No evidence for the inverted U-Curve: More demanding dual tasks cause stronger aversive memory degradation

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A B S T R A C T

Background and objectives: Simultaneously making eye movements and recalling a memory leads to competition in working memory (WM), which reduces memory vividness and emotionality. The dose-response relationship between WM taxation and aversive memory degradation is predicted to be either linear (i.e., more cognitively demanding tasks exhibit stronger effects) or follow an inverted U-curve (i.e., there should not be too little, but also not too much taxation).
Methods: Participants ($N = 44$) recalled four aversive autobiographical memories under four conditions that differed in WM taxation: complex, intermediate, simple, or no counting. Before and after each intervention, and at 24 h follow-up, participants recalled the aversive memory and rated it on vividness and unpleasantness. Using a Bayesian approach the linear and inverted U-shape relationships were directly compared.
Results: Pretest to posttest drops in vividness and unpleasantness became larger with increased WM taxation of the counting conditions. There was no support for either hypotheses from pretest to follow-up for memory unpleasantness, whereas for memory vividness anecdotal evidence was found for a linear relationship.
Limitations: A reaction time (RT) task was used to select counting tasks of varying difficulties. However, the validity of this task appears to be compromised under very strenuous conditions. Higher levels of WM taxation might have been possible with more difficult counting tasks.
Conclusions: There is strong evidence for a linear dose-response relationship between WM taxation and memory degradation immediately after the intervention, and some unconvincing evidence for this pattern one day later. There was no evidence for an inverted U-curve.

1. Introduction

Eye movement desensitization and reprocessing (EMDR) is a first-choice psychotherapy for post-traumatic stress disorder (PTSD: e.g., National Institute for Clinical Excellence, 2011; World Health Organization, 2013). It involves the recollection of traumatic memory representations while simultaneously making sets of horizontal eye movements (EM) by following the horizontally moving finger of the therapist. Meta-analyses show that EMDR effectively reduces PTSD symptoms (Bisson et al., 2007; Bradley, Greene, Russ, Dutra, & Westen, 2005; Seidler & Wagner, 2007) and that EM uniquely contribute to its effects (Lee & Cuijpers, 2013).

Over the past years, the working memory (WM) theory has received accumulating evidence in explaining how EM in EMDR exert their effects (Gunter & Bodner, 2008; van den Hout & Engelhard, 2012). WM theory builds on the well-established observation that WM capacity is limited (Baddeley, 2012). Thus, simultaneous trauma memory recall

and eye movements –both demonstrated to tax WM (Van der Stigchel & Hollingworth, 2018; van Veen, Engelhard, & van den Hout, 2016)– compete with each other for limited WM resources. This competition impairs memory recall, or prevents elaboration on the memory, resulting in immediate decreased memory vividness and unpleasantness. The desensitized or degraded update of the memory is then restored into long-term memory (van den Hout & Engelhard, 2012).

WM theory generates hypotheses that can be elegantly tested using a procedurally simple lab-model of EMDR (e.g., Andrade, Kavanagh, & Baddeley, 1997; van den Hout, Muris, Salemink, & Kindt, 2001). Using this model, participants typically select two autobiographical memories. Subsequently, one memory is recalled while tracking a moving dot on a computer screen, which induces horizontal eye movements (recall + EM); the other is recalled while keeping eyes stationary (recall only). Before and afterwards, memories are rated in terms of vividness and unpleasantness. Numerous studies adopting this model have shown that emotional memories are degraded more by

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recall + EM than recall only, indicating that dual taxation is a pre-requisite for the effects of EM in EMDR (see Lee & Cuijpers, 2013; van den Hout & Engelhard, 2012). According to WM theory, dual taxation does not need to be achieved by performing eye movements per se, and indeed research confirms that other WM taxing tasks, such as counting backwards (Engelhard, van den Hout, & Smeets, 2011), and complex tapping (Andrade et al. 1997), can degrade memories as well.

One important prediction of the WM theory is that more cognitively demanding tasks exhibit stronger effects than less taxing tasks, because cognitively demanding tasks interfere more with memory retrieval or elaboration. Several studies have indeed shown a linear dose-response relationship where faster EM reduce the vividness and unpleasantness of negative autobiographical memories to a greater extent than slower EM (Maxfield, Melnyk, & Hayman, 2008; van Schie, van Veen, Engelhard, Klugkist, & van den Hout, 2016; van Veen et al., 2015). Using a reaction times (RT) task, faster EM were empirically demonstrated to be more cognitively demanding than slower EM (van Veen et al., 2015). However, not all studies find that the most taxing dual tasks culminate in the strongest memory degradation. In a study by van den Hout et al. (2010) complex counting during memory recall was not more effective than simple counting, and a recent study by Mertens et al. (2018) showed no superiority of more demanding over less demanding EM tasks.

The observation that differences in WM load do not always translate to differences between tasks in degrading memories might be because the dose-response relationship is not linear in shape, but quadratic (i.e., an inverted U-curve). Just as low taxing tasks (e.g., slow EM, simple counting) do not cause sufficient competition for limited WM resources to exert effects, extremely taxing tasks might cause too much competition for WM resources. This leaves insufficient room for memory recall, and the memory remains unaltered. To test this inverted U-curve hypothesis, Engelhard et al. (2011) compared four mental arithmetic tasks that increasingly taxed WM: no subtraction (recall only), simple subtraction (1 from 1000 downwards), intermediate subtraction (2 from 1000 downwards), and complex subtraction (7 from 1000 downwards). All participants ($n = 20$ per condition) recalled a negative visual image of a national disaster (broadcasted on national television a few weeks before the experiment) while simultaneously performing one of the subtraction tasks. Participants in the simple and intermediate subtraction conditions reported greater reductions in memory unpleasantness than those in the recall only and complex subtraction conditions. These effects were only observed for unpleasantness, and not for memory vividness, providing only preliminary evidence for an inverted U-curve relationship between WM taxation and memory degradation.

It has been suggested that the beneficial effects of EM extend beyond the intervention because the degraded memories are restored into long-term memory. To assess these long-term effects, eight studies so far have included a follow-up test next to a standard pre and posttest. However, results of these studies have been mixed. Three studies found pre to follow-up reductions for both recall + EM and recall only (Littel et al., 2017; Schubert, Lee, & Drummond, 2011; van Veen, van Schie, van de Schoot, van den Hout, & Engelhard, 2019). Three studies showed temporary effects of recall + EM that did not last until the follow-up (Kavanagh, Freese, Andrade, & May 2001; Lee & Drummond, 2008; Lilley, Andrade, Turpin, Sabin-Farrell, & Holmes, 2009). Only, two studies showed superior effects for recall + EM from pretest to follow-up compared to control conditions (Gunter & Bodner, 2008; Leer, Engelhard, & van den Hout, 2014).

The current study's goal is twofold. First, it aims to shed more light on the issue of the inverted U-curve by providing an extended replication of the study by Engelhard et al. (2011). Instead of a between-subjects design, we opted to use a within-subjects design, with all participants recalling four aversive autobiographical memories that were subjected to four levels of dual WM taxation. Second, we extend the study of Engelhard et al. by adding a 24 h follow-up to assess the

permanent change of degraded memories. Thus, participants did not only rate memory vividness and unpleasantness before and after each WM taxation condition, but also at 24 h follow-up. Adopting a Bayesian approach, we are able to *directly* compare two competing hypotheses regarding the relationship between WM taxation and memory degradation; a linear and a quadratic shape are critically tested and assessed on likelihood.

2. Methods

2.1. Participants

The sample size was based on effect sizes calculated for differences between medium and easy/difficult tasks reported by Engelhard et al. (2011). A power analysis using an ANOVA (repeated measures, within factors, f's = 0.29 and .19 for emotionality and vividness, $\alpha = 0.05$, power = .80, measurements = 4) in G*Power 3.0 (Erdfelder, Faul, & Buchner, 1996) resulted in 18 and 40 participants respectively. Given potential data exclusion, the sample size was rounded up to 45 participants.

Fifty-four students from the Erasmus University Rotterdam signed up. Participants with specific knowledge of the memory degrading effects of EMDR or its proposed underlying working mechanism were excluded ($n = 9$). Data from one participant were excluded because of a pretest memory vividness score of 0, resulting in a final sample of 44 participants ($M_{age} = 21.34$, $SD_{age} = 1.93$, 19 males, 25 females). All participants provided written informed consent and received course credit for participation.

2.2. Pilot

In order to select four mental arithmetic tasks that increasingly taxed WM, 27 participants ($M_{age} = 23.19$, $SD_{age} = 2.77$, 12 males, 15 females) performed a RT task pilot. RTs were recorded to button presses in response to 40 beeps (50 ms, ISI 900–1500 ms), while subtracting 1, 2, 3, 6, 7, 9, 13, or 17 from 1000, or performing no dual task, in a counterbalanced order (9 × 9 Latin square). Slower RTs are indicative of more WM taxation (van den Hout et al., 2011). See Appendix for mean RTs per condition. A Wilcoxon signed-rank test indicated that RTs of 1, 2, and 7 (marginally) differed from each other as well as RTs of 1, 2, and 13 (smallest $Z = -1.71$; $p = 0.09$, between '2' and '1'). To stay close to the study of Engelhard et al. (2011), 1, 2, and 7 were included in the final experiment.

2.3. Materials and procedure

All participants selected four aversive, autobiographical memories and rated the emotional intensity of the memories on a scale from 1 (*not at all unpleasant*) to 10 (*very unpleasant*). If memories were rated below 6, participants were instructed to select a different memory that was more aversive. In order to help participants come up with four memories, a list with example memories was provided (e.g., a break-up, witnessing an accident, experiencing rejection). In line with the Dutch EMDR protocol (de Jongh & ten Broeke, 2012), participants selected the most emotionally intense image for each memory and labeled it with a unique keyword.

Participants were seated behind a computer screen and were instructed to recall one of their aversive images. Meanwhile they subtracted 1 from 1000 onwards (simple), 2 from 1000 onwards (intermediate), 7 from 1000 onwards (complex), or performed no subtraction (recall only) during 8 intervals of 24-s separated by 10-s breaks (cf. Leer et al., 2014). Conditions were counterbalanced across participants. Before (pretest) and after (posttest) each intervention, and at 24 h follow-up, participants recalled the aversive memory for 10-s and rated it on vividness and unpleasantness using digital Visual Analogue Scales ranging from 0 (*not vivid/not unpleasant*) to 100 (*very vivid/very*

unpleasant). All data were collected in the Erasmus Behavioural Lab. The follow-up was planned within 24 h ± 8 h after the posttest. The experimental task was presented with E-Prime 2.0 (Psychology Software Tools).

2.4. Data-analysis and design

We used the BIEMS software package to analyze the data. BIEMS allows for assessing the relative likelihood of different competing hypotheses (see Mulder et al., 2009; Mulder, Hoijtink, & de Leeuw, 2012; Mulder, Hoijtink, & Klugkist, 2010). In BIEMS a constrained hypothesis is compared to an unconstrained hypotheses and the relative likelihood is expressed as a Bayes Factor (BF: Kass & Raftery, 1995). A BF of 1 means that there is equal support for a specified constrained hypothesis compared to the unconstrained model; one does not outperform the other. BF > 1 indicates that the study hypothesis outperforms the unconstrained model, whereas BF < 1 means the opposite. It is possible to directly compare BFs of different constrained models by dividing them.

Pretest-posttest and pretest-follow-up difference scores were calculated for vividness and unpleasantness ratings in all four conditions, with higher scores indicating larger reductions in response to an intervention. Two competing hypotheses were directly compared: (1) the relationship between WM taxation and memory degradation follows a linear shape; and (2) the relationship between WM taxation and memory degradation follows an inverted U-shape. See Table 1 for constraints.

3. Results

3.1. Pre to post effects

As can be seen in Fig. 1 (grey bars), memory unpleasantness levels drop from pretest to posttest across conditions, and these drops show a linear increase from no subtraction ($M_{dif} = 1.59$, $SD = 18.22$), to simple subtraction ($M_{dif} = 4.82$, $SD = 20.69$), to intermediate subtraction ($M_{dif} = 11.84$, $SD = 20.48$), to complex subtraction ($M_{dif} = 14.61$, $SD = 23.55$). Bayesian analyses of these pre-post difference scores support this linear pattern with a BF of 11.00 for hypothesis 1, and BFs of only 0.16 and 1.18 for hypotheses 2a and 2b.

The results for memory vividness also provide strong evidence for a linear relation between WM taxation and memory degradation, and no evidence for the inverted U-curve relation, with a BF of 13.78 for hypothesis 1 and BFs of only 0.21 and 0.26 for hypothesis 2a and 2b. As can be seen in Fig. 2 (grey bars), there is a small pre to post increase in vividness after recall only ($M_{dif} = -3.39$, $SD = 16.81$). Vividness decreases from pre to posttest in the subtraction conditions, with difference scores increasing from the simple subtraction condition ($M_{dif} = 7.80$, $SD = 26.45$), to the intermediate subtraction condition ($M_{dif} = 8.93$, $SD = 22.30$), to the complex subtraction condition ($M_{dif} = 14.89$, $SD = 23.03$).

Table 1
Hypothesis constraints for vividness and unpleasantness difference scores (pretest minus posttest and pretest minus follow-up) for the hypotheses on a linear vs. inverted U-shape dose-response relationship.

	Linear relationship
Hypothesis 1	No subtraction < Simple < Intermediate < Complex
Hypothesis 2	Inverted U-curve relationship
2a	No subtraction < Simple = Intermediate > Complex
2b	No subtraction < Simple < Intermediate > Complex

Note. Based on the observations of Engelhard et al. (2011; p.36, Fig. 3), showing slightly larger effects for recall + intermediate subtraction than recall + simple subtraction, two slightly different constrained hypotheses were tested for the inverted U-curve relationship.
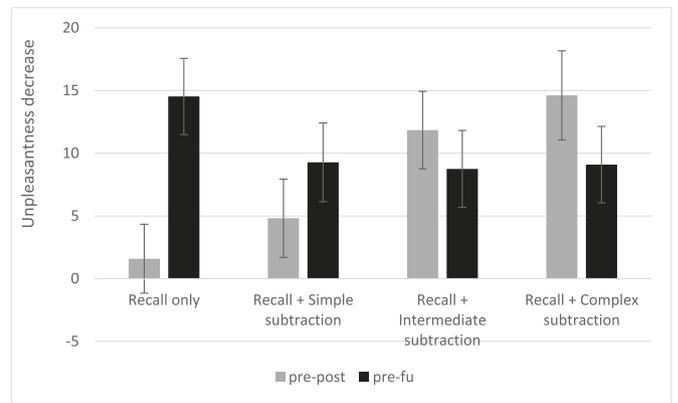

Fig. 1. Mean (SE) decreases in memory unpleasantness from pretest to posttest (grey bars) and from pretest to follow-up (black bars) in the four working memory load conditions.
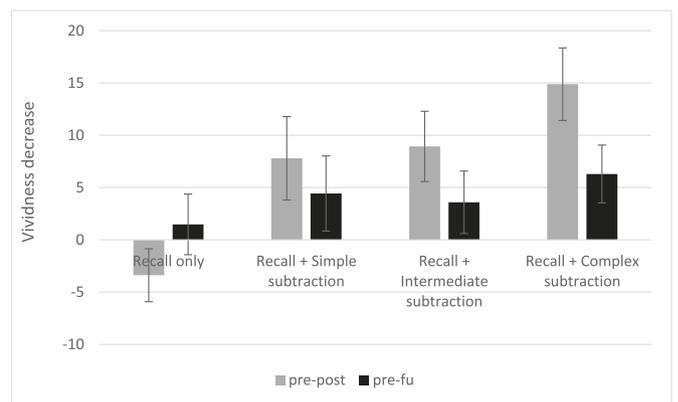

Fig. 2. Mean (SE) decreases in memory vividness from pretest to posttest (grey bars) and from pretest to follow-up (black bars) in the four working memory load conditions.

3.2. Pre to follow-up effects

From pretest to follow-up, unpleasantness levels drop approximately equally across simple, intermediate and complex subtraction conditions ($M_{dif} = 9.27$, $SD = 20.85$, $M_{dif} = 8.75$, $SD = 20.33$, and $M_{dif} = 9.09$, $SD = 20.21$), with the largest drop for the recall only condition ($M_{dif} = 14.52$, $SD = 20.14$). See Fig. 1 (black bars). Bayesian analyses of pre-test to follow-up test difference scores showed BFs of 0.08 for hypothesis 1, and BFs of 0.48 and 0.14, for hypotheses 2a and 2b, indicating no support for either of the hypotheses.

Drops in vividness continue to show a more linear increase from no subtraction ($M_{dif} = 1.48$, $SD = 19.25$), to simple subtraction ($M_{dif} = 4.43$, $SD = 23.84$), and intermediate subtraction ($M_{dif} = 3.59$, $SD = 19.81$), to complex subtraction ($M_{dif} = 6.30$, $SD = 18.36$), see Fig. 2 (black bars). BFs were 2.96 for hypothesis 1 and 1.93 and 1.01 for hypotheses 2a and 2b, suggesting that there is slightly more (anecdotal) evidence for a linear relation after 24 h follow-up. See Appendix for mean (SD) pretest, posttest, and follow-up unpleasantness and vividness ratings after the subtraction conditions.

4. Discussion

The WM theory suggests that the more difficult the dual task, the stronger the interference with memory retrieval or elaboration, and hence, the more effective the memory degradation. However, too much WM taxation might hamper memory retrieval, reducing the effectiveness of the intervention. Preliminary evidence for this inverted U-curve dose-response relationship was provided by Engelhard et al. (2011),

which the current study aimed to replicate using an extended design.

The present data yield strong evidence for a linear dose-response relationship between WM taxation and memory degradation immediately after the intervention, and some, yet unconvincing, evidence for this pattern one day later. There was no evidence for an inverted U-curve relationship; not from pretest to posttest, or from pretest to follow-up. In line with previous studies, heavier WM taxation appears to be more effective in degrading aversive memories than light taxation (Maxfield et al., 2008; van Schie et al., 2016; van Veen et al., 2015). Note that current results do not indicate that there is no optimal level of taxation per se. The dose-response relationship might still follow an inverted U-curve that is skewed to the left or a linear shape that eventually plateaus.

Memory unpleasantness substantially dropped after 24 h in all conditions, including the low and no taxation conditions. This was unexpected, as a different pattern was found for memory vividness, and reductions in emotionality have been observed to follow reductions in vividness (Smeets, Dijs, Pervan, Engelhard, & van den Hout, 2012). However, only two out of eight studies found evidence for superior delayed effects of recall + dual tasking over recall only for emotionality (Gunter & Bodner, 2008; Leer et al., 2014). Inconsistent findings on long-term effects might be inherent to the use of laboratory models of EMDR, which typically use brief intervention sessions, or might arise because its active control condition of recall only (i.e., a lab-based analogue of imaginal exposure therapy) is similarly effective over time (van Veen et al., 2019).

Note that the subtraction conditions were selected based upon results from a pilot RT task. Surprisingly, participants were slower to respond to beeps while counting backwards with 7 from 1000 than with 9, 13 or 17 from 1000, suggesting '7' was the most difficult subtraction condition. However, according to the experimenters' observations, participants were slower to count backwards with larger steps. It might be that participants strategically shifted attention away from counting when this became too difficult, improving their RTs. The RT task seems to be sensitive to a trade-off, or ironically: an inverted U-curve. To increase the reliability of the task, measures of performance on the dual task should be included in addition to RTs in future experiments assessing WM taxation of different dual tasks. In this particular design, this could be achieved by recording counting performance (number of correct subtractions), and divide the RT by this number. Task-performance measures are also advised for dual task interventions in future studies, to be able to indicate to what extent results are affected by a possible trade-off between the dual tasks. Other limitations to the current study are the use of a within design, which might have led to emotional carry-over effects between memories, and the use of a non-clinical sample, which limits generalizability to clinical populations.

Adopting a Bayesian approach, uniquely enabling a direct comparison between opposing hypotheses, data from the current study provide evidence for a linear relationship between WM taxation and memory degradation. There was no evidence for an inverted U-curve for memory unpleasantness as observed by Engelhard et al. (2011). Although studies diverged methodologically on several aspects, such as the design (within vs. between-subjects design), sample size (44 vs. 20 per condition), taxation duration (8 × 24s vs. 4 × 24s), and type of memory (personally relevant memories vs. images of a national disaster), none of these seem to convincingly explain the disparities in results.

Disclosure statement

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jbtep.2019.101484.

Appendix

Table A1
Mean (SD) reaction times (RT) to dots and mean (SD) number of recorded responses in the pilot RT task

Subtraction from 1000	RT (ms)	Number of recorded responses
None	305.35 (30.37)	37.59 (2.52)
1	469.58 (98.56)	36.85 (2.28)
2	499.80 (111.22)	36.70 (3.02)
3	525.45 (117.67)	36.59 (3.14)
6	525.10 (116.76)	36.78 (2.61)
7	540.33 (124.27)	36.37 (3.26)
9	528.95 (115.19)	36.96 (2.82)
13	540.09 (135.13)	36.81 (3.16)
17	529.75 (122.32)	36.89 (2.58)

Table A2
Mean (SD) pretest, posttest, and follow-up ratings for memory unpleasantness and vividness after recall only and the subtraction conditions.

		Recall only	Simple subtraction	Intermediate subtraction	Complex subtraction
Unpleasantness	Pretest	71.48 (17.23)	67.32 (21.32)	68.00 (15.08)	70.05 (18.54)
	Posttest	69.89 (20.88)	62.50 (23.33)	56.16 (21.49)	55.43 (23.78)
	Follow-up	56.95 (21.80)	58.05 (23.94)	59.25 (18.33)	60.95 (20.84)
Vividness	Pretest	72.07 (18.70)	75.16 (21.45)	68.16 (19.42)	76.25 (15.61)
	Posttest	75.45 (16.44)	67.36 (22.65)	59.23 (22.66)	61.36 (20.30)
	Follow-up	70.59 (14.83)	70.73 (14.15)	64.57 (18.22)	69.95 (15.68)

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