Do cognitive tasks reduce intrusive memory frequency after exposure to analogue trauma? An experimental replication

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Abstract

Cognitive task interventions that interfere with visuospatial working memory during the memory consolidation window hold promise for reducing intrusive memories in trauma-exposed people. Our study provides an independent replication study to test and verify findings that have primarily originated from a single research group. We hypothesised that participants engaging in a visuospatial task (cognitive task intervention including Tetris or D-Corsi) following a trauma film paradigm (TFP) would report fewer intrusive memories over the course of a week, when compared to controls. Participants (*N*=110) were randomly assigned to an experimental condition after viewing the TFP. Generalized linear mixed models indicated that the cognitive task including Tetris was associated with fewer intrusions for the TFP, compared to both the D-Corsi-intervention and control conditions. Our findings are congruent with existing literature indicating that cognitive tasks, such as an intervention including Tetris, may promote effective memory consolidation after exposure to a potentially traumatic event.

Key words: Intrusive memories, intrusions, trauma, memory consolidation, visuospatial tasks, visuospatial working memory, replication

The replicability of key findings in psychology has been called into question (Ioannidis, 2012; Zwaan, Etz, Lucas, & Donnellan, 2018). It is imperative that findings with clinical implications are subject to independent replication to ensure the veracity of findings and to protect patients and consumers from promising, but ultimately unreliable, interventions. One approach, posited as a science-informed intervention that may help to reduce trauma-related intrusions, is the use of cognitive interventions, which include a demanding visuospatial task, such as Tetris. Used in this way, Tetris is part of a brief intervention involving a) mental rotation practice b) reminder cue for the trauma event c) Tetris gameplay.

Several experiments have shown that a cognitive-based Tetris intervention is associated with fewer intrusive memories when administered in the first few hours following exposure to an analogue trauma (Holmes, James, Coode-Bate, & Deeprose, 2009; Holmes, James, Kilford, & Deeprose, 2010) or a potentially traumatic event (Horsch et al., 2017; Iyadurai et al., 2018), when memories are thought to be "consolidated" into long-term memory (Dudai & Morris, 2000). Given that other visuospatial tasks also hold promise in this regard (e.g. Deeprose, Zhang, DeJong, Dalgleish, & Holmes, 2012), the current climate of the "replicability crisis" in psychology demands independent replication of such encouraging findings.

In non-clinical samples, efficacy of visuospatial tasks administered in the consolidation phase of memory has been demonstrated for disruption to intrusive memories following exposure to analogue trauma utilising the Trauma Film Paradigm (TFP; see James et al., 2016 for an overview). Holmes and colleagues' (2009) initial study demonstrated that participants in a cognitive intervention involving Tetris reported fewer intrusive memories for the TFP over the course of a week, compared to controls (who were asked to sit silently), when Tetris was played for both 10- and 30-minutes after viewing a TFP and associated reminder cue to provoke intrusive symptoms. In a subsequent study, Holmes et al. (2010)

used 10-minutes of Tetris gameplay following a reminder task, with a verbal task (Pub Quiz), and silence as the comparison conditions at 30-minutes (Experiment 1) and 4-hours (Experiment 2) after viewing of a TFP and reminder cue also. In line with the earlier study, participants in the cognitive intervention including Tetris reported fewer intrusions over the following week as compared to the other conditions. The reminder cue appears to be an important component of the Tetris-based intervention, as indicated Lau-Zhu, Henson, and Holmes' (2019) findings that intrusion frequency was significantly lower for participants in the Tetris-plus-reminder condition, as compared to those in the Tetris-only, or reminder-only, conditions.

These initial findings have been extended by the original research lab in two clinical samples. Iyadurai et al. (2018) administered a cognitive task intervention including Tetris gameplay for 20-minutes, following game practice and a reminder cue, in a hospital emergency department to patients within 6 hours of participants experiencing or witnessing a car accident. Participants in the Tetris intervention condition reported fewer intrusive memories and less distress arising from intrusions at one-week follow-up compared to those in the control condition (activity log), as well as a more notable rate of decline over this period. Horsch and colleagues' (2017) proof-of-concept randomised controlled trial compared intrusion frequency in a cognitively-based Tetris intervention versus Control (usual-care) sample of women who had undergone emergency caesarean section. The Tetris intervention group reported fewer intrusive memories over a 1-week period, having played the game for single a 15-minute period.

Further encouraging findings have also been reported in studies of memory reconsolidation following exposure to analogue trauma after 24-hours (James et al., 2015), and 4-days (Hagenaars, Holmes, Klaassen, & Elzinga, 2017), and in a clinical PTSD sample (Kessler et al., 2018). Given that large effect sizes arising from small samples (Holmes et al., 2009; Holmes et al., 2010) are particularly vulnerable to not being robust, we sought to replicate and extend on the findings of Holmes et al. (2010).

Replications of the cognitive intervention including Tetris by independent groups are necessary in order to reliably determine if memory consolidation processes can indeed be influenced following exposure to a potentially traumatic event. However, unconvincing results in non-clinical samples have been reported (Asselbergs et al., 2018; Bruhl, Heinrichs, Bernstein, & McNally, 2019). Asselbergs and colleagues' (2018) study tested the effect of two different tasks on intrusive memory frequency for a TFP. The games were designed to tax working memory by having participants guide a plane through the sky (Experiment 1) and by playing a game designed specifically by the researchers that was akin to the Tetris intervention described previously (Experiment 2). Dual-task modes were also used in both experiments. No beneficial outcomes for any of the tasks were found in either experiment. The study of Bruhl et al. (2019) did not utilise a memory consolidation period of at least 10 minutes (Walker, Brakefield, Hobson, & Stickgold, 2003) or use a reminder cue of the film material and so differed from the original studies in this regard. This variation from a close replication not withstanding, Bruhl et al. also reported that Tetris did not result in fewer intrusions over the subsequent week when compared to a control group.

In order to enhance the evaluation process of scientific outcomes, there is a crucial need for independent investigation of propitious, novel findings (Zwann et al., 2018). Accessible and low-cost approaches to facilitating memory consolidation and reconsolidation to reduce intensity and frequency of traumatic intrusions are needed to improve clinical outcomes for the prevention and treatment of posttraumatic stress disorder (PTSD). Visuospatial tasks offer promise in this regard. For clinical utility to be optimised, the task should ideally require little clinician oversight or administrative burden (Kessler et al., 2018). Previous studies (Holmes et al., 2009; Holmes et al., 2010) have used a cognitive intervention with Tetris in 'marathon mode', thereby requiring the researcher to monitor finishing times and to be present to reset the task when participants were no longer able to clear the screen of blocks. As such, a time limited task with continuous gameplay awaits empirical examination.

With regard to clinical utility, previous studies (Holmes et al., 2009; Holmes et al., 2010) utilised paper-and-pen diaries to monitor intrusive memory frequency. Experience sampling methods via mobile devices may be an efficient manner to record this information by allowing participants to receive notifications advising of survey availability and for remote adherence monitoring, while also removing the possibility of participants retrospectively making entries outside of the window of time under investigation. From a clinical translation perspective, such technologies would enable practitioners to monitor client data in real-time and could also facilitate successful completion of between-session tasks by clients.

Finally, elucidation of how cognitive interventions which include Tetris impact on intrusive memories was a further factor in choosing to replicate and extend upon previous studies. Consolidation of memories requires cognitive processing resources such that a cognitively demanding competing task could conceivably interfere with consolidation. The ‘visuospatial hypothesis’ (Deeprose et al., 2012, p.759) posits that engagement in visuospatial tasks might reduce the occurrence of intrusive images by demanding sensory-perceptual cognitive resources that would otherwise be utilized for memory encoding purposes. In other words, given that working memory and cognitive processing are thought have a finite capacity (Baddeley & Andrade, 2000; Friedman & Miyake, 2000), taxing these resources may prohibit the cognitive processing of upsetting information and interfere with the encoding of features of trauma. Interestingly, the question of whether or not such competing tasks need to be of a similar sensory modality to that of the intrusions themselves, remains unresolved, with some suggestions that it might be the overall demand on working memory (through the “central executive”) which is critical, regardless of the modality which draws upon these resources (Gunter & Bodner, 2008).

Moreover, the modality of the activity is considered important: Iyadurai et al. (2018) proposed that cognitive interventions which include visuospatial Tetris tasks specifically interfere with the visual aspects of intrusive memories, rather than simply serving as distraction tools. Lau-Zhu, Holmes, Butterfield, and Holmes' (2017) finding of correlations between Tetris game play and visuospatial working memory (VWM), but not general or cognitive abilities, suggests the likelihood of VWM involvement in maladaptive imagery that warrants further investigation. To this extent, we implemented a second visuospatial intervention, D-Corsi, which was a modified, digital version of the Corsi task (Corsi, 1972) to test spatial and non-verbal components of working memory, in addition to a cognitive intervention including Tetris and the Control conditions. The D-Corsi intervention involved two components a) the reminder cue for the trauma event b) D-Corsi gameplay.

We therefore aimed to provide a test of replication of the study conducted by Holmes and colleagues (2010). In particular, the test of replication was of Experiment 2, with focus on only two of the original experimental conditions (the cognitive intervention including Tetris and the Control condition; Holmes et al., 2010). To assess data reproducibility and robustness, we used larger sample sizes. In consideration of clinical utility, our cognitive intervention included a structured Tetris task was used that allowed for time, difficulty and continuity to be managed prior to task implementation. A test of extension to a novel task (D-Corsi) was also used to help in identifying the key task characteristics required to interfere with consolidation processes and, in turn, the trajectory of intrusive memories. Specifically, D-Corsi was used, which, although cognitive and visuospatial in nature, differed from the Tetris intervention in three key ways: 1. D-Corsi did not require mental rotation, 2. D-Corsi task did not require constant visual engagement in the next object of interest, but rather attending to the blocks only as they are highlighted, and 3. D-Corsi required recall of block sequences.

Based on earlier studies, (Deeprose et al., 2012; Holmes et al., 2009; Holmes et al., 2010), we expected that participants in the visuospatial task interventions (Tetris-and D-Corsi-based) would report decreased intrusive memory frequency for the TFP over the course of a week as compared to those in the control condition. Previous clinical findings reported faster declines in intrusive memory frequency for participants in the cognitive intervention task that involved Tetris (Iyadurai et al., 2018). Therefore, our novel prediction in this non-clinical sample was that participants in both visuospatial task conditions would report faster declines in intrusive memory frequency as compared to controls.

Method

Participants

Participants were recruited through advertisements placed online, in the local community, and around the university campus. They were required to be aged 18-years or over and English speakers. Exclusion criteria were a) recent involvement in a motor vehicle accident (MVA) due to MVA content comprising a majority of the trauma film paradigm, b) current suicidal ideation or thoughts of self-harm as indicated by the Patient Health Questionnaire-9 (PHQ9; Kroenke, Spitzer, & Williams, 2001), c) active traumatic stress symptoms as indicated by the Trauma Screening Questionnaire (Brewin et al., 2002). Ethical approval was obtained from the Human Research Ethics Committee at the University of Technology Sydney (reference number: ETH17-1455) and all participants provided informed consent. Participants who completed all components of the study received a $30 e-gift voucher. The study was pre-registered on the Open Science Framework (https://osf.io/vutcw/).

Power

Previous studies, which have used cognitive interventions including Tetris, have detected medium to large-sized between group differences (e.g. $d = .91$ in Holmes et al., 2009; $d = .62$ & $.70$ in Holmes et al., 2010) in post-task intrusion frequency. Consistent with these studies, 26 participants per group condition were needed to be able to detect a large-sized between groups effect with a two-tailed α of 0.05 and 80% power. We oversampled to allow for attrition and the possibility that effect sizes may not be large. Figure 1 outlines the participant enrolment process.

Tasks and Materials

Trauma film paradigm (TFP). The purpose of the film was to serve as an analogue trauma condition in order to evoke intrusive memories and was similar to TFPs used in previous research (e.g. Holmes et al., 2009; Holmes et al., 2010; James et al., 2015). The TFP ran for 10.5-minutes and consisted of 11 different video clips involving injury, surgery, and themes associated with death. The clips were run together in a continuous movie format (.mp4) and were viewed on monitor screen (52cm x 29cm), with participants sitting 50cm away.

Film reminder cue. As participants completed the experimental ask during the memory consolidation phase for the TFP, the function of this reminder was to orient participants to the TFP content (Visser, Lau-Zhu, Henson, & Holmes, 2018). However, participants were only asked to give the slideshow their full attention, with no specific mention made of recalling the TFP. In line with previous studies (e.g. Deeprose et al., 2012; Holmes et al., 2010), the film reminder cue was a Powerpoint slideshow with a static image from each clip in the TFP being shown for three seconds, in the same sequence it appeared in the TFP. The static images were for the moment prior to the worst aspect of the clip (e.g. a paramedic before he is hit by an oncoming vehicle) to enhance likelihood of intrusive memory occurrences (James et al., 2015). The slideshow was presented on the same screen used for viewing the TFP. Immediately following, participants were asked to take part in the assigned experimental condition.

Cognitive intervention including Tetris. Tetris (UTS Research Version; Blue Planet Software, 2017) is a computer game that requires players to rotate seven different shaped and coloured blocks that fall from the top of the screen in order to create horizontal lines, which then disappear, earning the player points and causing the rate at which the blocks fall to continually increase. In standard modes, the game terminates when the player is unable to make any more lines and the screen becomes full. Consistent with previous research (Holmes et al., 2010), participants were able to see the next three blocks due to be presented and were asked to keep their attention on them also, and to imagine how they would mentally rotate these blocks to create the maximum number of horizontal lines. Tetris was played on a laptop (Macbook Pro) with screen size 29cm x 16cm. Participants used the arrows on the keyboard to rotate the blocks and to alter the descent speed.

Cognitive intervention including Digital Corsi (D-Corsi). The original Corsi tapping task (Corsi, 1972) uses nine wooden blocks on a board to assess VWM and involves participants ‘tapping’ the blocks to indicate the order in which the assessor presented them. This task is used in diagnostic assessments of VWM, and has been used in neuropsychological and experimental research (Berch, Krikorian, & Huha, 1998; Bo, Jennett, & Seidler, 2011). Previous research (Brunetti, Del Gatto, & Delogu, 2014) demonstrated that a digital version of the task (e-Corsi) yielded outcomes akin to those of studies that utilized the wooden blocks. We therefore created an automated, digital, 12-minute version of the Corsi task (D-Corsi) for use in our study using the Psychology Experiment Building Language (PEBL; version 0.14; Mueller, 2014; Mueller & Piper, 2014).

The digital blocks were nine blue squares that flashed yellow, in the same pre-determined sequence for each participant. The task was structured so that participants spent 8-minutes on forward block spans (with the number of blocks lighting up gradually increasing from two to six over this time) and 4-minutes going backwards (two to five blocks over this time). The flashing time was 800-msec and a 1400-msec gap was left between sequences. Participants were provided with feedback on the screen after each sequence advising them of whether they had responded correctly or incorrectly. This task was completed on a laptop (Macbook Pro) with screen size 29cm x 16cm, using PEBL 2 for MacOSX as the launcher. Participants used a mouse to click on the boxes in the correct sequence, with the mouse only becoming active once the sequence to be followed had been fully displayed.

Diary for intrusive memory recording. Participants downloaded the MetricWire app (Version 4.1.2; MetricWire, 2017) on to their IOS or Android phones to record intrusive memories of the TFP from Days 0-7. Using verbal and written instructions, participants were informed that intrusive memories could arise spontaneously or have been triggered, but were not those deliberately recalled. In line with previous research (Holmes et al., 2010; James et al., 2015), participants were advised that the memories could take the form of images in the mind or thoughts, and were also asked to include a phrase to describe the memories to ensure diary recordings were for memories of the TFP.

The MetricWire app was set up to make surveys available to participants at the same time on Days 1- 7, three times each day (8:30 am, 2:30 pm, 8:30 pm). On Day 0, participants made a single diary entry in the evening. In total, participants recorded 22 time points using the MetricWire diary app.

On each recording occasion, participants received a notification from the app advising that the survey was ready for them to take. If the survey was not taken within 30-minutes, a reminder notification was automatically sent via the app. The survey started by providing a brief description of an intrusive memory and then participants recorded frequency since last taking the survey, whether the memories arose spontaneously or were triggered (or both), and the perspective for the memory (first- or third- person, or both). As the triggers and vantage perspective of memories were not a focus of the current research, these analyses will be reported elsewhere. Participants were then presented with visual analogue scales to rate how intense, upsetting, and bothersome the memories were on a 0-100 scale and to comment on the content of the memory. If a participant reported zero intrusions for the preceding period, they were then asked to respond to four further questions unrelated to the study. This was done to reduce the possibility that participants would respond zero simply to reduce the burden of responding to the diary.

Demographics. A web-based questionnaire was used to obtain participant demographics of age, gender, main occupation/field of study, and first language.

Visual analogue scales (VAS). The online scales were anchored (0 to 100) on either end of a straight line. Participants dragged the slider to indicate their level of endorsement to questions including attention to the TFP, pre- and post-TFP mood ratings (sad, hopeless, fearful, depressed, horrified), task enjoyment, emotionality for intrusive memories, and diary compliance.

Screening questionnaires (see also Figure 1)**.**

Trauma. Active trauma was assessed for screening purposes only using the 10-item. Trauma Screening Questionnaire (Brewin et al., 2002). Participants selected either Yes (twice or more in the past week) or No in response to items asking about experiences such as *feeling upset by reminders of the event*. Responding *Yes* to six or more items was taken as likelihood of active trauma stress symptoms, and individuals with this rating did not continue on in the study.

Recent involvement in a car accident. Participants were asked if they had recently witnessed or been involved in a car accident. If they answered *Yes*, the survey terminated and they were advised that we recommended discontinuation, and were provided with email details for the researcher to make contact if needed.

Self-harm and suicidal ideation. Question 9 from the PHQ-9 (Kroenke et al., 2001) was used for screening purposes. If a participant endorsed this item at 1 (Several days) or higher, they were contacted by the researcher and were not eligible to continue in the study.

Self-report questionnaires.

Depression. The PHQ-9 (Kroenke et al., 2001) was used to assess levels of depression over the previous 2-weeks. Statements such as *feeling tired or having little energy* were assessed on a 4-point Likert scale (0 = Not at all to 3 = Nearly every day). Internal consistency for the PHQ-9 is strong as indicated by previous research (Berle & Moulds, 2014, Cronbach's α = .91) and the reliability level in the current sample (α = .84).

Anxiety. The PROMIS Short Form v1.0 - Anxiety 7a (Pilkonis et al., 2011) was used to assess anxiety over the past seven days. Statements such as *I felt fearful* and *I felt uneasy* were assessed on a 5-point Likert scale (0 = Never to 5 = Always). Internal consistency for the scale was strong in the current sample (Cronbach's α = .91).

Impact of Events Scale – Revised (IES-R; Weiss, 2007). The 8-item Intrusions subscale of the IES-R is used to assess subjective distress of traumatic events; findings for this measure will be reported elsewhere as distress for the TFP is not a focus of the current research. Participants were asked to respond to statements such as *Other things kept making me think about it* and *I had waves of strong feelings about it* in relation to the TFP for the previous seven days. Items were rated on a 5-point Likert scale (0 = Not at all to 4 = Extremely). The scale is internally consistent (α = .86, Sundin & Horowitz, 2002), with similar reliability in the present sample (α = .88).

Procedure

We commenced with a pilot study on 15 individuals to assess efficacy of the TFP in generating intrusive memories. Task instructions were then refined on the basis of the pilot data and in consultation with the authors of the primary studies (Holmes et al., 2009; Holmes et al, 2010). In our 'close replication' (Brandt et al., 2014) of Holmes and colleagues' study (2010), we included larger sample sizes to assess robustness of the data and reproducibility of findings. The flow of participants through the study is summarised in Figure 2.

Session 1. Participants provided written informed consent and demographic information, and then practiced both experimental interventions: Tetris for two minutes and Visuospatial tapping for six rounds (3 blocks each forward and backward for 3 rounds, approximately two minutes in total). For both tasks, participants were given verbal instructions by the experimenter and asked to repeat these aloud to ensure they had correctly understood the task requirements. Baseline questionnaires were administered for depression, anxiety, rumination, dissociation and intolerance of uncertainty, along with VAS for how sad, hopeless, fearful, horrified, and depressed they felt. Each participant viewed the TFP alone, in a darkened room after the experimenter had provided instructions on how to view the TFP. The VAS were re-administered including ratings for attention to the film. Participants were then asked to go about their day as usual for the next four hours.

Session 2. When participants returned to the lab after attending to their day as usual for four hours, measures were completed regarding activities over the past four hours, intrusion frequency, perspective and cause for the intrusive memories, and VAS asking about distress levels associated with the intrusive memories. Participants were also asked to use key words to describe the memories to ensure they were related to the TFP viewed. After viewing the film reminder cue, participants were then randomly allocated to 12-minutes of Tetris gameplay, D-Corsi or Control [Silence]. In all conditions, the experimenter stayed in the room. In the Control condition, participants were asked to sit quietly and were advised that they were free to think about anything, but not to use any electronic devices or to hold conversation with the researcher.

Afterward, VAS were again administered for intrusive memory frequency and also included task enjoyment. Participants were set up with the diary phone app (MetricWire) and instructions were provided to participants both verbally and via a handout which they were given in regard to monitoring of intrusive memories for the TFP. Prior to leaving the lab, all participants completed a checklist to ensure an understanding of requirements.

Days 0 – 8. Participants started monitoring memories that night (Day 0) using the MetricWire phone app, and then three times each day from Days 1 – 7. On Day 8, participants were contacted via email and provided with a link to the final online questionnaires. On completion, the e-gift voucher was sent to the participant to thank them for their participation in the study.

Statistical Analysis

Data were analysed using the IBM Statistical Package for Social Sciences (SPSS) version 25 and using SAS 9.4 and SAS/STAT 15.1. A non-directional alpha level of .05 was used for all statistical tests. Chi-square tests were used to analyse nominal data. One-way ANOVAs with Bonferroni-corrected pairwise comparisons were used for analysis of between-group differences for age, self-report questionnaire scores, and VAS.

Kruskal-Wallis ANOVAs with Mann-Whitney U tests for pairwise comparisons were used to determine whether there were between-group differences in self-reported attention to the film, diary adherence, and task enjoyment, due to violation of normality assumptions.

Generalized Linear Models with a negative binomial log-link function were used to analyse count variable frequencies of intrusive memories for the TFP post-break, post-task, and on Day 0.

A Generalized Linear Mixed Model (GLMM) was used for between-groups comparisons of intrusive memory frequency across Days 1 to 7. Days 1 to 7, rather than 0 to 7, were analysed given that Day 0 did not include a complete number of assessment occasions. A first order autoregressive covariance structure was specified.

The hypotheses for the multiple research questions investigated as part of the data collection had been specified as part of the preregistration process on the OSF. However, intrusion frequency is the focus of this particular paper and the statistical properties of the data required deviation from the pre-specified analysis plan. We have, therefore, uploaded a document titled *Rationale for Changes to Pre-specified Analyses*, to the OSF (https://osf.io/vutcw/) to allow readers to easily view any changes made during the analysis process.

Results

Initial data screening revealed that two participants completed only three of twenty-two diary entries for intrusive memories; therefore data for these respondents were not included in the study, leaving a sample of 107 participants aged 18-68 years. The Control group comprised n = 36; the cognitive intervention including Tetris, n = 35 (henceforth "Tetris"), and the cognitive intervention including D-Corsi, n = 36 (henceforth "D-Corsi"). As there were seven pronounced outliers in intrusive memory frequency, we report data for the final sample of 100 participants. Outliers were determined based on the total number of intrusions over the course of the week, where the total intrusive memories reported were more than three standard deviations beyond the mean (Tabachnick & Fidell, 2007). We also conducted a sensitivity analysis by repeating all analyses with the inclusion of outliers (N = 107); these analyses are summarized in Supplementary Tables 1 to 3.

Pre-Task Group Equivalency

Prior to hypotheses testing, group equivalency analyses were undertaken. Table 1 summarises the demographic characteristics, task and compliance measures, self-report questionnaire scores, and VAS outcomes for each of the groups. Outcomes for rumination, dissociation, and intolerance of uncertainty are beyond the scope of this paper and will be reported elsewhere.

Emotional valence. There were no between-group differences in emotional valence ratings for the film. Inspection of VAS ratings indicated that the TFP was associated with increased sadness, hopelessness, fear, horror, and depressed feelings (all repeated measures p-values < 0.001; see lower section of Supplementary Table 1).

Baseline intrusive memory frequency post 4-hour break. There were no between-group differences in intrusive memory frequency for the TFP, as reported by participants when they returned to the lab after the 4-hour interval, but prior to engagement in the assigned experimental task (Wald $\chi^2 = 2.21$, $df = 2$, $p = 0.33$ and all pairwise *p*-values n.s.). Mean reported numbers of intrusions were: Control = 8.32 (*SE* = 1.51, 95% CI [5.83, 11.88]), Tetris = 5.63 (*SE* = 1.08, 95% CI [3.86, 8.10]), and D-Corsi = 6.76 (*SE* = 1.24, 95% CI [4.72, 9.70]).

Post-task Analyses

Enjoyment. Between group differences were reported for task enjoyment, with participants in the Tetris condition reporting higher scores than those in the Control, but not the D-Corsi, condition, see Table 1.

Intrusive memory frequency during 12-minute task. There were significant between-group differences in intrusive memory frequency during the task period (Wald $\chi^2 = 29.50$, $df = 2$, $p < 0.001$). Posthoc pairwise comparisons indicated that the Tetris and D-Corsi groups each reported significantly fewer intrusive memories of the film than the Control group (*p*'s < .001), but were indistinguishable from each other ($p > 0.05$). Tetris and D-Corsi means were respectively 0.88 (*SE* = .23, 95% CI [.53, 1.45]) & (1.82, *SE* = .39, 95% CI [1.20, 2.77]) vs Control mean 4.71 (*SE* = .89, 95% CI [3.25, 6.81]).

Intrusive memory frequency Day 0. There were no significant between-group differences for total intrusive memories of the film reported at the end of the experimental day, that is for the period between participants leaving the lab and the first diary entry that night (Wald $\chi^2 = 4.95$, $df = 2$, $p = 0.08$ & all pairwise *p*-values > 0.05). Mean reported numbers of intrusions were: Control = 3.00 (*SE* = 60, 95% CI [2.02, 4.45]), Tetris = 1.77 (*SE* = .40, 95% CI [1.13, 2.76]), and D-Corsi = 3.38 (*SE* = .68, 95% CI [2.27, 5.01]).

Intrusive Memory Frequency Analysis Days 1 – 7. Our central hypotheses pertained to whether there were main effects favouring Tetris and D-Corsi across time, and whether there were significant interaction effects, indicating that visuospatial tasks result in a more rapid reduction in intrusions compared to control. Figure 3 summarises the total number of intrusions reported by each group across the seven days following the experimental task.

We first constructed a model which only included condition (Tetris, D-Corsi, Control) as a between-subjects factor and time (average total intrusions per day across days 1 to 7) as a within-subjects factor. The results indicated a significant main effect for both time (p < 0.001) and condition (p = 0.01). Averaged across time, the Tetris group reported fewer intrusive memories than either the D-Corsi (Mean Tetris intrusions per day = 1.41, *SE* = 0.20, 95% CI [1.07,1.87]), mean D-Corsi intrusions per day = 2.27, *SE* = 0.27, 95% CI [1.80,2.87]),; p = 0.008, *d* = .64) or Control groups (mean intrusions per day for Control group = 2.26, *SE* = 0.26, 95% CI [1.80, 2.85]); p = 0.008, *d* = .64) consistent with our first hypothesis with the exception that the D-Corsi group did not report fewer intrusions, on average, than the Control group (p > 0.98, *d* = .01).

We then extended the model to include a condition (Tetris, D-Corsi, Control) by time interaction term (average total intrusions per day across days 1 to 7). When we did this, the main effects for both time (p < 0.001) and condition (p = 0.008) were significant although the interaction of condition by time was not significant (p = 0.17).

Discussion

Reports that cognitive interventions including Tetris (Holmes et al., 2009; Holmes et al. 2010; Horsch et al., 2017; Iyadurai et al., 2018) and interventions that interfere with visuospatial processing (Deeprose et al., 2012) may reduce distressing intrusive memories when undertaken during memory consolidation hold important promise for the development of new, cognitive science-informed interventions following exposure to traumatic events. The present study is one of few fully independent attempts to provide a test of replication of these findings, consistent with scientific imperatives calling for increased evaluation of psychological study outcomes (Zwaan et al., 2018).

In regard to the key variable under investigation - intrusive memory frequency over the course of a week – the cognitive intervention including Tetris was superior to both the D-Corsi-based intervention and control conditions. This is congruent with the literature demonstrating associations between cognitive interventions which include Tetris-based interventions during memory consolidation and reduced intrusive memory frequency over the subsequent week when compared to conditions such as no-task and verbal computer games (Holmes et al., 2009; Holmes et al., 2010), activity logging (Iyadurai et al., 2018), and usual care (Horsch et al., 2017).

With respect to the Control condition, our findings are consistent with the main study modelled for replication (Holmes et al., 2010). Although we report similar outcomes and effect sizes for intrusive memory frequency over the course of the week following exposure to the TFP, our participants reported a higher number of intrusive memories across all conditions generally (see Supplementary Table 4, Supplementary Figure 1). In comparison to the primary study, our participants reported lower pre- and post-film mood, and intrusive memory frequency during the experimental condition. However game enjoyment for Tetris and diary compliance were similar (see Supplementary Table 4).

Our attempt to closely provide a test of replication of Holmes and colleagues' (2010) study yielded similar results despite a number of task differences relating to Tetris gameplay implementation, providing confidence in the robustness of the effect. Specifically, we used a Tetris variant that allowed for pre-setting of time and maximum difficulty levels, while also maintaining continuity by having the screen automatically empty to half way when the blocks filled the screen, rather than the game terminating. These pragmatic adjustments ensured that the duration of gameplay (or "dose") could be closely controlled in our study and might also enhance the clinical utility of this intervention due to low clinician oversight requirements.

Our prediction in regard to the D-Corsi intervention's influence on intrusive memory frequency was not supported. The D-Corsi task was not found to be more effective than the control condition in reducing intrusive memory frequency over the course of a week. This outcome is inconsistent with previous research demonstrating efficacy of a complex pattern-tapping task in reducing intrusive memory frequency (Deeprose et al., 2012). Our findings are also in discord with the visuospatial hypothesis (Deeprose et al., 2012), suggesting that D-Corsi did not utilise cognitive resources involved in memory encoding.

We note key differences between the cognitive features of the Tetris and D-Corsi interventions, which may have contributed to the discrepant findings between visuospatial conditions. D-Corsi demanded storage of sequential pattern information, whereas the primary feature of Tetris is the requirement for mental rotation of blocks. The Tetris set up allowed for preview of the three upcoming blocks, whereas D-Corsi only provided information on direction (forward or backward), but not on sequence length. It is possible therefore that D-Corsi did not sufficiently tax the visuospatial aspect of working memory, which has previously been demonstrated for Tetris gameplay (Lau-Zhu et al., 2017). We note that we chose D-Corsi as a comparison cognitive intervention on the grounds that the D-Corsi task itself is predominantly visual, much like Tetris. As such, our findings do not provide insights into whether competing tasks necessarily need to be modality-consistent or not (see

Engelhard, van den Hout, Janssen, & van der Beek, 2010 for a summary), such that this remains a question for further research.

Our hypothesis that participants in the visuospatial task interventions would report not only lower rates of intrusions but also greater rates of decline for intrusive memory frequency was also not supported. It is possible that this was due to the low frequency count for each condition at Day 1 in the context of an analogue paradigm, which did not allow for large reductions between days. In a clinical sample, Iyadurai et al. (2018) reported more than twice the daily number of intrusive memories for each condition, which may have created enough variance to document a time by intervention interaction in intrusive memory decay following engagement in a Tetris-based cognitive intervention. However, we note that our prediction regarding the increased rate of decline was not supported for the novel task introduced (D-Corsi) to extend on the main study modelled for replication (Holmes et al., 2010).

Of note is that while intrusion frequency was less for the participants allocated to the cognitive intervention including Tetris when *averaged* across the week, the *rate* of decline in intrusions did not differ between groups. This is consistent with the notion that Tetris-based cognitive interventions may interfere with initial encoding (Holmes, Brewin, & Hennessy, 2004), while memories are still malleable during the consolidation window (Visser et al., 2018), in a way which results in a reduced overall number of subsequent intrusions, but not necessarily differences in the way in which these resolve with time.

Limitations

Limitations of the current study should be considered when interpreting findings and in future investigations. From a replication perspective, we note that our study was a close (Brandt et al., 2014), rather than complete, replication of Holmes et al.'s (2010) study. In our attempt to extend upon previous findings minor amendments were made in addition to those noted above were made which we believe made a more robust evaluation of the effect noted. Further, participants used a mobile phone app rather than paper diary to record intrusive memories. It is conceivable that the reminder notification served as a trigger for memories of the TFP. However, this experience sampling methodology allowed for ease of adherence by participants, remote monitoring, objective measurement of compliance, and mitigation of the risk that participants might retrospectively complete their diaries, as the surveys expired soon after the allocated recording time.

Generalisability of findings may be limited given that the majority of the sample were university students, however we note the age span across adulthood for our sample and the larger sample sizes than earlier studies (Holmes et al., 2009; Holmes et al., 2010). Future research with community-based samples may assist in improving robustness of findings. A further limitation of the study was the reliance on self-report measures. Given the personal nature of intrusive memories, there is dependence on participants to provide accurate information, therefore, multi-method assessment may be beneficial in future studies.

Commentary on Replication

Findings from our pilot study highlight the importance of communication with the primary researchers when attempting replication studies. Prior to commencing the pilot study, we reviewed the publicly available information provided by two of the key authors (Emily Holmes and Ella James) on the Open Science Framework: *Computer game-play reduces intrusive memories of experimental trauma via reconsolidation update mechanisms*, in addition to methodology review of the papers published. We piloted TFP and study procedures based on this information before arranging video conferencing with the researchers of the primary study, consistent with recommendations that encourage consultation regarding methodological fidelity (Brandt et al., 2014; Iyadurai et al., 2018). Consultation included review of TFP footage, as well as study instructions and protocols via email.

These consultations led us to broaden the content of the TFP beyond motor vehicle accident (MVA) footage. As such, amendments were made to broaden the range of potentially distressing incidents comprising the TFP to include clips such as those depicting eyeball surgery, drowning, and extreme bleeding while shaving. This ensured that the content of our trauma film was similar to previous studies and, although we note a higher number of intrusions were reported in our study to that of the primary study, we report similar findings in regard to intrusive memory frequency comparisons for the cognitive intervention including Tetris and the control condition.

Consultation also led to refinements related to task delivery instructions and inclusion of documents to aid with participant adherence. Particular focus was given to practicing the delivery of the Tetris-based cognitive intervention and the TFP viewing instructions. The protocols for TFP viewing, understanding intrusive memories, and monitoring intrusive memories were enhanced by the addition of instructions for participants to relay their understanding of the verbal instructions back to the researcher, and through provision of a paper-and-pen checklist that participants completed prior to leaving the lab after the final session.

We also note, that the discrepancies between our findings and those of Asselbergs et al (2018) and Bruhl et al. (2019) may be better understood if additional information had been available regarding their respective interventions, which did not appear to reduce intrusive memories following exposure to a TFP. Thus, it remains possible that seemingly minor procedural differences between our study and that of Asselbergs et al. – such as differences in task instructions and visuospatial game design - may have served as important confounding variables. In the case of Bruhl et al. (2019), the absence of a reminder task for the TFP, the use of Tetris gameplay immediately following TFP viewing, and the duration of Tetris gameplay (2 minutes practice followed by 25 minutes gameplay) negates opportunity for outcome comparisons to those of our study.

Conclusion

The current study confirms the findings of a landmark investigation (Holmes et al., 2010), which has opened avenues for the implementation of a novel intervention in clinical settings. To our knowledge, this study is the first direct test of replication of Holmes and colleagues' (2010) influential research, providing confidence for further refinement and application of the approach. Intrusive memories are a core feature of PTSD that have been shown to prospectively predict overall symptomatology (Solberg, Birkeland, Hansen, & Heir, 2016) particularly in the acute phase after exposure to a trauma event (Bryant et al., 2017), and to influence PTSD cluster severity (Rubin, Boals, & Bernsten, 2008). Given that epidemiological studies indicate trauma exposure rates of up to 90% for the population (Kilpatrick et al., 2013), engagement in a relatively safe task, such as a Tetris-based cognitive intervention, holds promise for fostering more effective consolidation of memories following exposure to a potentially traumatic event.

Author Contributions

AB and DB contributed to the development of the study concept. AB developed the study design under the supervision of, and in consultation with, DB. Testing and data collection were performed by AB. AB and KR performed the data analysis and interpretation. AB and DB drafted the paper, and ZS provided critical revisions. All authors approved the final version of the paper for submission.

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Declaration of Conflicting Interests

The authors declared no conflicts of interest with respect to the authorship or the publication of this article.

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Figure 1. Participant Enrollment

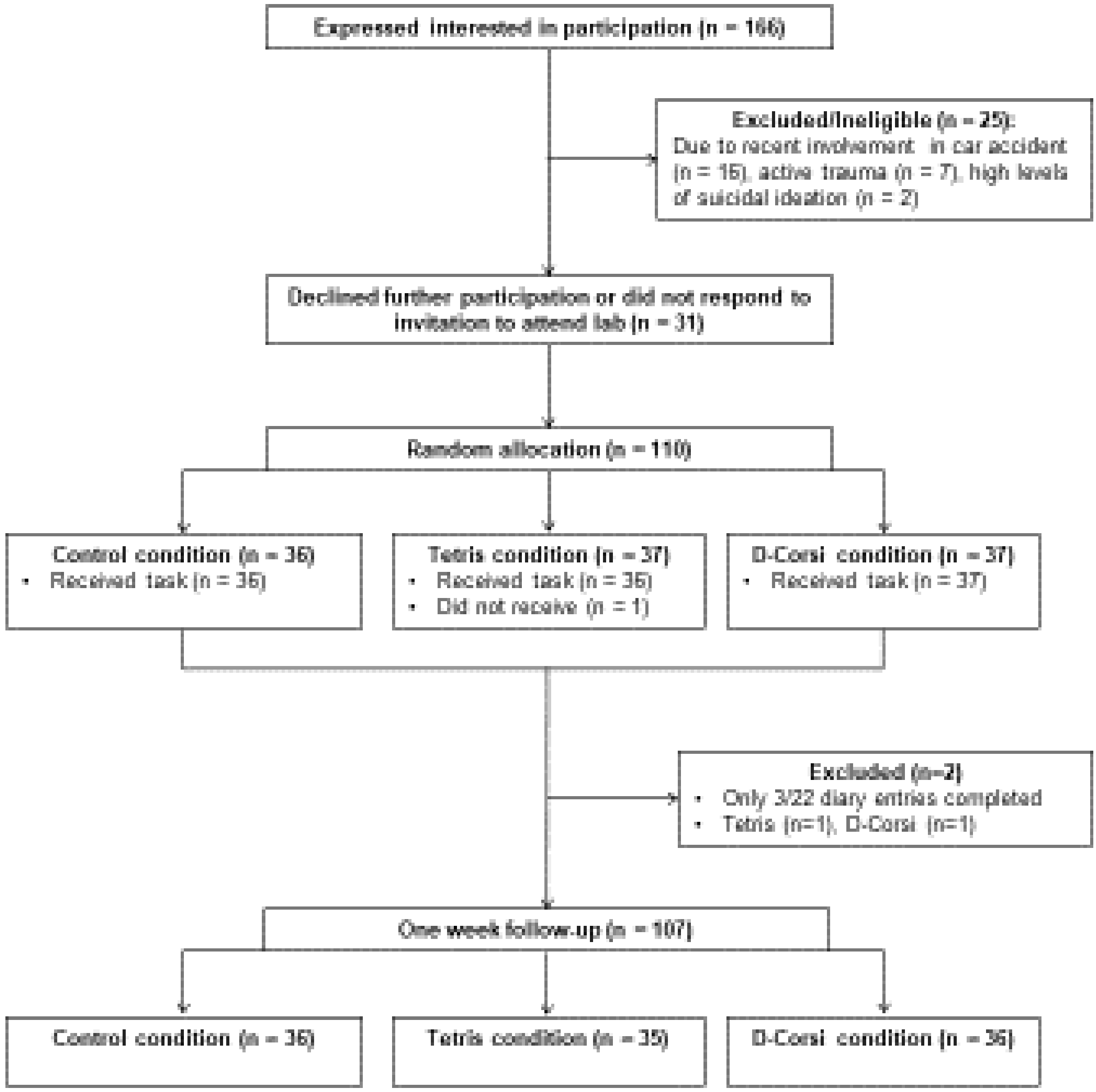

Figure 2: Outline of Study Procedure

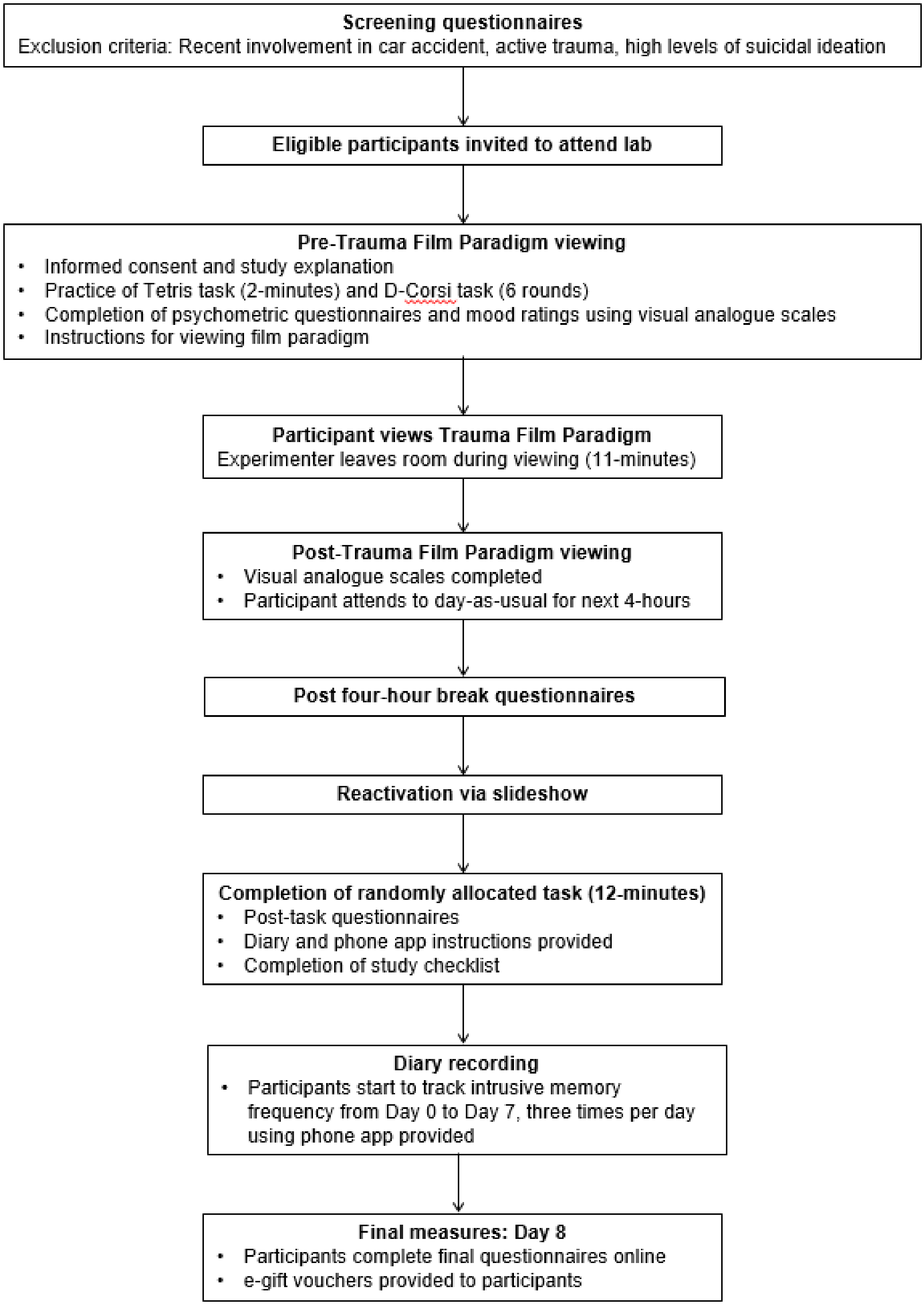

Table 1. Sample, task and compliance measures, self-report measures

Sample Characteristics		Condition						Between conditions comparisons
		Control (*n* = 34)		Tetris (*n* = 32)		D-Corsi (*n* = 34)		
Age (years)		*Mean*	*SD*	*Mean*	*SD*	*Mean*	*SD*	
		27.82	10.78	24.42	8.19	30.76	11.28	*F* (2,97) = .81
		n	*%*	*n*	*%*	*n*	*%*	
Gender								
	Female	23	67.6	20	62.5	17	50	χ^2 (1) = 2.33
	Male	11	32.4	12	37.5	17	50	
First language								
	English	17	50	20	62.5	21	61.8	χ^2 (4) = 1.73
	Asian	14	41.2	9	28.1	11	32.3	
	Other	3	8.8	3	9.4	2	5.9	
Main occupation								
	Student	27	79.4	22	68.8	19	55.9	χ^2 (2) = 4.38
	Other	7	20.6	10	31.2	15	44.1	
		n	*%*	*n*	*%*	*n*	*%*	
Task and compliance measures								
Prior Tetris experience		33	97	32	100	33	97^{+}	
		Mean rank		*Mean rank*		*Mean rank*		
Attention to film		56.84		45.23		49.12		*H* (2) = 3.34
Diary adherence		49.06		52.89		49.69		*H* (2) = 3.38
Task enjoyment		37.81		63.94		50.54		*H*(2)=13.38**
		Pairwise comparisons		*Mean ranks*		*U, z*		
		Control, Tetris		25.18, 42.34		261, -3.63***		
		Control, D-Corsi		30.13, 38.87		429.5, -.182		
		Tetris, D-Corsi		38.09, 29.18		397, -1.89		
		Mean	*SD*	*Mean*	*SD*	*Mean*	*SD*	
Self-report measures								
	Depression	13.18	4.47	12.25	3.47	12.59	3.43	*F* (2,97) = .50
	Anxiety	16.32	5.11	17.06	6.04	16.53	4.80	*F* (2,97) = .17
	IES-R	14.82	5.71	13.94	4.50	14.35	5.12	*F* (2,97) = .25
		Mean Difference#	*SD*	*Mean Difference*#	*SD*	*Mean Difference*#	*SD*	
Visual analogue scales: Pre to post film								
	Sad	43.91	28.16	39.44	26.64	33.62	27.99	*F* (2,97)=1.19
	Hopeless	19.79	30.97	14.19	25.18	15.59	29.63	*F* (2,97) = .34
	Fearful	36.74	30.82	26.09	31.95	31.94	29.72	*F* (2,97) = .98
	Horrified	47.03	32.32	49.25	32.49	47.91	30.49	*F* (2,97) = .04
	Depressed	28.32	28.04	22.97	25.45	17.21	23.41	*F* (2,97)=1.59

n = 100. Scale 0-100. ****p* < .001, ***p* < .01

Abbreviations: IES-R, Impact of Events Scale-Revised
[+]Between group comparisons not possible due to zero value for Tetris group
[#] Mean difference is calculated as post-film rating minus pre-film rating

Figure 3. Total number of intrusions, by condition, across 7-days.