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Counting During Recall: Taxing of Working Memory and Reduced Vividness and Emotionality of Negative Memories

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SUMMARY

While initially subject to debate, meta-analyses have shown that eye movement desensitization and reprocessing (EMDR) is effective in the treatment of posttraumatic stress disorder (PTSD). Earlier studies showed that eye movements during retrieval of emotional memories reduce their vividness and emotionality, which may be due to both tasks competing for limited working memory (WM) resources. This study examined whether another secondary task that taxes WM has beneficial effects, and whether the stronger the taxing, the stronger the reductions in vividness/adversity. A reaction time (RT) paradigm showed that counting backwards requires WM resources, and that more complex counting is more demanding than simple counting. Relative to a retrieval-only condition, counting during retrieval of emotional memories reduced vividness and emotionality during later recall of these memories. However, the counting conditions did not differ in the magnitude of this reduction, and did not show the predicted dose-response relationship. Implications for a working-memory explanation of EMDR and for clinical practice are discussed. Copyright © 2010 John Wiley & Sons, Ltd.

While Eye Movement Desensitization and Reprocessing (EMDR) has been the subject of a heated debate (Perkins & Rouanzoin, 2002), it is one of the best studied psychological interventions for posttraumatic stress disorder (PTSD). Independent meta-analyses indicate that the effects are substantial, and are as good as, for instance, cognitive behaviour therapy (CBT; American Psychiatric Association, 2004; Bisson, Ehlers, Mathews, Pilling, Richards, & Turner, 2007; Davidson & Parker, 2001). In the basic EMDR-protocol (see Gunter & Bodner, 2008), a client is asked to identify and focus on a traumatic image. Next, a set of eye movements is elicited by having the client follow a repetitive side-to-side motion of the therapist's index finger, while the unpleasant memory is held in mind. The client next reports current sensations, cognitions and emotions. Sets are repeated until the client reports minimal distress associated with the memory. The therapist guides the client to replace a negative cognition with a positive one. The clinical findings are corroborated by analogue studies showing that eye movements during recall of aversive memories

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reduce their vividness and emotionality (Andrade, Kavanagh, & Baddeley, 1997; Barrowcliff, Gray, Freeman, & MacCulloch, 2004; Gunter & Bodner, 2008; Kavanagh, Freese, Andrade, & May, 2001; Kemps & Tiggemann, 2007; Maxfield, Melnyk, & Hayman, 2008; Hout, Muris, Salemink, & Kindt, 2001).

These laboratory studies also provide an explanation for the clinical effects of eye movements during recall of aversive memories, an allegedly crucial ingredient of EMDR. Experiences during recall affect the reconsolidation of recalled memories (Baddeley, 1998). Retrieving memories requires working memory (WM) resources that are limited. If a secondary task is executed during recall, that also requires cognitive resources, fewer resources will be available for recall. The retrieved episode will be experienced as less vivid and emotional, and will be stored as such in long-term memory. Eye movements are considered to be a 'secondary' task that taxes WM and affects the reconsolidation of simultaneously recalled events. This may explain how eye movements during recall reduce vividness and emotionality of memories (Andrade et al., 1997; Barrowcliff et al., 2004; Gunter & Bodner, 2008; Kavanagh et al., 2001; Kemps & Tiggemann, 2007; Maxfield et al., 2008; van den Hout et al., 2001).

The WM account of the effects of eye movements is supported by further experimental data. Traditionally, during EMDR, lateral eye movements are made. In line with the WM account, vertical eye movements are equally effective (Gunter & Bodner, 2008). Crucially, the same effects occur if WM is taxed during recall with secondary tasks that do not involve eye movements, like auditory shadowing (Gunter & Bodner, 2008), copying a complex figure (Gunter & Bodner, 2008), or articulatory suppression (Kemps & Tiggemann, 2007). Likewise, recalling scenes from a film with traumatic content that the individual watched earlier, while playing a taxing computer game, reduces flashbacks of the film in the following week (Holmes, James, Coode-Bate, & Deeprose, 2009). Secondary tasks that are not taxing, like finger tapping, do not seem to have beneficial effects (van den Hout et al., 2001). In sum, laboratory data suggest that EMDR and related procedures derive beneficial effects from WM taxing during recall of emotional memories (Gunter & Bodner, 2008; Holmes et al., 2009; Maxfield et al., 2008).

The WM explanation of EMDR effects implies a dose-response relationship: The stronger the taxing, the stronger the effects on memory. Maxfield et al. (2008) assumed that irregular fast eye movements (on average, one movement per 0.8 second) are more WM taxing than slower/regular ones (one movement per 1.0 second), and compared the effects of both interventions in students who recalled negative memories. Both manipulations reduced vividness (experiment 1 and 2) and emotionality of memories relative to a no intervention control condition (experiment 2, but not experiment 1). The relative strength of the effects of fast and slow eye movements was determined by comparing the vividness and emotionality scores after the intervention. However, the pre-intervention scores were disregarded, which makes it difficult to evaluate whether the data reflect the predicted dose-response effect. Furthermore, it was assumed that the faster/irregular eye movements were more demanding, but this was not empirically assessed. Gunter and Bodner (2008) compared eye movements, verbal shadowing, and copying a complex figure in healthy participants. Verbal shadowing and eye movements had equally strong effects on vividness and emotionality of memories, but the effect of drawing was twice as large. The authors suggest that the drawing task was more beneficial, because it requires more WM resources than the other two tasks, but this explanation was not empirically evaluated.

The aim of the present study was to test whether a dose-response relation exists between the degree of WM taxing and the magnitude of reductions in vividness and emotionality by

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comparing two concurrent tasks during retrieval of unpleasant memories. A manipulation check was used before the experiment proper, with the same sample of participants, to verify that the two concurrent tasks tax WM in a dose-dependent way. This was measured with a simple reaction time (RT) task. We predicted that RTs would increase and accuracy of the RT task would decrease when the concurrent tasks would be carried out simultaneously. The rationale is that the depth of processing is positively associated with RTs, and that worsening of performance on one task (in this case, the RT task) provides a measure of how much processing resources are required by concurrent tasks (Bower & Clapper, 1989). According to Baddeley's (1998) influential working memory model, WM comprises three subsystems. The 'central executive' (CE) allocates and divides attention between tasks, selects retrieval strategies, activates memories, and inhibits distracters. Furthermore, two 'slave systems' are postulated: The visuospatial sketchpad (VSSP) is involved in the processing of visuospatial information, and the phonological loop (PL) processes verbal information. Some authors have argued that the concurrent tasks that induce reductions in vividness and emotionality of visual images tax the VSSP (Holmes et al., 2009). Kemps and Tiggemann (2007) found evidence for modality specificity. That is, a phonological concurrent task produced larger decreases in clarity and emotionality of auditory aspects of images, relative to visual aspects, whereas eye movements had stronger effects on visual aspects of images, relative to auditory aspects. It should be noted that this specificity was a relatively subtle effect, and was superimposed on a much larger general effect: Relative to the no-concurrent task (control) condition, eye movements and articulation each reduced visual *and* auditory aspects of memory. From the fact that many different concurrent tasks are able to reduce memory vividness/emotionality, Gunter and Bodner (2008) infer that taxation of the CE is mainly responsible for the effects of EMDR and the various concurrent tasks used in laboratory experiments. To ensure that the task to be used taxes the CE, and not merely the VSSP or the PL, we decided to use two versions of a prototypical non-visuospatial task (simple and complex counting) and assessed first if they interfere with a concurrent visuospatial RT task in a dose-dependant way. If so, it would follow that taxing of the CE is critically involved in the reduction of vividness/emotionality of memories due to counting during retrieval.

METHOD

Forty-one undergraduates (32 female; mean age 22 years; $SD = 2.2$) participated in exchange for course credit or money. Prior to the main task, a manipulation check was performed to assess whether the different task conditions tax WM in a dose-dependent way. The three conditions were retrieval only, simple counting (subtracting 2 from 450 onwards), and complex counting (subtracting 7 from 450 onwards). During these three tasks, the participants performed a visual RT task in which an 'X' or 'O' appeared on a screen 20 times each in semi-random order, with the restriction that there were no more than 4 consecutive presentations of the same letter. Stimuli were presented for 500 m seconds, while the inter-stimulus intervals ranged between 1500 and 3500 m seconds, with an average of 2500 m seconds. Participants were asked to respond to 'X' by pressing the *m*-key and respond to 'O' by pressing the *z*-key. WM taxing was operationalized as the slowing down of RTs and reduced accuracy in the counting conditions, relative to the retrieval-only task condition.

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Immediately after the RT task, participants were asked to recall three occasions that had made them very fearful or distressed, and still had some emotional impact (e.g. being unprepared for an examination or witnessing an accident). The participant wrote down labels for each negative memory (*cf.* van den Hout et al., 2001), and the memories were ranked in terms of adversity. Each individual participated in each of the three conditions described above: Retrieval only, simple counting and complex counting. The order of the conditions and assigning memories to conditions were counterbalanced as far as possible with 41 participants: The numbers of most, medium and least aversive memories were nearly identical in the three conditions. Before each condition, the experimenter said 'Form an image of ... (memory of the label) now. Remember where it happened, who was present, and anything else you can think of. Bring it to mind as vividly as if it were happening right now'. Participants were asked to recall the memory and rate its vividness and emotionality on 100 mm visual analogue scales (VASs) that ranged from 0 (not vivid, pleasant, respectively) to 10 (very vivid, very unpleasant, respectively).

In each of the three conditions, the participants held the memory in mind for 90 second. A 90 second interval was chosen to make the duration comparable to the 120 second RT task. During the retrieval-only task, there was no concurrent distracting task. In the simple counting condition, participants counted backwards during memory recall from 450 in steps of 2. In the complex counting condition, participants counted backwards during memory recall from 450 in steps of 7. After each condition, the participants were, again, asked to recall the memory and to rate its vividness and emotionality on the VASs. Apart from the counting, the procedure was identical to the eye movement procedure described by van den Hout et al. (2001) and replicated by Gunter and Bodner (2008).

RESULTS

Manipulation check: Taxing of WM as evidenced by performance on the RT task

The RTs for each condition are given in Figure 1 (left panel). *SD*s increased with task complexity; therefore the RTs were analyzed non-parametrically. Overall, RTs differed between the conditions, Friedman's $H(2) = 70.4$; $p < .001$. Wilcoxon tests revealed that all conditions differed from one another, all zs > 4.9; $p < .001$. In addition, the number of non-

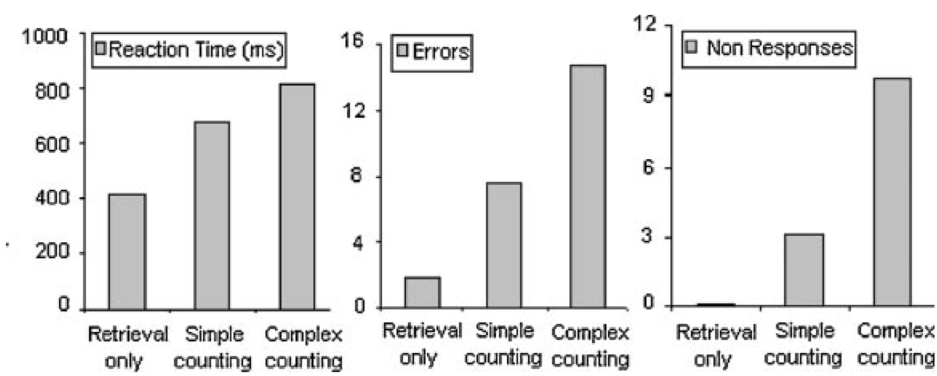

Figure 1. Reaction times, number of errors, and number of non-responses during retrieval only, simple counting and complex counting

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responses (i.e. not pressing a button during the inter-stimulus interval) was higher in the two counting conditions (see Figure 1, right panel). This overall effect was significant, Friedman's $H(2) = 71.3$; $p < .001$, as were all three pair-wise comparisons, all zs > 4.3; $p < .001$. Finally, the middle panel of Figure 1 indicates that the number of errors increased with task complexity. There was an overall difference between the conditions, Friedman's $H(2) = 69.8$; $p < .001$, and, again, all pair-wise comparisons were significant, all zs > 5.1; $p < .001$. Accordingly, despite the fact that participants slowed down in the counting conditions, they had more non-responses and made more errors. Apparently, both counting tasks use WM resources, and complex counting is more demanding than simple counting.

Emotionality and vividness of memory

Mean scores before and after the three interventions are given in Table 1, and a graphic illustration of changes in emotionality and vividness is given in Figure 2. Data were tested with 2×3 ANOVAs with Time (pre-test *vs*. post-test) and Condition (retrieval only *vs*. simple counting *vs*. complex counting) as within-subjects factors. The partial eta squared (η_p^2) is reported along with significant effects as an indication of effect size.

Table 1. Scores on vividness and emotionality before and after retrieval only, simple counting and complex counting

	Retrieval only		Simple counting		Complex counting	
	Emotionality	Vividness	Emotionality	Vividness	Emotionality	Vividness
Pre-retrieval	7.8 (1.1)	7.7 (1.7)	8.2 (1.5)	7.9 (2.0)	8.2 (1.3)	7.9 (2.0)
Post-retrieval	8.0 (1.3)	8.2 (1.5)	7.7 (1.4)	7.6 (2.1)	7.8 (1.5)	7.4 (2.3)

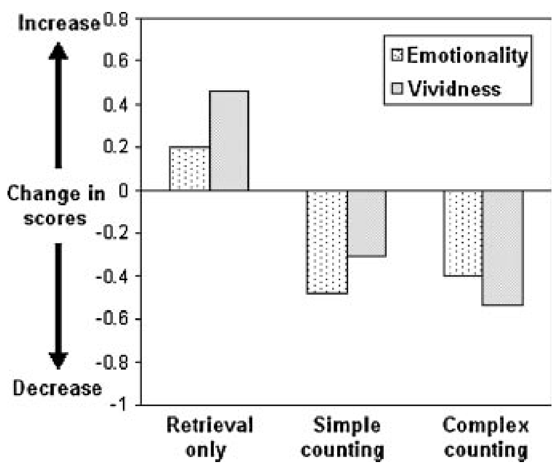

Figure 2. Changes in vividness and emotionality of aversive memories after retrieval only, simple counting and complex counting

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With regard to emotionality, there were no significant main effects for Time, $F(1, 40) = 3.6$; $p = .06$, and Condition, $F(2, 39) = 0.2$, but the crucial Time X Condition interaction reached significance, $F(2, 39) = 4.8$; $p = 0.01$; $\eta_p^2 = .11$. Pair-wise comparisons showed that the increase in emotionality in the retrieval-only condition (see Figure 2 left bar) was not significant, $t(40) = 1.2$, but the decrease in emotionality was significant in the simple counting condition, $t(40) = 2.5$; $p = .017$ as well as the complex counting condition, $t(40) = 2.1$; $p = .043$. The decrease in emotionality did not differ between the counting conditions, $t(40) = .43$. Meanwhile, relative to the retrieval-only condition, the pre-test to post-test drop in emotionality was significantly larger in the simple counting condition, $t(40) = 2.7$; $p = .010$, and in the complex counting condition, $t(40) = 2.26$; $p = .029$.

With regard to vividness, the main effects were not statistically significant for Time, $F(1, 40) = 0.5$, and Condition, $F(2, 39) = 0.4$, but the crucial Time $\times$ Condition interaction was significant, $F\ (2, 39) = 4.1$; $p = 0.02$; $\eta_p^2 = .09$. Pair-wise comparisons showed that in none of the conditions the change was significant [retrieval only: $t(40) = 1.87$; simple counting: $t(40) = 1.0$; complex counting: $t(40) = 1.6$)]. The two counting conditions did not differ, $t(40) = 0.77$. However, compared to the retrieval-only condition, the pre-test to post-test reduction in vividness was significantly larger in the simple counting condition, $t(40) = 2.3$; $p = .027$, and in the complex counting condition, $t(40) = 2.4$; $p = .024$.

Correlational analysis

Spearman correlations between vividness and emotionality at pre-test were significant for both counting conditions, smallest $r_s(41) = .38$; $p = .\ 014$, and showed a trend for the dual-task condition, $r_s(41) = .30$; $p = .061$. At post-test, the correlations between vividness and emotionality were significant for all conditions, smallest $r_s(41) = .39$; $p = .012$. The drops in vividness and emotionality were significantly correlated as well for the counting conditions, smallest $r_s\ (41) = .35$; $p = .025$, but not for the retrieval-only condition, $r_s\ (41) = .20$; $p = .22$. Finally, we tested whether the degree of WM taxation due to counting (indexed by the average slowing down in the two counting conditions relative to retrieval only) was associated with the average pre-test to post-test change in vividness and emotionality over the conditions. WM taxation correlated with drops in vividness, $r(41) = .31$; $p = .001$, and emotionality, $r(41) = .18$; $p = .047$.

DISCUSSION

The participants recalled aversive events without performing a second task or while performing simple or complex counting. Relative to the retrieval-only control condition, counting resulted in reductions of emotionality and vividness of recalled memories. The manipulation check was carried out before the experiment proper, and showed that in line with the expectations RTs to visual cues were slower during the simple task relative to the no-counting task, and during the complex task relative to the simple task. Despite this slowing down, participants made more errors during complex counting compared to simple counting, and during simple counting compared to no counting. Apparently, the counting tasks required WM resources in a dose dependent way. The fact that the phonological (counting) tasks interfered with the concurrent visuospatial task shows that the counting tasks did not merely tax the PL, but the CE as well. Thus, the observation that the counting conditions reduced image vividness and emotionality is in line with a CE account of

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EMDR and related procedures (Gunter & Bodner, 2008). Still, this does not rule out that, on top of general CE effects, visuospatial distracter tasks produce stronger interference on visuospatial aspects of memory relative to phonological aspects, whereas the opposite may hold true for phonological distracter tasks (Kemps & Tiggemann, 2007).

Individuals differ in the degree to which WM is taxed by concurrent tasks. The correlational analysis showed that the degree of taxation during counting was correlated with reductions in image vividness and emotionality. This also suggests that WM taxing during recall affects the reconsolidation of that memory. The present findings help to understand preliminary clinical findings that 'numerical distraction' during recall of traumatic incidents ameliorates PTSD (Isaacs, 2004). Retrieval-only was followed by small and non-significant increases in emotionality and vividness (see Figure 2). Comparable increases after merely recollecting emotional memories were reported by van den Hout et al. (2001) and recently by Maxfield et al. (2008); experiments 1 and 2). Although the increases were not significant, the absence of decreases after retrieval-only underlines that mere recall of emotional memories for a short interval is not sufficient to induce decreases in emotionality and vividness, and that the effects of eye movements (Maxfield et al., 2008; van den Hout et al., 2001) or counting (Kemps & Tiggemann, 2007; this study) cannot readily be explained by extinction due to unreinforced exposure.

The finding that memories became less emotional and less vivid when they had to compete for limited cognitive resources during recall argues in favour of a WM account of EMDR and related procedures, and adds to an expanding corpus of data.

Still, although complex counting required more WM resources than simple counting, both conditions were equally effective in reducing vividness and emotionality. While the pattern on vividness seems to match the predictions, the pattern on emotionality clearly does not: Changes in the simple counting condition were larger than in the complex counting condition (see Figure 2). Thus it seems unlikely that a lack of statistical power explains the absence of larger effects after complex counting.

Provided that taxation of WM was responsible for the observed effects, the question ensues if, in line with the arguments given in the introduction, the CE was critically involved. Note that three tasks were used: An RT task, counting, and retrieval of emotional memories. The latter is a clear example of a VSSP task.

In the RT task, participants had to respond to either an 'X' or an 'O'. These are letter symbols and one might argue that there may have been a verbal element to the task, and that the RT data would have been different if a square and rectangle would have been used instead. Following Smith and Kosslyn (2006), we assumed that counting especially requires CE resources. However, the counting was verbalized and one could argue that the counting tasks were largely taxing PL resources. Even if the RT task and counting tasks were to a small or large extent phonological tasks, this would not undermine the conclusion that the CE was critically involved in the effects of counting on emotionality/vividness. First, if an allegedly PL task (*cf.* counting) task interferes with a VSSP task (e.g. retrieving emotional images), WM theory implies that this must have been because adding the PL task to the VSSP task taxed the overarching CE. Second, if the manipulation check (RT task plus counting) would have only taxed the PL, it is impossible to explain the correlations between the RT measure and the changes in the VSSP task (i.e. drops in vividness/ emotionality).

Thus, it seems that the CE was crucially involved in the counting and RT tasks.

Why was the dose-response relation that was found on the RT task (Figure 1) not mirrored by ratings on vividness and emotionality (Figure 2)? The WM account is plausible

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(Gunter & Bodner, 2008; Kemps & Tiggemann, 2007; Maxfield et al., 2008), but may be wrong. Eye movements, counting, drawing, computer games may have something else in common that accounts for their vividness/emotion-reducing effects. It is unclear, however, what such other common denominator might be, and there does not seem to be a credible alternative for WM theory. There may be two ways in which WM theory might be reconciled with the absence of a dose-response relationship for vividness and emotionality. First, blurring of memory may occur once the availability of WM resources reaches a certain floor effect, and further reductions of resources may not yield extra blurring. Second, discussing this very issue, Gunter and Bodner (2008, p. 926) note: 'Although tasks that are more taxing of the central executive may produce larger benefits, this relationship may not be linear. A task that is overly taxing might preclude holding a memory in mind, thereby precluding benefits'. Thus, the relationship between the degree of taxing and blurring may have an inverted U shape. The complex counting task was extremely taxing. While the average RT doubled compared to the retrieval-only condition, in 24.5% of the trials (9.8/40; see Figure 1), participants were unable to respond at all in the complex counting condition. Following the argument of Gunter and Bodner, the complex counting condition, while still effective, may have been on the threshold of being too difficult and hence less effective. This issue can be empirically resolved by examining the effects of several levels of WM taxation, from very weak to intermediate to very strong.

Finally, it is unclear to what extent the task of recalling negative memories taxes WM resources. The retrieval of visual memories has been likened to visual imagery and consists of actively recreating the visual image, maintaining or refreshing it, and inspecting it in order to derive information from it (Kosslyn, 1994). With respect to the latter, it may be assumed that the assessment of emotional value involves some form of inspection, and that inspection itself may be taxing. Thus, when much of the available resources are already expended by the retrieval process itself, a relatively modestly taxing secondary task may be sufficient to fully exhaust the CE. Clearly there is room for research here, exploring how much CE resources are required for holding emotional memories in mind.

EMDR started with eye movements as a concurrent task. Over the last decade, EMDR therapist have assumed that bilateral stimulation is crucial to EMDR, and started to substitute eye movements with, for example, bilateral tactile stimulation and, especially, alternating binaural stimulation. There are no controlled studies of the clinical effects of binaural stimulation; the positive conclusions in meta-analyses about the effects of EMDR are based on eye movement studies (Maxfield, 2008). With an RT task, we recently found that, like counting, eye movements tax WM, but binaural stimulation hardly affects RT's which suggests that WM taxing due to binaural stimulation is absent or negligible (van den Hout et al., 2010). Given the explanatory and predictive success of WM explanations, this raises concerns about the effects of binaural stimulation.

The present data suggest avenues for further study. Do the presence of a dose-response relationship on CE taxing (*cf.* the RT data) and the absence of such a relationship on emotionality/vividness indicate that the WM account is untenable? Or would there be a critical level of taxing, with higher levels having no extra effects? Does the dose-response relationship follow an inverted U shape? WM theory of EMDR effects has a relatively sound empirical basis, but given that binaural stimulation hardly taxes WM (van den Hout et al., 2010), WM theory predicts that the latter intervention is clinically inert. What would outcome studies show? Given the importance of clinical problems treated with EMDR and the widespread use of binaural stimulation, the need for controlled research is unusually urgent.

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