# Digital EMDR: Are Reaction Time Tasks and Eye Movements Effective in Taxing Working Memory and Degrading Aversive Memories?

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## Abstract

*Background*: Eye Movement Desensitization and Reprocessing (EMDR) is a standard therapy protocol used to treat Post Traumatic Stress Disorder (PTSD). EMDR is based on a dual-task approach: By asking the patient to bring a traumatic memory to mind while simultaneously making eye movements (EM), working memory (WM) competition is present which reduces the emotional intensity of the memory. WM theory suggests that the dual-task component might be improved by addressing WM load and individual working memory capacity (WMC) while matching task modality with memory modality.

*Objectives*: The current study's aim was two-fold. In the first part, we examined the suitability of smartphone-delivered combined-modality (visual + auditory) reaction time tasks (RTT) as supplementation for EM to tax WM. In the second part, the effectiveness of a smartphone-delivered EMDR intervention using combined-modality RTTs and adaptive EM (speed based on WMC) in reducing emotionality and vividness of an induced emotional memory (i.e., trauma film paradigm) was tested experimentally.

*Method*s: In part 1, after a baseline measurement of single-modality visual and auditory reaction times (RT), participants responded to sets of combined-modality RTTs with increasing speeds of EM. In part 2, participants either just recalled negative memories induced by a traumatic film or while simultaneously carrying out combined-modality RTTs with adaptive EM. Vividness and emotionality were measured before and after the intervention and after 24 hours.

*Results*: In part 1, combined-modality RTTs resulted in increased cognitive load compared to the baseline. Increasing speeds of EM resulted in a linear increase in visual WM loading. In part 2, both conditions resulted in equal decreases in emotionality and vividness after the intervention and after 24 hours.

*Conclusion*: The results suggest that combined-modality RTTs and EM tax WM in a modality-specific and dose-dependent way. No evidence was found that combined-modality RTTs with adaptive EM are effective in degrading aversive memories. The active control condition and the possible WM overload are possible explanations for the missing effect. Future research is needed to validate current findings.

# Digital EMDR: Are Reaction Time Tasks and Eye Movements Effective in Taxing Working Memory and Degrading Aversive Memories?

Eye Movement Desensitization and Reprocessing (EMDR) is a first-choice treatment for Post-Traumatic Stress Disorder (PTSD), a trauma- and stressor-related disorder characterized by fear, helplessness, distressing flashbacks and intrusive thoughts resulting from exposure to traumatic experiences (Shapiro, 1989; Watkins et al., 2018). EMDR is based on a dual-task approach: By instructing the patient to make eye movements (EM) while recalling a traumatic memory, emotionality and vividness of the memory are reduced (Mertens et al., 2021; van den Hout & Engelhard, 2012). As not all patients respond equally well, enhancing the dual-task component is a crucial target for making EMDR more effective (Mertens et al., 2021).

## EMDR: How Does It Work?

In the late 1980s, EMDR emerged as a novel treatment for PTSD (Shapiro, 1989). Traditionally, the therapist asks the patient to bring a traumatic memory to mind and to focus on a specific disturbance. While holding the memory in mind, the therapist invites the patient to follow the therapist's moving finger simultaneously. The patient makes horizontal EM while holding the memory in mind and indicates a rating on a disturbance scale (Shapiro, 1989). Each disturbance related to the memory is targeted until the patient can visualise the memory without any disturbance (Buydens et al., 2014). Even though scepticism was the first response to this seemingly odd treatment procedure, several meta-analyses have indicated that EMDR is an effective treatment for PTSD and that EM indeed add to the treatment outcome (Cuijpers et al., 2020; Lee & Cuijpers, 2013). However, the working mechanism of EMDR is still a subject of debate which prevents a unified theoretical approach to EMDR research (Cuijpers et al., 2020; Lee & Cuijpers, 2013; van den Hout & Engelhard, 2012).

Several theories have been proposed to explain the effectiveness of EMDR (i.e., interhemispheric communication, triggering of REM; Matthijssen et al., 2018; van den Hout & Engelhard, 2012). Currently, working memory (WM) theory provides the most promising explanation suggesting that when keeping an aversive memory in mind and simultaneously taxing WM through a second task (i.e., EM), both tasks compete for limited working memory capacity (WMC; Baddeley & Andrade, 2000). Through reactivation of the memory, the previously consolidated memory may become labile and sensitive to disruption (Lewis, 1979). As a result of WM competition, the memory cannot be retrieved completely resulting in imagination deflation and consequently reduced emotional intensity (Maxfield et al., 2008; van Schie et al., 2016). It is suggested that the degraded memory is reconsolidated into long-term memory after this process (Maxfield et al., 2008; van den Hout & Engelhard, 2012). As WM taxation is seen as the main working mechanism, traditional EM have increasingly been replaced by other dual-tasks, such as drawing a complex figure, playing Tetris, or mental arithmetic tasks which are as effective as EM (Engelhard et al., 2010; Gunter & Bodner, 2008; Mertens et al., 2021). In contrast, passive bilateral stimulation such as alternating beeps or taps used based on competing theories (i.e., interhemispheric communication) are less taxing and thus less effective (Lee & Cuijpers, 2013; van den Hout & Engelhard, 2012). Consequently, the persistent finding that memories get less emotional and vivid after the execution of WM-taxing dual-tasks is in line with WM theory (van den Hout et al., 2010).

**Improving EMDR: Implications from WM theory**

Several implications can be derived from WM theory to improve the dual-task component of EMDR. Firstly, WM taxation may be optimized. Two lines of thought have emerged concerning the ideal amount of WM taxation for memory degradation effects. On the one hand, a linear dose-response relationship between WM taxation and memory degradation has been put forward (Littel & van Schie, 2019). Specifically, it is expected that more WM taxing produces more memory degradation. In line with this hypothesis, several studies found that more cognitively demanding dual-tasks (i.e., fast EM or complex mental arithmetic tasks) resulted in lower emotionality and vividness ratings than less taxing tasks (Littel & van Schie, 2019; Maxfield et al., 2008; Van Veen et al., 2015). On the other hand, it has been proposed that the relationship between WM taxation and memory degradation follows an inverted U-curve (Cuperus et al., 2019; Engelhard et al., 2011; van den Hout & Engelhard, 2012). Accordingly, dual-tasks resulting in moderate WM taxation are expected to be more effective in decreasing the emotionality and vividness of an aversive memory than simple or complex dual-tasks. Indeed, Engelhard et al. (2011) found that intermediate subtraction tasks resulted in stronger decreases in emotionality scores than simple or complex subtraction tasks (which differed significantly in required WM resources). As an explanation, it is suggested that extremely taxing tasks may interfere with holding an image in mind which in turn prevents memory degradation. Hence, the degrading effects of taxing WM may decrease when WM is "over-taxed" as there is not enough capacity left to activate the memory (Baddeley, 1998; Cuperus et al., 2019; Engelhard et al., 2011). Overall, it is still unclear whether the dose-response relationship of optimal WM taxation for memory degradation follows a linear or an inverted U-curve. One major issue of the previously discussed studies is their different conceptualisation of WM taxation. Due to varying dual-tasks and study designs, it is difficult to compare findings as “high WM taxing” might be nothing alike in different studies. Still, taking the conflicting evidence together, it may be that the less WMC available for retrieving the memory, the larger the effects of dual-tasks on emotionality and vividness of an aversive memory. However, as proposed by the inverted U-curve hypothesis, there might be a turning point for the effect of WM taxation on memory degradation as when WM is “over-taxed” and the memory cannot be sufficiently activated, the beneficial effects might decrease.

Secondly, WM taxation theory proposes that individual WMC differences should be addressed as these affect the effectiveness of dual-tasks. Gunter and Bodner (2008) found robust negative correlations between individual WMC (i.e., reading span scores) and dual-task benefits. This has been confirmed by two other studies that found the predicted relationship (van den Hout et al., 2010; van den Hout, Engelhard, Beetsma, et al., 2011). Hence, individuals with lower WMCs might benefit more from the dual-task procedure as their WM is more easily taxed which leaves less room for memory recall making the effect of the dual-task stronger (van den Hout & Engelhard, 2012). However, taking the previous discussion about the dose-response relationship into account, if there is indeed “too much of a good thing” (i.e., inverted U-curve), individuals with smaller WMCs should be exposed to weaker dual-task, while individuals with large WMCs need much more taxing dual-tasks to ensure that their WM is taxed sufficiently. Consequently, dual-task should maximize WM load while taking individual differences in WM into account to ensure optimal conditions.

Thirdly, WM theory proposes that the dual-task component of EMDR may be optimised by adjusting the modality of the dual-task to the specific memory modality. WM consists of three subsystems. While mental (auditory and visual) imagery occurs in the visuospatial sketchpad (VSSP) and the phonological loop (PL), the non-modal central executive (CE) allocates and divides attention between tasks, activates memories, and inhibits distracters (Baddeley, 2011). There is a debate around whether solely the CE is involved in reductions of emotionality and vividness or whether the two modality-specific systems are of relevance (Gunter & Bodner, 2008; van den Hout, Engelhard, Rijkeboer, et al., 2011). Generally, it is assumed that dual-tasks such as EM have general memory effects, affecting the CE component of WM (van den Hout, Engelhard, Rijkeboer, et al., 2011). Besides, visual tasks seem to specifically tax the VSSP while auditory tasks tax the PL (Baddeley & Andrade, 2000; Maxfield et al., 2008). Emerging evidence has been found suggesting that matching the modality of the dual-task to the memory may increase the effectiveness of dual-tasks in reducing emotionality and vividness of aversive memories, implying that modality-specific effects are superimposed on general effects (Matthijssen et al., 2019; Mertens et al., 2020). Based on the assumption of a subordinate role of VSSP and PL in degeneration effects, using both visual and auditory dual-tasks could yield more effective memory degradation as all three systems (CE, VSSP, and PL) are taxed possibly contributing to the overall effect of EMDR (Van den Hout et al., 2010). Examining the specific effect of combined-modality dual-tasks on WM taxation is called for.

Overall, WM theory proposes that the dual-task component of EMDR may be improved by addressing WM load and individual WMC of dual-tasks while matching dual-task modality with memory modality.

## Measuring and Taxing WM with RTTs

To incorporate the previously discussed implications, ordinary dual-tasks (i.e., EM) may be extended by reaction time tasks (RTTs). A major disadvantage of common dual-tasks is their missing adaptability. By using EM, it is neither possible to address individual differences in WMC nor memory modality. Besides, there is a limit when it comes to WM taxation intensity which could be circumvented by adding another task to EM (van Schie et al., 2016). Supplementing EM with RTTs might make up for these disadvantages as RTTs are adaptable, modality-specific and combinable. RTTs work by introducing a changing stimulus to which participants must respond as fast as possible. After this baseline measurement, a second task is added (i.e., EM). The degree to which reaction times (RTs) slow down produces a quantitative measurement of WMC required by the second task (Bower & Clapper, 1990; van den Hout & Engelhard, 2012). There are several modality-specific RTTs such as random interval repetition (RIR) tasks where beeps or changing visual stimuli are randomly presented and individuals must react as fast as possible to their presentation by pressing a button (Vandierendonck et al., 1998). Appealingly, RTTs have been found to draw on the same resource (WM) as other dual-tasks (van den Hout, Engelhard, Rijkeboer, et al., 2011; Vandierendonck et al., 1998). Thus, RTTs could supplement EM or other dual-tasks to incorporate implications from WM theory.

Firstly, by combining RTTs with EM a higher WM load may be achieved. Overall, the general WM load might be increased as RTTs draw on the CE (Vandierendonck et al., 1998). Secondly, as WM taxation is constantly measured, the difficulty of the task could be adapted to achieve optimal WM taxation based on individual WMC (Gunter & Bodner, 2008). Specifically, adaptive RTTs could achieve optimization by adjusting the difficulty of another task (i.e., speed of EM) based on the relative WM taxation of an individual as indicated by short or long RTs. An individual showing shorter RTs (i.e., indicating a larger WMC) should be exposed to a more difficult task (i.e., faster EM) to ensure optimal WM taxation. Thirdly, the preliminary advice of matching the modality of the dual-task with the modality of the memory might be implemented by using both visual and auditory RTTs. (Mertens et al., 2020). This way the dominant modality of the memory is addressed and superimposed modality-specific effects on the VSSP and PL might be achieved.

In sum, in an effort to improve the dual-task component of EMDR, implications derived from WM theory were incorporated in the form of smartphone-delivered combined-modality RTTs (visual + auditory) and adaptive EM (speed based on individual WMC).

**Smartphone-Delivered Online EMDR: Treatment Acceptability as a Moderator**

Since EMDR was established, technology was repeatedly introduced as a way of assisting therapy to make treatment more effective and time-efficient (Goga et al., 2022). As the aforementioned RTTs depend on a digital mode of presentation, it is natural to implement them in a digital form. Recent advances in technology have led to the development of mobile applications that aid in the desensitization phase of EMDR (Flores et al., 2015; Marotta-Walters et al., 2018). In the context generated by COVID-19, EMDR-assisting applications are especially useful when it comes to administering therapy online. In an open trial, Spence et al., 2013 administered EMDR via the internet by using an online tool and found large effect sizes from pre-treatment to 3-month follow-up measurements. In line with these developments and findings, the current intervention (combined-modality RTTs with adaptive EM) will also be implemented online in a smartphone-based EMDR intervention.

Besides clinical effectiveness and time efficiency, the treatment acceptability of online EMDR is an essential criterion likely to affect outcomes. Treatment acceptability is defined as "the degree to which an individual perceives a treatment procedure to be fair, reasonable, appropriate and unintrusive for a given clinical problem" (Milosevic et al., 2015, p. 456). Previous research about the acceptability of internet-based treatment has reported mixed results (Gun et al., 2011). In a recent study by Bursnall et al. (2022), acceptability of online EMDR was reported to be high. However, they argue that patient enthusiasm for online treatments should be viewed with caution as individuals more comfortable with online environments are more likely to respond to an online questionnaire. Importantly, treatment acceptability is interwoven with dropout rates and treatment success (Milosevic et al., 2015; Schottenbauer et al., 2008). Hence, as our intervention was delivered online, treatment acceptability was assessed as a possible explanatory factor for treatment differences due to its relevance for online treatments.

## The Current Study

The current study's aim was two-fold. The first part aimed at measuring the WM load of modality-specific RTT combinations (single-modality and combined-modality) while adding three different speeds of EM (slow, medium, fast) respectively. RTTs were used to tax WM but also to ensure reliably quantified WM taxation that can be compared to similar studies (Matthijssen et al., 2019; van den Hout, Engelhard, Rijkeboer, et al., 2011). Consequently, the first part of this study will provide further evidence to the dose-response relationship debate examining how increasing the complexity of WM-taxing tasks (combined-modality RTTs + EM) increases WM load.

For the first part, three hypotheses were tested. The first hypothesis was based on WM theory which states that more cognitively demanding tasks result in higher WM load (van den Hout, Engelhard, Beetsma, et al., 2011). This was determined by comparing the visual and auditory RTs of single-modality RTTs with combined-modality RTTs. It was hypothesized that executing combined-modality RTTs results in a higher WM load (i.e., longer visual + auditory RTs) compared to single-modality RTTs ($H_1$).

The second hypothesis was also based on WM theory and earlier findings which found that increasing speeds of EM would result in increasing WM taxing and specifically higher VSSP loading (Maxfield et al., 2008; van Veen et al., 2015). VSSP taxing was assessed by examining the increases in visual RTs. It was expected that adding increasing speeds of EM (slow, medium, fast) to the combined-modality RTTs results in increasingly higher VSSP load (i.e., longer visual RTs; $H_2$).

The third hypothesis was derived from Littel and van Schie's (2019) finding that RTTs seem to be a sensitive to a trade-off which is similar to an inverted U-curve. If a task is too difficult, participants might strategically shift away from one task which results in improved RTs for the other task. As two modality-specific RTTs and increasing speeds of EM were used, it was believed that this trade-off would occur and would be reflected in increased error rates. Thus, the most challenging RTT (combined-modality + fast EM) was expected to overload WM which would result either in (1) an increase in general error rates or (2) a strategic shift away from one RTT reflected in high error rates for one RTT, but stable RTs for the other (Littel & van Schie, 2019; $H_3$).

The second part aimed at assessing the effectiveness of an online EMDR intervention in decreasing the emotionality and vividness of an induced traumatic memory (i.e., trauma film paradigm) using combined-modality RTTs and adaptive EM. Specifically, implications from WM theory were incorporated in form of a visual and an auditory RTT which were presented simultaneously to ensure sufficient WM taxation. Besides, both general (CE) as well as modality-specific taxing (VSSP + PL) was expected (Maxfield et al., 2008; van den Hout, Engelhard, Rijkeboer, et al., 2011). A moving ball was presented to stimulate EM which will further tax the VSSP (Maxfield et al., 2008). Besides, an algorithm was used that either increased or decreased the speed of EM based on the respective RTs of the individual (indicating size of the WMC) to ensure optimal WM taxation (Gunter & Bodner, 2008).

For the second part, three additional hypotheses were tested. Hypothesis four was rooted in previous research and WM theory which suggest that taxing WM while individuals recall a negative memory makes the memory less emotional and vivid (Lee & Cuijpers, 2013; Maxfield et al., 2008; Mertens et al., 2021). Thus, in assessing the effectiveness of the online EMDR intervention in degrading the intensity of the induced traumatic memory, it was hypothesized that using a combined-modality RTT (visual + auditory) and adaptive EM (adjusting speed of EM to individual WMC) to tax WM while participants hold an image of an aversive memory in mind results in lower emotionality and vividness scores than just recalling the memory ($H_4$).

The fifth hypothesis dealt with the influence of WMC on the effectiveness of the EMDR intervention. In the current study, we aimed at addressing (and evening out) individual WMC by adapting the difficulty of the task (i.e., speed of EM) based on the RTs of the participants. While short RTs were indicative of a large WMC and increased speed of EM, long RTs were indicative of a small WMC and decreased speed of EM. Due to the novelty of this approach, the hypothesis was based on logical reasoning and must be treated tentatively. It was also assumed that (a) WMC is appropriately represented by the mean RTs of participants from part one of the study and that (b) adapting the speed of EM is adequate for making up for varying individual WMC. The fifth hypothesis was that due to adjusting the difficulty of the task (i.e., speed of EM) based on individual WMC (as indicated by RTs), there might be no difference in treatment effectivity despite differences in WMC (indicated by average RTs in part one; $H_5$).

Finally, the acceptability of the treatment was examined as a potential explanatory factor for differences in treatment effectivity. Due to the novelty and existing preconceptions, treatment acceptability is especially interesting for online treatments (Bursnall et al., 2022). Besides, high treatment acceptability has been found to be related to treatment success while low scores are interwoven with drop-out rates (Milosevic et al., 2015; Perski & Short, 2021; Schottenbauer et al., 2008). Thus, it was expected that high acceptability scores would result in increased EMDR intervention effectivity (lower vividness + emotionality) when compared to low acceptability scores ($H_6$).

## Methods

### Participants

A total of 56 Participants were recruited using convenience sampling via SONA (University of Twente BMS Subject Pool), social media advertisement, and flyers. Eligibility requirements included a minimum age of 18 years, normal to corrected vision and hearing, no use of psychoactive medication (antidepressants, antipsychotics, benzodiazepine or mood stabilizers), no use of alcohol or drugs 12 hours prior to participation, and no diagnosis of a mental disorder (i.e.: major depression, PTSD, psychosis, bipolar disorder or autism spectrum disorder). Participants were excluded from the second part of the study if the stressful film did not elicit sufficient distress (subjective unit of disturbance [SUD] scale below 6; Matthijssen et al., 2021). After exclusion of 4 participants due to technical difficulties, 9 participants reporting a SUD below 6, and 1 participant not completing the follow-up questionnaire, the final sample for the first part of the study (RT measurement) contained 52 participants (27 female, 25 male, *M*age = 22.1, *SD*age = 3.18) and 45 participants (23 female, 22 male, *M*age = 21.9, *SD*age = 4.37) for the second part of the study (EMDR intervention) who participated voluntarily in return for course credit and the chance to win a 20-Euro voucher. An a-priori power analysis for the between subjects analyses of the second part of the study (i.e., the experimental manipulation) with an ANOVA (repeated measures, between factors, groups: 2, measurements: 3) in G*Power (Erdfelder & Buchner, 1996) revealed that to achieve a power of 0.8 with an alpha of 0.05 and an estimated effect size of 0.25, 86 participants would be necessary. The study was approved by the Ethical Committee of the University of Twente (220219). Informed consent was obtained from all participants.

### Materials

**Software and Hardware.** The study was conducted online and participants needed a smartphone with a stable internet connection and a charged battery and a computer with stable internet connection to participate. Zoom was used to establish a video connection with the participant via a computer. RT measurements and the EMDR intervention were administered remotely using the online EMDR environment "Digital-EMDR" ("research.ut.digital-emdr.com"; developed by Moovd) operated from a computer by the research assistant and a smartphone by the participant. The environment consisted of a neutral image of an apartment, one button on the left and the right side of the screen (displaying a soundwave and an eye), and a session number on top of the screen. The environment could be controlled remotely from an interface by the research assistant (Appendix A).

**Part 1 - RTT Measurement**

***RTTs.*** Two types of RTTs were used to tax WM, one using a visual stimulus and one using an auditory stimulus. For the visual RTT, participants had to react as fast as possible to the transformation of a ball which randomly changed its shape to a cylinder by pressing a button on the right side of their screen (portraying an eye; see Appendix A). The ball changed its shape in an inter-stimulus interval ranging between 500 ms and 2000 ms (1250 ms average) resulting in around 25 RT measurements to be recorded per set. As soon as participants responded to the transformation, the cylinder changed back into a ball. When participants responded too late, the visual button changed its colour to red. For the auditory RTT, the participant had to react as fast as possible to a melody sound gradually increasing in pitch which was presented in an inter-stimulus interval ranging between 500 ms and 2000 ms (1250 ms average) resulting in around 25 RTs to be recorded per set. Participants had to react as fast as possible by pressing a button on the left side of their screen (portraying a sound wave). As soon as they responded, the sound stopped. If they responded too late (after the cylinder changed back into a ball / after the sound stopped), the respective button changed its colour to red. In addition, the ball moved horizontally in varying speeds. Specifically, slow (0,8 Hz), medium (1 Hz) and fast (1,2 Hz) movements were used to elicit EM. For RT measurement, both RTTs (visual + auditory) were presented separately as a practice phase and afterwards as a baseline measurement (single-modality). They were also presented in combination (combined-modality) both without EM and with three different speeds of EM (Table 1). In total, 10 sets of RTT measurements were conducted each lasting 60 or 120 seconds (depending on the mode of presentation[1]). WM taxing was operationalised as the extent to which RTs slowed down depending on the RTT condition. Besides two types of errors were recorded, including no-click errors and random click errors which were summarized in a total error score.

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[1] Either serial presentation lasting 120 seconds (i.e., stimuli occur one after each other) or parallel presentation lasting 60 seconds (i.e., stimuli may occur simultaneously) in combination tasks. N.B.: data from serial presentation were not used in the current study.

**Table 1**

*Reaction time task (RTT) conditions.*

| Condition | Stimuli | Duration |
|---|---|---|
| Practice | Visual | 30 s |
| Practice | Auditory | 30 s |
| Baseline | Visual | 60 s |
| Baseline | Auditory | 60 s |
| Parallel combination | Visual + Auditory (parallel) | 60 s |
| Parallel combination | Visual + Auditory + slow EM (parallel) | 60 s |
| Parallel combination | Visual + Auditory + medium EM (parallel) | 60 s |
| Parallel combination | Visual + Auditory + fast EM (parallel) | 60 s |
| Serial combination [a] | Visual + Auditory (serial) | 120 s |
| Serial combination [a] | Visual + Auditory + slow EM (serial) | 120 s |
| Serial combination [a] | Visual + Auditory + medium EM (serial) | 120 s |
| Serial combination [a] | Visual + Auditory + fast EM (serial) | 120 s |

*Note*. RTT combinations included two practice phases for visual and auditory RTTs, two baseline measurements (single-modality), four parallel measurements (combined-modality) with increasing eye movements (EM), and four serial measurements. Conditions were counterbalanced to address fatigue-effects. In total, six different orders were used distributing difficult and easy tasks evenly (Appendix B).

[a] Serial combination is not used in this study.

**Part 2 – EMDR Experiment**

***Trauma film.*** Based on the trauma film paradigm, in which non-clinical participants are shown aversive content to evoke short-lived psychological stress reactions, a 2 min 2 s excerpt from the film “Irréversible” (2002) has been chosen to induce a traumatic memory (for a review see Holmes & Bourne, 2008; James et al., 2016). The film introduces a dark scene taking place in a basement crowded with people and shows a man violently beating another man’s face using a fire extinguisher. The excerpt has been previously used (Nixon et al., 2009; Weidmann et al., 2009) and has been validated as effective research material as it evokes intrusive memories and feelings of anxiety (Arnaudova & Hagenaars, 2017). Participants watched the film on their computer in full-screen and were asked to use headphones.

***EMDR Intervention.*** In the treatment condition, participants were exposed to a combination of the visual and the auditory RTT (combined-modality) with adaptive EM in the online EMDR environment. They had to respond as quickly as possible to a ball changing its shape to a cylinder and a melody sound by pressing the corresponding buttons on the left and the right on their screen while following the movement of the ball and keeping the aversive memory in mind. The ball randomly moved horizontally, vertically and diagonally which made the movement less predictable. Based on the RT of the participant, the speed of the ball was adjusted (i.e., short RTs resulting in faster movement) to compensate for difference in WMC between participants. In the control condition, participants were asked to look at the empty apartment while focusing on the aversive memory.

**Measures**

***Subjective Unit of Disturbance (SUD).*** Participants indicated the perceived intensity of disturbance evoked from the trauma film on the SUD scale, a 11-point Likert Scale, ranging from 0 (no distress at all) to 10 (maximum distress). Specifically, participants were asked: “Thinking about the video clip, how unpleasant does it feel or how much distress do you feel, estimated on a scale from 0, no distress at all, to 10, maximum distress?”. The SUD scale is part of the standard EMDR protocol (Shapiro, 1989; Wolpe, 1975). Good psychometric qualities for measuring emotionality of memories have been found (Kim et al., 2008).

***Subjective Vividness.*** Subjective vividness of the memory that resulted from watching the trauma film was rated on a 11-point Likert scale, ranging from 0 (not vivid at all) to 10 (maximum vividness; “How vividly can you picture the video clip, estimated on a scale from 0 "not vivid at all," to 10, "very vivid"?”). Vividness is regularly measured as part of EMDR research (Matthijssen et al., 2021; van den Hout & Engelhard, 2012; K. van Schie et al., 2019).

***Treatment Acceptability.*** To measure how participants perceived the treatment in terms of acceptability, an adapted form of the Treatment Acceptability/Adherence Scale (TAAS) based on Milosevic et al. (2015) was used. The version used was adapted to fit the study design and consisted of six statements (e.g., ‘It was distressing to me to participate in this procedure.’) and participants could respond on a seven-point Likert scale ranging from 1 (“Disagree strongly”) to 7 (“Agree strongly”; Appendix C). Internal consistency has been found to be good in a previous study (students: $\alpha = .84$, clinical $\alpha = .88$; Milosevic & Radomsky, 2013) and was acceptable ($\alpha = .73$) in the current study.

**Design and Procedure**

As this study is composed of two parts, two separate designs were employed (see Figure 1). Part one employed a within-design with RTT condition (single-modality, combined-modality + EM) and RTT modality (visual, auditory) as independent variable and RTs and errors as dependent variables. For part two, a three (Time: pre, post, follow-up) by two (Condition: control, treatment) mixed design was used. While Time was a within-subjects variable, Condition served as a between-subjects variable. Participants were randomly allocated to either the treatment or the control condition in Qualtrics after the pre-test if they indicated a SUD above the threshold of 6 (Matthijssen et al., 2021).

**Part 1 – RTT Measurement**

Before participating in the study, participants received information about eligibility requirements, risks involved in participating in the study and information about the content of the stressful film clip. As the study was conducted online, after participants signed up for the study using SONA systems, they received a link directing them to Zoom to establish the online video connection. As participants joined the online meeting, the research assistant gave some practical information based on a verbal protocol ensuring appropriate conditions for conducting the study (Appendix D). After this short introduction, participants received a link to the online survey (Qualtrics) and started by reading an information sheet and completing the informed consent form including screening questions. Then, participants had to enter a code communicated by the researcher to ensure that they were actually in a session with the researcher and had to indicate their participant number. Next, participants answered some basic demographic questions (age, gender, nationality, educational level). Following this, participants were asked to open the online EMDR environment (research.ut.digital-emdr.com) using their smartphone. They were asked to select the role of the client and share their session code via the Zoom chat. The research assistant established a connection with the participant and explained the basic functionality of the environment. For the first part of the study, after a practice phase including both a 30 s auditory and a 30 s visual RTT (Mertens et al., 2020), the participant was exposed to ten sets of visual and auditory RTT combinations involving varying speeds of EM and different modes of presentation (Table 1). After each set, participants had a small break of 10 seconds. The order of combinations was counter-balanced to counteract fatigue effects (Appendix B; Van Den Hout et al., 2011).

**Part 2 – EMDR Experiment**

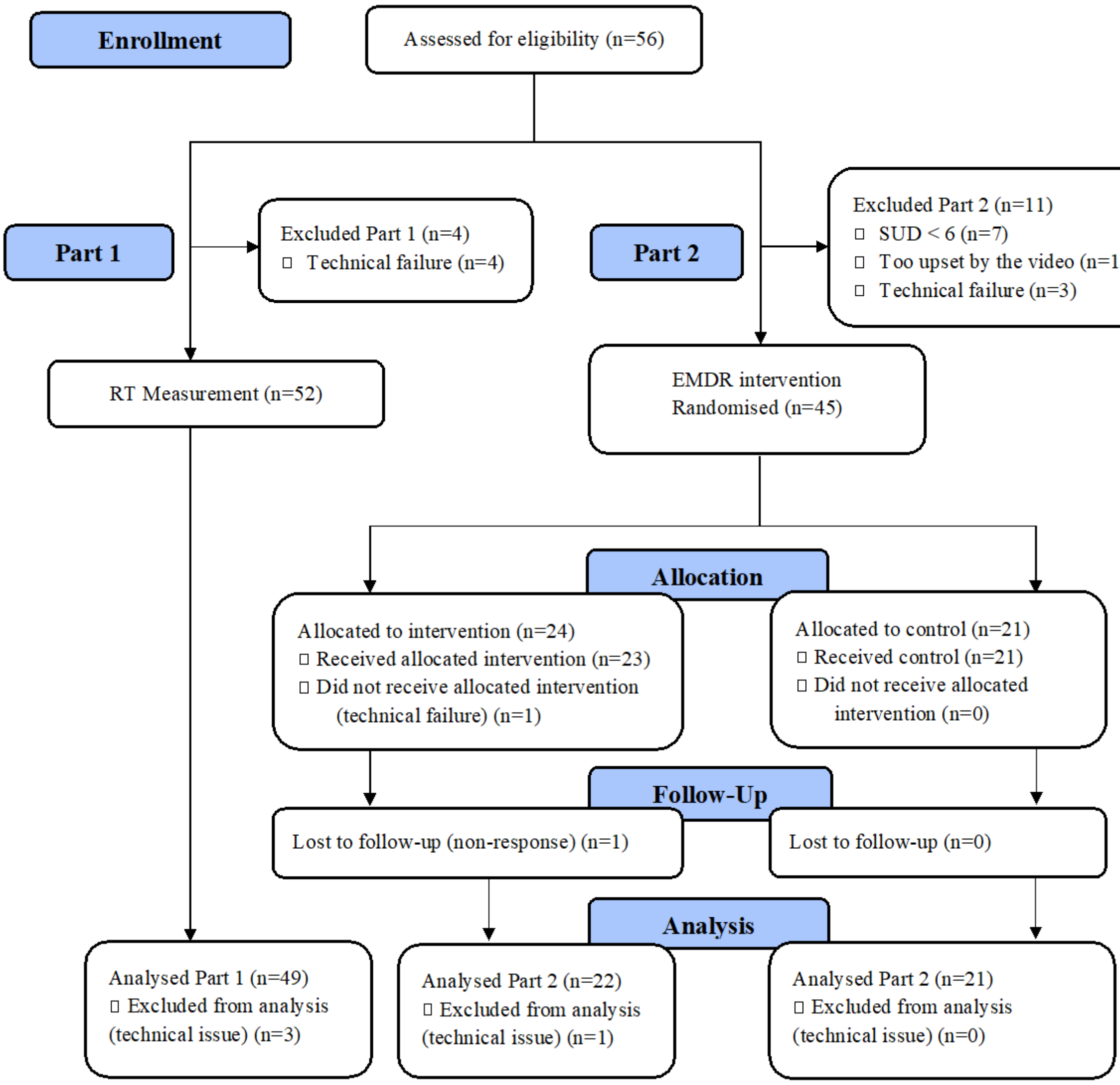
After a two-minute break, participants were informed that the second part of the study was starting and that they would watch an aversive film clip. Participants were instructed to watch the two-minute-long aversive film as if they were a bystander at the scene. The research assistant avoided distracting the participant by turning off their microphone and camera. Participants were monitored by the research assistant to ensure that participants could handle watching the film. After watching the film, a five-minute distractor task in which participants were asked to listen to classical music was introduced to make the resulting memory of the film more analogue to a real traumatic memory (van Schie et al., 2019). Afterwards, participants completed the SUD scale and the vividness scale (pre-test). If participants reported a SUD score below 6, they were excluded from the study (Matthijssen et al., 2021). Randomly and equally distributed, participants were either assigned to the treatment or the control condition by using the randomizer in Qualtrics. As the EMDR intervention was introduced, participants were asked to recall the most traumatic scene from the film. Specifically, they were asked to choose the image from the film that they found most distressing to watch and to pause their memory at that exact moment. Besides, participants had to indicate where in their body they feel the tension most strongly. The research assistant instructed the participant to focus on the disturbing image and the bodily tension evoked by that image. Participants in the treatment condition were exposed to 12 sets of 30 seconds of the adaptive EMDR intervention (combined-modality RTT + adaptive EM). In the control condition, participants were asked to relax while looking at the empty apartment in the EMDR environment for 12 sets of 30 seconds. In between sets in both conditions, participants were asked about what is going through their mind and, if it was relevant to the memory, instructed to focus on that in the next set. If participants said something unrelated, they were asked to focus on the most disturbing image again. After the intervention, the SUD scale and the vividness scale were rated again by participants (post-test). Following, participants filled out the TAAS and the avoidance behaviour questionnaire [2]. The participant received contact information of a clinical professional and the research assistant made sure that the participant can safely leave the session. One day later (24 h), participants received a follow-up questionnaire asking them to rate the most traumatic scene on the SUD and vividness scale once again. Besides, they responded to the avoidance behaviour questionnaire again. After the follow-up measurement, participants were offered a five-minute mindfulness session (Cuperus et al., 2016), were shown a short documentary explaining how the aversive film was made using special effects (van Schie et al., 2019), and received contact details of a clinical psychologist once again (James et

[2] The avoidance behaviour questionnaire was not used in the current study.

al., 2016). Finally, participants received reimbursement in form of course credit, could sign up for a 20-Euro voucher give away and were thanked for their participation.

**Figure 1.**

*CONSORT flowchart of participants*




## Data Analysis

All data was analysed using IBM SPSS Statistics 27. For calculating average RTs, the first RT response for every task was removed to exclude transition delays. RT data was visually scanned for irregularities and cases representing technical failure were removed ($n$ = 3). RT outliers were removed by filtering out RTs $M \pm 2$ $SD$ within task, modality, and participant ($n$ = 3674). As a relatively normal distribution and a large sample size was given for RT, parametric tests were used. Normality, independence and sphericity were tested. If the sphericity assumption was violated, the Greenhouse-Geisser ($\varepsilon < .75$) or Huynh-Feldt ($\varepsilon > .75$) correction were applied. First, to assess the difference between single-modality and combined-modality RTTs, paired-sample *t*-test were executed comparing visual and auditory RTs in the single-modality and the combined-modality RTT conditions. Secondly, to identify the effect of speed of EM and RTT modality on RT in combined-modality RTT conditions, a two-way within-subjects repeated measures analysis of variance (ANOVA) was conducted comparing the effect of speed of EM (slow, medium, fast) and RTT modality (visual, auditory) on RT. Thirdly, to examine the potential ceiling effect of RTTs, errors of the combined-modality medium EM and fast EM RTTs (most difficult condition) were analysed using Wilcoxon signed rank tests. Besides, outcomes of relevant preceding analyses were considered.

For the second part of the study, cases with a SUD below 6 and missing follow-up data were removed ($n$ = 7). To assess the effect of the EMDR intervention, two separate three (Time: pre, post, follow-up) by two (Condition: control, treatment) repeated measures ANOVAs with emotionality and vividness ratings as dependent variables were conducted. Next, to evaluate the influence of individual WMC on treatment effectivity, participants were split into a low and a high WMC group with a median split based on average RTs from RTTs of part one. The resulting variable was added as a between-subjects factor to the preceding model and tested for interaction. Non-significant effects were followed up with equivalence tests examining whether a 90% *CI* around the effect falls between smallest effect size of interest (SESOI) boundaries to test for equivalence of decreases in emotionality and vividness for both WMC groups (Lakens et al., 2018, 2020). Based on Cuijpers et al. (2020) and Lee & Cuijpers (2013), the SESOI was set at a Cohen's d of $d$ = 0.4. Thus, equivalence bounds of $d$ = - 0.4 and $d$ = 0.4 were used. Finally, treatment acceptability scores (TAAS scores) were added as a covariate to the preceding model and examined for interaction. P-values below .05 and marginally above were accepted as statistically significant.

## Results

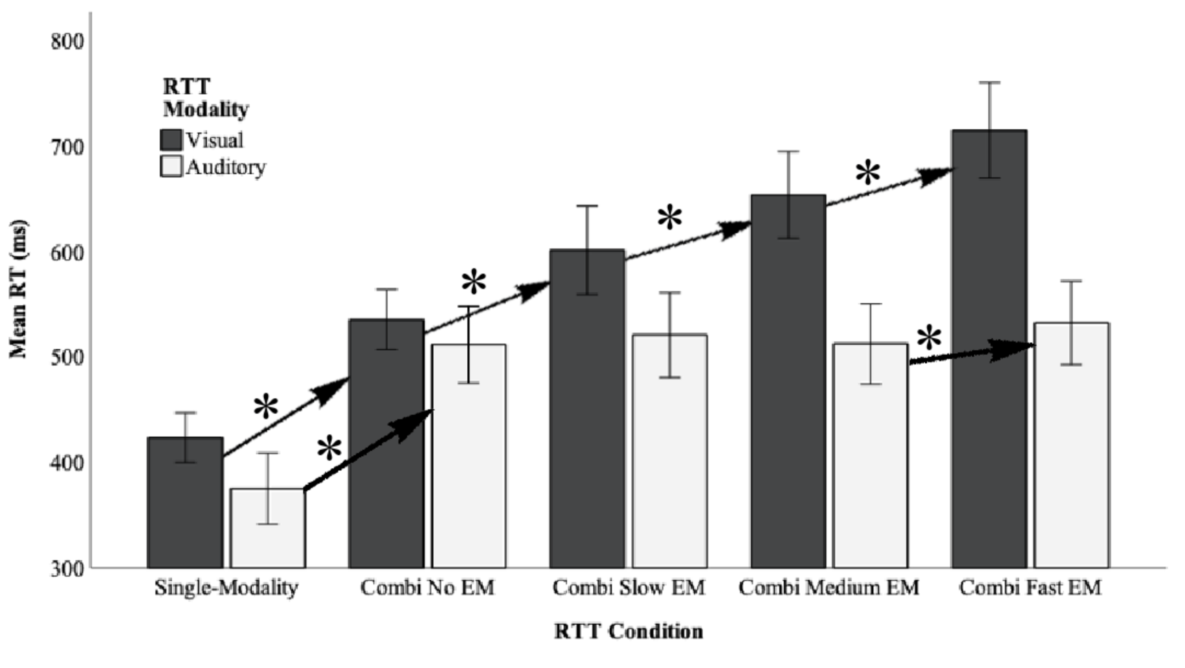
### Part 1 – Taxation of WM by Combined-Modality RTTs and EM

Average RTs are displayed in Figure 2 and varied significantly across RTT conditions and RTT modalities, $F(4, 172) = 54.98, p < .001, \eta_p^2 = .56$. To examine possible effects of the order of RTT presentation (see Appendix B), Order (6 counter-balancing options) was included as a between-subjects variable. There was no significant Order x Condition x Modality interaction effect, $F(20, 172) = 0.8$, $p = .709$, $\eta_p^2 = .09$, and no main effect for Order, $F(5, 43) = 1.2$, $p = .324$, $\eta_p^2 = .12$. Thus, the order of RTT presentation did not influence the RT outcomes.

Paired-samples *t*-test were executed comparing visual and auditory RTs in the single-modality and the combined-modality condition. Visual RTs were longer for the combined-modality (*M* = 535.21 ms, *SD* = 99.46) than for the single-modality RTT condition (*M* = 423.32 ms, *SD* = 81.78). This increase, 111.88 ms, 95%*CI* [96.07; 127.7], was statistically significant, $t(48) = 14.23$, $p < .001$. For the auditory modality, RTs also became longer in the combined-modality (*M* = 511.43 ms, *SD* = 127.27) compared to the single-modality RTT condition (*M* = 375.1 ms, *SD* = 117.2). The lengthening of 136.33 ms, 95%*CI* [120.44; 152.21], was statistically significant, $t(48) = 17.26$, $p < .001$. These results suggest that combined-modality RTTs produced a higher WM load compared to a single-modality RTT.

**Figure 2**

*Mean RTs (ms) for the different RTT conditions, including single-modality RTTs and combined-modality RTTs with three different speeds of EM. Error bars show 95%CIs (Arrows with asterisks indicate significant increases between adjacent RTT conditions, p < .05).*

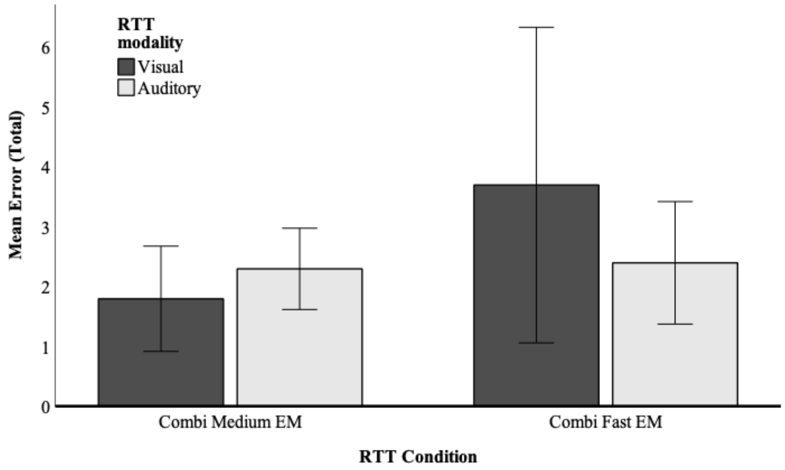



A two-way repeated measures ANOVA was conducted to compare the effect of speed of EM (no EM, slow EM, medium EM, fast EM) and RTT modality (visual, auditory) on RTs. A significant speed of EM x RTT modality interaction effect was found, $F(3,144) = 57.13$, $p < .001$, $\eta_p^2 = .54$. Looking at simple effects, for the visual modality, Mauchly's test indicated a violation of the sphericity assumption, $\chi^2(5) = 11.08$, $p = 0.05$. Since sphericity was violated (ε = 0.879), Huynh-Feldt correction was applied. Visual RTs were significantly influenced by speed of EM, $F(2.8, 134.59) = 79.73$, $p < .001$, $\eta_p^2 = .62$. Post hoc analyses revealed that visual RTs increased gradually as speed of EM increased, range $M_{\text{dif}} = 52.41$ ms - 61.03 ms, *p*s < .001 (see Figure 2). Auditory RTs also differed significantly between different speeds of EM, $F(3, 144) = 4.64$, $p = .004$, $\eta_p^2 = .09$. Post hoc analyses indicated that auditory RTs only differed between the fast EM and the medium EM condition. Auditory RTs were 20 ms longer in the fast EM compared to the medium EM condition, which was statistically significant, $t(48) = 3.38$, $p < .001$. Increasing EM lengthened visual RTs in an almost linear fashion while auditory RTs only slightly increased from the medium EM to the fast EM condition.

Total error (no-click + random-click errors) means for the visual and auditory RTT modality for the combined-modality medium EM and fast EM RTT conditions are shown in Figure 3. As errors were non-normally distributed, they were analysed non-parametrically. Wilcoxon signed rank tests were executed to compare error scores of visual and auditory RTTs between the medium EM and fast EM RTT condition. For visual RTTs, a Wilcoxon signed rank test showed a marginally significant difference ($Z = -1.849$, $p = .065$) between error scores with a hypothetical medium effect size of 0.39. For auditory RTTs, a Wilcoxon signed rank test indicated a non-significant difference ($Z = -0.813$, $p = .416$) between error scores with a hypothetical small effect size of 0.2. Error scores seemed to be equal between the combined-modality medium EM and fast EM RTT condition. While a tendency of error scores to increase from the medium EM to the fast EM RTT condition for visual RTTs can be derived from the plot (see Figure 3), this increase was non-significant.

**Figure 3**

*Error means of visual and auditory RTTs of combined-modality medium EM and fast EM RTT conditions with 95%CI.*



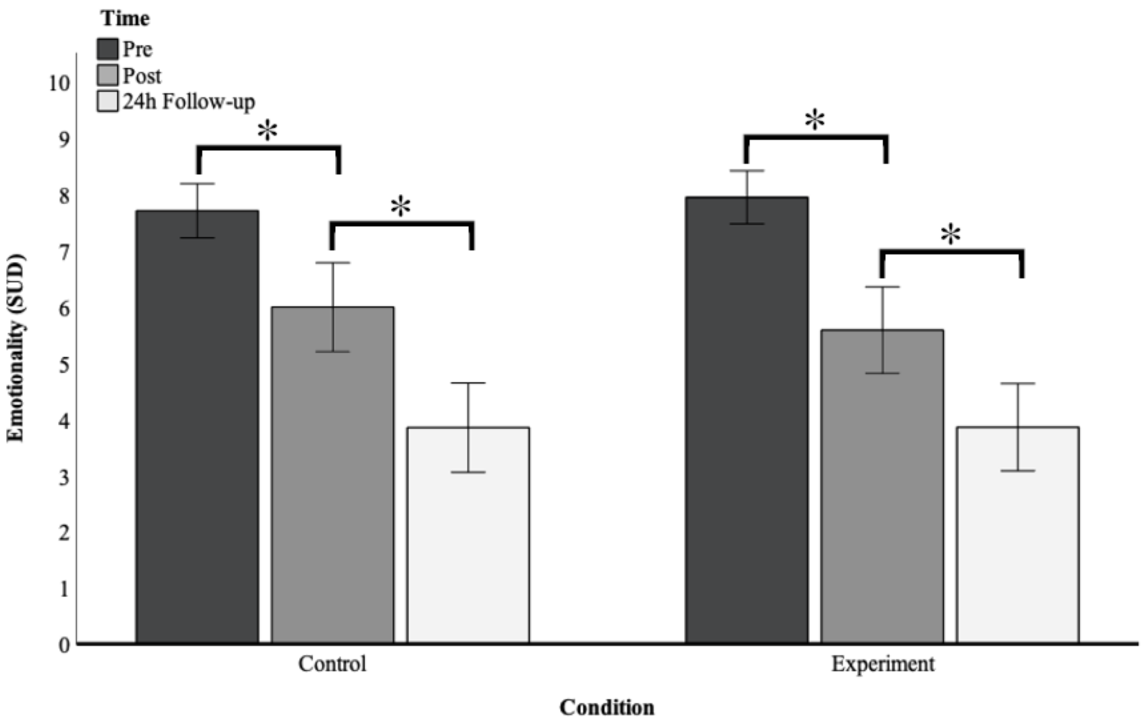
**Part 2 – Emotionality and Vividness of the Memory**

**Emotionality**

A three (Time: pre vs post vs follow-up) by two (Condition: treatment vs control) repeated measures ANOVA with emotionality (SUD) scores as dependent variable was conducted. A main effect for Time on emotionality was found, $F(2, 82) = 102.66$, $p < .001$, $\eta_p^2 = .715$. There was no main effect for Condition, $F(1, 41) = 0.02$, $p = .884$, $\eta_p^2 = .001$ and the crucial Time x Condition interaction effect was also non-significant, $F(2, 82) = 0.70$, $p = .498$, $\eta_p^2 = .02$. The emotionality scores at pre, post, and follow-up measurement are represented in Figure 4, showing that regardless of the condition, emotionality scores dropped from pre-, to post-, to follow-up measurement. As the interaction effect was not significant, no post-hoc analyses were performed.

**Figure 4**

*Pre-, post-, and follow-up emotionality (SUD) scores per condition. Error bars indicate 95%CI (asterisks indicate significant differences within Conditions, p < .05).*

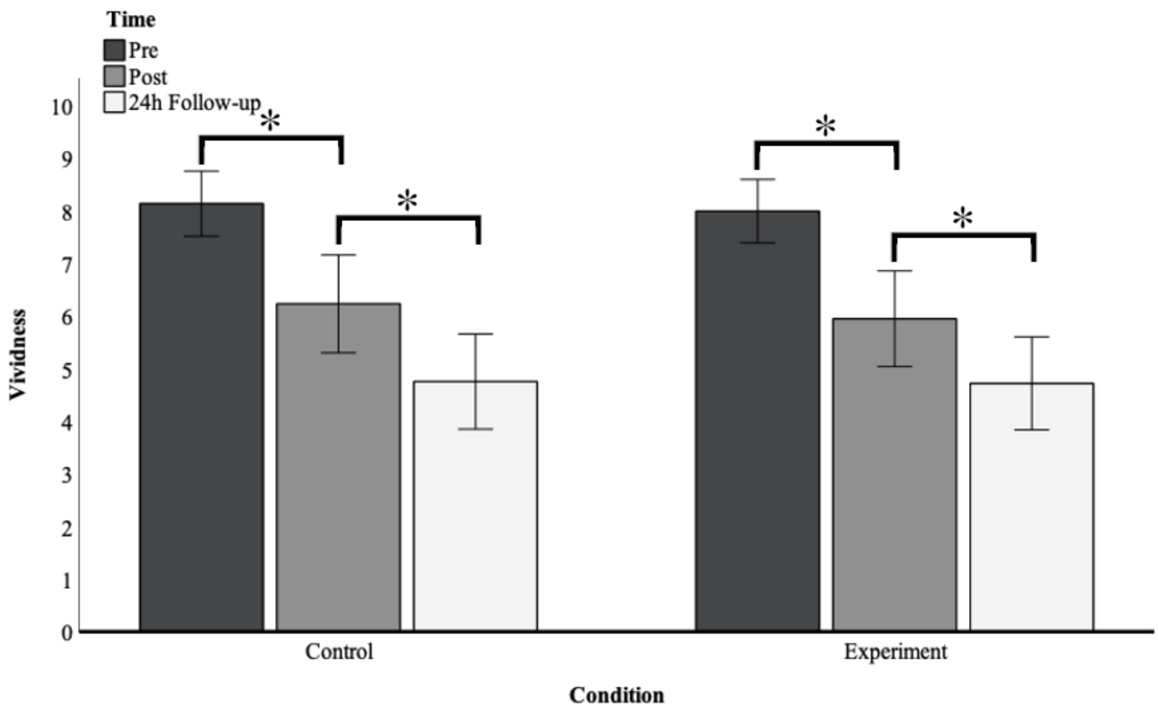



**Vividness**

A three (Time: pre vs post vs follow-up) by two (Condition: treatment vs control) repeated measures ANOVA with vividness scores as dependent variable was conducted. There was a main effect for Time on vividness, $F(2,82) = 72.33$, $p < .001$, $\eta_p^2 = .638$. However, there was no main effect for Condition on vividness, $F(1, 41) = 0.1$, $p = .748$, $\eta_p^2 = .003$, and the crucial Time x Condition interaction effect was also non-significant, $F(2, 82) = 0.1$, $p = .904$, $\eta_p^2 = .002$. Figure 5 shows vividness scores at pre, post, and follow-up measurements for both conditions and indicates that vividness scores decreased regardless of the condition. Due to the non-significant Time x Condition interaction effect, no post-hoc analyses were performed.

**Figure 5**

*Pre-, post-, and follow-up vividness scores per condition. Error bars represent 95%CIs (Asterisks indicate significant differences within Conditions, p < .05).*




### Differences in WMC

WMC was operationalised as the mean RT over all RTT conditions (part one). The overall mean RT for all participants was 538.4 ms (*SD* = 0.02), with a minimum of 320 ms and a maximum of 770 ms. In the relevant treatment condition, the overall mean RT was 519.5 ms (*SD* = 0.03) with a minimum of 320 ms and a maximum of 770 ms. Participants were divided into high and low WMC groups using a median split performed on the mean RT. WMC (low, high) was added as a between-subjects factor to the preceding ANOVAs examining the effect of Time (pre, post, follow-up) as within-subjects factor and Condition (treatment, control) as between-subjects factor on emotionality and vividness. A non-significant Time x Condition x

WMC interaction was found for emotionality, $F(2, 74) = 0.22$, $p = .801$, $\eta_p^2 = .006$, and for vividness, $F(2, 74) = 1.88$, $p = .16$, $\eta_p^2 = .05$. An equivalence test using equivalence bounds of $d = - 0.4$ and $d = 0.4$ was used to confirm equivalence between both groups. Calculating a 90% *CI* of the effect size for changes in emotionality resulted in [-0.249, 0.479] for the post-test and [0.009, 0.744] for our follow-up measurement. The 90% *CI* of the effect size for changes in vividness was [-0.166, 0.562] for the post-test and [-0.107, 0.624] for the follow-up measurement (Lenhard & Lenhard, 2016). Thus, comparing our boundaries with the found CIs shows that all CIs extend our boundaries which shows that we cannot reject the presence of an effect that might be large enough to be clinically meaningful.

### Treatment Acceptability

Over both the treatment and the control condition, the mean treatment acceptability score was 26.95 ($SD = 1.01$), with a minimum of 11 (TAAS min = 7) and a maximum of 40 (TAAS max = 42). While in the treatment condition the average score of treatment acceptability was 28.27 ($SD = 0.94$, $N = 22$), the average score was 25.57 ($SD = 1.80$, $N = 21$) in the control condition. This difference was non-significant, $F(1, 41) = 1.83$, $p = .184$. To examine the effect of treatment acceptability on treatment effectivity, the preceding repeated measures ANOVAs examining the effect of Time (pre, post, follow-up) as within-subjects factor and Condition (treatment, control) as between-subjects factor on emotionality and vividness were carried out, including treatment acceptability as a covariate. A non-significant Condition x Acceptability interaction was found for emotionality, $F(2, 80) = 0.27$, $p = .77$, $\eta_p^2 = .01$, and for vividness, $F(2,80) = 0.15$, $p = .86$, $\eta_p^2 = .004$. However, a significant Time x Acceptability interaction was found for emotionality, $F(2, 80) = 4.90$, $p = .01$, $\eta_p^2 = .11$, but not for vividness, $F(2,80) = 1.57$, $p = .215$, $\eta_p^2 = .04$. Overall, reductions in emotionality scores in both conditions were influenced by treatment acceptability scores while vividness reductions were not affected.

## Discussion

The current study aimed at evaluating implications derived from WM theory that are relevant for improving the dual-task component of EMDR. In the first part of this study, participants executed sets of increasingly complex RTTs with single- and combined-modality RTT conditions (visual + auditory) and increasing speeds of EM (slow, medium, fast) to test whether increasingly complex RTTs tax WM progressively as predicted by WM theory (Baddeley & Andrade, 2000; Maxfield et al., 2008). In the second part of the study, the memory degrading effect of smartphone-delivered combined-modality RTTs (visual + auditory) and adaptive EM (adapting speed of EM to individual WMC) was tested experimentally.

**Part 1 – Taxation of WM by Combined-Modality RTTs and EM**

Similarly to other studies that used alternative means to tax WM than EM (drawing a complex figure, playing Tetris, mental arithmetic tasks), combined-modality RTTs tax WM at least as good as EM (Mertens et al., 2021). An average increase of 112 ms in visual RTs and 136 ms in auditory RTs compared the baseline was found for the combined-modality RTT which is in line with studies finding a 100 ms difference for EM (Engelhard et al., 2010; Van den Hout et al., 2011; van den Hout & Engelhard, 2012; van Veen et al., 2015) and a 250-400 ms difference using other dual-tasks (Cuperus et al., 2016; Engelhard et al., 2010; van den Hout et al., 2010). Most studies used a different way to measure RT (e.g., single-modality stimulus discrimination), which makes the results less comparable. However, there is evidence suggesting that combined-modality RTTs tax WM ($H_1$) and thus tap the same process as EM and other dual-tasks (van den Hout, Engelhard, Rijkeboer, et al., 2011).

Adding EM to the combined-modality RTT resulted in longer visual RTs compared to no EM for all speed levels, indicating that EM when supplemented with a combined-modality RTT taxes WM. With increasing levels of speed of EM, an almost linear increase of visual RTs could be observed as visual RTs increased around 50 ms for each speed level (see Figure 2). Interestingly, but in line with WM theory, auditory RTs remained constant with only one marginal increase from medium EM to fast EM of around 20 ms. In a previous study, using six EM speed levels, van Veen et al. (2015) could not replicate the current findings as only the fastest condition (1.2 Hz) differed from the slower ones. The less taxing baseline task (single-modality RT) and the slower EM speed levels (0.4 Hz – 1.2 Hz) used might be explanations. Currently, in line with WM theory, dose-dependent WM-taxing of EM was observed with strong visual (i.e., VSSP) and only limited auditory influence (i.e., PL; $H_2$; Maxfield et al., 2008; Van Den Hout et al., 2011; van Veen et al., 2015).

Limited evidence for the expected WM overloading of the most difficult RTT (combined-modality with fast EM) was found. There is an indication that participants shifted away their attention from the visual RTT while consistently responding to the auditory RTT reflected in increased errors for the visual RTT and stable RTs for the auditory RTT. However, as this increase is only marginally present, the results are inconclusive. Littel & van Schie (2019) argue that a strategic shift-away from one task should result in improved RTs for the other task which was not the case here. An explanation for the increasing errors for the visual

RTT with stable auditory RTs may be the fast EM interfering with the visual RTT. Several participants mentioned that they struggled to see the changing ball due to the fast movement of the ball which may resulted in increased errors. Consequently, there is inconclusive support for the overloading of WM of the most difficult RTT ($H_3$).

**Part 2 – Degradation of Memory**

Analogue studies of EMDR found that compared to just recalling an aversive memory, taxing WM (e.g., EM) while recalling the memory leads to reduced emotionality and vividness of that memory (Mertens et al., 2021). In the current study, both treatment and control conditions resulted in immediate and 24h reductions in emotionality and vividness. Unexpectedly, there were no differences in reductions between both conditions making the control condition (i.e., recall-only) equally effective as the treatment condition (RTT + EM; $H_4$). Thus, current findings are not in line with the WM account of EMDR (Baddeley & Andrade, 2000; Maxfield et al., 2008) and could not replicate previous findings (Cuperus et al., 2016, 2019; Engelhard et al., 2011; Littel & van Schie, 2019; Matthijssen et al., 2021; Mertens et al., 2021; van den Hout et al., 2014).

The lack of differentiation between the conditions may be explained by the implemented WM-taxing task and possibly missing memory activation. The current study was the first one to utilise combined-modality RTTs with adaptive EM as a dual-task for EMDR. As seen in part one of the study, combined-modality RTTs supplemented with EM taxed WM and thus seemed appropriate as a dual-task for EMDR. The word “dual-task” may be out of place as participants were technically exposed to four tasks (recalling the memory, auditory + visual RTT + EM) which points towards a possible problem with these tasks. Baddeley (1998) argues that a memory trace must be activated to become labile which requires WM capacity (Matthijssen et al., 2019). Following, one could argue that the implemented task overloaded WM and thereby made it impossible for participants to keep the memory in mind which prevented reductions in emotionality and vividness. An algorithm possibly adapted the task difficulty to individual WMC. However, as could be seen in part one of the study, combined-modality RTTs with slow or medium EM already resulted in substantial WM taxing much higher than ordinary EM (Engelhard et al., 2010; Van den Hout et al., 2011; van den Hout & Engelhard, 2012; van Veen et al., 2015). Thus, the algorithm was possibly not able to adapt the difficulty of the task to achieve optimal WM load. Instead, the baseline task could already have been too difficult. This explanation is in line with the proposed inverted U-curve relationship between WM taxation and memory degradation (Cuperus et al., 2019; Engelhard et al., 2011).

Remarks made by several participants who admitted that they were happy to engage in the task so that they did not have to think about the distressing memory add to this explanation. Future studies should incorporate a memory activation check after the post-test to examine whether memory activation actually takes place and make sure that the dual-task leaves room in WM for the memory to be activated (by means of a pre-test).

Another explanation for the missing effects of the intervention might be the active control condition used in which participants were actively encouraged to expose themselves to the aversive image. Specifically, the same instructions as in the treatment condition were given (i.e., asking participants to focus on the image and related bodily sensations) with the difference that instead of simultaneously engaging in the adaptive RTT, participants were looking at an empty apartment for 12 sets of 30 seconds. One may argue that the control condition bears similarity with imaginal exposure therapy which is an effective treatment for PTSD (Watkins et al., 2018). Using a similar active recall-only condition, van Veen et al. (2020) could only find a beneficial effect of the dual-task condition compared to recall-only condition after 4 sets of the intervention but not after 30 sets or after 24h which is in line with present findings. They argue that after the first block of the intervention (4 sets), imagination inflation took place in the recall-only condition (increasing memory intensity), while memory intensity was reduced in the dual-task condition. This was also observed in other studies using relatively brief intervention duration (4-6 x 24 s, e.g., van den Hout & Engelhard, 2012; van Schie et al., 2016). Hence, they suggest that initial working mechanisms in the dual-task conditions become less active over time while the working mechanisms in the recall-only condition (i.e., imaginal exposure) show delayed effects resulting in equal decreases in emotionality and vividness Hence, in the dual-task condition effects become less active over time while in the recall-only condition (i.e., imaginal exposure) delayed effects are present resulting in equal decreases in emotionality and vividness. Following this reasoning and acknowledging how our control condition might serve as imaginal exposure potentially explains the unexpected missing difference between the control and treatment conditions. Research should focus on the effect of different control conditions, intervention duration and include follow-up measures to examine this possibility.

Finally, the missing effect of the EMDR intervention may be explained by the possibly insufficient means of inducing a traumatic memory with the trauma film paradigm. The standard laboratory model for dual-task interventions involves healthy participants recalling negative autobiographical memories and rating their emotionality and vividness before and after a dual-task intervention (Mertens et al., 2021). The trauma film paradigm constitutes an alternative to autobiographical memories as participants watch a validated aversive film resulting in “short-lived psychological and physiological stress reactions” (Arnaudova & Hagenaars, 2017, p. 67). Several meta-analyses found that trauma processes can be examined in a non-clinical sample in a controlled and prospective way using the trauma film paradigm (Holmes & Bourne, 2008; James et al., 2016). An advantage of the trauma film paradigm is the increased experimental control over nature, duration and intensity of the traumatic material (Cuperus et al., 2016). However, van Schie et al. (2019) question the suitability of the trauma film paradigm in EMDR research as watching a trauma film hardly compares to a real trauma as different processes are at work. More specifically, they suggest that taxing WM may work differently during consolidation processes (novel memories) compared to reconsolidation processes (recalling autobiographical memories). Arguably, the induced traumatic memory might have a different quality compared to an autobiographical memory making the EMDR intervention possibly less effective. In line with this reasoning, a recent meta-analysis by Mertens et al. (2021) found memory degradation to be more pronounced for autobiographical memories compared to newly acquired memories (i.e., trauma film paradigm). Besides, research finding no difference between dual-task conditions and recall-only conditions mostly tested memory for newly acquired memories instead of autobiographical events which provides further evidence to the preceding explanation (Houben et al., 2018; van Schie et al., 2019; van Schie & Leer, 2019). As there has been previous research using the trauma film paradigm finding an effect of dual-task interventions on memory degradation (Holmes et al., 2009), this explanation is less probable but might interact with the preceding explanations. By directly comparing autobiographical memories with novel material (i.e., trauma films), the effects at work during consolidation compared to reconsolidation could be further examined.

Concerning individual differences in WMC, it was expected that individuals with low and high WMC would benefit similarly from the EMDR intervention as an algorithm was used to possibly address differences in WMC (Gunter & Bodner, 2008). Even though there was no general effect of the EMDR intervention, equivalence of decreases in emotionality and vividness between high and low WMC groups were examined using equivalence testing. Based on a conversative SESOI (Lee & Cuijpers, 2013), the results do not allow us to reject the presence of an effect of WMC on decreases in emotionality and vividness. Consequently, the algorithm did not rule out the influence of WMC and its functionality could not be supported. Another plausible explanation might be that contrary to what WM theory predicts, adjusting WM taxation based on individual differences in WMC does not add anything to treatment effectivity. This is suggested by van Schie et al. (2016) who offered faster speeds of EM to individuals with high WMC but could not find a beneficial effect of doing so. For the current findings, as there was no main effect of the general intervention, the described results have limited meaningfulness. Besides, the previous explanations, especially about the possible overloading of the initial task (combined-modality RTTs) and possible missing activation of the memory as well as the downsides of the trauma film paradigm have to be taken into account when interpreting these results. Overall, the tentative nature of the expectations concerning the functionality of the algorithm and the inconclusive results suggest that the algorithm possibly did not rule out the influence of WMC ($H_5$). Further research using pre-tests to establish the functionality of an algorithm adapting the difficulty of a dual-task to individual WMC is needed to assess whether such a measure is appropriate to account for differences in WMC and optimize WM taxation.

Finally, treatment acceptability was believed to account for differences in reductions in emotionality and vividness scores of the EMDR intervention (Milosevic et al., 2015; Schottenbauer et al., 2008). High acceptability scores were expected to result in stronger reductions when compared to low acceptability scores. Overall, acceptability scores were not different between conditions which is surprising as participants in the recall-only condition did not get a distinct treatment. However, as the recall-only condition bore similarity with imaginal exposure, participants possibly perceived being exposed to the aversive memory with or without a WM-taxing task as equally acceptable. As no general effect of the EMDR intervention was found, treatment acceptability scores did not specifically affect memory degradation in the treatment condition. However, an effect was found across both conditions. While general emotionality reductions were influenced by treatment acceptability scores, vividness reductions were not affected. An explanation might be that increased treatment acceptability is related to being more open toward the treatment procedure resulting in a higher willingness to let oneself be affected by the procedure. As emotionality is a highly subjective measure, emotionality scores may be more affected by such a willingness than vividness scores which are more objective. As this effect was found across conditions, it also points towards a non-specific placebo effect meaning that the expectation of experiencing a reduction in emotionality actually resulted in a reduction (Lohr et al., 1999). As treatment acceptability has not been examined as a potential explanatory factor before, the current study is the first one to shed light on the effect but failed to find conclusive evidence (*H6*).

The results of this study should be interpreted within the context of the study's strengths and limitations. A first strength is the novelty when it comes to the EMDR study conduction. The study was conducted remotely and the online EMDR intervention was smartphone-delivered. With the increasing demand for remote treatments, the current study was the first one based completely online. A second strength is the standardization allowing for experimental control due to the trauma film paradigm and an EMDR instruction protocol. A first limitation of this study relates to the varying study conditions due to the remote nature of this study. Arguably, every participant had slightly different study conditions, namely a different screen size and different distractors (i.e., notifications) which is especially relevant for the treatment condition. A second limitation is the non-clinical sample and missing clinical outcomes measures. It is questionable whether the same effects would have been found in a sample of PTSD patients. A third limitation is the sample size. While the power calculation indicated that 86 participants should be included, only 45 participants were included for analyses of reductions in emotionality and vividness. Statistical power was limited reducing the chance of detecting a true effect (Button et al., 2013). This resulted in small observed power for the crucial effects (Power < .165). The study should be replicated with a larger sample size using a clinical sample and clinical outcome measures (i.e., symptom severity). By making it a lab study, experimental control could be further improved.

**Conclusion**

The current study was the first in utilizing RTTs and adaptive EM as a dual-task for EMDR by drawing on implications from WM theory. In two parts, we examined (1) whether combined-modality RTTs and EM tax WM in accordance with WM theory and (2) whether carrying out RTTs and adaptive EM while recalling an induced aversive memory reduce the emotionality and vividness of that memory. In sum, the results are inconclusive. For part one of the study, we found the expected WM taxation patterns in line with WM theory: modality-specific, dose-dependent WM taxation of increasingly complex RTTs and EM was found. For part two of the study, findings were contrary to WM theory and most previous research: an equal reduction in emotionality and vividness of the aversive memory for both the treatment and the control condition was found. Combined-modality RTTs with adaptive EM did not reduce memory intensity as they possibly overload WM leaving no room for memory activation. It must be borne in mind that a non-clinical sample and relatively small sample size were used. Due to their adaptability, RTTs still constitute a promising alternative to ordinary dual tasks and further investigation is warranted. Future studies may improve the intervention by including a pre-test and increase validity by focusing on intrusive autobiographical memories.

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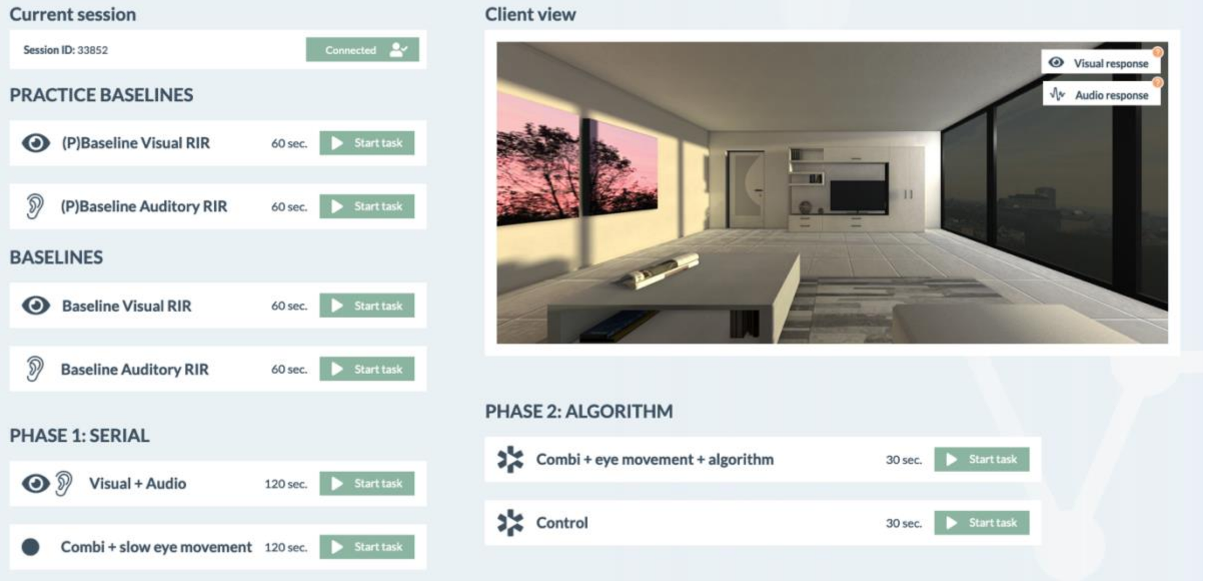
# Appendices

## Appendix A: EMDR Environment




**Appendix B: Counterbalancing RTT Options**

| Order | Option 1 | Option 2 | Option 3 | Option 4 | Option 5 | Option 6 |
|---|---|---|---|---|---|---|
| 1 | V | VAPef | V | VAP | A | VAPes |
| 2 | VAPem | VASem | VASef | VAPes | VAS | VAPem |
| 3 | VASes | VAPes | VAP | A | VAPef | V |
| 4 | VAPef | VAS | VAS | VASef | VASes | VAS |
| 5 | A | VAPem | VAPes | VAS | V | VAPef |
| 6 | VAPes | V | VAPem | VAPem | VAPem | VASes |
| 7 | VASem | VASef | A | VASes | VASem | VAP |
| 8 | VAS | VAP | VASem | VAPef | VAP | VASem |
| 9 | VASef | VASes | VASes | V | VASef | A |
| 10 | VAP | A | VAPef | VASem | VAPes | VASef |

**Appendix C: Treatment Acceptability/Adherence Scale (TAAS)**

- The offered procedure was effective in reducing the distress that I felt after seeing the movie scene.
- I find this procedure exhausting. (R)
- I was inclined to stop with the procedure. (R)"
- It was distressing to me to participate in this procedure. (R)
- I would recommend this procedure to a friend who is experiencing distress because of a negative memory.
- Overall, I find this procedure intrusive. (R)

**Appendix D: Verbal Protocol**

**´PART I**

**7.1 Introduction (10 min)**

*Hello, my name is [NAME]. Thank you for your participation.*

*Can you see and hear me well? (…)*

*My oral instructions will be read from a protocol to make sure that every participant receives the same instructions.*

*Welcome to our study in which we will investigate the effectiveness of an online trauma treatment. During the study, you will execute some sets of Reaction Time tasks. In the second part, you will be asked to watch a film clip that should evoke a strong negative emotional reaction. After watching the movie clip, you will complete an online task.*

*I can see you are connected on Zoom with your laptop or PC. If possible, have headphones ready to connect to your laptop/PC later. Do you also have your phone at hand? (…)*

- **NO**: *You will need it to access the online application. Could you please get it, so you have it ready later on?*
- **YES**: *Good you will need it later to access the online application.*

*Is your phone charged (at least 40%?) and are you in a calm and non-distracting environment? (…)*

- **NO**: *Maybe you can get a charger and relocate to a calm and non-distracting environment*
- **YES**: *Great*

*Before we begin, do you have any questions or comments for me at this time? (...)*

*Good, in SONA / chat you can find a link to Qualtrics, an online survey tool. Please open the link and follow the instructions in the questionnaire. Read the information carefully and make sure you don't fulfill any of the exclusion criteria. Let me know if there are any questions and when you are finished reading the information.*

*After reading this information, do you definitely want to participate in the study? (…)*

- **NO***: Ok, I understand that you do not agree with the conditions of this survey. You have, of course, every right to do so. However, may I ask which part you do not agree with or why you do not agree?* Make a note of any important points and then finish the conversation.
- **YES:** *All right. I would like to emphasize that you may stop participating in the study at any time. If you are ready, we will start the study.*

*Please continue in the survey and start by filing out the informed consent form in the survey. (…)*

*When you are asked to enter a code, let me know. (…)*

*The code is "**EMDR**". Please continue the survey. When you get to a QR code in the survey, please let me know.*

### 7.2 Connecting EMDR Environment (5 min)

*Please scan the QR code with your phone camera now. If it doesn't work, you can also manually enter the link below into your smartphone browser. Now please select "Client," scroll down and tap accept. Then please hold your phone horizontally. If the screen does not rotate, please disable the "lock screen rotation" function on your phone and try again.*

*On the left, you see a button for audio tasks, which you have to press as quickly as possible when you hear a drumming sound. The button on the right is for visual tasks. You will see a ball that occasionally changes its shape into a cylinder. When this happens, press the right button as quickly as possible. After you have tapped the button, the cylinder will immediately change back into the ball (or for the audio task the sound will stop). Please only tap when the ball changes into a cylinder, not the other way around. The ball will sometimes also move around. Do you understand the instructions? (…)*

- **NO**: *Is there anything that is unclear?*
- **YES**: *Great, then please tap "start session."*

*Now you see an empty apartment and a Session ID at the top of the screen. Could you please tell me this ID or type it into the chat, so I can connect with you? (…)*

### 7.3 Reaction Time Experiment (20min)

*Thank you, you will now go through a set of response tasks. Please turn your phone volume up, so you can hear the sound well. Please hold your phone around 30 cm from your face. First, we will have a little practice phase, first for the visual stimulus, then for the auditory so you get a feeling for the task. So again, as soon as you either see the ball changing into a cylinder or hear the drumming sound, tap the respective button as fast as you can. Are you ready? (…)*

*Okay, then let's start.*

- **START** Practice Visual

*Do you see how this is working?*

- **NO**: *What is the problem?*

- **YES**: *Great, Let's continue with the auditory practice phase*
- **START** Practice Auditory

*Do you see how this is working? Could you hear the sound and respond to it?*

- **NO**: *What is the problem?*
- **YES**: *Great, now that we've finished the practice phase, we will go through a number of different sets, where the different stimuli may occur at the same time and the ball may move around. So please press the respective buttons again. Each set will last one to two minutes, and you'll have a 10-second break in between the sets. In total, it will take approximately 15minutes to complete all tasks. Try to react as quickly and accurately as possible.*

*If you experience any issues, let me know. Are you ready? (…)*

*Let's go.*

- **LOOK** at counterbalancing condition (Excel)
- **START** respective task
- **AFTER** timer is over, **STOP** respective task

Between tasks: *I will start the next task*

*Thank you, now we're done with the first part of the study. You can put your phone away for now, but we will need it again shortly. Please continue with the questionnaire now. (…)*

*As you can see, you can take a short break now. You can turn off your microphone and camera if you want. I'll see you again in two minutes.*

*Let me now when you are ready to continue (…)*

**PART II**

**7.4 Trauma Film Clip**

*Welcome back. Now we can go to the second part of our study. Please continue in the questionnaire until you can see the video clip. Before you start it, let me know.*

*Please read the information carefully. You will be shown a short video clip of about 2 minutes. Please sit quietly and watch the video clip carefully. I am going to ask you questions about this video clip later.*

*I do not want you to watch this film as you normally would. I want you to try to imagine that you are present as a bystander at the scene of the video. You are watching the situation unfold right before your eyes, really engaging with the situation and trying to blend in. Please keep your attention on the video and try not to look away or close your eyes. I will turn off my own camera so you can concentrate on the film, but your camera will stay on. Is that okay with you? (...)*

- **NO**: *Ok, what is bothering you?*
- **YES**: *It is very important that you watch the video according to these instructions. Just to check that you understood the instructions correctly, would you summarize what I just explained (…)*

*Please start watching the film which will have some French dialogue in full-screen and turn up the screen brightness.*

- **STOP** if the participant is very upset by the movie. It is okay to be a little shocked but crying or being upset is emphatically not the intention. IF IN DOUBT, ALWAYS STOP!
- **IF UPSET:** *I see that you are very upset by seeing the video clip. Do you want to stop the experiment? We did not intend for you to become so upset by the video clip. (...)*

  *I am sorry for the fact that the film upset you so much. When participants in this study get very distressed, the protocol is that you receive the contact details of a clinical psychologist whom you can talk with.*

*To let the memory sink in, you will have a 5-minute break during which I ask you to listen to the music. After the countdown is over, please let me know and continue with the survey.*

**7.5 PRE SUD-Measurement**

*You have just seen a video clip. I would like to ask you to recall the memory you have of the video clip:*

*Thinking about the video clip, how unpleasant does it feel or how much distressed do you feel, estimated on a scale from 0, no distress at all, to 10, maximum distress?*

*And how vividly can you picture the video clip, estimated on a scale from 0 "not vivid at all," to 10, "very vivid"?*

*Please indicate your answers in the questionnaire.*

- **EXCLUDE** if SUD = 5.5 or lower
- **IF 5.5 OR LOWER**: *Based on the scores you just mentioned, we have to exclude you from this study. The movie doesn't seem to do much with you and therefore you are unfortunately not suitable for this study. I would like to thank you for your participation, and I will make sure you will receive your compensation/participant points.*

**IF 5.6 OR HIGHER:** *Please continue*

**7.6. Conditions**

*As soon as you see a QR code again, please let me know.*

*Please scan the QR code with your phone camera now. If it doesn't work, you can also manually enter the link below it into your smartphone browser. Now please select "Client", scroll down and tap accept. Then please hold your phone horizontally. Tap "start session.". Could you please tell me the session ID or type it into the chat, so I can connect with you?*

LOOK at Condition (Excel): Control or Experimental

7.6.1 Control

7.6.2 Experimental

**7.6.1 Control Condition: Recall Only**

*In a moment I will ask you some questions about your memory of the video clip that we are going to work on.*

*From your memory of the whole video clip, choose the image that you find most distressing to watch right NOW. In other words: what is at this moment, when you look at it from here and now, the most disturbing image of this memory, or which image evokes the most distress at this moment? Imagine looking at the video clip again and then pausing it- at the second - so that it becomes an image.*

*Which image is the most disturbing image of the event / Which part of the memory evokes the most distress? (...)*

*Where in your body do you feel it ('that distress/tension') most strongly? (...)*

*You are supposed to keep your eyes open and look at the screen. Is that okay? (…)*

*Take the most disturbing image in mind, do you have that? (...)*

*Be aware of the tension in your [location of tension].* Give the participant a moment to concentrate. *Focus on the memory and relax while looking at the screen.*

*We will now start with the sets.*

- **FOR 12 SETS:**
    - o **START** Recall Only Condition
- **AFTER** 30s have a small break and say:

*What comes to mind? / What is going through your mind? / What do you notice?*

- **If someone names something related, say:** *Focus on that, continue with that.*
- **If someone says nothing comes up or names something unrelated, say:** *Okay, now focus again on the most disturbing image again.*

*I'll put the task back on NOW.*

### 7.6.1 Experimental Condition: Recall + Dual Task

*We will now continue with the task that you have practiced with before. Do you remember what to do in this task? (...)*

- **If necessary,** explain the task again.

*In a moment we are going to do this task several times. Please press the buttons as fast as possible again when you see the cylinder or hear the sound. But when you do the task this time, I'll also ask you to do something else as well.*

*I'm going to ask you some questions about your memory of the video clip that we're going to work on. From your memory of the whole video clip, choose the image that you find most distressing to watch NOW. In other words: what is at this moment, when you look at it from the here and now, the most disturbing image of this memory, or which image evokes the most tension at this moment? Imagine looking at the video clip again and then pausing it- at the second - so that it becomes an image.*

*Which image is the most disturbing image of the event / Which part of the memory evokes the most distress? (...)*

*Where in your body do you feel it ('that distress/tension') most strongly? (...)*

*We are about to start the task, so look at the screen and meanwhile take the most disturbing image in mind, do you have that? (…)*

*Be aware of the tension in your [location of tension].* Give the participant a moment to concentrate.

*Pay attention, follow the ball, and react to the tasks. I am starting the task NOW.*

- **FOR 12 SETS:**
  - **START** Combi + EM + algorithm Condition
- **AFTER** 30s have a small break and say:

*What comes to mind? / What is going through your mind? / What do you notice?*

- **If someone names something related, say:** *Focus on that, continue with that.*
- **If someone says nothing comes up or names something unrelated, say:** *Okay, now focus again on the most disturbing image, follow the ball, and react to the task.*

*I'll put the task back on NOW.*

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### 7.7 POST SUD Measurement

*Please continue in the questionnaire*

*I would like to ask you to recall the memory you have of the video clip.*

*Thinking about the video clip, how unpleasant does it feel or how much distressed do you feel, estimated on a scale from 0, no distress at all, to 10, maximum distress?*

*And how vividly can you picture the video clip, estimated on a scale from 0 "not vivid at all," to 10, "very vivid"?*

**7.8 Conclusion**

*Thank you, we are done with the phone application now. Please proceed with the questionnaire. When you reach the end of the questionnaire, please let me know.*

If participant doesn't know where to find SONA number: *You can find your SONA identification number when you log into SONA* (https://utwente.sona-systems.com/Default.aspx?ReturnUrl=%2f)*, go to my profile, there should be your identification code on the left side of the screen.*

*We have now come to the end of this appointment. How are you doing now? (...)*

- **IF THE PARTICIPANT IS STILL UPSET** by the movie, again give the option to speak with the clinical psychologist.
- **If still upset:** *I am sorry for the fact that the film upset you so much. When participants in this study get very distressed, the protocol is that you receive the contact details of a clinical psychologist who you can talk with.*

*As you just read, you will receive an email tomorrow with a follow-up questionnaire, which only takes around 5 minutes. I would like to ask you to complete it tomorrow as soon as possible. I will also remind you again that if you feel you need someone to talk to about the stressful memory, feel free to reach out to Youri, our psychological professional. After the follow-up survey tomorrow, there will also be some measures to relieve potential tension. Do you have any final questions or remarks? (...)*

- **YES:** Briefly discuss how to help
- **NO**: *Great, that concludes today's session then. Thank you for participating.*

*Would you like to participate in the voucher give-away?*

- **YES:** *Then I will need your email address. Please use the chat function for this. Thank you.*
- **NO**: *Have a nice day.*