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Visuospatial computer game play after memory reminder delivered three days after a traumatic film reduces the number of intrusive memories of the experimental trauma

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ABSTRACT

Objective: The experience of intrusive memories is a core clinical symptom of posttraumatic stress disorder (PTSD), and can be distressing in its own right. Notions of dual task interference and reconsolidation-update mechanisms suggest novel approaches to target intrusive memories. This study tested the hypothesis that a single-session cognitive intervention (memory reminder task plus *Tetris* gameplay) would reduce the occurrence of experimental trauma memories even when delivered 3 days post-trauma. Critically, this study tested effects against two control groups: Reminder-only, and reminder plus another computer game (a form of *Quiz*).

Methods: 86 healthy volunteers (59% female, age $M = 24.35$, $SD = 4.59$ years) watched a trauma film and then recorded their intrusive memories in a diary for 3 days (pre-intervention). They then returned to the lab. After presentation of visual reminder cues for the film plus a 10 min wait period (memory reminder task), participants were randomized into one of three task conditions (*Tetris* game play, *Quiz* game play, vs. reminder-only). They then kept the diary for a further 3 days (post-intervention).

Results: As predicted, after the experimental manipulation, the reminder + *Tetris* group experienced significantly fewer intrusions than the reminder-only group ($d = 1.37$). Further, the reminder + *Tetris* group also experienced significantly fewer intrusions than the reminder + *Quiz* ($d = 0.65$) group. Contrary to predictions, the reminder + *Quiz* group experienced significantly fewer intrusions than the reminder-only group ($d = 0.69$). Prior to the experimental manipulation, there was no significant difference between groups in number of intrusions. Recognition memory test scores for facts of the trauma film after 6 days were comparable between groups.

Conclusions: We demonstrated that 3 days after experimental trauma (i.e. after memory consolidation) an intervention comprising a reminder task prior to a 15 min cognitive interference task (one of two computer games) led to a reduction in intrusion occurrence compared to reminder only. We interpret and discuss our findings within the framework of supposed reconsolidation-update mechanisms and competition for limited (visuospatial) working memory resources. Should these effects hold true in clinical populations, this type of simple intervention approach could help contribute to reducing intrusive memories of trauma.

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1. Introduction

Many people will be exposed to a traumatic event during their lifetime (WHO, 2013), a significant minority of whom eventually go on to develop conditions such as posttraumatic stress disorder (PTSD; Kessler et al., 2005). Although there are effective treatments for established PTSD (administered at least 1 month after experiencing a traumatic event; NICE, 2005), only a minority of patients receive such treatment, leading to suffering and societal costs (Kessler, 2000). It is possible that symptoms such as intrusive memories can develop after an even wider range of events than those we currently classify as trauma (Mol et al., 2005). Further, evidence-based treatments to *prevent* the development of intrusive memories or future PTSD after a traumatic event are lacking; new methods to ameliorate psychological distress soon after a trauma are therefore needed (Iyadurai et al., 2018; Roberts, Kitchiner, Kenardy, & Bisson, 2010; Rose, Bisson, Churchill, & Wessely, 2002).

A core clinical symptom (Kupfer & Regier, 2011) of PTSD and acute stress disorder (ASD) is the "recurrent, involuntary and intrusive distressing memories of the traumatic event(s)" (American Psychiatric Association, 2013). Intrusive memories are experienced as sensory-perceptual (typically visual) mental representations of the traumatic event(s) (Brewin, 2014; Ehlers & Clark, 2000). It has been argued that emotional memory is perceptual (Arntz, de Groot, & Kindt, 2005) and likewise that mental imagery has a powerful impact on emotion (Holmes & Mathews, 2005).

Image-based intrusive memories as a symptom post-trauma may offer a translational treatment target in their own right.

Cognitive models of PTSD suggest that intrusive memories arise due to the differential processing that can occur during the encoding of a traumatic event: There is a shift towards enhanced perceptual processing (associated with a focus on sensory-perceptual information, sometimes termed data-driven processing), and reduced 'conceptual' processing, associated with a focus on information related to reasoning, organizing information, creating meaning from an event (Brewin, 2014; Ehlers & Clark, 2000; Holmes & Bourne, 2008). The predominance of perceptual processing at encoding is thought to lead to the subsequent involuntary triggering of sensory-perceptual image based memories by perceptual cues (both external and internal) in the environment (Brewin, 2014; Ehlers & Clark, 2000; Holmes & Bourne, 2008).

We need to find novel ways of working with emotional mental imagery (Arntz, Tiesema, & Kindt, 2007; Holmes, Arntz, & Smucker, 2007). Recent advances in memory research, concerning memory reconsolidation, open up hypotheses about new techniques that could be used to modify emotional memories. Following an event, new memories undergo a time-dependent process of stabilization, involving molecular and cellular processes, termed memory consolidation (Davis & Squire, 1984; McGaugh, 2000). During this discrete time-window new memories are fragile and vulnerable to interference, before becoming gradually resistant to change (Shadmehr & Holcomb, 1997; over approximately 6 h; McGaugh, 2000).

Insights into the neuroplasticity of memory suggest a consolidated memory may be rendered malleable following its reactivation via a retrieval cue (Alberini, 2005; Nader & Einarsson, 2010), necessitating restabilization in order for the memory to persist. During memory reconsolidation, a labile memory can be disrupted or enhanced via an intervention (Misanin, Miller, & Lewis, 1968; Nader, Schafe, & LeDoux, 2000b). Animal studies have shown successful weakening of conditioned fear memories with pharmacological agents (the protein synthesis inhibitor anisomycin) when applied during reconsolidation (Nader, Schafe, & Le Doux, 2000a). Recent studies conducted in humans provide initial evidence that conditioned fear memories (Kindt, Soeter, & Vervliet, 2009; Schiller et al., 2010) and episodic memories (Kroes et al., 2014) can also be modified in line with the idea of reconsolidation update mechanisms.

Cognitive models of working memory and dual-task studies suggest additional strategies to reduce intrusive memories of trauma. Working memory (WM) is a limited capacity system which temporarily maintains and stores information (Baddeley, 2012; Baddeley & Hitch, 1974) to "… support human thought processes by providing an interface between perception, long-term memory and action" (p. 829; Baddeley, 2003). Such WM models assume some form of limited-capacity "central executive" that oversees two types of storage systems: one for visuospatial information and one for auditory-verbal information.

Dual task experiments demonstrate reduced information processing when similar cognitive tasks compete for shared resources. For example, performing a visuospatial task selectively interferes with actively holding a sensory-perceptual mental image in mind. Research has shown that visuospatial dual-task interference can result in a visual image being held in WM becoming less vivid and, consequently, less emotional (e.g. Andrade, Kavanagh, & Baddeley, 1997; Baddeley & Andrade, 2000; Engelhard, van Uijen, & van den Hout, 2010; Engelhard, van den Hout, & Smeets, 2011; Van den Hout, Muris, Salemink, & Kindt, 2001).

Within experimental psychopathology, the trauma film paradigm (Holmes & Bourne, 2008; James et al., 2016), has long been used to investigate the generation of emotional intrusive mental images after trauma, and their modification – for example with imagery rescripting (Hagenaars & Arntz, 2012). Arntz and colleagues have argued that stimuli used in traditional experimental psychopathology approaches such as fear conditioning are too simple to model the learning/unlearning of complex emotional memories, and thus alternative approaches are needed to evolve novel therapeutic interventions concerning trauma memories (Kunze, Arntz, & Kindt, 2015).

Using the trauma film paradigm has allowed the investigation of the impact of engaging in visuospatial cognitive tasks on subsequent image-based intrusive memory development. Volunteers view a film with distressing content in the laboratory (an experimental trauma) and then over the following days keep a diary in which they record any intrusive memories of the film. Visuospatial tasks administered either during (e.g. undertaking a complex sequence tapping task; Holmes, Brewin, & Hennessy, 2004) or soon after (e.g. playing the computer game 'Tetris'; Holmes, James, Coode-Bate, & Deeprose, 2009; Holmes, James, Kilford, & Deeprose, 2010a) an experimental trauma have led to significantly fewer intrusions during the following week compared to no-task (control). Further, a study by Holmes et al. (2010a) suggested that these effects may be modality specific: A task (*Tetris*) supposedly taxing visuospatial WM (Lau-Zhu, Henson, & Holmes, 2017) reduced intrusive memory frequency compared to a no-task control, whereas a verbal-based task (the general knowledge computer game *Quiz*) did not. While a review of the literature by Brewin (2014) suggests that, on balance, visuopatial tasks more consistently lead to a reduction in intrusions than do so-called verbal ones, it is important to note that in some studies verbal tasks have also been shown to reduce intrusions (Hagenaars, Holmes, Klaassen, & Elzinga, 2017; Krans, Näring, & Becker, 2009).

Thus far, most studies investigating cognitive task interference on intrusive memory have focused on a time window of 24 h or less between experimental trauma exposure and intervention. For example, studies examined the effects of cognitive interference during or shortly after (e.g. up to 4 h) watching the trauma film (e.g. Holmes et al., 2009; 2010b). A recent study showed that a visuospatial interference task (reminder cue plus Tetris game play) reduced subsequent intrusive memory frequency after a longer time delay of 24 h (i.e. the experimental manipulation was administered 24 h after experimental trauma; James et al., 2015). However, from a clinical perspective there are still challenges associated with reaching people within 24 h of a traumatic event. Hence, an extension of the time frame of intervention delivery beyond 24 h post trauma within a secondary prevention approach could benefit greater numbers of individuals who have recently experienced a trauma.

In the current research we built upon the above-mentioned study (James et al., 2015), which had used a similar cognitive interference

procedure 24 h after experimental trauma. James et al. (2015) compared four between-subject conditions, and found that only a memory reminder task in combination with *Tetris* game play (but neither task in isolation) led to a reduction in intrusive memories of a trauma film. Results appear to be in line with reconsolidation update mechanisms in that both memory reactivation (reminder cue) and a blockade (*Tetris* game play) were required. However, this study did not test modality-specific task effects during this time frame since no non-visuospatial control task was used (James et al., 2015). Here we extended the approach taken by this previous study and had three aims:

i) Can a visuospatial interference intervention (involving reminder cue and *Tetris*) reduce intrusive memories of a trauma film even if delivered *72 h (3 days) after the film*? Were such an effect obtained, this might enhance the range of applications for this kind of secondary prevention intervention for people who seek help later than 24 h after a traumatic event.
ii) Is such an effect of the "reminder cue and *Tetris*" condition reducing intrusions also apparent when compared not only to a reminder cue alone condition – as used in the James et al. (2015) study – but also to an *active* control condition (i.e. with an alternative task to Tetris game play, akin to a placebo group)?
iii) Is any effect on reducing intrusions *modality specific*, i.e. would the non-visuospatial control intervention (reminder cue plus a *Quiz* game) also reduce intrusions when compared to the reminder cue condition?

Thus, the current study tested the hypotheses that a single session cognitive intervention (memory reminder task followed by 15 min *Tetris* gameplay) would reduce later intrusive trauma memories when delivered 3 days after experimental trauma (a film) compared to two control groups: (1) *reminder only*: a memory reminder task followed by no cognitive interference task (sitting quietly in the laboratory for an equivalent period of time to the computer gameplay); and critically (2) an *active control group*: the memory reminder task followed by 15 min *Quiz* gameplay (an active control for the computer game play component). Intrusions of the trauma film were recorded in a diary, both pre-intervention (days 1–3 after film viewing) and again post-intervention (days 4–6). We assessed recognition memory (voluntary recall) for the trauma film on day 7. We predicted recognition memory test scores would be comparable in all three groups in line with findings showing an interference task involving *Tetris* selectively impedes the intrusive nature of the memory and not the content of recall per se (Lau-Zhu et al., manuscript under review).

2. Materials and methods

2.1. Participants

Ninety participants were recruited from two university campuses and a nursing school. Hence, all participants were students. Participants were screened and judged ineligible to participate in the study if they reported previously experiencing 6 or more traumatic events on the Essen Trauma – Inventory (ETI; Talgay et al., 2007). Further, participants were excluded from analysis if they failed to participate in the second session of the study, or did not send in their completed intrusion diary on Day 7 (n = 2 reminder + *Tetris* group, n = 2 reminder-only group). The final sample included 86 participants (51 females, age range = 18–42; Supplementary Table 1). Participants were reimbursed for their participation (cinema tickets). The study was approved by the ethics committee of the medical faculty of the Ruhr-University of Bochum, Germany (Ref. Nr. 4902–14).

2.2. Procedure

Pre-laboratory baseline questionnaires (ETI, SCL-90-R, ERQ, and STAI) were completed via email prior to attending the laboratory on Day 1. On the first laboratory session (Day 1, see Fig. 1) participants provided written informed consent. Demographic information (age, gender) was collected before viewing the trauma film. Participants completed mood ratings immediately prior to watching the film. Immediately afterwards they repeated the mood ratings and completed further ratings of attention and emotional response to the film.

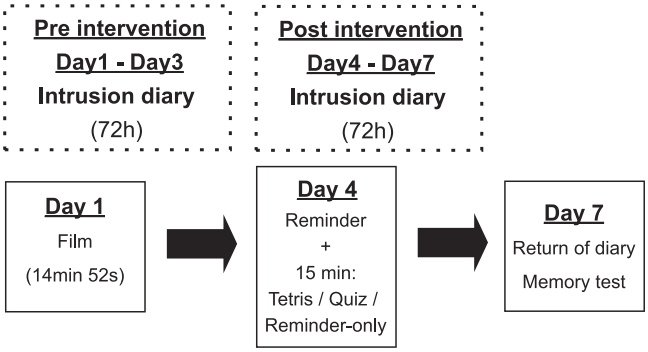

Fig. 1. General study design.

Participants were then given instruction on how to keep the Intrusion Diary to record any intrusive memories of the film they experienced over the subsequent 3 days (Holmes & Bourne, 2008; Holmes et al., 2010a; James et al., 2015, 2016).

Participants returned to the laboratory 72 h after the experimental trauma. They were randomly allocated to group (reminder-only, reminder + *Tetris*, or reminder + *Quiz*) using a minimization scheme (see below). All participants practiced playing *both* computer games (*Tetris* and *Quiz)* for 3 min. This was to ensure that participants would know how to play their allocated game (if applicable) after the reminder task, and to keep all experimental procedures prior to the reminder task matched across groups. After this practice, participants in all groups completed the memory reminder task. They then played *Tetris* or *Quiz*, or sat quietly for 15 min, according to their group allocation. After this period, participants allocated to *Tetris* or *Quiz* provided ratings of concentration, enjoyment, difficulty and distraction.

All participants were then reminded of the instructions for the diary and were asked to record intrusions in the diary for a further 3 days, after which (on Day 7) participants were asked to send back their completed diary by post. On Day 7 participants also completed three last questionnaires as a final assessment via email (IES-R, verbal recognition memory test, and finally game-related impact rating).

2.3. Tasks

2.3.1. Memory reminder task

The memory reminder task procedure consisted of two parts, i) film reminder cue presentation followed by ii) a music filler task for 10 min:

2.3.1.1. Film reminder cue presentation. Two static visual images were presented side by side (using PowerPoint) as reminder cues for the trauma film (viewed 3 days previously). Altogether there were 32 images, two for each of the 16 scenes within the film. All images were taken from a moment briefly before the traumatic content, i.e. they were *not* of the worst moments themselves. Participants were instructed to view each pair of images and to press a key when they identified which film clip the pair of images related to. A subsequent slide prompted participants to close their eyes and recall that film clip as vividly as possible. When they had finished recalling the clip they were instructed to press the key again in order to have a short self-paced break before moving on to the next pair of images. The time participants took to recognize the still images as being from the film, time spent recalling the film clip with closed eyes, and time taken for

the subsequent break were all recorded.

2.3.1.2. Music filler task. Following the presentation of the reminder cues, to allow time for the potential memory reconsolidation processes to be initiated, there was a short time interval before the intervention. This was based on the time interval used in both some animal (Nader et al., 2000a) and human studies (Agren et al., 2012; Schiller et al., 2010). We used a 10 min interval containing a music filler task, in which participants listened to and rated the pleasantness of music clips (as used in James et al., 2015).

2.3.1.3. Computer game (cognitive interference) tasks

2.3.1.3.1. Tetris computer game. In *Tetris*, 7 differently shaped geometric blocks fall one at a time from the top to the bottom of the screen in a random sequence. As they fall, the blocks can be moved (left, right, rotated 90° clockwise or accelerated) using the keyboard arrow keys. The aim is to fit the blocks together to create complete horizontal lines across the playing area. Each time a full horizontal line is created it disappears, and the participant is awarded points. In the current experiment participants were instructed to focus on the three blocks due to fall after the one that they were currently manipulating (these blocks were displayed in a preview to the right of the screen). Participants were asked to work out in their 'mind's eye' where best to place these blocks in order to create the horizontal lines. The computer game *Tetris* (set to "Marathon" mode, *Tetris* Zone version 1.2.1) was played for 15 min on a 15 inch laptop (n = 16) or a 22 inch (n = 12) colour monitor with no sound. The participants with the highest score in *Tetris* and in *Quiz* (see below) were told that they would each win a prize (two cinema tickets).

2.3.1.3.2. Quiz computer game. In the *Quiz* game a series of questions, each with four possible multiple-choice answers, are displayed one at a time on the screen. The objective of the game is to gain points by selecting the correct answer using the mouse. Participants were instructed to answer as many questions correctly as possible within the 15 min of game play, and were told that the participant with most correct answers would win a prize, to ensure that both the verbal and visuospatial computer games had similar temporal constraints. Questions were from the general knowledge domain (e.g., *with what item of clothing would you associate the word Panama? A= scarf, B=Gloves, C=hat, D=coat*). The computer game itself is called QUIZPro IV (https://litschi.de/edv-service/software-2/quizpro) and was played on a 15 inch laptop (n = 16) or a 22 inch (n = 14) colour monitor with no sound. Note this also a commercially available computer game (freeware), but differs from the one used by Holmes et al. (2010), called "PubQuiz", mainly in that it is in German.

2.3.1.3.3. Reminder-only. Participants in the reminder-only group sat quietly in the laboratory for 15 min and were told they could think about anything they like unrestricted. However they were not permitted to undertake any other activity, such as looking at their mobile phone.

2.4. Trauma film

The trauma film lasted 14 min 52 s and consisted of 16 different scenes depicting traumatic events to people, i.e. events involving exposure to actual or threatened death, or serious injury to others (American Psychiatric Association, 2013), as well as aversive scenes of trauma involving non-human animals. Each scene of the film contained footage with different content, e.g. a young girl hit by a car with blood dripping out of her ear; a boy gets hit by a van while texting on his mobile phone and falls to the road; beheading of an animal. The film contained some new scenes compared to earlier studies, and details about the scenes and their source can be found in Supplementary Table 3. The film was presented in a darkened room using a 15 inch laptop computer (n = 45) or a 22 inch computer monitor (n = 41), both with a viewing distance of approximately 12 inches. Participants were instructed not to view the film as they might do normally, but to pay close attention and to imagine they were there as a bystander at the scene. The experimenter waited outside the room while participants viewed the film.

2.5. Measures

2.5.1. Pre-laboratory baseline questionnaire

Prior to laboratory testing participants completed questionnaire measures administered via a standardized email for inclusion eligibility and baseline measures:

2.5.1.1. Essen Trauma – inventory (ETI; Talgay et al., 2007). Prior trauma history was reported using the ETI trauma list (not the complete ETI questionnaire). Participants were provided with a list of 15 different traumatic events and indicated which they had experienced during their lifetime. A cut-off of 6 events was used to exclude participants from the study (developed from the experience with other studies with healthy participants in our lab).

2.5.1.2. Symptom checklist-90-revised (SCL-90-R; Franke, 1995). Psychological symptoms and distress were measured using the SCL-90-R. This self-report symptom inventory has 90 items spanning nine symptom dimensions. Distress symptoms can be measured using individual symptom dimensions or by 3 summary global scores referred to as the Global Severity Index (GSI), the Positive Symptom Distress Index (PSDI) and the Positive Symptom Total (PST). The GSI global score was used to assess participants' distress levels. Internal consistency of the GSI (as well as of PSDI and PST) is reported to be between 0.96 and 0.98. Test-retest reliability for GSI is r = 0.90 (Franke, 1995).

2.5.1.3. Emotional regulation questionnaire (ERQ; Gross & John, 2003; Abler & Kessler, 2009). Emotional experience and emotional expression was measured using the EQR. The self-report questionnaire asked participants to rate 10 statements such as '*I control my emotions by not expressing them*' (expressive suppression) and '*when I want to feel less negative emotion, I change the way I'm thinking about the situation*' (cognitive reappraisal) on a scale from 1 '*strongly disagree*' to 7 '*strongly agree*'. For each scale a sum score was calculated. Internal consistency of the German version is 0.74 for the expressive suppression subscale, and 0.76 for the reappraisal subscale (Abler & Kessler, 2009). Test-retest reliability over 3 months is r = 0.69 for both scales (Gross & John, 2003).

2.5.1.4. State-trait anxiety inventory – trait (STAI-T; Spielberger, Gorsuch, Lushene, Vagg, & Jacobs, 1983). The STAI-T measured levels of anxiety and is a 20 item self-report measure. Each item is rated on a four point scale, with scores ranging from a minimum of 20 to a maximum of 80, where higher scores represent greater levels of trait anxiety. Internal consistency is 0.90. Test-retest reliability after 63 days is between r = 0.77 and r = 0.90 (Laux, Glanzmann, Schaffner, & Spielberger, 1981).

2.5.2. Memory measures

2.5.2.1. Intrusion diary. Participants were asked to keep a pen and paper diary to record any intrusive image-based memories of the experimental trauma (film) they experienced during their daily lives (e.g. Holmes et al., 2004; James et al., 2015). The diary was kept over the course of 6 day; days 1–3 (pre-intervention) and then days 4–6 (post-intervention) and returned to the experimenter on day 7. Each day in the diary was represented by a separate printed box, each further split into three sections (morning, afternoon and evening). Participants were asked to tick a box in the appropriate section when they experienced an intrusive memory (or to indicate that they had experienced none by drawing a line though that section of that

particular day). They were then asked to briefly describe the content of each of their intrusions marked in the diary (e.g. a silver car crashing on the freeway) so that the experimenter could later use these descriptions to confirm whether the intrusion related to the film. Participants were asked to record all intrusions immediately after they had occurred, or as soon as possible thereafter, and to set aside regular time slots each day to check that their diary was up-to-date. Verbal and written instructions were provided with the diary. Intrusive memories were defined as any memory of scenes of the film that appeared spontaneously in their mind (e.g. "*spontaneously pop into your mind when you are not deliberately thinking about the film*"). Participants were instructed not to include memories that they deliberately recalled and were also given instructions about the form of intrusive memories, that is 'mental images' (e.g. "*in the form of pictures in your mind's eye")* rather than verbal thoughts in the form of words/phrases. Experimenters checked that the intrusion descriptions in the diary were matched to scenes in the film (rather than for example of different films, or everyday life). In this study 100% were matched to the films and were included in subsequent data analyses.

Importantly, days 1–6 were defined by 24 h intervals and not by calendar days (as in other studies using similar set-ups, e.g. James et al., 2015; Hagenaars et al., 2017). That is, day 1 was the first 24 h period after the first lab session (e.g. if this session ended at 4pm, it would run from 4pm that day to 4pm the next day), day 2 the second 24 h period, and so on. Day 4 was the 24 h period immediately following the second lab session, and the beginning of day 4 as a post-intervention time period was marked clearly (visually) in each diary to ensure that days 1–3 and days 4–6 were clearly separated as pre-intervention and post-intervention for all participants.

2.5.2.2. Intrusion diary compliance rating. Participants rated their compliance with the diary at 2 time points, in the second laboratory session for the first 3 days (pre-intervention), and on day 7 via email for the subsequent 3 days (post-intervention). Ratings were made on a scale anchored from 1 '*not compliant*' to 10 '*very compliant*'.

2.5.2.3. Impact of event scale-revised (IES-R; Weiss & Marmar, 1997). The IES-R was administered on final day of the experiment (Day 7) using the German version (Maercker & Schützwohl, 1998). It was used to assess participants' distress related to the experimental trauma during the past 7 days (i.e. items were anchored to the trauma film). The IES-R is a 22-item self-report measure. Each item is rated on a scale from 0 'not at all' to 4 'extremely'. The IES-R Total score ranges from a minimum of 0 to a maximum of 88, where higher scores indicate higher levels of distress. The IES-R consists of three subscales, "Intrusion", "Avoidance" and "Hyperarousal". Internal consistency (Cronbach's α) for the German version is: 0.90 (intrusion subscale), 0.90 (hyperarousal subscale), and 0.79 (avoidance subscale). Test-retest reliability is 0.80 for the intrusion subscale, 0.79 for the hyperarousal subscale, and 0.66 for the avoidance subscale (Maercker & Schützwohl, 1998). Although used most commonly to measure levels of distress on a continuum, a cut-off of 33 has been proposed (Creamer, Bell, & Failla, 2003) for a likely diagnosis of PTSD, with a sensitivity of 0.91.

2.5.2.4. Verbal recognition memory test. The recognition memory test comprised 48 'true/false' written statements relating to each of the 16 scenes that made up the trauma film (3 per scene). Examples included 'Scene 1: *The sun was shining in the cemetery*' and 'Scene 3: *A white car was involved with the accident*'. Participants indicated '*yes*' or '*no*' (on paper) as to whether or not they recognized the written statement as belonging to the film viewed 7 days before.

2.5.3. Film measures

2.5.3.1. Pre-to post-film mood ratings. Participants rated the emotions sad, scared, calm, disgusted, hopeless, happy, aghast, frightened, and helpless on 9 visual analogue scales (VAS) given pre- and post-film. Participants rated how they felt '*right at this very moment*' on scales anchored from 0 '*not at all*' to 10 '*extremely*'. A composite mood score was calculated by summing the 9 emotions, with happy and calm reverse-scored.

2.5.3.2. Film attention and affect rating. Following film viewing participants also rated how much attention they had paid to the film, and how much they were emotionally affected by the film on scales anchored from 0 '*not at all*' to 10 '*extremely*'.

2.5.4. Computer game play ratings

Following computer game play in both active conditions, ratings for levels of game concentration [*How well did you concentrate during game play?*], enjoyment [*Did you enjoy the game you just played?*], difficulty [*How difficult did you find the game you just played?*], and distraction [*How distracted were you when you played the game?*] were made on separate scales anchored from 0 '*not at all*' to 10 –'*very well*'/10 –'very much'/10 –'extremely'/10 –'maximally';

Participants were asked to rate how much they believed playing the game *Tetris or Quiz* 3 days after the emotional film would increase or decrease intrusive images of the film (of the type recorded in the diary) from −10 '*extreme decrease*' to 0 '*no effect*' through to 10 '*extreme increase*' to check for demand characteristics at the end of the experiment (impact rating).

2.6. Data analysis and statistics

2.6.1. Sample size

Sample size was calculated based on findings of prior studies (Holmes et al., 2009, 2010a) albeit at an earlier intervention time point, i.e. we expected a medium to large effect size (d = 0.70, corresponding to f = 0.42). Given this effect size, we calculated a total sample size of n = 90 with power set to 0.95 and α = 0.05 (G*Power 3.1.7).

2.6.2. Random allocation to groups

A minimization scheme was used to allocate participants to group (Altman & Bland, 2005; Scott, McPherson, Ramsay, & Campbell, 2002). Initially, participants were randomly allocated to one of the three groups. Then, after an interim check, to reduce differences in baseline measures between the groups occurring by chance, the final 45 participants were allocated to group based upon three selected baseline scores (reported number of intrusions over the first three days, age, and STAI). This allowed us to minimize possible baseline differences between the three groups on these three variables, which were deemed likely to affect intrusion frequency.

2.6.3. Data analysis

Number of intrusions, baseline variables (Age, SCL-90-R, STAI-T, ERQ), trauma questionnaires (ETI, IES-R), diary compliance, film ratings, recognition memory test, ratings of computer game play and the reminder cue presentation measures were skewed, thus between-group comparisons (reminder + *Tetris* vs. reminder + *Quiz* vs. reminder-only) were conducted using the Kruskal-Wallis-test for independent samples, and planned comparisons were conducted using the Mann-Whitney-test. For comparisons of mood pre- and post-film we first conducted a Friedman test for dependent variables to analyze mood deterioration and then compared difference scores of mood pre-to post-film by a Kruskall-Wallis test. Gender was analyzed between groups using a Chi-squared test.

Primary outcome. A Kruskal-Wallis test was used for between-group comparisons in the mean number of intrusions at baseline (pre-intervention, days 1–3). Baseline imbalances were subsequently controlled for using a Quade test (non-parametric ANCOVA; Quade, 1967) for between-group comparisons in the mean number of intrusions post-intervention (days 4–6) followed by planned comparisons (see Fig. 2). The Quade test involves a ranking of both the dependent (intrusions

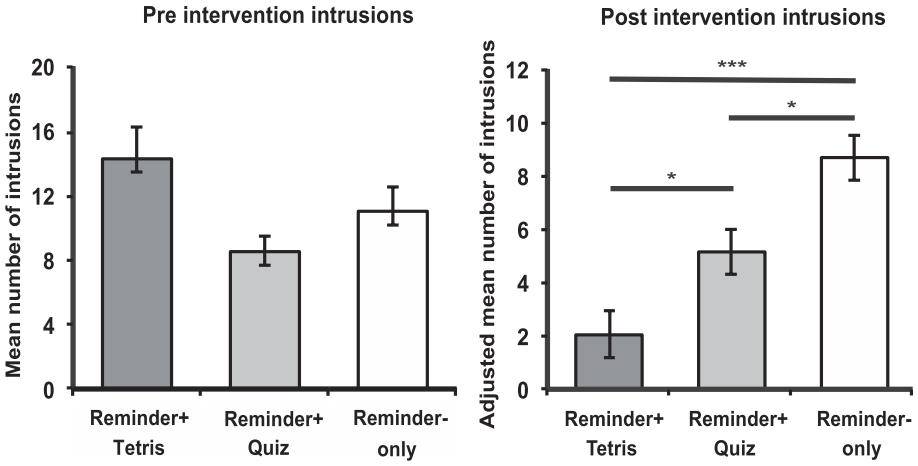

Fig. 2. Intrusive memories of experimental trauma pre intervention (left) and post intervention controlling for pre intervention intrusive memories (right). Error bars depict s.e.m. *p < 0.05, ***p < 0.001.

post-intervention) and the covariate variable (intrusions pre-intervention) ignoring the grouping factor. In a second step a regression analysis of the dependent variable on the covariate is conducted saving the unstandardized residuals as a new dependent variable. In a final step these residuals are tested between groups by running a one-way analysis of variance.

Additionally, day-to-day differences in the number of intrusions were calculated, and entered into a two-way mixed ANOVA with time as within-subjects factor and group as between-subjects factor. Post-hoc one-way ANOVAs were performed to detect for which day-to-day changes there were differences between the groups, followed by independent sample t-tests.

Two-tailed tests and an alpha level of 0.05 were used for statistical comparisons.

3. Results

3.1. Pre-laboratory baseline questionnaires

There were no statistically significant differences between groups on prior trauma history (ETI; $X^2(2, N = 86) = 3.37$, p = 0.185, d = 0.404), the GSI of the SCL-90-R $X^2(2, N = 85) = 0.602$, p = 0.740, d = 0.169, ERQ cognitive reappraisal $X^2(2, N = 86) = 0.339$, p = 0.844, d = 0.126, ERQ expressive suppression $X^2(2, N = 86) = 0.756$, p = 0.685, d = 0.188, STAI-T $X^2(2, N = 86) = 0.933$, p = 0.627, d = 0.210. Further there were no group differences for gender $X^2(2, N = 86) = 0.31$, $p = 0.86$, d = 0.120, or age $X^2(2, N = 85) = 1.96$, p = 0.376, d = 0.307 see Supplementary Table 1.

3.2. Primary outcome measure: diary intrusions post-intervention

A Kruskal-Wallis test on the distribution of number of intrusions per group pre-intervention (day 1–3) revealed no significant differences between groups at baseline $X^2(2, N = 86) = 4.798$, p = 0.091, $\eta^2 = 0.067$ (Fig. 2 and Table 1). As the distribution of intrusions pre-intervention was skewed ($M_{Tetris} = 14.25$ (10.67), $M_{Quiz} = 8.50$ (4.97), $M_{reminder\text{-}only} = 11.00$ (8.21)) and contained outliers, a Quade test controlling for pre-intervention intrusions was calculated to analyze differences between groups in post-intervention intrusions (see methods section 2.6.3). As a part of the Quade test, the one-way ANOVA of unstandardized residuals of a regression analysis (pre-intervention intrusions on post-intervention intrusions) showed a significant effect of intervention type ($F_{2,83} = 12.89$, p < 0.001, $\eta_p^2 = 0.237$).

As predicted, planned comparisons (Games-Howell corrected) between all groups showed that the reminder + *Tetris* group experienced significantly fewer intrusions post-intervention (days 4–6) compared to the reminder-only group ($M_{Tetris} = 3.18$ (2.83), $M_{reminder\text{-}only} = 8.61$ (8.10); Mean $difference_{Residuals} = -25.29$, SE = 4.90, p < 0.001, d = 1.37). Critically, the reminder + *Tetris* group also experienced significantly fewer intrusions post-intervention than did the reminder + *Quiz* group ($M_{Quiz} = 4.13$ (4.06); Mean $difference_{Residuals} = -11.22$, SE = 4.48, p = 0.040, d = 0.653). Contrary to predictions, we found that the reminder + *Quiz* group experienced significantly fewer intrusions post-intervention (days 4–6) compared to the reminder-only group (Mean difference = −13.97, SE = 5.32, p = 0.030, d = 0.693), see Fig. 2.

Fig. 3 depicts the trajectory of the mean number of intrusions over the 6 days of continuous recording split by intervention group allowing visual inspection of the within-groups comparison. Interestingly, only in the reminder-only group do intrusions *increase* significantly from day 3 to day 4 ($M_{day\ 3} = 2.64$ (3.12), $M_{day\ 4} = 5.68$ (7.63), z = −2.24, p = 0.025, d = 0.935).

In a more detailed analysis, to test whether changes in the number of intrusions from one day to the next differed between groups, a two-way mixed ANOVA was performed, with time as a within-subject factor, and group as a between-subjects factor. This analysis revealed a significant main effect of time ($F_{2.29,\ 190.11} = 12.92$; p < 0.001; $\eta_p^2 = 0.135$; Greenhouse-Geisser-Correction used), a significant main effect of group ($F_{2,\ 83} = 5.80$; p = 0.004; $\eta_p^2 = 0.123$), and a time × group interaction ($F_{4.58,\ 190.11} = 3.89$; p = 0.003; $\eta_p^2 = 0.086$).

Table 1
Number of intrusive memories of experimental trauma pre- and post-intervention, and verbal recognition memory test scores, in each of the three conditions.

Measure	Reminder-only (*n* = 28)		Reminder + *Tetris* (*n* = 28)		Reminder + *Quiz* (*n* = 30)	
	M	*SD*	*M*	*SD*	*M*	*SD*
Pre-intervention number of intrusions in Diary (days 1–3)	11.00	8.21	14.25	10.67	8.50	4.97
Post-intervention number of intrusions in Diary (days 4–6)	8.61	8.10	3.18	2.83	4.13	4.06
Verbal recognition memory test scores	36.25	5.01	34.07	5.79	36.27	5.23

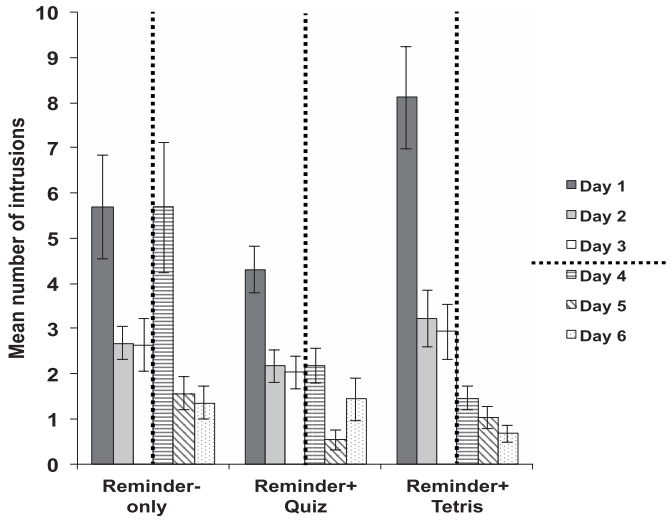

Fig. 3. Trajectory of mean number of intrusive memories of experimental trauma over all 6 diary days per condition. Days 1, 2 and 3 are pre-reminder and intervention, while Days 4, 5 and 6 are post-reminder and intervention. Error bars depict s.e.m.

Post-hoc one-way ANOVAs showed group differences in the change in number of intrusions from day 3 to day 4 ($F_{2,83} = 6.51$; $p = 0.002$; $\eta^2 = 0.136$), and from day 4 to day 5 ($F_{2,83} = 4.48$; $p = 0.014$; $\eta^2 = 0.097$), but not between the other days. From day 3 to day 4 (i.e., from the 24 h period prior to the intervention period to the 24 h period immediately afterwards), the number of intrusions increased in the reminder-only group (M = 3.04, SD = 7.41), remained stable in the reminder + *Quiz* group (M = 0.13, SD = 2.21), but decreased in the reminder + *Tetris* group (M = −1.46, SD = 2.98). T-tests indicated significant differences between all 3 groups (reminder + *Tetris* vs. reminder-only: $t_{54} = 2.98$, $p = 0.004$, $d = 0.81$; reminder + *Tetris* vs. reminder + *Quiz*: $t_{56} = 2.33$, $p = 0.023$, $d = 0.62$; reminder + *Quiz* vs. reminder-only: $t_{56} = 2.05$, $p = 0.045$, $d = 0.55$). From day 4 to day 5, number of intrusions tended to decrease, with the most pronounced decrease in the reminder-only group (M = −4.11, SD = 7.79; reminder + *Tetris*: M = −0.43, SD = 1.53; reminder + *Quiz*: M = −1.63, SD = 2.08), with significant differences between the reminder + *Tetris* and the reminder-only groups ($t_{54} = 2.45$; $p = 0.018$, $d = 0.67$), the reminder + *Tetris* and the reminder + *Quiz* groups ($t_{56} = 2.50$; $p = 0.015$, $d = 0.67$), but not between the reminder + *Quiz* and reminder-only groups ($t_{56} = 1.68$; $p = 0.099$, $d = 0.45$).

3.3. Intrusion diary compliance

For the 3 days pre-intervention, there was no significant difference between groups on ratings of diary compliance $X^2(2, N = 86) = 0.884$, $p = 0.643$, $\eta^2 = 0.010$. This was also the case for the 3 days post-intervention $X^2(2, N = 72) = 1.07$, $p = 0.585$, $\eta^2 = 0.015$, see Supplementary Table 2.

3.4. Impact of event scale-revised intrusion subscale

Analysis of the IES-R showed a significant difference post-intervention between groups for the "Intrusion" subscale $X^2(2, N = 86) = 6.64$, $p = 0.036$, $\eta^2 = 0.077$. However, planned comparisons Dunn-Bonferroni-corrected showed no significant differences between the reminder + *Tetris* group and the reminder-only group ($z = -2.12$, $p = 0.103$, $d = -0.470$), nor between the reminder + *Quiz* group and the reminder-only group ($z = -0.191$, $p = 1.00$, $d = -0.041$). There was no significant difference between the reminder + *Tetris* group and the reminder + *Quiz* group ($z = -2.34$, $p = 0.057$, $d = -0.522$), see Supplementary Table 1.

3.5. Verbal recognition memory test

Scores on the written recognition memory test for the film did not differ significantly between groups ($X^2(2, N = 86) = 2.53$, $p = 0.282$, $\eta^2 = 0.029$, Table 1, Supplementary Fig. 1).

3.6. Film measures

3.6.1. Mood pre-to post-film

Tthe Friedman test revealed a significant difference between pre-film and post-film mood ($X^2(2, N = 86) = 82.05$, $p < 0.001$, $\eta^2 = 0.954$). Comparison of the difference scores showed no significant difference of mood deterioration between groups ($X^2(2, N = 86) = 1.06$, $p = 0.588$, $\eta^2 = 0.012$), see Supplementary Table 2. This verified that mood scores deteriorated after viewing the trauma film, but that this deterioration was not different between groups.

3.6.2. Film attention and affect

There was no significant difference between groups for ratings of how much attention participants paid to the film, $X^2(2, N = 86) = 0.099$, $p = 0.952$, $\eta^2 = 0.001$, and how much they were affected by the film, $X^2(2, N = 86) = 5.042$, $p = 0.067$, $\eta^2 = 0.059$; see Supplementary Table 2.

3.7. Computer game play ratings

Participants in the reminder + *Tetris* and reminder + *Quiz* groups showed no significant difference between rating scores for concentration, enjoyment, difficulty and distraction: Concentration, $z = 0.103$, $p = 0.918$, $d = 0.027$; Enjoyment, $z = 0.024$, $p = 0.981$, $d = 0.006$; Difficulty, $z = 0.581$, $p = 0.561$, $d = 0.153$; Distraction, $z = 1.26$, $p = 0.209$, $d = 0.336$, see Supplementary Table 2.

Participants in the reminder + *Tetris* and reminder + *Quiz* groups did not differ in their impact (demand) ratings for their allocated intervention (i.e. *Tetris* in the reminder + *Tetris* group and *Quiz* in the reminder + *Quiz* group), $z = 1.19$, $p = 0.234$, $d = 0.319$, or their unallocated intervention, $z = -0.360$, $p = 0.719$, $d = -0.097$, see Supplementary Table 2.

3.8. Reminder cue presentation measures

The duration of the cue presentation (presentation of images on power point), recall for each clip following the cue, and break was not statistically different between groups: cue presentation duration, $X^2(2, N = 86) = 3.50$, $p = 0.174$, $\eta^2 = 0.041$; recall duration, $X^2(2, N = 86) = 2.41$, $p = 0.299$, $\eta^2 = 0.028$; break, $X^2(2, N = 86) = 0.121$, $p = 0.941$, $\eta^2 = 0.001$, see Supplementary Table 2.

4. Discussion

Results showed that the frequency of intrusive memories (reported in a daily diary) of an experimental trauma (film) was lower for participants who underwent an intervention procedure – a memory reminder task followed by *Tetris* game play - delivered 3 days after the experimental trauma, compared to two control conditions (1) participants who underwent a memory reminder task followed by *Quiz* (a verbal computer game), and (2) participants who completed only the memory reminder task only, both in line with predictions. Contrary to predictions, results showed that a reminder task followed by *Quiz* game play led to a significant reduction of intrusive memories compared to the reminder-only condition, which is of interest for a variety of reasons. Declarative memory (recognition memory test) for the film appeared to be equivalent across conditions. Hence our study provides results relating to all three aims formulated in the introduction: i) The

visuospatial intervention (memory reminder task followed by *Tetris* game play) was effective even if administered 3 days after the film; ii) this effect held not only against a simple control task (reminder only) but also against an *active* control condition with another computer game (memory reminder task followed by *Quiz*); iii) The effect of the active control condition (memory reminder task followed by *Quiz*) in reducing intrusive memories (albeit weaker than that for the memory reminder task followed by *Tetris*) questions the postulated modality specificity of the intervention rationale.

Participants in the three groups did not differ in terms of baseline variables (e.g. trauma history, emotion regulation), with similar ratings for diary compliance and mood deterioration from pre-to post-film. Crucially, participants in the two gameplay conditions also reported comparable levels of enjoyment, concentration, difficulty, distraction and expected impact regarding the two computer games. Differences in pre-intervention intrusions were controlled for in the analyses. Hence, these variables are unlikely to have accounted for the effect of the active intervention conditions.

A detailed view of the day-to-day changes confirms the main results. Crucially, between days 3 and 4, i.e. from immediately before to immediately after the intervention, the three groups differ significantly in their change in number of intrusions: Overall, there is a similar pattern of change in intrusions, with a greater decrease in the number of intrusions from pre-to post-intervention in the reminder + *Tetris* group compared to each of the other two groups, in line with the hypotheses. Further, there is a greater decrease in the reminder + *Quiz* group compared to the reminder-only group. The only other point where groups differ significantly is the change between days 4 and 5, with greater decreases in number of intrusions in the reminder-only and reminder + *Quiz* groups than the reminder + *Tetris* group. This could in part simply reflect the more substantial reduction in number of intrusions that occurred the previous day in the reminder + *Tetris* group, potentially precluding the possibility of observing further large decreases. However, if the pattern of results is interpreted as indicating that reminder + *Tetris* led to an immediate reduction in intrusion frequency, but no greater rate of decay thereafter, this could raise questions about the longevity of effects over time. A limitation of the study is that it cannot answer questions about longevity of effects, as there is no data beyond day 6, and the rapid natural decay in the number of intrusions resulting from the film stimuli used means that we would not expect to be able to observe longer-term effects in such an experimental study. However, within clinical studies it would be useful to investigate the longevity of any effects on intrusions and other clinical outcomes.

Interestingly, our current data indicates that the memory reminder task delivered in isolation in the intervention session (72 h after the experimental trauma), without a further interference task led to a significant *increase* in intrusions over the next day (Fig. 3 from day 3 to day 4). Such effects remain to be better understood, but one hypothesis is that by coming back for the second visit the memory trace was reactivated in the same context where the film was shown (laboratory) and the memory for the film may have been strengthened leading to more intrusions. Further work should examine this possibility.

A driving interest in the current study was the time frame of the delivery of the experimental intervention. Thus, a key finding of our study is that the intervention involving memory reminder plus *Tetris* was effective *3 days* after an experimental trauma. Previously, the study on which the current design was based had tested the intervention only at 24 h post experimental trauma (James et al., 2015). Prior to this the time interval between the event and the intervention had been even shorter and within 6 h post-event (e.g. Holmes et al., 2009, 2010). These early time window studies inspired clinical translation to a related intervention delivered within 6 h of real trauma (Horsch et al., 2017; Iyadurai et al., 2018). However, there is both theoretical interest and clinical relevance of pushing the time window back even further. Thus the James et al. (2015) experimental study was the first to our knowledge to test the experimental intervention outside the so-called memory consolidation time window, i.e. once the memory was assumed to have consolidated. Subsequently, another study has also extended the intervention time window to several days post analogue trauma (Hagenaars et al., 2017). This study also showed effects of competing task-based interventions on older intrusive memories, in line with reconsolidation-based approaches (Monfils & Holmes, 2018). Further extending the time window for intervention is of interest both as a conceptual test of replication at longer time intervals, and because demonstrating effects at longer time intervals post-event would enhance the range of applications in real life. Many people experiencing a traumatic event may not seek professional help until later than 24 h post-trauma. Thus, if we seek to develop a secondary prevention intervention to reduce intrusive memories in the aftermath of trauma, a time-window of effectiveness of more than 24 h will be useful.

A critical limitation of the James et al. (2015) study was that it lacked a non-visuospatial control task (James et al., 2015). We addressed this here by the addition of the reminder + *Quiz* group. We do not know why the *Quiz* game also led to a reduction in intrusions compared to the control condition (reminder-only). It may be that working memory tasks may help reduce intrusions by a general taxation that is not modality specific (e.g. Engelhard et al., 2011; Van den Hout & Engelhard, 2012), an important point that remains to be further explored (see later). Previous studies that have tested *Quiz* (or other verbal tasks, e.g. backward counting) in the memory consolidation (rather than reconsolidation) time window have not typically found a significant reduction in intrusions between such verbal tasks compared to no-task control groups. On the contrary, in some studies verbal tasks even led to an increase in intrusions (Bourne, Frasquilho, Roth, & Holmes, 2010; Holmes et al., 2004, 2010a). However, a recent study, like the current one, also indicates a beneficial effect of a word game task at a longer time interval post experimental trauma, also when compared to a reactivation-only condition (Hagenaars et al., 2017). In this study, the reactivation plus word games condition appeared to result in fewer intrusions than did the reactivation plus Tetris condition. Another intriguing possibility in the current experiment is that the impact of the verbal task compared to control is driven not simply by the verbal task, but rather by the *increase* in intrusions seen in the reminder-only condition. This makes the comparison between the two computer games (which both include the reminder) particularly important. Critically, when comparing the memory reminder task followed by *Tetris* game play with the reminder task followed by *Quiz* game play, there is a significantly lower frequency of intrusions in the procedure including *Tetris*. On balance, our results indicate that the procedure using *Tetris* may have a more powerful effect on reducing intrusions than did the other computer game. However, given the findings by Hagenaars et al., 2017 this should be explored further.

Nevertheless, results from our study thus call into question the modality specificity of the effect of cognitive task interference on subsequent intrusion frequency. Task modality is an important area of future enquiry given the mixed findings in the field (Gunter & Bodner, 2008; Krans et al., 2009; Engelhard et al., 2010; Krans, Näring, Holmes, & Becker, 2010; Logan & O'Kearney, 2012; Brewin, 2014). Future work should continue to contrast alternative games hypothesized to share visuospatial or verbal working memory resources, to test the role of modality-specificity in reducing intrusions and ascertain which tasks are mostly likely to be helpful. Objective tests that could tease apart both how much load, and of which modalities, would help in this endeavor. For future studies, it might therefore be fruitful to also assess *verbal* intrusions in the diary in order to potentially discover differential effects of task modality on intrusion modality. Tied to this, future studies could also implement a *Quiz* control condition in a less visuospatial way, providing *Quiz* questions orally rather than on a screen. From a translational perspective we are interested in all tasks that might be helpful in reducing intrusions (and should take care not to use ones that might increase intrusions).

Returning to the translational interest in helping ameliorate post-

traumatic stress symptoms, early stage trials with patients have provided positive results suggesting that emotional memories can be influenced by the noradrenergic beta-blocker propranolol (Kindt & van Emmerik, 2016). There have also been negative findings, i.e. traumatic memories in PTSD were *not* influenced by propranolol or the glucocorticoid antagonist mifepristone across three studies (Wood et al., 2015). However, drawing on concepts from reconsolidation-update mechanisms may open up a new way to encourage treatment innovation for PTSD and other disorders (Debiec, 2012; Monfils & Holmes, 2018), here within a cognitive behavioral rather than pharmacological approach. To date, early steps at clinical translation of this approach have predominantly looked at the memory consolidation window (within 6 h of the traumatic events; Horsch et al., 2017; Iyadurai et al., 2017) rather than older trauma memories (i.e. a reconsolidation time window; > 24 h). Future clinical translation studies at longer time intervals post-trauma are warranted and are underway (Kessler et al., 2018).

One clinically important aspect of our results is the fact that both the *Tetris* and *Quiz* intervention left recognition memory for aspects of the trauma film intact while reducing diary intrusions. This finding is in keeping with previous research (e.g. Brewin & Saunders, 2001; Deeprose, Zhang, DeJong, Dalgleish, & Holmes, 2012; Holmes et al., 2009; Holmes et al., 2010a; Krans et al., 2010). Findings may suggest a dissociation between perceptual memory intrusions versus episodic memory for traumatic events (e.g. Brewin, 2014), see also Lau-Zhu et al., (manuscript under review). Future work is required to understand the precise mechanisms of action. From a legal and subjective perspective, it is often important for patients not to forget the events per se but to be able to discuss them without intense reliving in the form of intrusive memories (Holmes, Sandberg, & Iyadurai, 2010b).

There are several limitations of this work. Although the idea of "reconsolidation-update mechanisms" guided our hypotheses, study design and explanation of results, our study itself does not provide evidence for reconsolidation processes per se. Due to the lack of 'no-reminder + *Tetris/Quiz*' control groups, we could not demonstrate that reactivation is a necessary prerequisite for an interference task *(Tetris* or *Quiz)* to be effective. Another limitation relates to the use of film footage as an experimental analogue of traumatic events. One could argue that this does not mirror real-life trauma and hence conclusions are hard to draw regarding clinical applications (James et al., 2016). Although this remains a valid criticism, it should be noted that the DSM-5 (American Psychiatric Association, 2013) was updated to potentially include (when work-related) viewing of aversive film footage as a possible source of traumatization (A criterion). Another limitation concerns the fact, that participants rated their compliance with the diary on a self-report scale. This is potentially biased and does not necessarily capture true variations in how diligent participants were in recording their intrusions.

In sum, in the current study we demonstrated that 3 days after experimental trauma (after the time frame for memory consolidation to have occurred), an intervention comprising a memory reminder task and short delay prior to a 15 min cognitive interference task (*Tetris*) led to a reduction in intrusion occurrence, compared to both an active control (reminder + *Quiz*), and compared to a reminder-only condition. The fact that both computer games showed an effect on reducing subsequent intrusion frequency compared to reminder-only questions the assumed modality-specificity of the intervention, and also calls for further examination of the reminder-only condition in possibly increasing intrusions. Of the two games, the *Tetris* procedure showed a significantly greater reduction in intrusions, and therefore it is possible that visuospatial tasks may have additional benefits as a choice of task in translating such work to clinical populations. Our findings open the possibility of developing new interventions to reduce the impact of intrusions after trauma. Should related effects hold true for older memories in clinical populations (as an initial case series study suggests; Kessler et al., 2018), then such a brief intervention approach (memory reminder task plus cognitive interference) might provide a relatively language-free, cost-effective and scalable specific treatment technique to help people reduce intrusive memories of trauma that happened more than 24 h ago (Monfils & Holmes, 2018). This could significantly enhance the range of possible applications as a secondary prevention intervention, as many people may seek help only more than 24 h after experiencing a traumatic event.

Conflicts of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Author contributions

HK, A-CS, SEB, AK, NA and EAH conceived and designed the study. ELJ, SEB, IAC and EAH provided methodological support. MvR and KH performed the experiments. HK, A-CS, SEB, AK, NA and EAH analyzed the data. HK, A-CS, ELJ, SEB, AK, NA and EAH drafted the paper. MS and SH provided additional critical revisions to the manuscript's intellectual content. All authors contributed to and approved the final manuscript.

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Data availability

The dataset is stored on local systems and can be made available on reasonable request.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jbtep.2019.01.006.

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