Digital EMDR: Does an Increase in Task Complexity by Combining Visual and Auditory Tasks and Presenting Them Serially or Parallel Enhance a Higher Working Memory Taxation?

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Abstract

Background and objectives: Posttraumatic-stress disorder (PTSD) can be effectively treated with eye-movement desensitization and reprocessing (EMDR) therapy. Moving the eyes and simultaneously recalling the memory tax the limited capacity of the working memory which reduces the vividness and emotionality of aversive memories. In this study, an online EMDR therapy application delivered on a smartphone was analysed for its effectiveness in taxing the working memory with innovative dual tasks. The aim was to examine whether increasing task complexity by combining tasks and presenting tasks serially or in parallel enhances a higher working memory taxation and whether a modality-specificity of attention increases taxation.
Methods: Forty-nine students performed different sets of RTTs to assess the degree of working memory taxation of a visual and auditory task. Both tasks were assessed independently and in combination. In combination sets, visual and auditory stimuli were either presented serially or in parallel. In addition, three different levels of eye movement speed were administered (slow, medium, and fast).
Results: Both tasks, single and combined, taxed the working memory. Of combined tasks, a serial presentation of stimuli was more taxing than a parallel presentation for the visual task only. No difference in RTs was found for the auditory task. Eye movements amplified the taxation for the visual task. Auditory RTs remained constant among eye movement speeds, except for the fast eye movement speed level.
Conclusion: Combining tasks loads the working memory to a greater extent than a single task. During a serial stimuli presentation, attention needs to be switched between modalities, leading to a switch cost and higher taxation compared to a parallel presentation where attention needs to be divided among modalities. Results partially support a modality specificity of processing stimuli located within the same modality. Further research is needed to test the exact influence of each factor on working memory taxation. The tasks applied in a smartphone application seem to be taxing and thus might be effective in online EMDR treatment.

Keywords: EMDR, working memory, visual, auditory, eye movement, modality-specificity

Digital EMDR: Does an Increase in Task Complexity by Combining Visual and Auditory Tasks and Presenting Them Serially or Parallel Enhance a Higher Working Memory Taxation?

Posttraumatic Stress Disorder (PTSD) is a severe mental health disorder that is relatively common in the general population. According to de Vries and Olff (2009), 80.7% of the Dutch population experiences a potential trauma at least once in their lifetime, and even more strikingly, the lifetime prevalence of being diagnosed with PTSD is 7.4%. Many PTSD patients experience immense subjective distress due to the formation of intrusive memories that involuntarily enter the consciousness. These intrusive memories or flashbacks often appear as visual images and are frequently sensory reexperienced by the patient (Iyadurai et al., 2019). To the patient's suffering, negative emotions often accompany flashbacks that hinder the patient from living an anxiety-free life. Therefore, it is of high importance to effectively treat PTSD.

An accepted treatment for PTSD is eye movement desensitization and reprocessing (EMDR) therapy (APA, 2020). Traditionally, during several sessions, the patient is asked to recall the traumatic memory internally while simultaneously performing horizontal eye movements (EM) externally (dual task). EMDR effectively reduces the vividness if the patient indicates lower numbers of disturbance and no longer experiences the memory as distressing. Indeed, several meta-analyses have shown that PTSD symptoms can be effectively reduced with EMDR (e.g., Bisson et al., 2007; Chen et al., 2014), and Chen et al. (2014) concluded that EMDR therapy successfully reduces the subjective distress in PTSD patients. Correspondingly, there is a great number of research investigating the effectiveness of eye movements as a dual task on traumatic memories. In those studies, healthy participants either recalled only the memory without performing a dual task or recalled the memory and additionally performed EM. The 'recall only' condition did not reduce vividness and emotionality, whereas 'recall + EM' did (Gunter & Bodner, 2008; Leer et al., 2014; Maxfield et al., 2008), revealing that a dual task (EM) is associated with memory change.

Working Memory Theory

How does EMDR work? An explanation for the effectiveness of EM provides the theory of working memory (WM). It is well known that working memory capacity is limited. Concentrating on eye movements taxes the working memory, as attention is paid to actively moving the eyes (Baddeley, 2007). When performing eye movements simultaneously to recalling the aversive memory, both take up limited space in the WM. This competition of working memory resources hinders the recall of aversive memories and thus, according to van den Hout and Engelhard (2012), decreases the vividness and emotionality of such memories. The labile memory is then newly restored in the long-term memory (van den Hout & Engelhard, 2012). Interestingly, vertical eye movements yield the same effect as horizontal eye movements (Gunter & Bodner, 2008).

Dose-Response Relationship

One significant indicator of the working memory theory is the dose-response relationship between loading the WM and the modification of vividness and emotionality. This relationship proposes that the greater the taxation of WM, the greater the changes in memory. In a study by Maxfield et al. (2008), the effect of fast EM (0.8 seconds per movement) was compared to slow EM (1 second per movement), suggesting that fast EM are more taxing and thus decrease the vividness more than slow EM. Indeed, their results showed that faster EM yielded a greater reduction of vividness than slow EM, indicating a linear dose-response relationship. Several studies have shown proof of this (e.g., Maxfield et al., 2008; Little & van Schie, 2019). On the contrary, some researchers discovered disproving results of a linear relationship and suggested an inverted U-shape relation (van den Hout & Engelhard, 2012; Mertens et al., 2019). Research by Gunter and Bodner (2008) proposed the inverted U-curve hypothesis. This hypothesis states that the recall of memory and executing a dual task should tax the WM with a similar amount. If the working memory is taxed too little, there is too much room for recalling the vividness and emotionality of a memory. In contrast, too much taxing of WM leaves too little room for a recall. Therefore, an optimal taxing level lies in between “too little” and “too much”. Independent of which theory applies to explain the effects of EMDR, the core of the effectiveness of EMDR is a WM taxation with dual tasks.

Interestingly, in traditional EMDR, EM as a dual task were thought to be a necessary component for taxing the WM. Nevertheless, more recent research found evidence that besides EM, other dual tasks also influence the emotionality and vividness of aversive memories, such as drawing complex figures (Gunter & Bodner, 2008) or doing arithmetic (van den Hout et al., 2010). Additionally, research showed that playing Tetris is as effective as EM in the modification of memories (Engelhard et al., 2010). Even though other dual tasks seem to be as effective as eye movements, research still highly emphasises EM. This might be due to results like those of van den Hout et al. (2011). Their research team investigated the different effects of EM and binaural stimulation in the form of beeps on taxing the working memory. Their results suggested that both binaural stimulation and EM decrease the vividness of aversive memories, but EM yielded larger effects.

Working Memory Modalities

Another significant indicator of the working memory theory is the cognitive structure of the WM. The working memory is divided into three subsystems (Baddeley, as cited in van den Hout et al., 2011). The central executive (CE) is seen as processing information generally, splitting the attention between tasks and activating memories. The visuospatial sketchpad (VSSP) processes visual and spatial information, whereas the phonological loop (PL) processes verbal information. Based on this theory, two explanations could justify the effectiveness of EM and other dual tasks in EMDR. First, both EM and a visual image compete for the limited capacity of the VSSP, which would argue for modality-specificity (Andrade et al., 1997). Dual tasks targeting the same modality showed a larger effect on the reduction of vividness than dual tasks that did target different modalities (Andrade et al., 1997). Second, the more general view implies that the CE plays a dominant role in the vividness of memories. The more (complex) tasks tax the CE, the more the imagery is weakened. This view suggests that any task that loads the CE could be adopted to load the working memory, thus influencing the vividness of memories. Several studies supported the essential role of CE over VSSP and PL (e.g., Gunter & Bodner, 2008; Kristjánsdóttir & Lee, 2011). However, both explanations do not rule out the possibility of the other.

Attention and Modality-Specificity

Importantly for understanding how dual tasks tax the WM is the concept of attention because, for a taxation of the WM, patients need to focus on different stimuli while performing a dual task. As a means to react to stimuli of a dual task, one needs to focus attention on the different features of each stimulus. This selection is known to be a perceptual process that is limited in its capacity (Kastner & Ungerleider, 2000). Thereby, attention often needs to be divided, i.e., allocated between input information when several tasks are performed simultaneously (Hahn et al., 2008). However, performing tasks simultaneous reduces performance accuracy (Pashler, 1994). Different explanations justify a drop in performance accuracy. First, an overall processing capacity is distributed among different tasks. Thus, when performing several tasks at the same time, fewer processing capacities are available for each task, and performance declines (Pashler, 1994). Second, researchers found evidence that input processing heavily depends on which sensory modality the input targets. If the same modality is targeted with different simultaneous tasks, performance declines. Thus, it is content-dependent (Pashler, 1994).

Whether the limited attentional capacity is more limited for simultaneous stimuli presented within the same modality or for simultaneous stimuli presented in different modalities will be further explored within the current research. Overall, the former view is more substantiated and supported by many studies (Duncan et al., 1997; Martens et al., 2010, Talsma et al., 2006), meaning that there is a limited attentional capacity for simultaneous stimuli presented within the same modality. This is, for instance, demonstrated in the study by Talsma et al. (2006). Participants attended to a series of letters that were either accompanied by unisensory visual, unisensory auditory, or multisensory audio-visual stimuli. They concluded that attending additionally to an auditory stimulus does not affect the processing of the visual stimulus but attending additionally to a visual stimulus impaired the processing of the visual stimulus, indicating that attentional capacity is relatively independent across sensory modalities. On the contrary, the latter view is supported by research from Eimer and Schröger (1998). Their study demonstrated that attentional control areas are intermodal or supramodal, meaning that a single network of brain areas controls attentional processes of visual and auditory stimuli. A modality-specificity could influence the effectiveness of dual tasks on taxing the WM. Therefore, it is essential to understand how dual tasks tax the working memory to increase the effectiveness and efficiency of EMDR therapy.

Current research

The Dutch company Moovd developed a digital EMDR application for online treatment that incorporated relatively new dual tasks to tax the WM of patients. Specifically, in times of Covid-19, where online access to therapy is of enormous importance, the application by Moovd may be a valuable innovation to therapy possibilities. In the online application, patients focus on two dual tasks besides recalling the memory that both require motoric responses similar to those made in reaction time tasks (RTTs). How and to what extent (online) dual tasks tax the working memory is still a matter of debate. Therefore, the main aim of this study is to investigate the taxing of the new online dual tasks on WM to add clarification to online EMDR treatment and research. Furthermore, modality specificity raises more questions on how dual tasks tax WM differently. Hence, another aim of this study is to examine whether an intra-modularly interference exists. RTTs are used to measure WM load.

A slowing in reaction times (RTs) is a valid measure to determine the taxation of WM. Mainly, RTs are used to measure the speed of processing basic thought. This includes perception, attention, retrieving memory, and executing muscle movements as a reaction. Therefore, a RTT measures the time a participant needs to react to task A. Additionally, task B is administered to task A. Measuring RTs again, the extent to which the RT of task A is slowed down provides a determination of the cognitive capacities used by task B, hence measuring the taxation of working memory. Thus, it is understood that the more the RT is slowed down, the more cognitive capacity is used by task B (van den Hout & Engelhard, 2012).

Generally, the dual tasks in the online environment consist of visual and auditory RTTs. Note that both tasks are referred to as dual tasks in this study, meaning that the online application operates two dual tasks. Participants are asked to react quickly and accurately to the visual and auditory tasks. The visual task is composed of a ball occasionally changing its shape into a cylinder (visual stimulus). The auditory task consists of a sound wave (auditory stimulus). To determine a mean RT and thus an indication of WM taxation, both stimuli are presented independently of each other in a baseline measurement (single modality task). In addition, both stimuli will be presented in combinations (combined modalities, i.e., visual + auditory) to assess a potential slowing down in RTs for each stimulus. They either appear serial or are presented in parallel. The task presentations are thought to enhance WM taxation due to attentional processes that take up additional WM capacitates.

Serial combination sets are a randomised series of visual and auditory stimuli occurring within a random interval of 0.5 to 2 seconds. A maximum of the same four consecutive stimuli may occur. Participants must react to the stimuli by pressing a button requiring a motoric response. Additionally, they need to switch frequently in-between modalities, i.e., from a visual stimulus to an auditory stimulus and vice versa. This attentional switch between modalities uses limited WM capacity and hence leads to a switch cost noticeable in longer RTs (Baddeley et al., 2001). Therefore, it is hypothesised that the mean RT for the visual stimulus will be longer in serial presentation tasks than in the single visual modality tasks (H1a); and the mean RT for the auditory stimulus will be longer in serial presentation tasks than in the single auditory modality task (H1b).

In parallel combination sets, visual and auditory stimuli appear simultaneously but run independently from each other with a random interval of 0.5 to 2 seconds. The working memory theory suggests that simultaneously performing a dual task interferes with the performance of a primary task and hence leads to longer RTs. The underlying concept of this theory may include the idea of divided attention (Pashler, 1994). When focussing on different tasks simultaneously, performance often declines because attention needs to be divided among demanding tasks. Therefore, it is hypothesised that when stimuli are presented in parallel, the participants' working memory is loaded higher. RTs are longer for the visual stimulus in parallel presentation tasks than in the single visual modality task (H2a) and RTs are longer for the auditory stimulus in parallel presentation tasks than in the single auditory modality task (H2b).

Based on the previous hypotheses for serial and parallel combination tasks, this study will additionally and exploratively compare serial and parallel presentations among themselves. It is not yet researched whether switching attention between modalities or dividing attention among modalities takes up more WM capacity. Nevertheless, it is assumed that processing stimuli simultaneously interfere with performance accuracy to a greater extent than alternating attention between stimuli. Therefore, it is hypothesised that the mean RT for the visual stimulus will be longer when stimuli (visual + auditory) are presented in parallel than serially (H3a); and the mean RT for the auditory stimulus will be longer when stimuli are presented in parallel than serially (H3b). Importantly, this study is not thought to investigate this issue thoroughly but rather to build preliminary evidence on what attentional concepts might be more effective in online EMDR treatment.

To further investigate whether attention is modality-specific or supramodal, speed as an additional visual stimulus will be included in the analysis. Each speed variation uses a different eye movement pace to mimic eye movements used in the online EMDR application. The speed level ranged from no EM, i.e., the ball (visual task) will not move around, to fast EM, i.e., the ball moves horizontally with a speed of 1.2hrz. Previous research shows that modality-specificity influences the performance of simultaneous tasks within the same modality, i.e., RTs are longer for stimuli occurring within the same modality (Martens et al., 2010; Talsma et al., 2006). Therefore, in the current study, it is hypothesised that combination tasks (serial & parallel) are more taxing for the visual stimulus with different speed levels because EM compete with the visual stimulus for attention (H4a). However, there will be no difference in RTs for the auditory stimulus across different speed levels (no EM to fast EM) because there is no attentional competition between different modalities (H4b).

Lastly, errors will be measured to indicate task complexity. Van den Hout et al. (2010) demonstrated that the number of errors made increased with the complexity of tasks. They compared RTs for a "recall-only" condition to a recall condition that simultaneously performed either simple counting tasks or complex counting tasks. Their results showed that errors increased progressively with more complex dual tasks. Similar results were found by van den Hout et al. (2011). Therefore, it is hypothesised that the absolute number of errors will increase with higher speed levels in serial presentation tasks (H5a) and in parallel presentation tasks (H5b).

In sum, this study focuses on five factors regarding WM taxation in the online application, i.e., the visual stimulus, the auditory stimulus, combined stimuli in a serial and parallel presentation, eye movements and different speed levels.

Methods

Participants

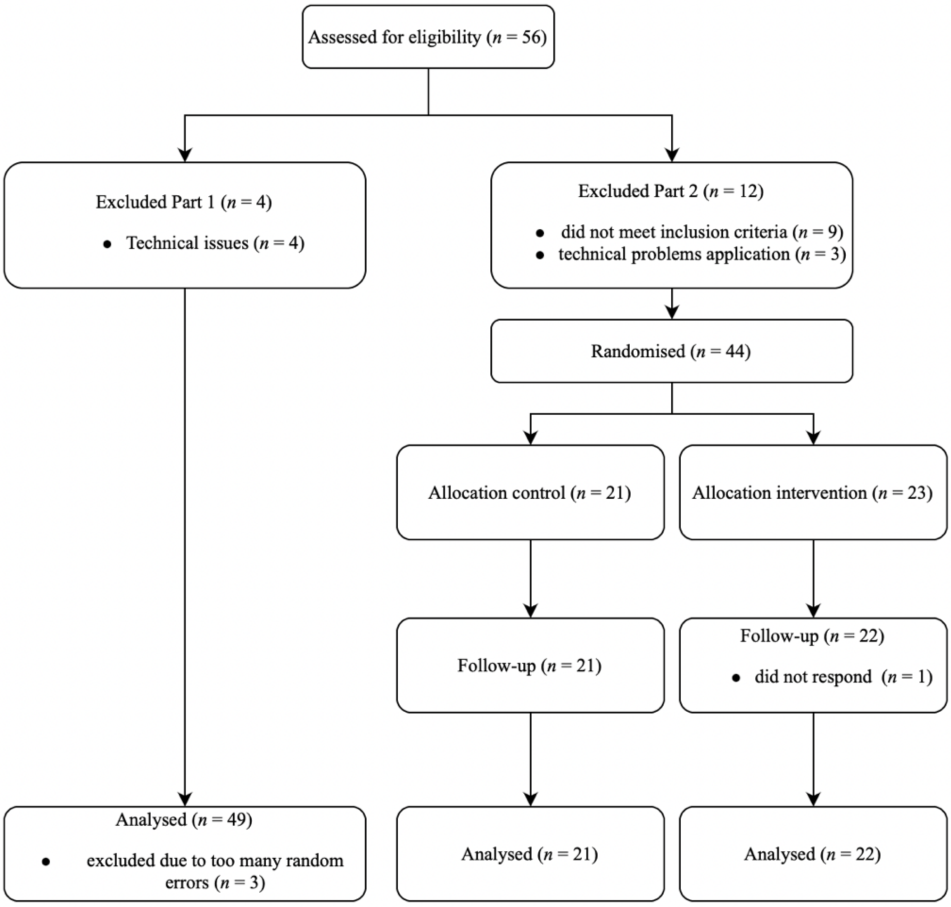
In total, fifty-six students gave their written consent (see Appendix A) to take part in the study. Participants were recruited internally through SONA, a test subject pool of the University of Twente and externally through media advertisement on WhatsApp. Students were allowed to take part in the study if they had normal to corrected vision and hearing, did not consume medication (antidepressants, antipsychotics, benzodiazepine or mood stabilisers) at the time of the study, and were not diagnosed with one of the following disorders: major depression, PTSD, psychosis, bipolar disorder or autism spectrum disorder. Furthermore, students were excluded if they had experience with EMDR therapy less than three years ago. In total, seven participants were excluded for the first part of the study because of technical problems with the application, leaving 49 participants for analyses (see Figure 1). Eleven participants were excluded for the second part of the study because their subjective units of disturbance were too low (lower than 6) or reacted too disturbed (e.g., crying).

In general, for the first part, participants' age ranged from 18 to 39 (M = 22.02; SD = 3.25). Most participants were female (N = 26), had a high school degree or equivalent (N = 37) and were German (N = 32). As a form of reimbursement, participants recruited internally received 2.25 SONA credits for partaking in the experimentation, and, if wanted, each participant was admitted to a drawing to win a 20€ voucher at the end of the study.

Lastly, a power analysis was conducted prior to the study to specify a suitable sample size. Using the programme G*Power (UCLA, 2021), a sample size of N = 86 was determined. This analysis was conducted with following settings: A repeated measures ANOVA, between factors for F-tests; η^2 = .25; α = .05; power = .8; number of groups = 2; number of measurements = 3; correlation among rep measures = .5.

Figure 1

Flowchart of Participants



Note. Only participants from the first part are included in this study (left path).

Design

The first part of the study consisted of a within-subject design with three independent variables to test WM taxation. Thereby, the independent variables were stimuli (visual, auditory), combination (serial, parallel) and speed level (no EM, slow, medium, fast). RTs and errors formed the dependent variables. RTs and errors were measured in every RTT. The second part of the study consisted of a mixed design with time (pre-, post-measurements) and condition (experimental, control) as independent variables and vividness and emotionality as dependent variables. Vividness and emotionality were measured once before the intervention started and twice after the intervention was completed. This study was conducted online in which participants first completed 12 sets of RTTs to examine the taxation of WM by a combination of the independent variables, and after a break, watched a traumatic film to elicit stressful memories that consequently were desensitised with an online EMDR treatment. Participants were randomly allocated to either the experimental condition or the control group.

Materials

Participants were required to use a computer with a stable internet connection. The distance from participants to the computer amounted to approximately 30 centimetres. Zoom was used to establish a one-to-one conversation with the participants. Additionally, participants needed a working smartphone with a stable internet connection and charged battery to open the digital EMDR application developed by Moovd (see Appendix B). For the first part of the study, different combinations of stimuli (visual and auditory) were presented in the online EMDR application. The application measured reaction times and errors. For the second part of the experiment, intrusive memories were elicited by watching a two-minute film excerpt from the French film "Irreversible". The online application was once used again to perform the EMDR therapy. During the therapy sessions, a combination of all stimuli (visual and auditory) was presented. Lastly, questionnaires about participants' demographics and their experience with the online EMDR application were used.

Part 1

Stimuli. The stimuli were presented on a screen depicting a living room in the online application (Appendix B). The visual stimuli included a ball changing to a cylinder. Every time the ball changed to a cylinder participants needed to press a button on the right side of their smartphones' screens. Auditory stimuli consisted of a sound wave for which participants needed to press a button on the left side of their screens. When participants pressed the respective buttons, the ball changed back to its ball shape and the sound wave stopped. These stimuli were practised separately in one single task set. Additionally, EM ranging in speed from slow (0.8hrz), medium (1hrz) to fast (1.2hrz) were applied.

In Table 1, the set-up of the first part of the study, which consisted of 12 different RTTs, is depicted. RTs for both visual and auditory stimuli were measured separately in two baseline single modality tasks as well as jointly in combinations. Visual and auditory stimuli were either presented serially or parallel in combination tasks. Serial combination sets are a randomised series of visual and auditory stimuli occurring within a random interval of 0.5 to 2 seconds. A maximum of the same four consecutive stimuli may occur. The tasks lasted for 120 seconds. In parallel combination sets, visual and auditory stimuli appear simultaneously but independently from each other with a random interval of 0.5 to 2 seconds, resulting in approx. 25 data points. The tasks lasted for 60 sec.

For the second part of the study, the sessions consisted of randomised visual and auditory stimuli. The ball changed its speed (EM) based on an algorithm. The algorithm worked with participants' RTs towards the visual stimulus, with shorter RTs resulting in faster speed and slower RTs causing a slower speed. As a result, the speed of EM was adapted to each individual.

Table 1

Conditions With Different Stimuli and Time Intervals for RTT

Condition	Stimulus	Length
Practice	Visual	30
Practice	Auditory	30
Baseline	Visual	60
Baseline	Auditory	60
Combination Serial	Visual + Auditory + No EM	120
Combination Serial	Visual + Auditory + Slow EM	120
Combination Serial	Visual + Auditory + Medium EM	120
Combination Serial	Visual + Auditory + Fast EM	120
Combination Parallel	Visual + Auditory + No EM	60
Combination Parallel	Visual + Auditory + Slow EM	60
Combination Parallel	Visual + Auditory + Medium EM	60
Combination Parallel	Visual + Auditory + Fast EM	60

Note. Length of each condition is depicted in seconds.

Part 2

Trauma Film. The trauma film used to elicit traumatic memories was a film excerpt from the French film “Irreversible”. It depicts a murderer in a night club who uses a fire extinguisher to smash the head of a man violently. This clip lasted for 2min 2sec. The fragment was used in previous studies (Nixon et al., 2009; Verwoerd et al., 2011) and showed an effect on eliciting intrusive memories (Arnaudova & Hagenaars, 2017). Since the study was conducted online, participants watched the film at home on a laptop or PC. The researcher muted himself and turned off the camera to minimise disturbance.

Emotionality. To measure the emotionality of participants’ memories, participants rated the unpleasantness of their distressing memory on the adapted Subjective Units of Disturbance (SUD; Wolpe, 1990) scale (see Appendix C), which is traditionally incorporated in the standard EMDR protocol. The 11-point Likert scale is repeatedly integrated into research (Shapiro, 2018) and ranges from 0 (not distressed at all) to 10 (maximum distress).

Vividness. To measure the vividness of participants' memories, participants rated the vividness of their distressing memory of the movie on an 11-point Likert scale (Appendix C), ranging from 0 (not vivid at all) to 10 (very vivid). Vividness is a frequent measure in EDMR research (e.g., van den Hout & Engelhard, 2012).

Treatment Acceptability and Adherence Scale. To measure participants' acceptance of the EMDR treatment, participants rated their experience on the adjusted Treatment Acceptability and Adherence Scale (TAAS; Milosevic et al. (2015); see Appendix D). The adjusted scale incorporates six items in total to measure acceptability (e.g., the offered procedure was effective in reducing the distress that I felt after seeing the movie scene), adherence (e.g., I would recommend this procedure to a friend who is experiencing distress because of a negative), and distress (e.g., overall, I find this procedure intrusive). Participants were to rate their experience on a 7-point Likert scale from 1 (strongly disagree) to 7 (strongly agree). The internal consistency has shown to be good ($\alpha = .84$) in samples from other studies (Milosevic & Radomsky, 2013). Certainly, in this study, Cronbach's alpha was .73, which shows acceptable reliability.

Ethical Considerations

The Ethical Committee of the Behavioural and Management Science (BMS) Faculty ethically approved the study (approval code: 220219). The study conducted by van Schie et al. (2019) was used as a reference for the current research. To ensure that participants were not exposed to serious mental health effects, the study followed certain safety strategies. Firstly, participants were informed prior that they would watch a shocking film clip to elicit stressful memories. The clip was summarised in a few sentences. Secondly, Participants received oral and written instructions that they could stop watching the clip at any time if it became too disturbing. Thirdly, participants diagnosed with PTSD, bipolar disorder, major depression, and autism spectrum disorder were excluded from partaking. Lastly, the participants were offered contact details of a licensed clinical, received a guided exercise for mindful breathing to relieve tensions and a documentary that explained how the scene was shot with special effects. These were mentioned in the follow-up measure. The contact details of the psychologist were already given during the experimentation to ensure direct applicability.

Procedure

Part 1

As the study took part online, the researcher established a video connection via Zoom on a computer with each participant, one at a time. In general, instructions were alongside written instructions communicated verbally (see Appendix E) to ensure consistency throughout the process of data collection. Participants received a link for Qualtrics, an online platform that was used to read instructions, sign the consent form and answer demographic questions. After participants received written information about the study, they signed a written consent form (Appendix A). Next, participants filled in a questionnaire about their demographics. Afterwards, the researcher instructed the participants to open the online application for EMDR on their smartphones using the link https://research.ut.digital-emdr.com/. After selecting the role of the client, a connection to the therapist (researcher) was established through a session code.

Participants received instructions on how to perform the RTTs. The RTTs were operated by the researcher. During the RTTs, the researcher turned off their microphone to avoid distraction. Participants first performed two practice phases, where each stimulus (visual and auditory) was presented for 30 seconds, divided by a 10-second break. Next, students were subjected to 10 sets of different combinations of visual and auditory RTTs (Table 1), which were divided by a small break of 10 seconds. The RTTs were counterbalanced to counteract an order effect. Therefore, six different options were created that were successively distributed among participants prior to recruitment (see Appendix F). One option applied to one participant. After finishing the first part of the study, students had a two-minute break to counteract fatigue.

Part 2

The second part of the study started off by giving written instructions for the trauma film. During the two-minute film clip, the researcher turned off their camera and microphone to distract the participants as little as possible. After watching the film clip, a five-minute break followed during which participants passively listened to classical music. After the break, participants were instructed to recall the most stressful memory and rate it on an 11-point Likert scale (0-10) based on its emotionality and vividness (pre-test). If participants indicated a 5.5 or lower on the scale of emotionality, they were excluded from the study. Participants were randomly allocated to the conditions and either followed the treatment in the experimental condition or no treatment in the control group. After completing 12 intervention sets of 30 secs, both groups indicated the emotionality and vividness of their memory in a post-test on the same scale used in the pre-test. Further, the participants were instructed to fill in the post-intervention measurements and the TAAS. After 24 hours, a follow-up via e-mail assessed the emotionality and vividness of participants' memory again (post-test 2).

All participants received full debriefing in another questionnaire linked in the e-mail. The debriefing included a link to watch a short documentary clip that explained how the scene was shot with special effects to support processing the information, contact details of a licensed clinical psychologist who works independently of this study in case they needed to talk to someone about this experience, and a link to a YouTube video to perform a guided mindful practice to relieve stress and discomfort. When participants who took part via the SONA system sent the follow-up survey, they were reimbursed 2.25 SONA credits. Lastly, all participants were allowed to take part in a drawing of a 20€ voucher provided by Moovd at the end of the study.

Note that this study specifically only used data and materials from the first part. Information from the second part was not included in the current study.

Data Analysis

The data is analysed with SPSS statistics 27. Outliers were removed if the RTs were $M \pm 2$ *SD*. RTs from practice sets were removed as well as those for the experimental condition. RTs showed an ex-gaussian distribution which is a normal distribution for RTs, and thus were analysed with parametric tests. Assumptions of normality, independence and sphericity were tested. First, to analyse changes in RTs among different tasks, combination, and stimuli and to explore possible interactions a repeated measures ANOVA with Stimulus (2: visual, auditory), Speed (4: no EM, slow, medium, fast) and Combination (2: serial, parallel) was performed. Second, to answer whether serial (H1a&b) and parallel (H2a&b) tasks tax the working memory to a greater extent than single modality tasks, paired t-tests were carried out. Moreover, paired t-tests were also performed to analyse the difference between serial and parallel combination tasks (H3a&b). Third, to test whether limited attentional capacity is modality specific (H4a&b), two 2 (combination: serial, parallel) x 4 (speed: no EM, slow, medium, fast) repeated measures ANOVA were performed: one each to analyse changes in RTs among different speed levels for the visual and auditory stimulus.

Lastly, histograms revealed that errors were not normally distributed and thus were analysed with non-parametric tests. Friedman's test was carried out to test for an increase in the absolute number of errors among different speed levels (H5a&b). The alpha level was set at .05 for all analyses.

Results

For a general overview of the data, the RTs for the combination tasks were analysed with a within-subjects 2 (stimulus: visual and auditory) x 4 (EM speed: no EM, slow, medium, fast) x 2 (combination: serial and parallel) ANOVA. The results showed a significant main effect of stimulus $F(1,48) = 27.54$, $p < .001$, $\eta_p^2 = .37$ and combination $F(1,48) = 50.84$, $p < .001$, $\eta_p^2 = .51$. Since sphericity is violated (ε = .788) a Huynh-Feldt correction was applied for the variable speed. Results demonstrated a significant main effect with a large effect size of speed $F(2.49,119.73) = 85.34$, $p < .001$, $\eta_p^2 = .64$. These effects indicate that RTs differed for each factor. There were significant interaction effects for stimulus x speed $F(2.76,132.5) = 82.9$, $p < .001$, $\eta_p^2 = .63$ and stimulus x combination $F(1,48) = 84.34$, $p < .001$, $\eta_p^2 = .64$ which also show large effect sizes. However, remarkably, there was no significant interaction effect for speed x combination $F(3,144) = 1.73$, $p = .164$, $\eta_p^2 = .04$. Results demonstrated a significant three-way interaction of stimulus x speed x combination $F(3,144) = 5.34$, $p = .002$, $\eta_p^2 = .1$.

Pairwise comparisons of the simple effects showed that the difference in mean RTs between the visual and auditory stimulus became increasingly greater with EM speed, with the largest difference in fast EM (visual: $M = 677.86$; auditory: $M = 527.67$) (see Figure 2 & 3). However, mean RTs between visual ($M = 522$) and auditory ($M = 506.05$) stimuli did not differ for the no EM speed level $F(1,48) = 1.49$, $p = .228$, $\eta_p^2 = .03$. Moreover, the mean RTs for visual and auditory stimuli significantly differed for the serial combinations $F(1,48) = 45.99$, $p < .001$, $\eta_p^2 = .49$ (Figure 2) and for the parallel combinations $F(1,48) = 11.81$, $p = .001$, $\eta_p^2 = .2$ (Figure 3). Additionally, there was a significant difference between serial and parallel combination tasks for the visual stimulus $F(1,48) = 102.56$, $p < .001$, $\eta_p^2 = .68$ (see Figure 7), but not for the auditory stimulus $F(1,48) = .44$, $p = .508$, $\eta_p^2 = .01$ (see Figure 8).

Figure 2

Serial Presentation of Combined Visual and Auditory Stimuli With Increasing Speed Levels

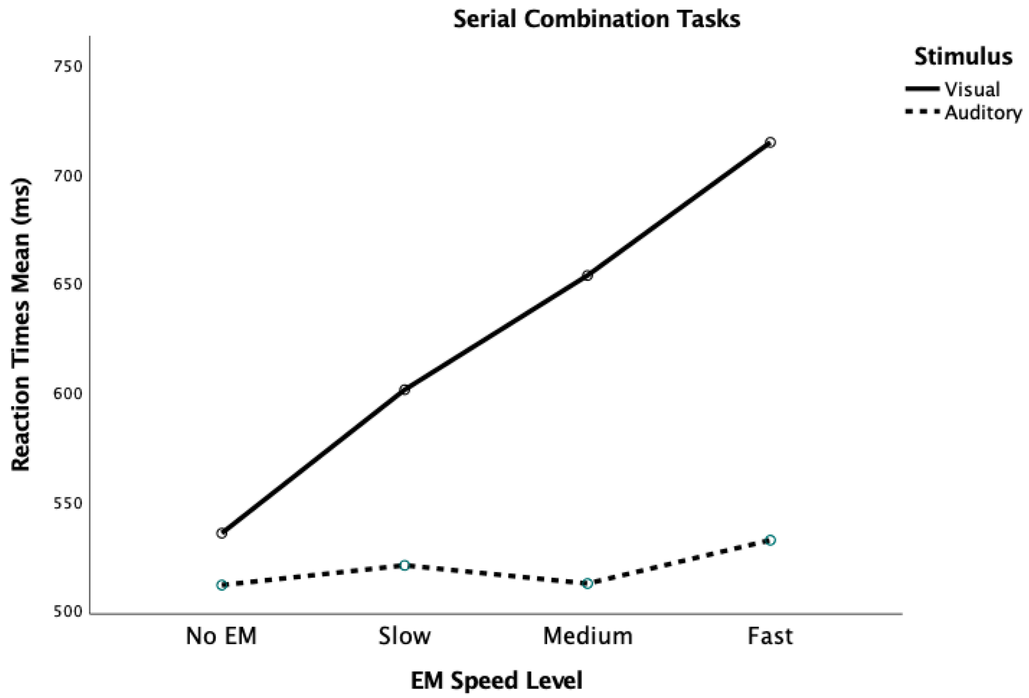
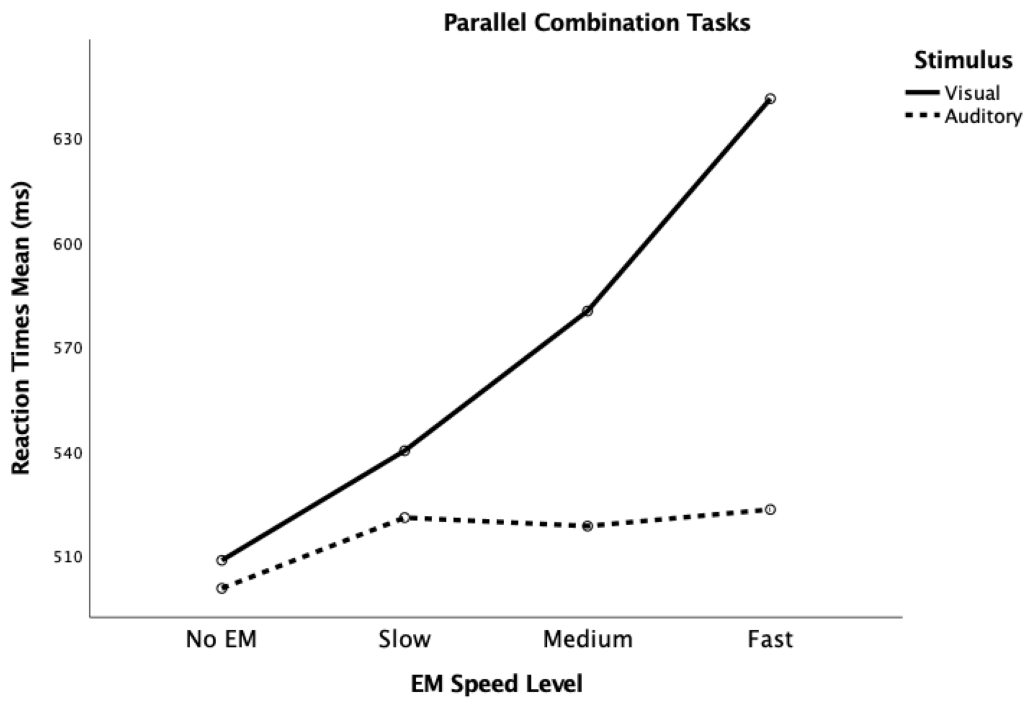


Figure 3

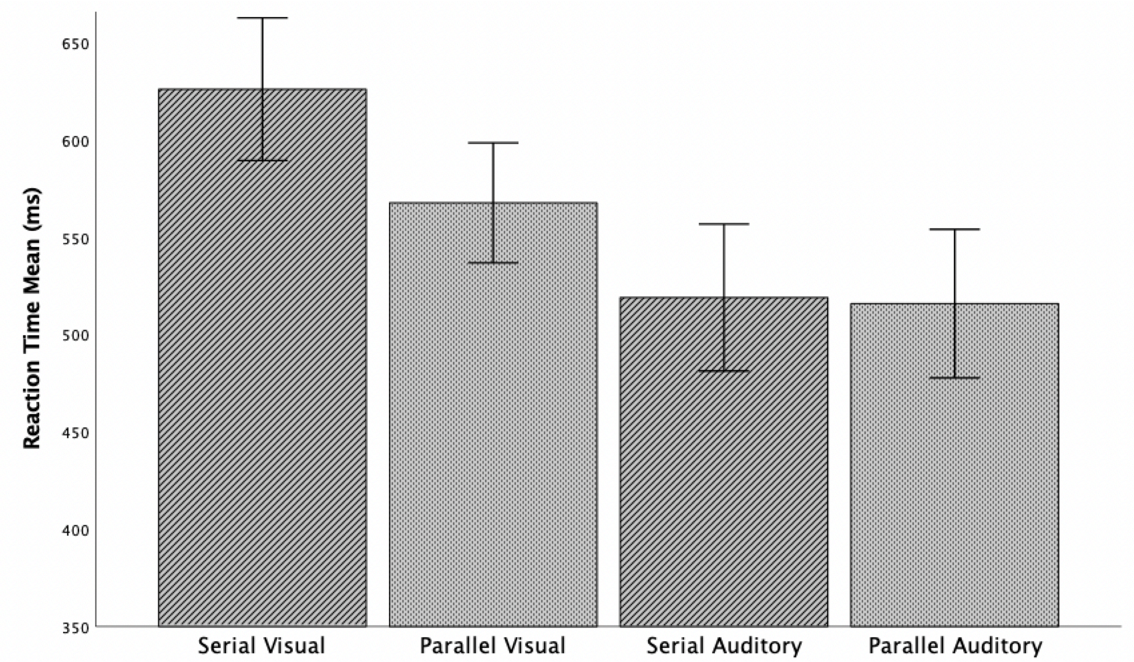
Parallel Presentation of Combined Visual and Auditory Stimuli With Increasing Speed Levels



Remarkably, in combination sets, i.e., both the visual and auditory stimuli were either serially or parallel combined, including increasing EM, the RTs for the visual stimulus (H3a) were longer when stimuli were presented serially (*M* = 626; *SD* = 128.29) than when presented parallel (*M* = 567.64; *SD* = 107.94). The paired t-test showed a significant difference $t(48) = 10.13$, $p < .001$ (see Figure 4). In contrast, the paired t-test showed no significant difference between serial and parallel combination conditions for the auditory stimulus $t(48) = .67$, $p = 508$ (H3b).

Figure 4

Mean RTs for Visual and Auditory Stimuli Comparing Serial and Parallel Combinations

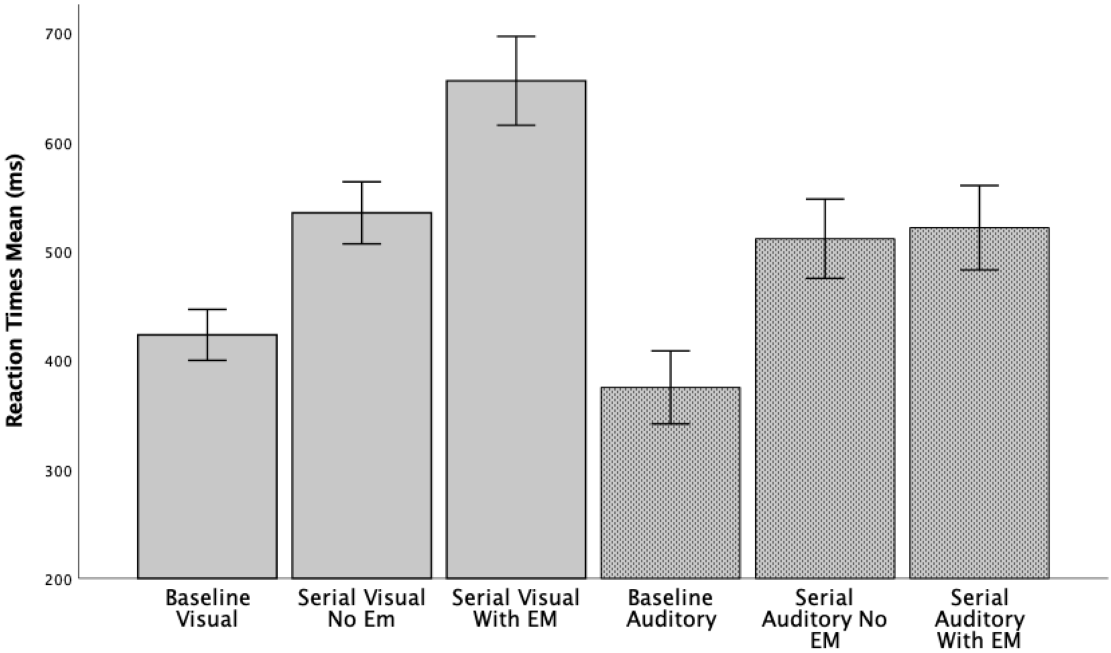


Note. Error bars represent standard errors. Serial and parallel presentations represent the mean RTs of all four tasks appertaining.

Additionally, paired t-tests were performed to compare RTs for serial and parallel combination tasks to single baseline tasks. First, in Figure 5, RTs for the visual stimulus were longer when presented serially with no EM (*M* = 535.2; *SD* = 99.46) and longest when presented serially with increasing EM (*M* = 656.27; *SD* = 142.61) than when the visual stimulus was presented in the single baseline task (*M* = 423.32; *SD* = 81.78) (H1a). The paired t-tests demonstrated a significant difference for the visual stimulus between the single baseline task and combination tasks with no EM $t(48) = 14.23$, $p < .001$ and between combination tasks with no EM and combination tasks with EM, i.e., slow, medium and fast EM combined, $t(48) = 10.31$, $p < .001$. Moreover, results demonstrated that mean RTs for the auditory stimulus (H1b) were longer when presented serially with no EM speed (*M* = 511.43; *SD* = 127.27) than when presented in the single baseline task (*M* = 375.1; *SD* = 117.2). The paired t-test showed a significant difference $t(48) = 17.26$, $p < 001$ (Figure 5). However, for the auditory stimulus, serial tasks with combined EM speed ($M = 521.54$; $SD = 135.35$) did not differ from serial combination tasks with no EM speed. Paired t-test showed no significant differences $t(48) = 1.65$, $p = .053$, $d = .24$.

Figure 5

Mean RTs for Visual and Auditory Stimuli in Serial Combination Tasks



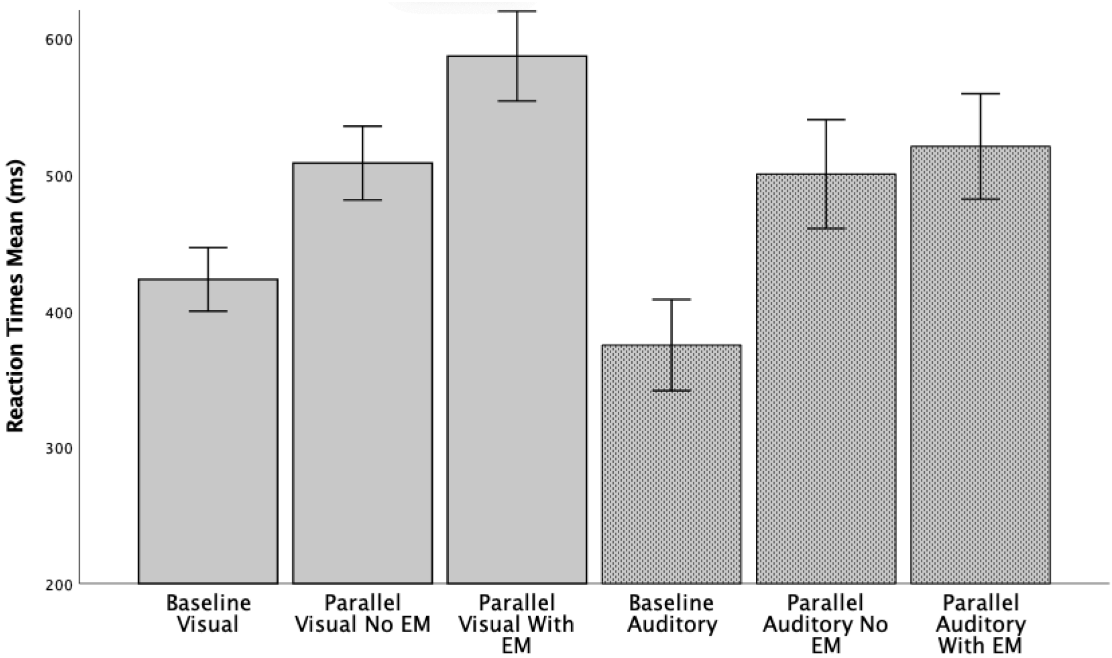
Note. RTs of serial combination tasks are shown separately for visual and auditory stimuli. The mean RT for a single modality task (baseline) is compared to serial combinations with no EM and compared to serial combinations with EM speeds (slow, medium, fast). Error bars show standard errors.

A similar trend was observable for the parallel combination tasks. In Figure 6, RTs for the visual stimulus were longer when presented in parallel with no EM ($M = 508.73$; $SD = 94.85$) and longest when presented in parallel with increasing EM speed ($M = 587.28$; $SD = 115.35$) than when the visual stimulus was presented in the single baseline task ($M = 423.32$; $SD = 81.78$) (H2a). The paired t-tests demonstrated a significant difference for the visual stimulus between the single baseline task and combination tasks with no EM $t(48) = 10.12$, $p < .001$ and between combination tasks with no EM and combination tasks with EM speed $t(48) = 9.72$, $p < .001$. Moreover, results demonstrated that mean RTs for the auditory stimulus (H2b) were longer when presented parallel with no EM speed ($M = 500.68$; $SD =$

139.87) and longest when presented with increasing EM (*M* = 520.96; *SD* = 135.5) than when presented in the single baseline task (*M* = 375.1; *SD* = 117.2) (Figure 6). The paired t-test showed a significant difference for the auditory stimulus between the single baseline task and combination tasks with no EM $t(48) = 12.09$, $p < .001$ and between combination tasks with no EM and combination tasks with EM $t(48) = 2.13$, $p = .019$.

Figure 6

Mean RTs for Visual and Auditory Stimuli in Parallel Combination Tasks



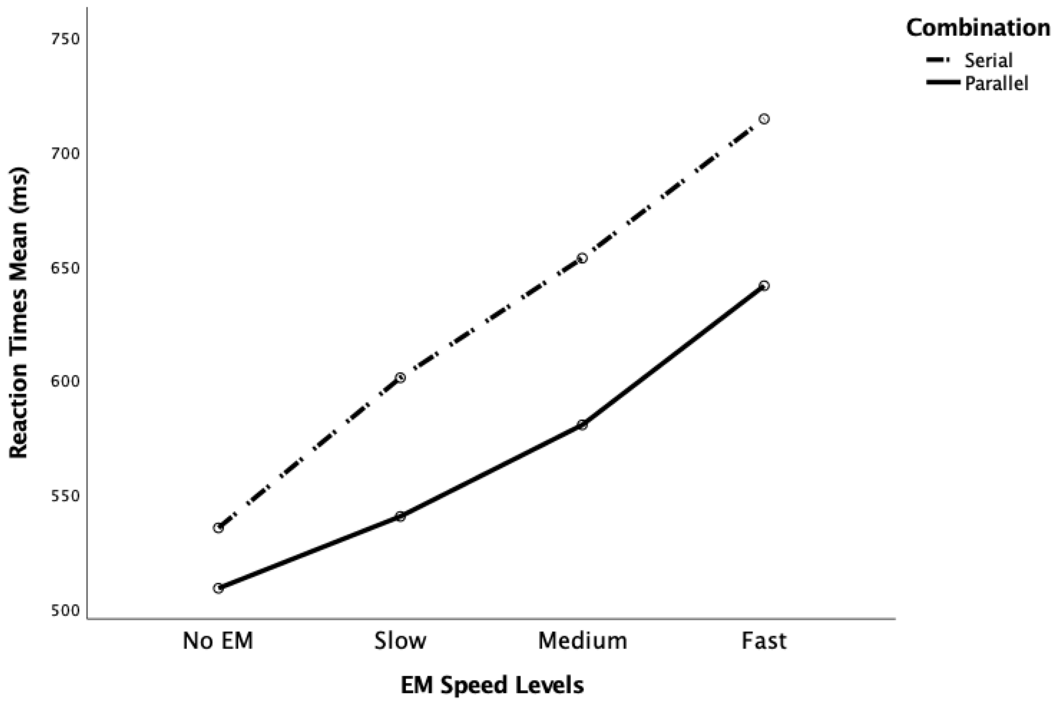
Note. RTs of parallel combination tasks are shown separately for visual and auditory stimuli. The mean RT for a single modality task (baseline) is compared to parallel combination tasks with no EM and compared to parallel combination tasks with EM speeds (slow, medium, fast). Error bars show standard errors.

The RTs for the visual stimuli were analysed with a within-subjects 2 (combination: serial, parallel) x 4 (EM speed: no EM, slow, medium, fast) ANOVA. There was a significant main effect of combination $F(1,48) = 102.56$, $p < .001$, $\eta_p^2 = .68$, indicating that RTs differed for serial and parallel combination tasks. Since sphericity is violated (ε = .759), Huynh-Feldt corrected results are reported for the variable speed. There was a significant main effect of speed $F(2.4,114.98) = 120.66$, $p < .001$, $\eta_p^2 = .72$, indicating that RTs became longer with increasing speed (H4a). Moreover, the analysis demonstrated a significant combination x speed interaction effect $F(3,144) = 5.18$, $p = .002$, $\eta_p^2 = .1$, however much smaller in effect than the main effect of speed. Noteworthy, in Figure 7, it is observable that the increase in RTs from no EM to fast EM is almost perfectly linear, regardless of the stimuli presentation.

Pairwise comparisons of the simple effects disclosed that the difference between serial and parallel is significant for each speed level, with significant differences for no EM $F(1,48) = 11.24$, $p = .002$, $\eta_p^2 = .19$, slow EM $F(1,48) = 30.54$, $p < .001$, $\eta_p^2 = .39$, medium EM $F(1,48) = 46.85$, $p < .001$, $\eta_p^2 = .49$, and fast EM $F(1,48) = 45.72$, $p < .001$, $\eta_p^2 = .49$. However, the largest difference measurable was for fast EM, with RTs longer for serial ($M = 714.42$) than for parallel ($M = 641.3$) combination tasks. Additionally, the different speed levels differed significantly from each other within serial combination tasks ($F(3,46) = 62.91$, $p < .001$, $\eta_p^2 = .8$) as well as in parallel combination tasks ($F(3,46) = 37.68$, $p < .001$, $\eta_p^2 = .71$). The largest difference in mean RTs for the serial combinations occurred from no EM ($M = 535.2$) to fast EM ($M = 714.42$) (H4a). Similar results were found for the parallel combinations, with the largest difference between no EM ($M = 508.73$) to fast EM ($M = 641.3$).

Figure 7

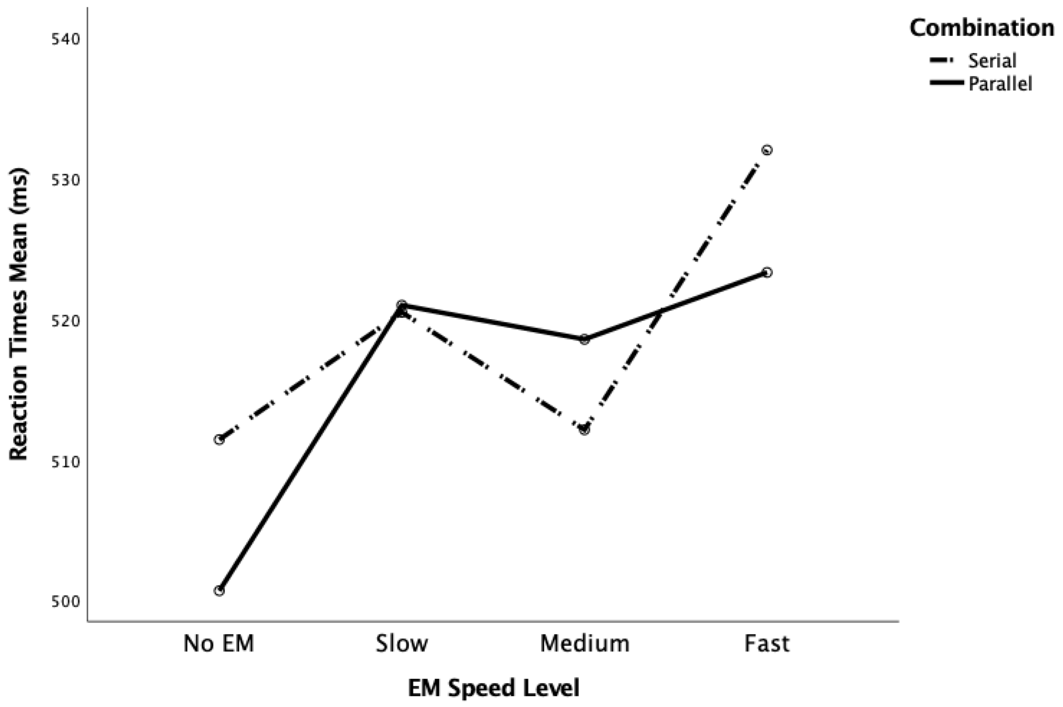
RTs for Serial and Parallel Combinations Across Four Different EM Speed Levels for the Visual Stimulus



The RTs for the auditory stimuli were analysed with a within-subjects 2 (combination: serial, parallel) x 4 (EM speed: no EM, slow, medium, fast) ANOVA (H4b). The ANOVA showed a non-significant main effect of combination $F(1,48) = .444$, $p = .508$, $\eta_p^2 = .01$. Participants performed likewise in serial combination tasks ($M = 519.02$) as well as in parallel combinations ($M = 515.89$). There was a significant main effect of speed $F(3,144) = 4.97$, $p = .003$, $\eta_p^2 = .09$. However, the post hoc analysis with a Bonferroni correction showed mainly insignificant differences between speed levels, while only RTs for no EM ($M = 506.05$) were significantly shorter than for fast EM ($M = 527.67$) and RTs for medium EM ($M = 515.37$) were significantly shorter than for fast EM ($M =527.67$) (Figure 8). Finally, results demonstrated a non-significant combination x speed interaction effect $F(3,144) = .844$, $p = .472$, $\eta_p^2 = .02$.

Figure 8

RTs for Serial and Parallel Combinations Across Four Different EM Speed Levels for the Auditory Stimulus



The errors were analysed with Friedman's non-parametric test, as statistics disclosed non-normal distributions for both error types (type 1: stimulus was clickable, but no response was recorded; type 2: click was detected, but the stimulus was not clickable). In general, there were no type 1 errors for the auditory stimulus detected. Therefore, only type 1 errors for the visual stimulus were analysed. For the serial combination tasks, a Friedman's two-way (condition: serial; speed: no EM, slow, medium, fast) was performed because not enough valid cases were detected for a Friedman's test. The overall effect was not significant $H(3) = 3$, $p = .392$. Thus, there was no difference among the distributions of errors for each speed level of serial combinations (H5a). For the parallel combination tasks, there was neither a non-significant difference $\chi^2(3) = 2.84$, $p = .418$ (H5b).

For errors of type 2 concerning the visual stimulus, the results showed no significant difference for all speed levels in serial combination tasks $\chi^2(3) = 2.87$, $p = .412$ (H5a). A similar non-significant effect was found for parallel combination tasks $\chi^2(3) = 2.81$, $p = .421$ (H5b). For the auditory stimulus, the test demonstrated a non-significant difference $\chi^2(3) = 3.08$, $p = .38$ for all speed levels in serial combinations (H5a). Lastly, there was no significant difference in errors type 2 for all speed levels in parallel combination tasks $\chi^2(3) = 4.5$, $p = .93$ (H5b).

Discussion

The first part of this study aimed to investigate how and to what extent visual and auditory tasks used in the online EMDR application provided by Moovd tax the working memory. Participants needed to press a button when the ball changed into a cylinder (visual stimulus), and they were asked to press another button when they heard a drumming sound (auditory stimulus). In addition to that, horizontal EM were applied with different speed levels (additional visual stimulus) to increase task difficulty. Thereby, special attention was paid to combining different modalities in parallel and serial combination tasks and exploring the differences in WM taxation by comparing mean RTs and errors. Results can be briefly summarised as follows:

Firstly, analyses have demonstrated strong relations between WM taxation and dual tasks, as well as task presentation and EM speed. This suggests that the innovative design of tasks presented in the application, the increase in EM speed and a serial and parallel presentation of stimuli led to a high WM taxation. Secondly, combining visual and auditory stimuli in a serial presentation showed that the visual and auditory tasks were more demanding for the working memory than single modality tasks. The same holds for combination tasks with parallel stimuli presentation, where RTs for visual and auditory stimuli were significantly longer than in single modality tasks. Remarkably, for the visual stimulus, a serial presentation of visual and auditory stimuli was more taxing than a simultaneous presentation of stimuli. In contrast, both presentations were similar taxing for the auditory stimulus. Thirdly, results showed that adding different speeds of EM to the task presentations progressively increased the load on the WM for the visual stimulus, which may indicate that attentional capacity is modality specific. In contrast, adding slow and medium speed levels of EM did not change the amount of taxation of the WM for the auditory stimulus. Interestingly, fast EM appeared to lead to a higher WM taxation for the auditory task, yet the relation between fast EM and WM taxation within the auditory modularity is slight. Lastly, regardless of the type of error and condition, participants made an equal number of errors with increasingly complex tasks (no EM up to fast EM).

Task Presentations

As expected, combining the visual and auditory stimuli in a serial presentation led to a WM taxation for the visual and the auditory stimulus. Switching between both stimuli meant switching between modalities (Baddeley et al., 2001; Spence et al., 2001). This switch led to a switch cost which additionally took up limited working memory capacity as opposed to processing the stimulus and executing the motoric response for pressing the respective buttons in single modality tasks. Furthermore, adding EM as a simultaneous task in the serial combination tasks increased the switching cost and impaired performance further (Baddeley et al., 2001). To what extent EM increased the WM load of visual and auditory tasks is explained in more detail in the next section. Moreover, a similar effect of performance decline was found for a parallel presentation of stimuli. For this presentation, attention did not need to be switched but divided as both stimuli occurred roughly at the same time. Consequently, speed and performance accuracy were reduced (Pashler, 1994). Indeed, RTs did increase significantly for the visual and auditory stimulus when presented parallel with no EM speed compared to single baseline tasks. Generally, both serial and parallel combination tasks are more taxing than single modality tasks.

No research compared a serial and parallel presentation of tasks regarding WM taxation in EMDR therapy. Remarkably and in contrast with the hypotheses, this study found that a serial presentation taxes the WM to a greater extent than a parallel presentation, at least for the visual task. Considering that a modality switch taxes the WM additionally, the first RTs directly after a switch should be relatively long. Indeed, looking at the data without performing appropriate analyses, it is observable that RTs were longer as soon as modalities needed to be switched and were shorter as soon as the same consecutive stimuli followed (see Appendix G). However, this conclusion needs to be stated carefully and requires more thorough analyses for appropriate inferences. Additionally, in serial presentations switching between stimuli, i.e., between modalities, might have led to an unexpected switching response for participants as stimuli occurred in a random order (Spence et al., 2001). This could have resulted in a higher WM taxation. Nonetheless, there is still the question of why the auditory task was similar taxing in serial as well as in parallel combination tasks. It could be that the auditory stimulus intensity reduced response latencies (Carlsen et al., 2007) in serial and parallel presentations. Participants in the current study were instructed to turn up their phone volume to hear the auditory task clear and loudly. This increase in volume may have intensified the auditory stimulus' characteristics, and thus the auditory stimulus was detected earlier (St Germain et al., 2020). Therefore, an increase in decibel (dB) levels may have decreased RTs (Kohfeld, 1971).

Modality-Specificity

Many studies have shown that performing EM compared to no EM increased working memory taxation (Engelhard et al., 2010; van den Hout et al., 2010; Mertens et al., 2019; van Veen et al., 2019). This study found similar effects of EM on taxing the WM. However, adding EM yielded different effects for the visual and auditory stimulus. As expected, when EM were applied to the visual task, RTs significantly and progressively increased. The faster the EM, the longer the RTs, suggesting that EM as a visual stimulus competed with the visual RTTs for limited capacity within the same modality. So far, no research has found similar effects in the EMDR research field. However, it is in line with previous research about attention conducted by Talsma et al. (2006) and Martens et al. (2010). They found that attention is limited in its capacity within sensory modalities and is larger across modalities. The linear increase in RTs for the visual task and the increase in task complexity due to faster EM underline that attentional capacity could be limited within the same modality (Pashler, 1994). Analyses comparing a serial and parallel presentation of tasks confirmed this finding. When EM were applied additionally to serial and parallel tasks compared to combination tasks with no EM, RTs significantly increased for the visual stimulus.

Remarkably, adding EM to the auditory stimulus loaded the WM more strongly only when EM were applied at a high rate. Van den Hout et al. (2011), as well as Van Veen et al. (2019), used an auditory RTT to measure the effect of EM. In their studies, eyes moved horizontally at approximately 1hrz. They concluded that EM taxed the central executive (CE) because auditory and visual stimuli competed for limited capacity within the CE. Their speed level is comparable to the medium speed level used in this research, which showed no difference in RTs when compared to combination tasks with no and slow EM. This suggests that EM taxed the visuospatial sketchpad (VSSP) rather than the CE, because no competition between auditory and visual stimuli was assessed. Nonetheless, there was an effect for the fast EM condition (1.2hrz) regardless of the stimuli presentation, implying that the complexity of fast EM tasks taxed the CE. Looking at research by Andrade et al. (1997) who found a modality-specificity in memory modification, the current findings indicate that tasks targeting the visual modality might be more effective in reducing the vividness and emotionality of visual images (Kemps & Tiggemann, 2007), while rather complex tasks could be effective in reducing any memory (Kristjánsdóttir & Lee, 2011; Mathijssen et al., 2017). It is important to state these interpretations carefully at this point. This study focused on many factors influencing WM taxation and merely suggests what combination of factors might be suitable to tax the WM in EMDR therapy.

Considering the findings of this study, it seems that an increase in EM speed results in higher task complexity, at least for the visual task. However, in contrast to the hypotheses, errors did not increase with increasingly complex tasks. This might be because participants were instructed to react as fast and accurately as possible to the visual and auditory stimulus. This instruction may have led to slower responses but more accurate ones, resulting in an equal number of errors across conditions (van den Hout et al., 2011). According to the results of van den Hout et al. (2011), changing the instruction to "react as fast as possible" could make a difference in RTs, because this approach might be more sensitive to variations in working memory loading.

Implications

According to van den Hout and Engelhardt (2012), EMDR therapy works effectively when the WM is taxed through performing a dual task and recalling the aversive memory at the same time, i.e., when both tasks, dual task and recall, compete for limited WM capacity. If there is a linear dose-response relation between loading the WM and decreasing vividness and emotionality of memories, as suggested by Littel and van Schie (2019), complex tasks should decrease vividness and emotionality to a greater extent than simple tasks. Considering that a serial, as well as a parallel presentation of two tasks in the online application, led to a greater WM taxation than single modality tasks suggest that combing two dual tasks might be more beneficial in reducing the vividness and emotionality of aversive memories than one dual task because either the attentional switch or the division of attention additionally loads the WM (Baddeley et al., 2001; Pashler, 1994). Additionally, the different levels of EM speed seemed to enhance task complexity and WM taxation of the visual stimulus almost perfectly linearly, suggesting that different levels of EM speed could allow for customising task complexity when the same modality is targeted with different dual tasks. Other research supports the idea that more cognitively demanding tasks lead to a greater change in stressful memories (Maxfield et al., 2008; van Schie et al., 2016; van Veen et al., 2015).

Moreover, the relation between EM speed and WM taxation was comparably strongly opposed to the interaction between a serial and parallel presentation and EM speed on WM taxation, indicating that the increase in EM was relatively equally strong for both serial and parallel tasks. Hence, there might be no apparent difference in using either a serial or parallel presentation of tasks for a visual task and different speeds of EM.

Lastly, results concerning modality specificity might indicate that both EM and the reaction to the ball taxed capacities of the VSSP. The VSSP is important in processing visual and spatial information, i.e., pictures (Baddeley, 1998, as cited in van den Hout et al., 2011). If the VSSP is taxed with EM and a visual dual task in EMDR therapy, this might mean that vividness and emotionality of visual images can be reduced more effectively with visual dual tasks. Indeed, Kemps and Tiggemann (2007) found that EM decreased ratings of visual memories greater than did articulation, whereas articulation decreased auditory memory ratings more than EM. More research found similar results (Andrade et al., 1997; Baddeley & Andrade, 2000). Contrastingly, other research showed that this modality-specificity does not affect the vividness and emotionality of memories targeting different senses (Gunter & Bodner, 2008; Kristjánsdóttir & Lee, 2011; Mathijssen et al., 2017). For instance, Mathijssen et al. (2017) have shown that visual taxation and auditory taxation reduced the emotionality of visual and auditory memories to a similar extent. Because in the current study, a partial modality specificity of attention was examined, future research is needed to explore further whether memories can be targeted in a modality-specific way.

Limitations, Strengths and Recommendations for Future Research

The visual and auditory stimuli presented in the Moovd application are rather innovative and not accurately comparable to dual tasks used in earlier research. Most of the research to which this study was compared was conducted physically in an offline environment (e.g., van Veen et al., 2019). Not only the originality of the online tasks in this study but other factors such as screen size and the online environment might have influenced the outcome of this online study too. Nonetheless, it is to emphasise that results from this study have shown that both tasks used in the online application taxed the WM of participants. Moreover, combining tasks seemed to be more demanding than single modality tasks, and different levels of EM speed enhanced task complexity which may lead to a greater reduction in vividness and emotionality of stressful memories (Maxfield et al., 2008; van Schie et al., 2016; van Veen et al., 2015). As a result, this research provides preliminary information about the degree of taxation of online tasks but requires further research to make precise statements and interpretations. Furthermore, since the tasks used in the application taxed the

WM of participants, the online application by Moovd might be a beneficial online EMDR treatment application (Marotta-Walters et al., 2018). However, to what extent the tasks used in the online application are helpful in decreasing the vividness and emotionality of stressful memories cannot be answered by this research. Future research is needed to see how this application performs as opposed to traditional EMDR and existing online EMDR by comparing these techniques directly and exploring the effects of the online application on symptom reduction in PTSD patients.

Importantly, PTSD patients may show a difference in reaction times. According to Schweizer and Dalgleish (2011), the WM of PTSD patients showed impairments. Meaning, that less taxing tasks for healthy participants may already be highly taxing for PTSD patients. Thus, slow EM in a serial or parallel stimuli presentation may already be highly taxing for PTSD patients. Note that if the linear increase in WM taxation for the visual task is indeed a prediction for rising WM steadily, then this research would be helpful in finding a suitable WM taxation for PTSD patients. However, future research is needed to investigate how PTSD patients react to the tasks and different levels of EM speed in the online application.

Lastly, studies such as those conducted by van den Hout et al. (2011) and van Veen et al. (2019) investigated to what extent counting and eye movements exclusively taxed the working memory. Both studies measured the taxation independently with a Random Interval Repetition (RIR) task. Note that neither counting nor eye movements require a motoric response. In contrast, in this study, the extent to which the visual or auditory tasks taxed the WM was not assessed with a RIR task. Rather both tasks were measured in a baseline single modality task which served as an indication of WM taxation compared to combination tasks. This approach might have been convenient because it assessed WM taxation based on how the tasks are applied in real-life scenarios, but it is unclear what WM taxation would look like in an independent measure for every single task. Correspondingly, it is questionable how much WM taxation is due to the motoric response needed for both online tasks. It might be convenient to measure WM taxation in independent tests for more precise and accurate interpretations, i.e., using, for instance, a tactile RIR to test taxation of the visual task and to examine WM taxation of the auditory task (van den Hout et al., 2011).

Conclusion

In summary, this study found that the visual and auditory tasks used in the online application by Moovd taxed the working memory. In addition, a serial presentation of both tasks was more taxing than a parallel presentation and increasing the speed of EM progressively taxed the WM to a higher degree, specifically for the visual tasks, suggesting a modality specificity of processing stimuli located within the same modality. In therapy, EM are more and more replaced by other dual tasks to tax the WM. The current application underlines that a combination of different dual tasks taxes the WM too. Nonetheless, EM have shown to amplify this taxation significantly. Now it is crucial to test this application on (online) EMDR treatment effectiveness and to investigate whether a modality specificity in dual tasks could increase the effectiveness and, thus, help patients live an anxiety-free life.

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Appendix A
Written Consent

Dear participant,

We would like to invite you to take part in our online study, which will take you around **45 minutes** to complete. Please note that you need a **laptop/PC and a mobile phone** to participate.

Before you decide to participate, please read the following information carefully.
Eye movement desensitization and reprocessing (EMDR) is an evidence-based therapy often used to treat post-traumatic stress disorder (PTSD). Our research aims to investigate the effectivity and efficacy of a digital EMDR application (developed by Moovd; www.moovd.nl). We aim to find out how different combinations of sensory information (visual and auditory stimuli) differ in levels of working memory taxation, which will be assessed through reaction time tasks. Using this application, we want to research if taxing the working memory, using different combinations of sensory information, can reduce the emotionality and vividness of memories after watching a shocking film scene.

During the study, you are asked to fill out **questionnaires** and engage in **two online experiments**. In the first part, you will need to perform different **reaction time tasks** as fast and accurately as possible (using your smartphone). In the second part of this study, you will watch a short **shocking film** that is used to elicit stressful memories. Then, you will be either assigned to a control group or the experimental group engaging in a **digital EMDR intervention** to desensitise your stressful memory. After 24 hours, a **follow-up measure** is planned via email. You will need to fill in a short questionnaire about the experiment. Additionally, we will provide you with detailed information about the film and a mindfulness breathing exercise to relieve tension. Before and after finishing the experiment, you will receive contact details of a **licensed clinical psychologist** whom you can contact in case you would like to talk about this experience or have troubles of any kind.

During the study, you are exposed to a short excerpt of a shocking film depicting a man assaulting another man violently. You are asked to recall the most disturbing scene. **Risks** you may be exposed to include **psychological stress and physical discomfort**. In the short-term, you might be reminded of a similar experience (i.e., flashbacks) or experience general discomfort. In the long-term, anxiety, intrusive thoughts and feelings, flashbacks to the films, or difficulties sleeping (i.e., nightmares) might emerge. The research has been reviewed and **approved by the BMS Ethics Committee**. Your participation is **voluntary**, and you can **withdraw** from the study at any time without any reason.

You are **NOT** allowed to participate if you:

- Are **younger than 18** years old.
- Have impaired vision or hearing.
- Currently **use** benzodiazepines, antidepressants, antipsychotics or mood stabilizers.
- Are **diagnosed** with bipolar disorder, major depression, PTSD, psychosis or autism spectrum disorder.
- Had **EMDR** treatment less than three years ago and/or more than ten sessions.
- Used **alcohol** or **drugs** 12 hours prior to participation.

For our research goal, we need to store your responses to the questionnaires and your (reaction time) responses during the experiment. The anonymized data will be treated confidentially and solely be used for our research report, which can be accessed by our research team as well as the UT teaching staff. If you are interested in the results of the study, you can send an email to one of the researchers (m.c.gerdemann@student.utwente.nl). You will receive **2.25 SONA credits** as a reimbursement for your participation.

Table A1

Informed consent

	Yes	No
Taking part in the study		
I have read and understood the study information dated 29/03/2022. I have been able to ask questions about the study and my questions have been answered to my satisfaction.		
I consent voluntarily to be a participant in this study and understand that I can refuse to answer questions and I can withdraw from the study at any time, without having to give a reason.		

I understand that taking part in the study involves answering several questionnaires, taking part in a reaction time experiment and a digital EMDR intervention.

Risks

I understand that taking part in the study involves the following risks:

- Exposure to a shocking film (depicting extreme violence)
- Physical or mental discomfort (i.e., flashbacks, anxiety)

I have read and understood the eligibility requirements. I can honestly confirm that I fulfil the requirements.

Use of the information in the study

I understand that information I provide will be used for student reports and perhaps a journal publication.

I understand that personal information collected about me that can identify me, such as my name, will not be shared beyond the study team.

Future use and reuse of the information by others

I give permission for the (anonymised) reaction time data that I provide to be archived in Moovd's data base so it can be used for future research and learning.

Appendix B

Digital EMDR Application and Online Environment

Figure B1

Screenshot View Researcher and Participant: log in

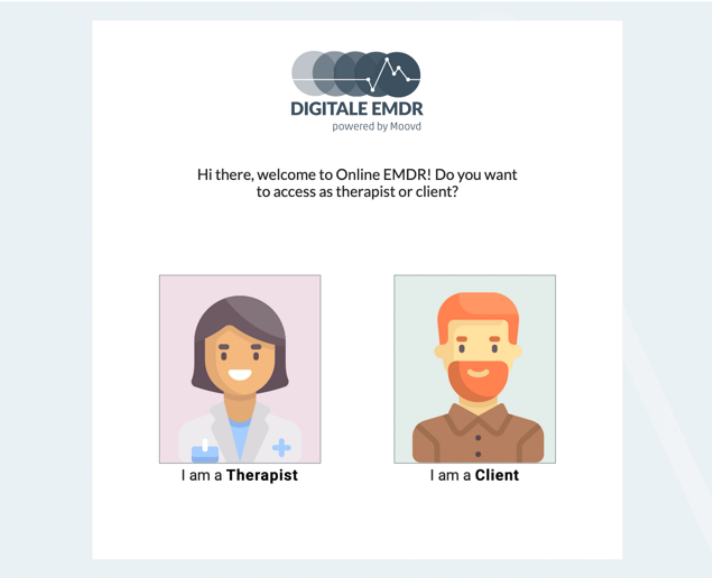


Figure B2

Screenshot View Researcher: Connection With Participant

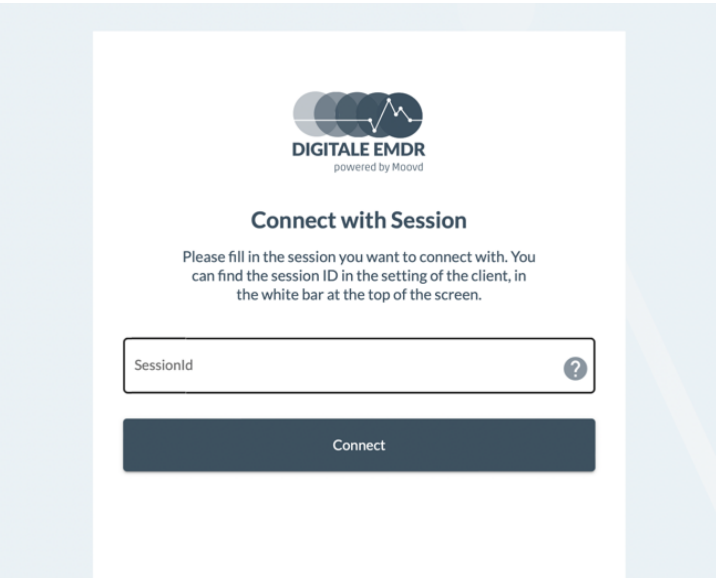


Figure B3

Screenshot View Researcher: Different Conditions of First and Second Part of Study

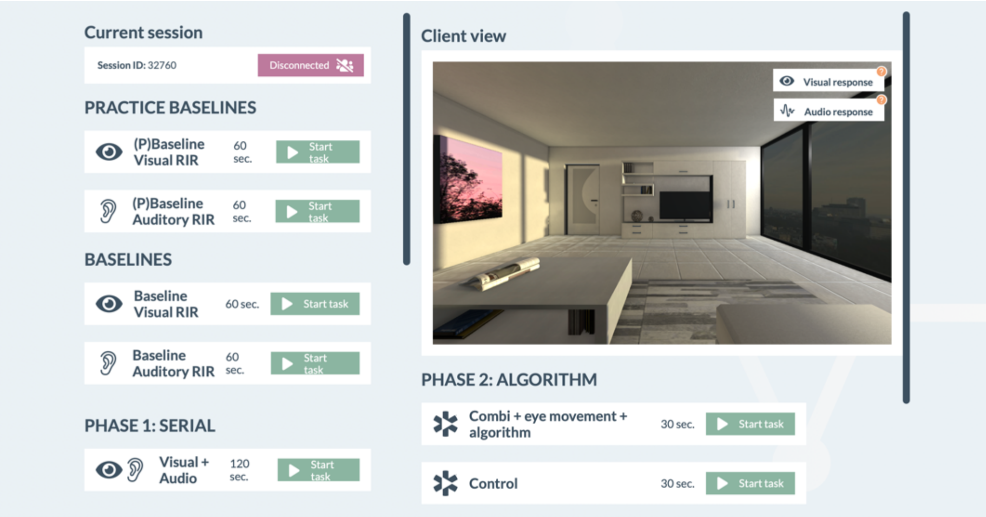


Figure B4

Screenshot View Researcher: Different Conditions of First and Second Part of Study

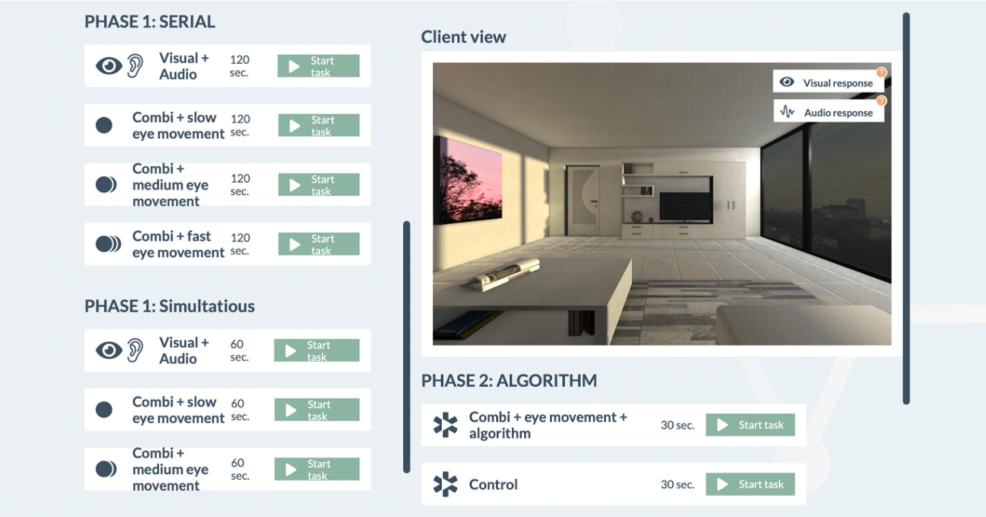


Figure B5

Screenshot View Participant: Start Screen

Figure B6

Screenshot View Participant: Online Environment Living Room

Figure B7

Screenshot View Participant: Visual Stimulus

Appendix C

Scales to Measure Emotionality and Vividness

Participants indicated their emotionality and vividness on a 11-Point Likert Scale from 0 (not at all) to 10 (maximum).

The item for the measurement of emotionality:

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?

The item for the measurement of vividness:

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

Appendix D

Treatment Acceptability and Adherence Scale

	Strongly Disagree	Somewhat Disagree	Neither Agree nor Disagree	Somewhat Agree	Strongly Agree
I find this procedure exhausting.					
It was distressing to me to participate in this procedure.					
Overall, I find this procedure intrusive.					
The offered procedure was effective in reducing the distress that I felt after seeing the movie scene.					
I would recommend this procedure to a friend who is experiencing distress because of a negative memory.					
I was inclined to stop with the procedure.					

Appendix E

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:

1. *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?*
2. *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:

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 + Eye-movement + 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.*

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.

1. *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?*
2. *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.*

Appendix F

Counterbalanced Conditions

Option 1	Option 2	Option 3	Option 4	Option 5	Option 6
V	VAPef	V	VAP	A	VAPes
VAPem	VASem	VASef	VAPes	VAS	VAPem
VASes	VAPes	VAP	A	VAPef	V
VAPef	VAS	VAS	VASef	VASes	VAS
A	VAPem	VAPes	VAS	V	VAPef
VAPes	V	VAPem	VAPem	VAPem	VASes
VASem	VASef	A	VASes	VASem	VAP
VAS	VAP	VASem	VAPef	VAP	VASem
VASef	VASes	VASes	V	VASef	A
VAP	A	VAPef	VASem	VAPes	VASef

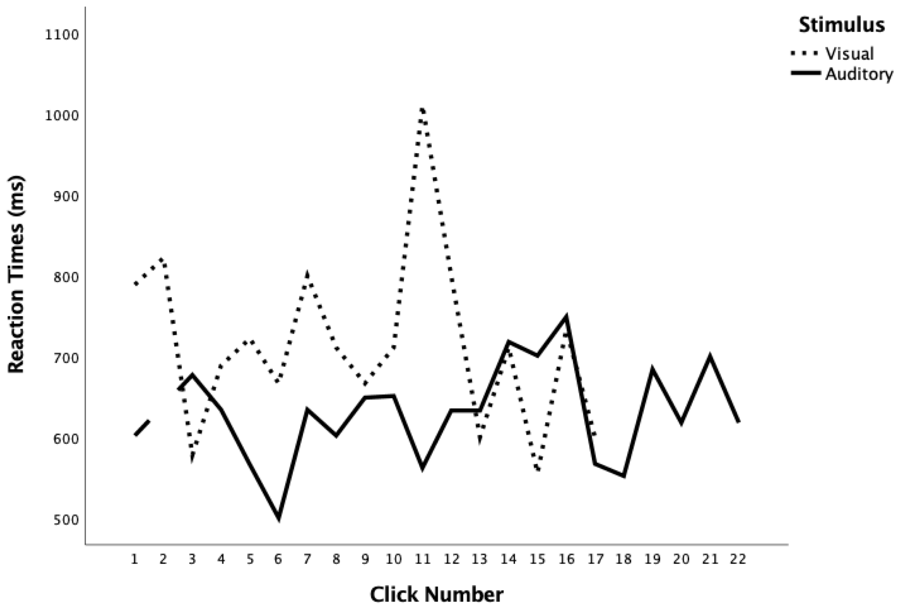
Note. V = Visual stimuli; A = Auditory stimuli; S = Serial presentation of stimuli; P = Parallel presentation of stimuli; es = slow eye movements; em = medium eye movements; ef = fast eye movements.

Appendix G

Additional Analysis to Test for a Switch Cost after Switching Modalities in Serial Presentation Sets Without Eye Movements

Figure G1

Reaction Times for Visual and Auditory Stimuli during Serial Presentation Without Eye Movements (Participant 1)



Note. Click number defines every click or error detected for the visual and auditory stimulus.

Figure G2

Reaction Times for Visual and Auditory Stimuli during Serial Presentation Without Eye Movements (Participant 25)

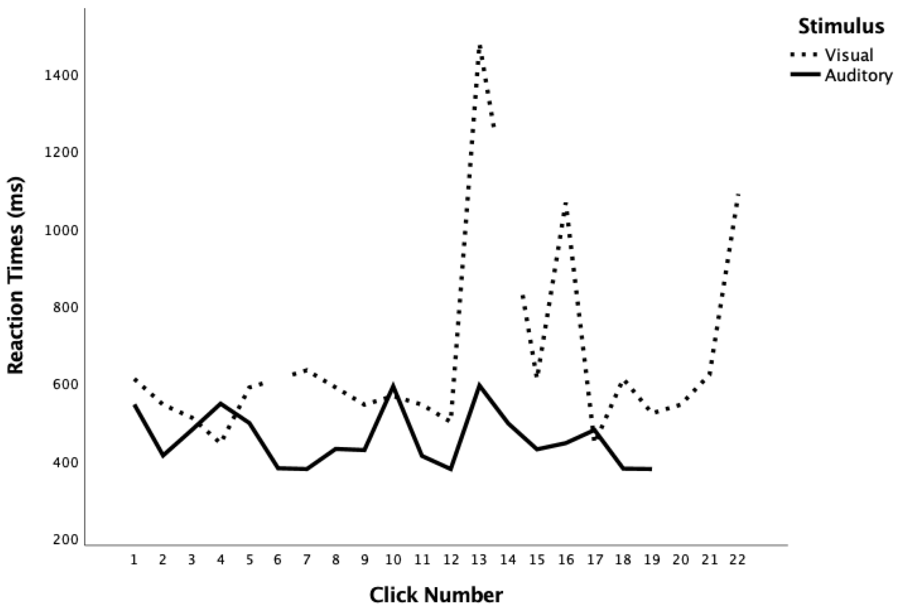


Figure G3

Reaction Times for Visual and Auditory Stimuli during Serial Presentation Without Eye Movements (Participant 34)

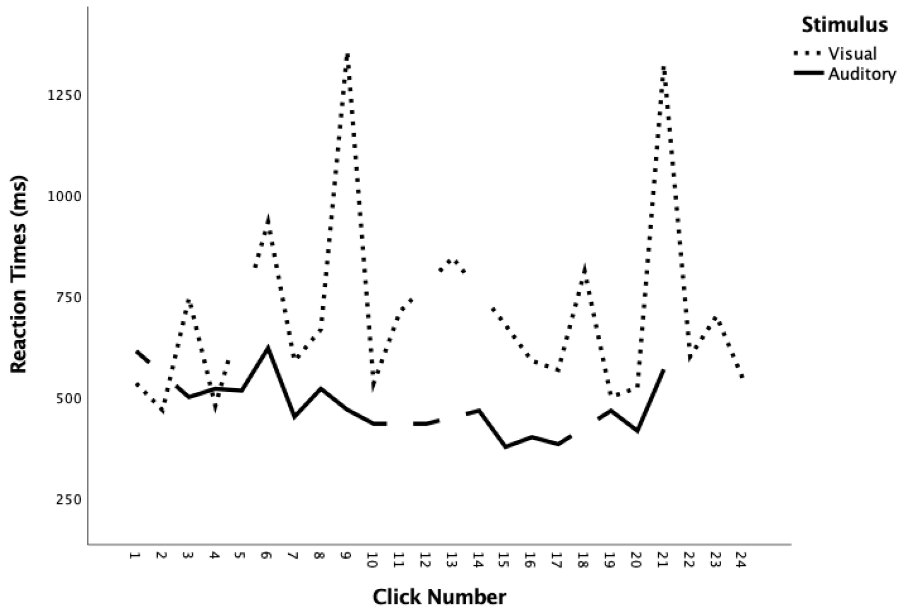


Figure G4

Reaction Times for Visual and Auditory Stimuli during Serial Presentation Without Eye Movements (Participant 41)

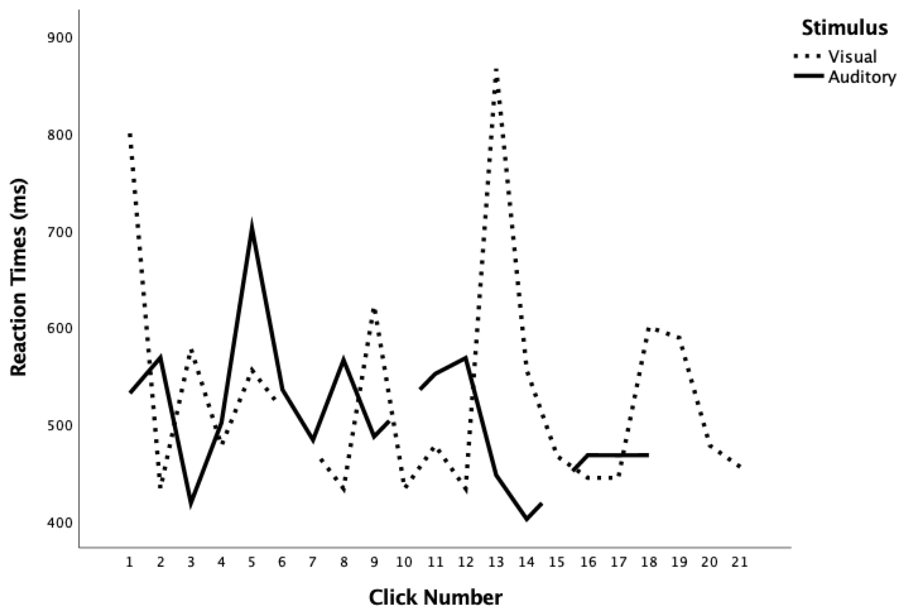


Figure G5

Reaction Times for Visual and Auditory Stimuli during Serial Presentation Without Eye Movements (Participant 56)