differences in baseline scores between orders with regard to emotionality ($F(5, 189) = 3.52$, $p = .005$, $\eta_p^2 = 0.09$), which could be attributed to the fifth randomization order (EO-VR EM-EM) differing from the first (VR EM-EM-EO) and the second order (VR EM-EO-EM) (Bonferroni corrected p -values $< .05$). With regard to vividness, there was no evidence for a difference between the randomization orders ($F(5, 189) = 0.83$, $p = .528$, $\eta_p^2 = 0.02$). Lastly, and most importantly, we added randomization order to the model used in the main analyses (described under 3.2). We found no evidence for significant time*condition*order effects with regard to emotionality ($F(9.22, 349.65) = 0.61$, $p = .797$, $\eta_p^2 = .02$) and vividness ($F(9.40, 368.71) = 0.34$, $p = .965$, $\eta_p^2 < 0.01$, meaning that there was no evidence for differing change trajectories on the basis of order assignment).

3.2. Primary analyses

The difference scores were calculated for the pre-post scores and their respective 95% confidence intervals per condition (see Fig. 3). Then, we used these values to compute difference scores for the eye movement conditions compared to the exposure only condition, which were then plotted together with the non-inferiority margins extracted from Mertens et al. (2021) (see Fig. 4).

3.2.1. Emotionality

Firstly, for the main hypotheses, the confidence intervals were plotted in Fig. 4. The lower bound of 4.50 was used (Mertens et al., 2021) as the non-inferiority margin. Since the mean and 95% confidence

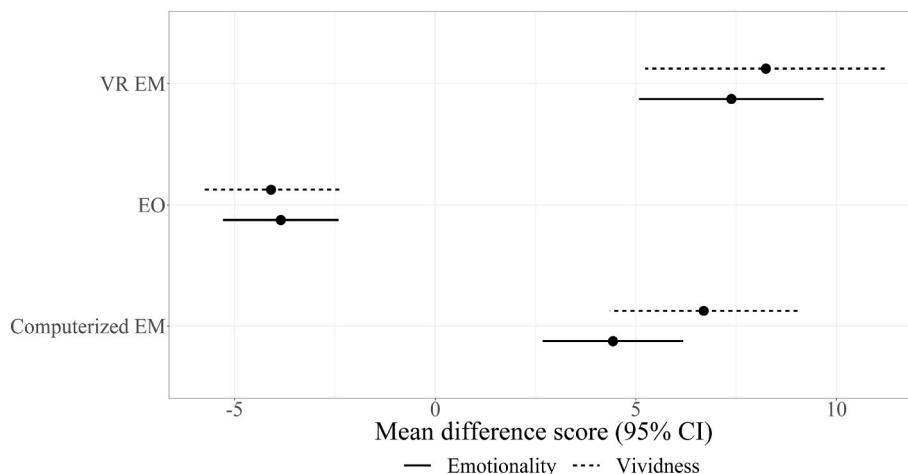


Fig. 3. Confidence intervals (95%) plotted for the pre-post difference scores per condition (VR EM, EO and Computerized EM) for emotionality and vividness.

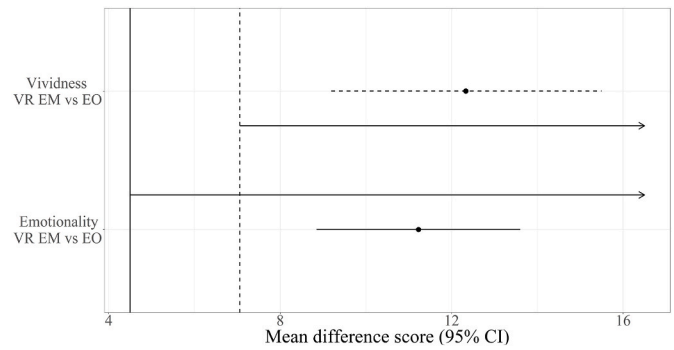


Fig. 4. Confidence intervals (95%) plotted for comparison between the VR eye movements (VR EM) and exposure only (EO) conditions using the difference scores in Fig. 3.

Note. The vertical lines represent the non-inferiority margins (Mertens et al., 2021): the dotted line is vividness and the regular line is emotionality. As can be seen from the graph, the confidence intervals fall to the right, which means that non-inferiority can be concluded for both emotionality and vividness.

intervals of the data do not overlap with the lower bound (and lay to the right), we can conclude non-inferiority for emotionality.

Secondly, a repeated measures ANOVA revealed all significant effects: time ($F(1, 194) = 13.73$, $p < .001$, $\eta_p^2 = .07$), condition ($F(1.92, 371.44) = 10.95$, $p < .001$, $\eta_p^2 = .05$) and crucially time*condition ($F(1.84, 357.58) = 57.75$, $p < .001$, $\eta_p^2 = 0.23$). We explored the significant interaction effect further with paired samples t -test with a Bonferroni corrected p -value threshold (required $\alpha = 0.017$). The first comparison between Computerized EM and EO showed that Computerized EM reduced emotionality significantly more than EO, $t(194) = 8.81$, $p < .001$, $d = 0.63$. The second comparison showed that VR EM reduced emotionality significantly more than Computerized EM $t(194) = 2.74$, $p = .007$, $d = 0.20$. The third and last comparison showed that VR EM reduced emotionality significantly more than EO $t(194) = 9.25$, $p < .001$, $d = 0.66$.

3.2.2. Vividness

Firstly, for the main hypotheses, the confidence intervals were plotted in Fig. 4. We used the lower bound of 7.06 (Mertens et al., 2021) as a non-inferiority margin. Since the mean and 95% confidence intervals of the data don't overlap with the lower bound, we can conclude non-inferiority for vividness as well.

Secondly, a repeated measures revealed all significant effects: time ($F(1, 194) = 16.67$, $p < .001$, $\eta_p^2 = 0.08$), condition ($F(1.83, 355.52) = 10.65$, $p < .001$, $\eta_p^2 = .05$) and crucially time*condition ($F(1.88, 365.37)$

= 41.26, $p < .001$, $\eta_p^2 = 0.18$). Then, we explored the significant interaction effect further with paired samples t -test with a Bonferroni corrected p -value threshold (required $\alpha = 0.017$). The first comparison between Computerized EM and EO showed that Computerized EM reduced vividness significantly more than EO, $t(194) = 8.37$, $p < .001$, $d = 0.60$. The second comparison showed that there was no evidence for a difference between VR EM and Computerized EM $t(194) = 1.01$, $p = .312$, $d = 0.07$. The third and last comparison showed that VR EM reduced vividness significantly more than EO $t(194) = 7.70$, $p < .001$, $d = 0.55$.

3.3. Post hoc analyses

3.3.1. Emotionality

Because of the negative difference score in the EO condition, we decided to conduct a post hoc paired t -test to see whether this qualifies as a sensitization effect. Results showed that emotionality increased significantly from pre to post measure in the EO condition, $t(194) = -5.23$, $p < .001$, $d = -0.38$.

3.3.2. Vividness

Lastly, because of the negative difference score in the EO condition, we decided to conduct a post hoc paired t -test to see whether this qualifies as a sensitization effect. Results showed that vividness increased significantly from pre to post measure in the EO condition, $t(194) = -4.71$, $p < .001$, $d = -0.34$.

4. Discussion

With the current study we aimed to assess non-inferiority of a novel VR application of a dual tasking intervention (eye movements) in aversive autobiographical memory in a student sample. We confirmed our expectation that VR eye movements was non-inferior compared to computerized eye movements. However, for emotionality, we not only showed non-inferiority, but also found evidence for superiority of VR EM over computerized EM. Additionally, post hoc tests indicated a sensitization effect in the exposure only condition. This is the first study to assess a VR dual tasking paradigm.

While we did find the expected non-inferiority of VR eye movements (compared to computerized eye movements), this seemed to go beyond non-inferiority and even to superiority for emotionality only (small effect (Cohen, 1988), $d = 0.20$). Several reasons could be brought forward as possible explanations for this effect. Firstly, the immersiveness of the VR environment may have played a role. As a key strength of VR, immersiveness in the therapeutic context is usually used to present the core of the problem (such as in VR exposure therapy). This is different in the context of the current study as our VR app mimics a room in which the dual tasking procedure takes place. Working memory might provide a framework in which this finding could be explained. We controlled many aspects of the VR task so that it matched the regular eye movement tasks as closely as possible, but we could not control participants looking around in the 3D environment in between sets. This seems a plausible explanation, but it can only remain a speculation since we did not assess working memory load with a Random Interval Repetition (RIR: Goten et al., 1998) task. Secondly, wearing an HMD offers sensory deprivation which may have contributed to the participants' ability to focus on the task at hand. Lastly, it is possible that the superior effect for decrements in emotionality can simply be attributed to a 'novelty' effect (Clark, 1983) of VR.

Another factor which might have influenced our results lies in our attempt at matching viewing angles in our computerized EM and EO conditions with the VR condition. This resulted in requiring participants to sit quite close to the screen (26 cm) compared to many other dual tasking studies (e.g., approximately 60 cm: van Veen et al., 2020, or 45 cm: Engelhard et al., 2010) which may have been an uncomfortable experience. Albeit anecdotally, this is commentary that we heard during

the study. In the computerized eye movements condition, this may have dampened the effects and in the exposure only condition there was no secondary task to distract the participant from the discomfort which might have translated into our outcome measures. This effect seems especially pronounced with regard to emotionality, and this might have caused the significant difference between the VR condition and computerized eye movements. Although it is unclear why this effect emerged for emotionality and not for vividness, it is plausible that emotionality is more in sync with affective systems, making it possible that feelings of discomfort might have seeped into the emotionality measurement.

Interesting to note is that usually scores in the exposure only condition seem to stay stable in dual tasking studies (Houben et al., 2020; Mertens et al., 2021), but that the current study joins several recent studies that report sensitization effects in the control condition on the short term (e.g., IJdema et al., 2021; van Veen et al., 2020). The current study used the same protocol with regard to memory recall as van Veen et al. (2020) and showed similar results (with the main difference being that the speed of the eye movements in the current study were more traditional: 1hz vs 1.2hz).

We answered our main hypotheses about non-inferiority of dual tasking in VR and showed that nausea does not seem an issue for this VR app. Because of this, future researchers are encouraged to pursue researching the technology in more afflicted (clinical) samples. Research into psychotherapy postulates that adapting therapy to the patient is important (Norcross & Wampold, 2018), meaning that adding a new way of offering therapy is beneficial. From a patient service standpoint, treatment preferences for patients in PTSD seem quite evenly distributed among different evidence-based treatments (Schwartzkopff et al., 2021). Combined with the fact that meeting treatment preferences could positively influence outcomes (Williams et al., 2016), this highlights the need to develop and offer more alternatives of trauma treatment in this upcoming modality.

Traditional dissemination approaches have been targeted mainly at clinical systems and therapists (Santucci et al., 2012). Another (complementary) approach could be a direct pathway to consumers or blended formats. These strategies mainly concern themselves with increasing 'pull' by increasing public knowledge about evidence-based therapies (Karlin & Brenner, 2020), but also by increasing adoption of minimal contact web-based interventions (Santucci et al., 2012). Several examples of digital interventions have been reported (see Fairburn & Patel, 2017). With the advent of consumer VR technology (technology becoming more powerful and cheaper), recent events (COVID-19), new investments in digital VR environments ('Metaverse') by Meta (formerly known as Facebook: Meta, 2021) and possibilities for customization of these devices with eye tracking hardware, this seems a promising avenue to explore for future research. Though, as has been noted elsewhere (Fairburn & Patel, 2017), this might be intertwined with unknown adverse effects that would most likely only appear when widespread adoption occurs. It is recommended that researchers think about addressing these matters in trials (Fernández-Álvarez et al., 2020), even more so because implementing this technology means more unsupervised moments in most formats. In any case, we argue that studies like the current should be at the base of more extensive clinical trials or dissemination attempts.

Several limitations and strengths need to be pointed out. Firstly, regarding limitations, we did not assess the working memory load of the VR eye movements, thus it is unclear whether a difference herein was the driving factor of the superior (small) effects. Secondly, we did not recruit a clinical sample, meaning that we have no data on how the VR app would be received in a clinical PTSD population. However, the current study can serve as the first step building towards that goal. Thirdly, our randomization checks pointed at possible problems with randomization, which might have influenced our results. While we are aware that lower baseline scores in some orders (in our case one baseline score of EO) and higher baseline scores in other cases (two scores for the

VR condition) could have contributed to our results with regard to emotionality, we expect that this effect is modest. This is because of two reasons: 1. our final analysis in which we added order to the primary model did not indicate different change trajectories (see 3.1.1), and 2. the mean baseline emotionality scores in the orders that scored differently were still in the common bandwidth of the emotionality inclusion criterium ($90 > \text{emotionality} > 60$). With regard to strengths, due to the conservative power analysis, the study had large power. Lastly, we took strong measures to standardize the characteristics of our different conditions, adding to the robustness of the findings.

4.1. Conclusion

The current study aimed to research an innovation in dual tasking research. We looked at a novel VR eye movements tool in comparison to regular eye movements. Not only did we find non-inferiority, but we even found evidence for superiority of VR eye movements over regular eye movements (for emotionality only). Additionally, we found a sensitization effect in the exposure only condition. These findings show that VR eye movements is a viable dual task and might serve as the first step to research VR eye movements in clinical practice.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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