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BASIC RESEARCH ARTICLE

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Investigating the effect of proactive interference control training on intrusive memories

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ABSTRACT
Intrusive re-experiencing is a hallmark symptom of Posttraumatic Stress Disorder (PTSD). According to prominent models of intrusive phenomena, intrusive memories may result from impairments in the efficiency of working memory capacity (WMC), more specifically proactive interference control. Yet, experimental research is scarce. Therefore, the present study aimed to investigate experimentally the role of proactive interference control in intrusive memories. We randomly assigned 57 healthy participants to either receive a high interference control training or a low interference control training. Participants were then exposed to highly distressing film clips. WMC was assessed before and after the training. Intrusion symptoms were assessed directly post-training and after one week using an Intrusion Provocation Task (IPT), a one-week intrusions diary, and the retrospective intrusion subscale of the Impact of Event Sale – Revised (IES-R). Results indicated that both groups reported improvements in WMC and fewer intrusions on the second IPT post-training, with no differences between groups. Similarly, no group differences on intrusions were found at one-week follow-up (i.e., intrusion diary and IES-R). To conclude, these data are not consistent with the hypothesis that WMC plays a role in intrusive re-experiencing. Implications for future research are discussed.

Investigando el efecto del entrenamiento de control de interferencias proactivas en las memorias intrusivas
La re-experiencia intrusiva es un síntoma distintivo del trastorno por estrés postraumático (TEPT). De acuerdo con los prominentes modelos de fenómenos intrusivos, las memorias intrusivas pueden resultar en deterioros en la eficiencia de la capacidad de memoria de trabajo (CMT), más específicamente del control proactivo de interferencias. Sin embargo, la investigación experimental a este respecto es escasa. Por lo tanto, el presente estudio tuvo como objetivo investigar experimentalmente el papel del control proactivo de interferencias en las memorias intrusivas. Asignamos aleatoriamente 57 participantes sanos a recibir, ya sea, un entrenamiento de control de alta interferencia o un entrenamiento de control de baja interferencia. Luego, los participantes fueron expuestos a videoclips de películas altamente angustiantes. La CMT fue evaluada antes y después del entrenamiento. Los síntomas de intrusión se evaluaron directamente después del entrenamiento y después de una semana utilizando una Tarea de Provocación de Intrusión (IPT), registro diario de intrusiones (por una semana), y la subescala de intrusión retrospectiva de la Escala del Impacto del Evento - Revisada (IES-R). Los resultados indicaron que ambos grupos experimentaron mejoras en la CMT y reducción de intrusiones en la segunda IPT posterior al entrenamiento, sin diferencias entre los grupos. De manera similar, no se encontraron diferencias de grupo en las intrusiones en el seguimiento de una semana (es decir, en el diario de intrusiones y la IES-R). Para concluir, estos datos no son consistentes con la hipótesis de que la CMT desempeña un papel en la re-experiencia intrusiva. Se discuten las implicaciones para futuras investigaciones.

研究主动干扰控制训练对闯入性记忆的影响
闯入性再体验是创伤后应激障碍（PTSD）的标志性症状。根据闯入现象的经典模型，闯入性记忆可能是由工作记忆容量（WMC）效率的损害引起的，更具体地说是主动干扰控制。然而，这方面实验研究很少。因此，本研究通过实验研究主动干扰控制在闯入性记忆中的作用。我们随机分配了57名健康被试，以接受高干扰控制训练或低干扰控制训练。然后被试接触到令人非常痛苦的电影片段。在训练前后对WMC进行了评估。在训练后和一周后随访使用闯入激发任务（IPT），一周闯入症状日记以及事件影响量表修订版

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关键词
闯入; 工作记忆能力; 情绪障碍; 创伤; 抑制控制; 创伤影片范式; 操作广度任务; 阅读广度任务

HIGHLIGHTS
• Intrusions in PTSD may result from impairments in proactive interference control (PIC).
• This study manipulated PIC.
• There was no difference in outcomes of high versus low PIC training.
• Results do not support a causal role of PIC.

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（IES－R）的回顾性闯入子量表直接评估闯入症状。结果表明，两组均报告WMC改善，第二次IPT训练后闯入较少，两组间无差异。同样，在一周的随访中没有发现闯入的群体差异（即闯入日记和IES-R）。总之，这些数据与WMC在闯入性再体验中发挥作用的假设不一致。文中讨论了对未来研究的启示。

Posttraumatic Stress Disorder (PTSD) is characterised by involuntary, intrusive phenomena, such as intrusive re-experiencing (American Psychiatric Association [APA], 2013). One of the core symptoms of PTSD are intrusive memories, i.e., spontaneous, involuntary memories of the trauma (DSM-5; APA, 2013). They often occur in the form of vivid flashbacks or nightmares, and can cause high levels of distress for the individual. Elucidating factors contributing to the development of intrusions has been an important target for research in experimental psychopathology. A great body of research focused on the role of working memory capacity (WMC), following assumptions of cognitive models postulating that impairments in WMC are a risk and maintaining factor of intrusive memories (e.g., Brewin & Smart, 2005; Dalgleish, 2004). WMC is critical to executive control and refers to the ability to maintain goal-directed information active in working memory and suppress interfering, irrelevant information (Engle, 2002; Kane & Engle, 2000). It is usually assessed in tasks in which participants have to remember consecutively presented stimuli in combination with attention demanding distractor tasks, such as e.g., the reading span task (Rspan) or the operation span task (Ospan; for an overview, see Engle, 2001).

Within research of WMC, the link between the ability to control inhibition of irrelevant information (i.e., inhibitory control) and the development of intrusions has been studied intensively. To illustrate, Verwoerd, de Jong, and Wessel (2008) found a predictive relationship between low inhibitory control and intrusion frequency. The specific inhibitory process responsible for this association is thought to be proactive interference (e.g., Verwoerd, Wessel, & de Jong, 2009; Verwoerd, Wessel, de Jong, Nieuwenhuis, & Huntjens, 2011), which implies that newly learned information interferes with the recall of similar, previously learned information. Here, Verwoerd et al. (2009) showed that resistance to proactive interference was related to a lower frequency of intrusive memories, providing tentative evidence that impairments in proactive interference control reflect a vulnerability factor for intrusive memories. However, the cause-effects relationship between proactive interference control and intrusive memories is unclear since most studies used correlational approaches. An exception is the study by Bomyea and Amir (2011). That is, they experimentally manipulated inhibition requirements in a WMC task, and evaluated the effect of this training on intrusive thoughts during a thought suppression task. Unselected undergraduate participants were randomly assigned to repeatedly practice an adapted version of the Rspan task requiring either high interference control (HIC; training condition) or low interference control (LIC; control condition). Results indicated that individuals in the HIC group exhibited greater improvements of WMC performance from pre- to post-training relative to LIC group, as well as fewer intrusions during a thought suppression task, as measured with the intrusion subscale of the Impact of Event Scale-Revised (IES-R; Weiss & Marmar, 1996). More recently, Bomyea, Stein, and Lang (2015) tested the effects of an eight-session training among patients with PTSD. Results showed that HIC, compared to LIC, improved in WMC performance, while reducing re-experiencing symptoms. However, PTSD-related symptomatology and distress improved equally across both training conditions. To conclude, there is some first evidence showing that high interference control training may yield beneficial effects on WMC and symptoms of intrusive re-experiencing (for a review on information processing biases and cognitive trainings in PTSD, see e.g., Vasterling & Hall, 2018; Woud, Verwoerd, & Krans, 2017).

However, there is a clear need for additional research. First, the above-mentioned research mostly examined factors maintaining intrusive memories. This leaves the unanswered question whether WMC plays a causal role in the initial development of intrusive memories. Second, additional research is needed from a theoretical perspective in order to test and refine the role of WMC in cognitive models of PTSD. Third, no studies have explored whether WMC performance may be a suitable target in the development of novel therapeutic approaches or preventive interventions in survivors of recent trauma. Finally, replication studies are needed since WMC training is in its early stages of scientific development.

Accordingly, the main aim of the present study was to further advance our understanding of interference control in intrusion development. Based on published interventions to manipulate WMC, we administered either high or low interference control training (HIC vs. LIC, see Bomyea & Amir, 2011; Bomyea et al., 2015) to healthy participants. Extending these prior studies, we subsequently confronted participants with traumatic film clips as an analogue traumatic event (for review, see James et al., 2016). Intrusions were assessed during the session by means of an Intrusion Provocation Task (IPT; see James et al., 2015) and after a week by means of an intrusion diary and the intrusion subscale of the Impact of Event Scale – Revised (IES-R (Weiss & Marmar, 1996). The latter approach thus clearly extends previous approaches: Instead of relying on one, static single time-point perspective of intrusions, we cover a broader time range and therefore can also assess potential delays in trauma-relevant processing. We expected to find training-congruent differences in WMC, i.e., better performance from pre- to post-training for those receiving HIC versus LIC training. Further, we expected that HIC compared to LIC training, would lead to fewer intrusive memories during the session and after a week. Finally, we investigated the correlation between WMC performance post–training and intrusive memories (Intrusion Provocation Task after a week, intrusions reported in the intrusion diary, and the intrusion subscale of the Impact of Event Scale – Revised), expecting that better WMC performance would be associated with fewer intrusive memories.

1. Methods

1.1. Participants

The sample included 57 healthy participants (46 women). The study was advertised via flyers, poster, and social media. Participants who were interested in the study received a screening questionnaire and were invited to take part in the study if they met the eligibility criteria. The screening questionnaire assessed demographic information and included four questionnaires, i.e., the Beck Depression Inventory-II (BDI-II; Beck, Steer, & Brown, 1996), the Spontaneous Use of Imagery Scale (SUIS; Reisberg, Pearson, & Kosslyn, 2003), the State and Trait Anxiety Inventory -Trait (STAI-T; Spielberger, Gorsuch, Lushene, Vagg, & Jacobs, 1983), and the Trauma History Checklist (THC; Holmes & Steel, 2004). We used the validated German versions of these questionnaires (SUIS: Görgen, Hiller, & Witthöft, 2016; BDI-II: Hautzinger, Keller, & Kühner, 2006; STAI-T: Laux, Glanzmann, Schaffner, & Spielberger, 1981). The German version of the Trauma History Checklist has been used in previous studies of the first author (e.g., Woud et al., 2018). Participants were included if they were fluent in German, have never been diagnosed with a PTSD or psychosis, did not suffer from a blood-/injury- or injection-phobia, were not colour blind, had no visual or hearing problems, did not take medication that could alter their performance on the computer tasks (e.g., antidepressants), did not watch films with violent contents on a regular base, had a BDI score lower than 18, and reported no suicidal tendencies.

1.2. Mood ratings

Five mood states were assessed over the course of the study, i.e., fear, horror, anxiety, sadness, hopelessness and depression (see James et al., 2015) using 11-point scales ranging from 0 (*not at all*) to 10 (*extremely*). Scores across the 4 scales were averaged to provide a single mood index.

1.3. Trauma films

The trauma films (Kessler et al., 2019) consisted of 16 scenes displaying various highly distressing events (e.g., a corpse washed up at the coast, real-life road traffic accident; James et al., 2016). The compilation lasted for about 15 min. Participants were asked to imagine being a bystander while watching the scenes and to pay close attention without looking away. Consistent with previous studies (e.g., Woud et al., 2018; Woud, Holmes, Postma, Dalgleish, & Mackintosh, 2012), the film was presented in a separate, darkened room and participants were left alone while watching the movie. Participants' engagement with the films was assessed by means of an 11-point Likert-scale (0 = *no attention*, 10 = *full attention*).

1.4. Assessment working memory: operation span task (Ospan; Bunting, 2006; Unsworth, Heitz, Schrock, & Engle, 2005)

During the Ospan task, participants had to solve simple math problems while simultaneously trying to remember unrelated letters. It consisted of three practice stages and the actual Ospan task. During the first practice stage, two letters were always presented consecutively in the middle of the screen for 800 ms. Participants had to remember the letters and select them in the presented order out of a 12-letter matrix presented on the screen (no time limit). Responses were followed by accuracy feedback. There were four practice trials. In the second practice stage, participants were required to solve 15 simple math problems as quickly as possible, e.g., *'(7/1) – 5 = ?'*. Each math problem was followed by a potential solution, which participants had to approve or reject. In this stage, participants received feedback after each trial and for their overall performance. Further, for each participant, response times were averaged and 2 standard deviations were added in order to obtain an individual time limit for the actual task. The third practice stage combined the assignments of the two previous stages. That is, participants were instructed to remember and recall letters while simultaneously solving math problems. This third practice stage contained four trials, i.e., two trials with each two math problems and two letters, and two trials with each three math problems and three letters.

Feedback was given when participants responded incorrectly or exceeded the time limit. Further, at the end of each trial, feedback was provided on the math and recall performance. The combined practice stage was followed by the actual task. Here, sets varied in size from two to six math problem and letters. Each set was presented three times, resulting in 15 trials with a total of 60 math problems and 60 letter presentations. Math problem/letters were generated randomly for each participant. As an index of working memory capacity, we used the traditional absolute scoring method. That is, the Ospan score reflects the sum of all correctly recalled sets (e.g., Unsworth et al., 2005). For a visual presentation of the task see Figure 1.

1.5. Working memory training – reading span task (Rspan; Lustig, May, & Hasher, 2001)

During the Rspan task, participants were required to memorise items while evaluating sentences as 'meaningful' or 'meaningless'. The task contained two conditions: The high proactive interference condition (HIC), which used the same stimulus type (i.e., words) for both memorised and interfering items, and the low proactive interference condition (LIC), which used two different stimulus types (i.e., words and numbers). Accordingly, the HIC required more inhibition of proactive interference than the LIC, and thus served as the WMC training condition. Like the Ospan task, the Rspan task started with a three-stage practice phase. During the first practice stage, participants practiced either memorising words (HIC) or words and numbers (LIC). The stimuli were presented consecutively in the middle of the screen for 800 ms. After that, response boxes appeared in which participants were required to enter the recalled stimuli in the correct order. This was followed by feedback about participants' performance. There was no time limit during this stage. In the HIC, participants completed four trials, i.e., two trials of two words and two trials of three words. In the LIC, participants also completed four trials, however, the four trials consisted of one trial of two words, one trial of two numbers, one trial of three words, and one trial of three numbers. In the second practice stage, participants were asked to evaluate short sentences (9–14 words) as meaningful or meaningless. Each sentence was presented on the screen and participants were instructed to click the mouse as soon as they had evaluated the sentence. Next, a response screen appeared on which participants had to indicate whether the presented sentence was meaningful or not. A total of 15 sentences were displayed. Participants received feedback after every response and for their overall performance. Participants' average response time of this stage plus 2 standard deviations was set as time limit for the actual task. The third practice stage combined the assignments of the two previous practice stages. That is, participants were instructed to remember and recall items while simultaneously evaluating sentences. The combined practice stage consisted of four trials

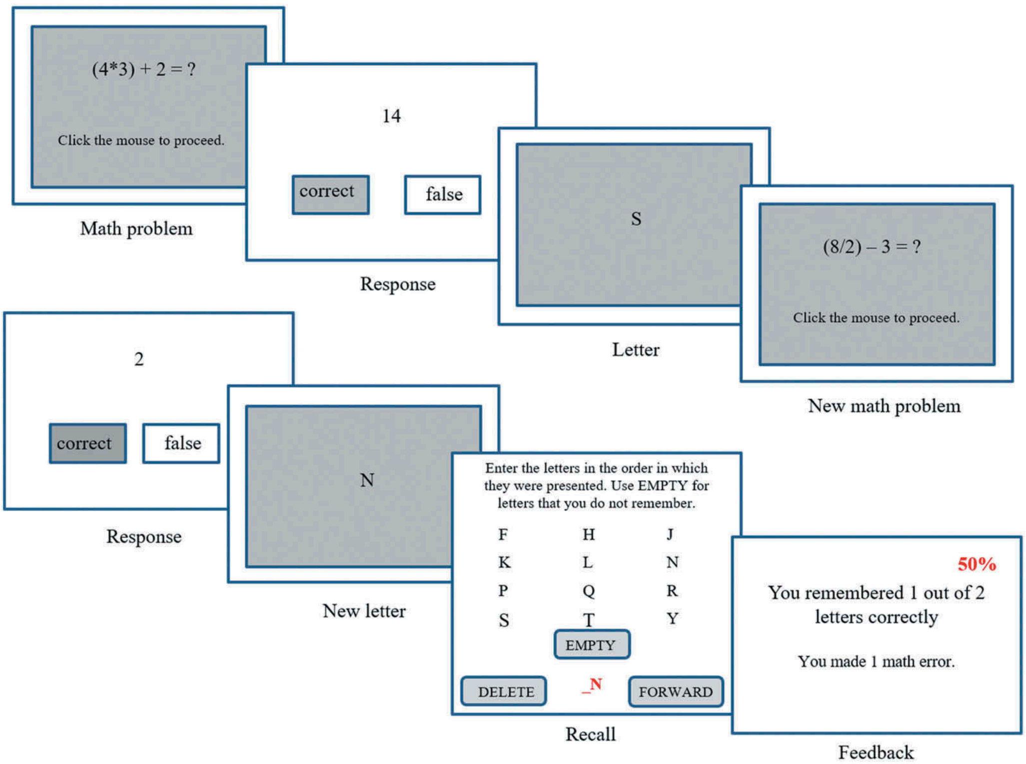

Figure 1. Set example of the OSpan task.

analogue to the trials in the first practice stage, whereby the stimuli depended on the training condition (i.e., during HIC training, words only were presented, during LIC training, words and letters were presented). In the actual task, participants in both conditions received sets that varied from two to six sentence and word/letter combinations. Each set was presented three times, resulting in 15 trials with 60 sentence presentations and 60 word/number presentations, with a mean duration of approx. 20 mins. We note that this is a shorter training than that used by Bomyea and Amir (2011), who included 45 trials in a training lasting approximately 30 mins. For a visual presentation of the two conditions see Figures 2 and 3.

1.6. Outcome measures intrusions

1.6.1. Intrusion provocation task (IPT; adapted from James et al., 2015)

In this task participants were presented with 16 blurred pictures, one from each scene of the trauma film, which depicted the moment just before the aversive event of the scene occurred. The pictures were in the same order as the scenes in the trauma film. Each picture displayed on the screen for 2 s without an inter-stimulus interval. When viewing the scenes, participants were instructed to imagine being a bystander of the scene. After the presentation of all pictures, participants closed their eyes for two minutes. During this period, participants were asked to press a key on the keyboard each time a mental image of the movie popped into their mind. Per participant, an overall IPT intrusion score was calculated by summing up all key presses (James et al., 2015).

1.6.2. Intrusion diary

We recorded film-related intrusions over a one-week period via a pen-and-paper diary (e.g., Woud et al., 2018, 2012). Participants were asked to write down any intrusion evoked by the film with a short description of its content, nature (mental images, verbal thoughts, or a combination of both), and distress (0 = *not distressing*, 100 = *extremely distressing*). Intrusions were defined as 'any memory of the film (or part of the film) that appears apparently spontaneously in your mind. Do not include any memories of the film that you deliberately or consciously bring to mind'.

1.6.3. Impact of event scale-revised (IES-R; Weiss & Marmar, 1996)

The IES-R is a self-report measure of traumatic stress including three subscales, i.e., intrusion, avoidance, and hyperarousal. Of main interest here was the intrusion subscale. Instructions of the IES-R were adapted in such that participants were asked to relate their responses in regard to their experiences evoked by the

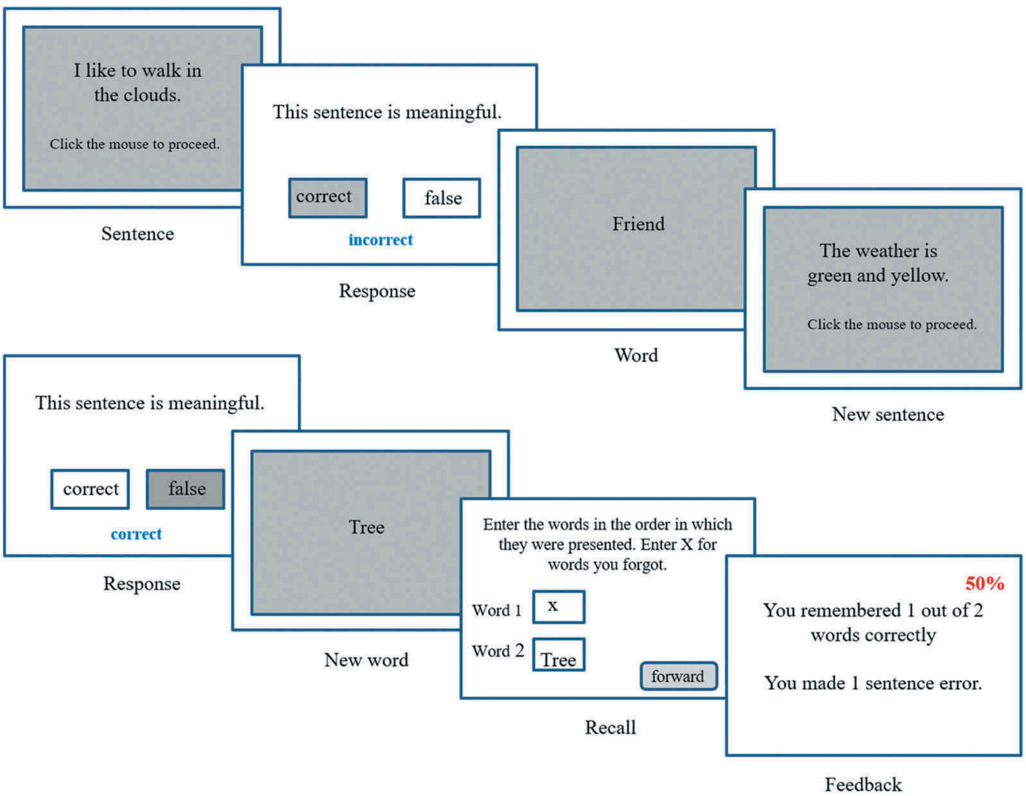

Figure 2. Set example of the HIC training condition.

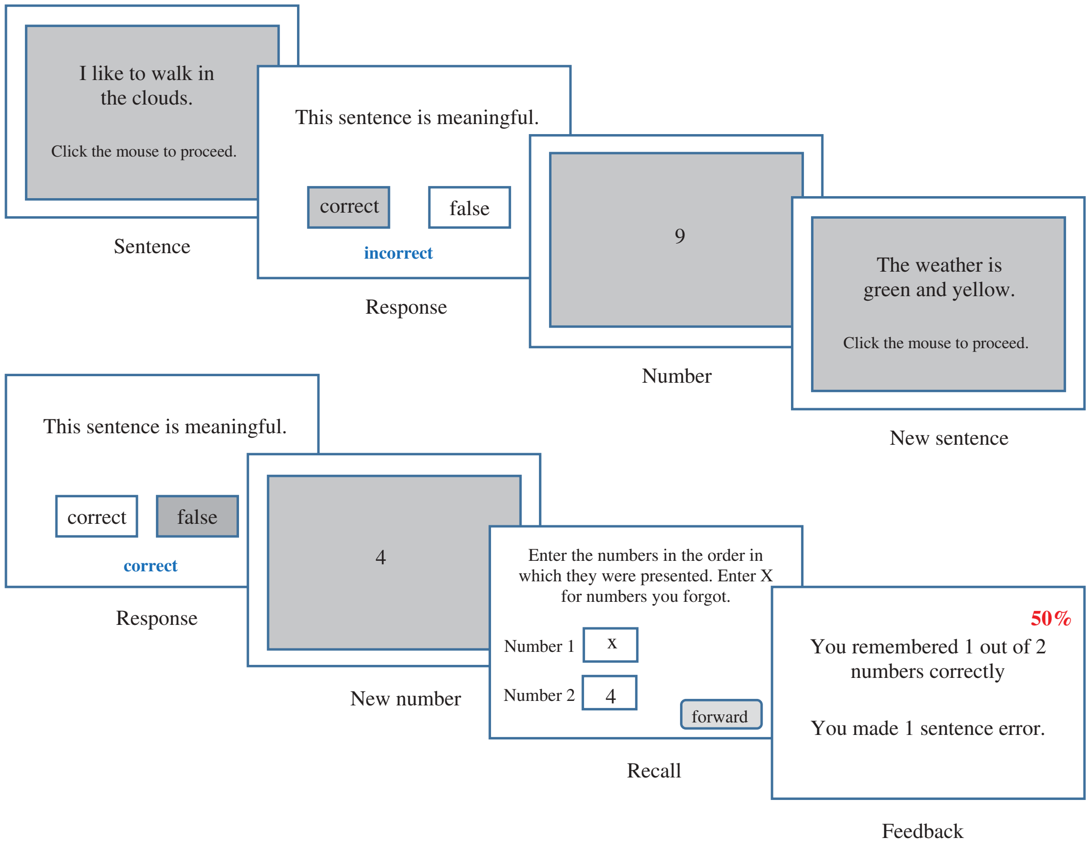

Figure 3. Set example of the LIC training condition.

trauma film. We used the validated German versions of the IES-R (Maercker & Schützwohl, 1998).

1.7. Memory test trauma films

Participants' memory about the trauma film was tested via a questionnaire including simple 'yes or no' questions about the movie's contents, i.e., one for each scene (16 in total, with 8 questions requiring a 'yes' and 8 questions requiring a 'no' answer). Correct answers were scored with '*1*', incorrect answers with '*0*'.

1.8. Compliance rating diary

Participants rated their diary completion in relation to the statement, 'I have often forgotten (or have been unable) to record my intrusive thoughts or images in the diary', on a scale ranging from 0 (*not at all true of me*) to 10 (*completely true for me*). Furthermore, they had to indicate how accurately they had completed their diary, on a scale ranging from 0 (*not at all accurate*) to 10 (*very accurate*).

1.9. Statistical approach main outcome measures

The present study used a between-subjects design which included two groups: HIC and LIC. Repeated-measures ANOVAs were conducted to examine changes in working memory capacity and intrusions during the session from pre- to post-training. Time x Group interactions indicate the outcomes of interest. Outcomes at follow-up were compared using between-groups tests. Means, standard deviations, and statistics of the baseline characteristics are presented in Table 1. The analysed

Table 1. Baseline characteristics for the HIC and LIC group.

	LIC (n = 28, 23 female)	HIC (n = 26, 21 female)	
	M (SD)	*M (SD)*	Statistics
Age	21.18 (4.03)	21.31 (3.13)	$t(52) = .313, p = .896$
SUIS	60.93 (9.13)	63.11 (8.29)	$t(52) = .919, p = .362$
BDI-II	5.07 (4.54)	6.43 (5.34)	$t(52) = 1.01, p = .319$
THC	.49 (.83)	.60 (0.96)	$t(52) = .429, p = .670$
STAI-T	34.22 (9.02)	34.65 (7.07)	$t(52) = .193, p = .848$
Mood pre film	2.93 (6.42)	2.85 (4.44)	$t(52) = .054, p = .957$
Ospan score pre	41.29 (14.85)	45.00 (12.81)	$t(52) = .981, p = .331$
IPT Session 1	14.43 (16.71)	14.88 (8.75)	$t(52) = .124, p = .902$

LIC/HIC = low/high interference condition in working memory training; SUIS = Spontaneous Use of Imagery Scale; BDI-II = Beck Depression Inventory-II; THC = Trauma History Checklist; STAI-T = Spielberger State-Trait Anxiety Inventory – Trait version; Ospan ccore = operation span Score assessing working memory capacity; IPT = Intrusion Provocation task dataset can be obtained via the open science framework via the following link: https://osf.io/ykdsr/?view_only=aa5b3d9878734d49ab64ff5fb6c83b26

1.10. Procedure

The study included two visits. At the first visit, participants completed the mood questionnaire and the Ospan task, and were then assigned to the one of the two WMC conditions (i.e., by using pre-defined counterbalancing). Immediately after the training, participants completed the second Ospan task and were exposed to the trauma films, completed the second mood questionnaire, and the attention and distress questionnaire, respectively. Participants also completed the first Intrusion Provocation Task (IPT) and received the intrusion diary. After seven days, participants returned for the follow-up session in which the intrusion diary was checked. Participants also completed the Impact of Event Scale – Revised (IES-R), the second Intrusion Provocation Task (IPT), the diary compliance rating, and the memory test. Participants were the debriefed and received compensation (15 euros or course credits).

2. Results

2.1. Participant characteristics

Following Bomyea and Amir (2011), we removed three participants with a math accuracy below 85% in the Ospan task from all analyses, resulting in a final sample of n = 54. Gender was equally distributed between the groups, χ^2 (1) = .017, p = .897, and there were no group differences between the HIC and LIC in baseline characteristics (see Table 1 for means, standard deviations and statistics).

2.2. Changes in working memory capacity pre-post training

To test whether the training affected WMC performance, a repeated measures ANOVA was conducted including the between-subjects factor Group (HIC, LIC) and the within-subjects factor Time (pre-training, post-training). The crucial Group x Time interaction, however, was not significant: F(1,52) = .126, p = .724, η_p^2 = .002 (pre LIC: M = 41.29, SD = 14.85; post LIC: M = 45.93, SD = 12.34; pre HIC: M = 45.00, SD = 12.81; post HIC: M = 48.77 SD = 13.04). Instead, we found a main effect of Time, showing that both groups improved over the course of the training: F(1,52) = 11.69, p = .001, η_p^2 = .184 (pre: M = 43.07, SD = 14.00; post: M = 47.30, SD = 12.64) (main effect Group: F(1,52) = .925, p = .341, η_p^2 = .017).

2.3. Film related ratings: attention, mood and memory

HIC and LIC did not differ concerning their attention while watching the film t(52) = .389, p = .699 (HIC: M = 9.04, SD = 1.00; LIC: M = 9.14, SD = .97) or distress evoked by the film t(52) = .732, p = .467 (HIC: M = 6.27, SD = 2.78; LIC: M = 6.75, SD = 2.01). Further, participants' mood became more negative from pre- to post-movie: main effect Time: F(1,52) = 91.78, p < .001, η_p^2 = .638 (pre: M = 2.89, SD = 5.51; post: M = 16.98, SD = 11.80). However, the groups' mood did not change differentially from pre- to post-movie (Time x Group: p = .972). Finally, results showed that participants of the LIC group had higher scores on the film memory test than participants of the HIC group: t(52) = 2.263, p = .028 (HIC: M = 9.42, SD = 1.60; LIC: M = 10.25, SD = 1.04).

2.4. Intrusions

2.4.1. Intrusion provocation task (IPT)

A repeated measures ANOVA including the between-subjects factor Group (HIC, LIC) and the within-subjects factor Time (Session 1, Session 2) did not reveal the expected Group x Time interaction: F(1,52) < .001, p = .988, η_p^2 < .001, or a main effect of Group: F(1,52) = .029, p = .865, η_p^2 = .001. However, we did find a main effect of Time F(1,52) = 32.31, p < 001, η_p^2 = .383, indicating that both groups reported fewer intrusions on the second compared to the first IPT, (Session 1: HIC: M = 14.88, SD = 8.75; LIC: M = 14.43, SD = 16.71; Session 2: HIC: M = 8.38 SD = 5.84; LIC: M = 7.89, SD = 9.13.

2.4.2. Intrusion diary

Results of an independent t-tests showed that the two groups did not differ in the number of experienced intrusions a week after the training: t(52) = −.548, p = .586, d = .15 (LIC: M = 7.86, SD = 5.54; HIC: M = 8.88, SD = 8.09). Further, there were no differences in intrusions distress: t(52) = .241, p = .810, d = .07 (LIC: M = 41.43, SD = 21.75; HIC: M = 39.94, SD = 23.61). When analyzing the three types of intrusions separately (i.e., mental images, verbal thoughts or a combination of both), results did not change (p's frequency: > .224, p's distress: > .386). There were no group differences in diary compliance (p's > .102).

2.4.3. Impact of event scale – revised (IES-R)

There were no group differences on the intrusion subscale, t(52) = .121, p = .904 (LIC: M = 10.50, SD = 6.64; HIC: M = 10.73, SD = 7.41) (total score: t(52) = .185, p = .854).

2.4.4. Correlational data

Correlational analysis between the working memory performance post training and intrusive memories revealed no significant relationships on any measure: Intrusion Provocation Task (IPT) during session 2: r (54) = .075, p = .588, intrusion diary: r (54) = −.123, p = .375, intrusion subscale of the Impact of Event Scale – Revised (IES-R): r (54) = −.016 p = .906.

3. Discussion

The present study sought to experimentally investigate the role of WMC in intrusive re-experiencing. To this end, we aimed to replicate an experimental WMC manipulation that compares a high with a low interference control training (HIC vs. LIC; Bomyea & Amir, 2011; Bomyea et al., 2015), followed by the presentation of distressing film clips as an analogue traumatic event. Intrusions of these film clips were assessed directly post training (first Intrusion Provocation Task, IPT 1) and after a week (second Intrusion Provocation Task, IPT 2; intrusions diary; intrusion subscale of the Impact of Event Scale – Revised, IES-R). Results showed that HIC training was followed by improvements in WMC performance. However, in contrast to prior studies, HIC did not outperform the LIC training. Regarding our measures on intrusive memories, no differences in intrusion were found between the two training groups, neither immediately after the training nor at one-week follow-up. However, results of the Intrusion Provocation Task showed that both groups reported fewer intrusions during the second assessment at one-week follow-up. Finally, correlational analysis between levels of working memory post training and intrusive memories revealed no significant relationships on any of the intrusions measures. To summarise, we did not find the expected interaction effects indicative of differential training effects on WMC and intrusive memories, respectively. Consequently, our findings seem to be at odds with the hypothesis that high levels of WMC, compared to low levels of WMC, have beneficial effects on intrusive re-experiencing. However, before interpreting the absence of an effect on intrusions, one has to take a cautious step back: We were unable to contrast different WMC levels in the HIC and to the LIC conditions. Hence, from a theoretical perspective, it is quite a plausible consequence that the two training groups did not differ on intrusive experiencing. In the following section, we discuss the potential implications of these findings for models of intrusive memories, as well as for experimental manipulations of WMC.

The observation that both training conditions exhibited an increase in WMC performance can be explained as follows: Items of the LIC training consisted of letters and numbers, and while this reduces interference with the evaluation of the sentences' meaningfulness, this condition forced participants to switch between numbers and letters. This could be also considered as an active WMC training, namely one that fosters cognitive flexibility. If correct, this would thus imply that both conditions trained aspects of WMC, which both could have served as a buffer to develop intrusions (see also Bomyea et al., 2015). The fact that we found a main effect of Time on the Intrusion Provocation Task (IPT) with fewer intrusions at session 2 for both training groups supports this explanation.

However, these clearly are post-hoc explanation, and additional research is needed to advance our understanding of the functional properties of the two training conditions. Further, it is important to also discuss alternative explanations for the results we found. Regarding the results on the Intrusion Provocation Task (IPT), previous studies showed that intrusion frequencies naturally declines over the course of one week (see James et al., 2016). As such, the simple passage of time could explain the decline in intrusions we found. Regarding the finding that both groups exhibited indistinguishably significant improvement in WMC performance, the present findings are also consistent with the hypothesis that the improvement from baseline to post-training may merely result from a practice effect (for a discussion, see Heeren, Coussement, & McNally, 2016). That should not come as a surprise; several neuropsychological studies have indeed shown that changes in WMC capacity are likely to be affected by practice effects, specifically for an intervention involving a short test-retest period (for a meta-analysis, see Calamia, Markon, & Tranel, 2012). However, researchers from the field of neuropsychological rehabilitation have suggested that practice effects may have prognostic and treatment implications. For instance, in three distinct clinical conditions (i.e., mild cognitive impairment; human immunodeficiency virus; Huntington's disease), practice effects predicted longer-term general daily functioning (Duff et al., 2007). Likewise, practice effects also predicted treatment response to memory training (Calero & Navarro, 2007; Duff, Beglinger, Moser, Schultz, & Paulsen, 2010). Unfortunately, to our best knowledge, such issues have never been explored in trauma research.

Another important issue relates to our procedure to trigger and assess intrusive memories. In Bomyea and Amir (2011), effects of HIC versus LIC emerged only after participants had to actively suppress their intrusions. In contrast, we assessed spontaneously occurring intrusions via the Intrusion Provocation task (IPT) and the intrusion diary. Although speculative, this pattern may suggest that WMC training has beneficial effects only within an active cognitive control context, i.e., if intrusions are suppressed or if intrusions interfere with a current goal. In addition, some types of involuntary cognition may be more sensitive to WMC training effects than others. Support for this idea comes from Takarangi, Strange, and Lindsay (2014, for a commentary, see Meyer, Otgaar, & Smeets, 2015), who exposed participants to trauma films and measured involuntary thoughts about the film during an unrelated reading task. Importantly, participants were instructed to report sudden thoughts about the film, and some participants were additionally prompted at unpredictable times whether they were currently thinking about the film. The authors conceptualised these two types of involuntary cognition as 'mind-wandering with' or 'without meta-awareness', respectively. Interestingly, only 'mind-wandering without awareness' correlated with deteriorated reading task performance. For the Intrusion Provocation Task (IPT) in the present study context, these findings suggest that the (self-caught) intrusions may be relatively unaffected by WMC, especially in the absence of a concurrent task causing goal interference. Therefore, an interesting next step would be to extend the Intrusion Provocation Task (IPT) and diary methods with an unrelated reading task, and to assess how strongly reading performance is disturbed by memories of the trauma film. This may help to clarify the overlap and differences between mind-wandering and clinically relevant intrusive trauma memories, which are still poorly understood (for discussion, see Meyer, Otgaar, & Smeets, 2015; Takarangi et al., 2014). Moreover, such an operationalization would allow testing goal interference as a potential moderator in the link between WMC and intrusive re-experiencing.

On a related note, it might be fruitful to extend the measurement of explicit memory as well. Interestingly, we found that participants in the LIC group tended to score better on the film memory questionnaire than the HIC group. This unexpected effect might suggest that the trainings affected explicit recognition memory rather than involuntary memories. Notably, in our study this effect cannot be attributed to changes in WMC. Future studies may want to address the role of WMC in explicit memory more directly, using extended memory tests that allow a more fine-grained exploration of recognition memory, e.g., establishing hit and false alarm rates or item versus relational aspects of memories (regarding the latter, see Zlomuzica et al., 2018).

Statistical power also has to be taken into account when interpreting the present findings. We conducted a post-hoc power calculation based on Bomyea and Amir (2011) on both the training and intrusion data. Regarding the effect of HIC versus LIC on WMC performance, an effect size equivalent of d = .77 was reported for the increase in Ospan scores in the HIC compared to the LIC from pre- to post training (Group x Time interaction: η_p^2 = .13, converted to d in line with the formulae provided by Cohen, 1988), which indicated that 28 participants per group would have been needed to provide 80% power at $\alpha = 0.05$. As such, our study did have sufficient power to find an effect on the Ospan score but not on the intrusion data. However, given recent concerns about the robustness and replicability of results reported in the field of psychology, a more thorough look at the present study's effect sizes seems worthwhile. Here, we particularly focus on the effect sizes of the main outcomes, i.e., results of the working memory training and intrusion data (IPT and intrusion diary). Studies with insufficient statistical power have a lower chance to find a true effect. Further, even if a statistically significant result is found, there is a decreased likelihood that such a result reflects a true effect. This has two consequences: An overestimation of the effect size and a lower change to reproduce the reported findings (Button et al., 2013). Applied to the present context, the effect sizes reported by Bomyea and Amir (2011) might suggest that their own study was in fact underpowered, and thus their reported effect sizes overestimations of the 'true' effect (if any). Hence, although our study was sufficiently powered to find their reported effect size for WMC performance, it may have also been underpowered for the 'true' effect (if any). Adequately powered follow-up work is therefore needed to systematically investigate the impact of working memory training on intrusions. However, to further explore this possibility, we calculated Bayes factors (BF01) using default priors in JASP (version 0.9; JASP team, 2018) to express the likelihood of the null (H0) over the alternative hypothesis (H1) given the data. We tested interactions against the respective models including the respective main effects. A BF under 3 is conventionally considered to indicate 'anecdotal' evidence, while a BF under 10 indicates 'moderate' evidence. Accordingly, we found moderate evidence against a training effect (i.e. for the null hypothesis) on WMC scores (BF01 = 3.79), IPT intrusions (BF01 = 3.51), and diary intrusions (BF01 = 3.22). Taken together, these analyses suggest that the pattern of findings cannot be attributed solely to a lack of power.

Finally, our training may not have been long enough to produce a robust training effect, as it contained fewer trials than that used by Bomyea and Amir (2011). However, the fact that there was no relationship between WMC (as assessed using the OSpan task) and intrusions suggests that even had we achieved greater average improvement in WMC, this would not have been associated with a smaller number of intrusions in the HIC compared to LIC group. The lack of a correlation between working memory and intrusions further emphasises that the robustness (or otherwise) of the relationship between WMC and intrusions is an important issue for follow-up work. When looking at studies investigating the association between WMC, operationalized via the Ospan task, and intrusions, we get a rather heterogeneous picture. Indeed, a number of studies found a correlation between WMC and intrusions (Bomyea & Amir, 2011; Bomyea, Amir, & Lang, 2012; Brewin & Smart, 2005; Klein & Boals, 2001). However, there are also studies revealing mixed results (Wessel, Huntjens, & Verwoerd, 2010) or even no relation (Nixon, Nehmy, & Seymour, 2007). To illustrate, a recent study by Voss, Ehring, and Wolkenstein (2018) manipulated left dorsolateral prefrontal cortex (dlPFC) activation via transcranial direct current stimulation (tDCS), and it was expected that such a stimulation would influence resistance to proactive interference control, which, in turn, would affect intrusive memories. However, there was neither an effect of tDCS (neither on resistance to proactive interference nor intrusions) nor a correlation between proactive interference control and intrusions. Results of Wessel et al. (2010) showed that the association between WMC and intrusions depends on participants' circadian preferences, rendering it questionable whether the relation between WMC and intrusion should be considered as a stable and robust phenomenon. For the present study, this implies that WMC performance and thus also WMC training effects may be more subtle than initially expected, which in turn requires fine-tuned follow-up work.

In follow-up research several issues require further examination. First, more fine-tuned training versions have to be developed in order to ensure that there is only one active training condition (for more detailed elaborations on control conditions during cognitive trainings, see Blackwell, Woud, & MacLeod, 2017). Second, the role of thought suppression needs to be investigated. That is, future research should compare the effects of HIC versus LIC training while participants do or do not actively suppress their intrusions. Third, circadian rhythm should be taken into account e.g., by testing participants in the morning versus evening to examine whether this leads to differential findings (e.g., van Wessel et al., 2010). Finally, we relied on the trauma-film paradigm as an analogue stressor, implying that our findings may not generalise to clinical samples exposed to traumatic stress.

In sum, the present results do not support the hypothesis that WMC plays a role in intrusion development. Our paper demonstrates the pressing need to refine interventions to train WMC whilst further disentangling the effects of this type of cognitive training.

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Ethical approval

All procedures performed in the present study involved human participants and were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. The study was approved by the local ethic committee of the Ruhr-Universität Bochum (ethical approval number: 181).

Informed consent

Informed consent was obtained from all individual participants included in the study.

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