



Effect of sleep manipulations on intrusive memories after exposure to an experimental analogue trauma: A meta-analytic review



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ABSTRACT

Sleep plays an important role in memory processing and is disrupted in individuals with post-traumatic stress disorder (PTSD). A growing body of research has experimentally investigated how sleep – or lack thereof – in the early aftermath of a traumatic experience contributes to intrusive memory formation. The aim of this meta-analytic review was to examine the effects of various experimental sleep manipulations (e.g., sleep deprivation, daytime naps) on intrusive memories following exposure to an experimentally induced analogue traumatic event. Eight eligible studies were systematically identified through PsycInfo and PubMed and provided sufficient data to contribute to a meta-analysis of the effects of sleep versus wakefulness on intrusive memory frequency. Sleep was found to reduce intrusive memory frequency when compared to wakefulness at a small but significant effect size (Hedge's $g = 0.29$). There was no evidence of publication bias and heterogeneity of effect sizes across studies was moderate. Results suggest that sleep plays a protective role in the aftermath of exposure to a traumatic event with implications for early post-trauma intervention efforts.

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1. Introduction

In the early aftermath of exposure to a traumatic event, individuals commonly report experiencing intrusive memories of the trauma [1,2]. Intrusive memories are brief, intense sensory fragments of memories for the traumatic event that come to mind repeatedly, involuntarily, and often without an obvious trigger [1,3,4]. These intrusive memories most often take the form of visual imagery (e.g., seeing oncoming headlights as they were seen shortly before a head-on car crash), but can also take the form of other sensory impressions [5,6]. Intrusive memories are often accompanied by intense negative emotions that closely mirror those experienced during the traumatic event itself (e.g., fear [7]).

For most people who experience a traumatic event, intrusive memories become less frequent and less distressing as time passes [8,9]. Current theories of normative trauma recovery suggest that trauma memories become integrated into existing

autobiographical networks and threat-related vigilance naturally declines with repeated exposure to trauma-related stimuli (e.g. Ref. [6]). However, a clinically significant minority of trauma-exposed people go on to develop post-traumatic stress disorder (PTSD), a diagnosis that is characterized by the presence of at least one intrusive re-experiencing symptom that persists for at least one month post-trauma [10]. Intrusive memories are considered to be a prominent, core feature of PTSD, which has been characterized as a “disorder of memory” [11].

Understanding the processes that impact intrusive memory formation early after trauma exposure is critical for efforts aimed at preventing the development of PTSD. One such process is sleep. There is a wealth of evidence indicating that sleep is critical for the modification of memories after they have been formed [12–15]. According to general models of sleep-dependent memory processing, neural structures that are active during memory encoding are reactivated during sleep and allow the brain to modify memories into more adaptive forms for long-term storage [16]. In particular, rapid eye-movement (REM) sleep is thought to be important for the successful processing of emotional memories, including habituation to emotional stimuli [17], retention of emotionally salient stories and images [18,19], and reduction of next-day negative affect associated with a distressing memory [20].

Abbreviations: IES-R, Impact of Event Scale Revised; PTSD, post-traumatic stress disorder; REM, rapid eye movement.

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According to the influential “Sleep to Remember, Sleep to Forget” hypothesis [21], REM sleep enhances the episodic components of emotional memories while stripping away their emotional tone. The result of this process – which is thought to unfold over multiple nights of sufficient sleep quantity – is that an individual can consciously call to the mind the details of an emotional event but does not experience the same emotional intensity that they experienced during encoding. Trauma-exposed individuals who struggle with intrusive, emotionally laden memories of what happened to them benefit from this type of sleep-dependent memory modification.

Importantly, however, this process is hypothesized to go awry in PTSD, which is characterized not only by intrusive re-experiencing symptoms during the day but also by prominent sleep disturbances. Chronic, terrifying nightmares that feel like near-veridical reenactments of traumatic events are an illustrative example of the role of post-traumatic sleep-related memory processes in PTSD. Notably, intrusive memories and nightmares both fall under the intrusive re-experiencing category of symptoms in the diagnosis of PTSD, and it has been suggested that there is phenomenological overlap between these two processes [22] although it is unknown whether they have shared mechanisms. Nightmares primarily occur during REM sleep, when the brain is hypothesized to be extracting and reducing the emotional content of memories for more useful gist-like storage [23]. Nightmares in trauma-exposed individuals who do *not* go on to develop PTSD may represent a successful attempt to reactivate, emotionally process, and assimilate trauma memories into older, related autobiographical memory structures [24]. On the other hand, chronic nightmares in individuals with PTSD may represent repeated and failed attempts of this process during sleep [23,25] just as intrusive memories may represent repeated and failed attempts to process a memory during wakefulness.

Because of sleep’s hypothesized role in traumatic memory processing, one candidate method for preventing the formation of distressing intrusive memories is to manipulate sleep in the early aftermath of trauma exposure. Two competing hypotheses and separate lines of research merit a brief discussion here. One hypothesis, derived primarily from pharmacological research on rodents (e.g. Refs. [26,27]) but with some support from studies in humans [28,29], is that depriving individuals of sleep in the aftermath of a traumatic event may prevent the natural reactivation of the memory during sleep and thereby prevent the development of intrusive re-experiencing symptoms. A contrasting theory, derived from the previously discussed “Sleep to Remember, Sleep to Forget” hypothesis [21], is that depriving individuals of sleep after trauma eliminates or reduces the opportunity to decouple the episodic components of the memory from emotions experienced during encoding, and ultimately results in more frequent and distressing intrusive memories. Determining which theory is a better reflection of traumatic stress reactions is crucial for developing effective sleep-focused strategies for reducing PTSD risk.

Because the consequences of testing these hypotheses in individuals who have directly experienced real-life traumatic events are high, researchers interested in the role of early sleep after trauma have primarily relied on experimental paradigms of trauma induction. One promising experimental method is the trauma film paradigm (or analogue trauma paradigm) in which healthy participants are exposed to a film or compilation of film clips that depict serious, life-threatening traumatic events occurring to others. This paradigm was first developed to study psychological reactions to stress [30] and has since been shown to reliably induce intrusive memories comprised of footage and/or sounds from the

film for several days post-exposure [31–34]. A significant advantage of the trauma film paradigm is the ability to measure “analogue” symptoms of post-traumatic stress – such as intrusive memory frequency – without relying on the occurrence of naturalistic but distressing and unpredictable traumatic events. Relatedly, this paradigm allows researchers to experimentally manipulate processes – such as sleep – that occur after film exposure and are thought to play a role in intrusive memory development in a controlled, standardized fashion.

Several narrative reviews have synthesized the existing literature on the impact of various sleep manipulations (e.g., total sleep deprivation, daytime naps) on intrusive memories after exposure to a trauma film (e.g. Ref. [35]). Findings thus far have been characterized as mixed, even within this narrow domain of research: an initial study’s results suggested that sleep loss prevents intrusive memory formation [36], while others suggest that sleep plays a protective role [37–40], while still others report no effects [41–43]. To date, no quantitative meta-analysis has been conducted to integrate findings on the effects of sleep versus wakefulness on intrusive memory frequency following analogue trauma exposure. While a relatively small number of studies have made use of both a standardized trauma induction paradigm *and* a controlled manipulation of post-exposure sleep duration, a meta-analytic estimate that integrates this set of experimentally rigorous studies will provide a more statistically robust summary of the current state of this literature than previously published reviews and has the potential to inform future studies that make use of more naturalistic paradigms. This review aims to provide such a quantitative synthesis with the hope of contributing to both theoretical accounts of sleep’s role in traumatic stress reactions and to practical guidelines aimed at reducing PTSD risk in the early aftermath of trauma exposure.

2. Method

The present study was conducted according to PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines aimed at improving the reporting of systematic reviews and meta-analyses [44]. Covidence [45] was used to store search results, mark duplicate references, facilitate the screening of retrieved articles between raters, and manage extracted data; all quantitative analyses were performed in R [46].

2.1. Study selection

Comprehensive searches of the PsycInfo and PubMed databases were conducted in May 2022. Searches required that a term related to sleep (*sleep* OR *nap*), a term related to intrusive memories (*memor** OR *intrusi** OR *involuntar**), and a term related to the analogue trauma film paradigm (*trauma** OR *emotion**) AND (*analog** OR *film** OR *stor**) appear anywhere in the full-text article.

A study was considered eligible if it (1) was a published or unpublished empirical paper; (2) included adults over age 18 that were characterized as “healthy” by the paper’s authors; (3) involved a direct manipulation of sleep duration to allow for the comparison of a “sleep” group to a “wake” group (e.g., nighttime sleep versus total sleep deprivation; nap versus daytime wakefulness); (4) utilized an analogue trauma film paradigm (i.e., participants were exposed to either videos or picture stories with audio illustrating an event that depicted physical or sexual violence); and (5) assessed intrusive memory frequency at least once after the sleep manipulation with at least one of the following methods: (i)

self-report daily intrusion diary (i.e., participants record intrusive memory occurrences over the course of several days following trauma exposure), (ii) the Impact of Event Scale – Revised (IES-R) or the IES-R Intrusion subscale, or (iii) an in-lab intrusion triggering task (i.e., participants are exposed to fragments of the trauma stimulus and indicate whether they experienced an intrusive memory). No language, publication date, or publication status restrictions were imposed.

The first author reviewed the titles and abstracts of all retrieved articles to assess for eligibility and then reviewed the full text of all eligible articles. A random subset of 25 full-text articles were reviewed for eligibility by a second rater.

2.2. Risk of bias assessment

Included studies were assessed for bias using the Cochrane Collaboration's published tool [47]. A set of seven items were used to judge the risk of six potential biases: (1) selection bias (assessed via two items); (2) performance bias; (3) detection bias; (4) attrition bias; (5) reporting bias; and (6) other bias. For each item, the risk of bias in each study was rated as "low," "high," or "unclear."

2.3. Data extraction

Data were extracted from each study using a standardized data extraction form implemented in Covidence. Authors were contacted when studies did not report sufficient data to generate an effect size for the effect of the sleep manipulation on the frequency of intrusive memories (i.e., this review's primary quantitative outcome measure). If authors failed to respond but included a figure in their work depicting the missing data visually, a plot digitizing tool was used to extract numerical estimates for missing data [48].

2.4. Meta-analytic strategy

A meta-analysis was performed to examine the effects of sleep versus wakefulness on intrusive memory frequency.

Calculating effect sizes. Hedge's g [49] was selected as the common effect size because it has good small sample properties and can be used when sample sizes between two groups are unequal. Hedge's g values were computed for each study by subtracting the average intrusive memory frequency in the sleep group from the average intrusive memory frequency in the wake group and dividing by the pooled variance weighted by the sample size in each group. Therefore, positive Hedge's g values indicate fewer intrusive memories in the sleep group as compared to the wake group (i.e., a protective effect of sleep). Hedge's g can be interpreted similarly to Cohen's d , wherein an effect size of 0.2 is considered small, an effect size of 0.5 is considered medium, and an effect size of 0.8 is considered large [50].

Pooling effect sizes. A random-effects model was used to pool effect sizes across the eight included studies. The restricted maximum likelihood estimator [51] was used to calculate the heterogeneity variance because the critical outcome measure – intrusive memory frequency – is continuous. Knapp-Hartung adjustments [52] to calculate the confidence interval around the pooled effect were made to reduce the chance of false positives due to the small number of included studies.

Heterogeneity. Study heterogeneity was assessed with Cochran's Q test [49] – in which a significant result indicates that variations between study effect sizes may represent sampling from different populations – and with the I^2 index [53], which estimates the proportion of the variance in study effect size estimates that is due to heterogeneity. I^2 values range from zero (i.e., variability in

effect sizes can be explained by chance alone) to one; I^2 values less than 0.25 indicate low heterogeneity, between 0.25 and 0.5 indicate moderate heterogeneity, and over 0.5 indicate heterogeneity [53].

Publication bias. Publication bias can inflate effect sizes estimated through meta-analyses when the field contains studies that have been conducted but not published. In order to mitigate the risk of publication bias, a funnel plot was examined and an Egger's test [54] was conducted. Funnel plots depict effect size estimates from individual studies against a measure of each study's size. In the absence of publication bias, effect estimates from smaller studies should scatter symmetrically at the bottom of the plot around the pooled effect size, with the spread narrowing among larger and more powerful studies towards the top, resulting in an inverted funnel shape. Egger's test quantitatively tests funnel plot asymmetry such that a significant result indicates potential publication bias.

3. Results

3.1. Selection, inclusion, and characteristics of studies

In total, 465 unique studies were identified from database searches. One additional potentially relevant study was identified through an announcement on a professional listserv. After the titles and abstracts of all 466 papers were reviewed, 409 studies were screened out either because they were not empirical investigations or because ineligibility was apparent from the abstract alone. The full-text articles of the remaining 57 studies were reviewed by the first author, of which eight were deemed eligible. A second rater reviewed a random subset of 25 full-text papers (44% of the total full-text papers assessed by the first rater) for eligibility and achieved perfect interrater reliability. Since the final set of eligible studies yielded multiple articles written by the same research group, these articles were checked to ensure that samples did not overlap; none of the eight included articles had overlapping samples. Fig. 1 depicts a flowchart of the search process and reasons for the exclusion of articles. Seven of the eight studies directly reported sufficient data to generate an effect size for use in the quantitative meta-analysis; one study included a figure from which relevant data were successfully extracted [48]. In all, a total of eight studies yielded a total of 437 participants included in the present meta-analysis.

Table 1 includes selected characteristics and key findings of the eight included studies. Notably, a high degree of heterogeneity existed among study designs – even though a relatively small number of studies was included – highlighting the need for strict inclusion criteria. This was particularly evident with respect to the design of the experimental groups. Of the eight included studies, four compared nighttime sleep to total sleep deprivation, one compared nighttime sleep to partial sleep deprivation, two compared a daytime nap opportunity to daytime wakefulness, one compared nighttime sleep to daytime wakefulness, and one compared nighttime sleep to total sleep deprivation or daytime wakefulness. There was also considerable variability in the setting in which participants completed their assigned sleep manipulations (e.g., at home versus in the laboratory), the analogue trauma stimulus used (e.g., a single movie scene versus a compilation of clips versus picture stories), and measures included to assess sleep and intrusive memories of the trauma stimulus (e.g., daily intrusion diary versus an in-lab intrusion triggering task). Table 2 provides a summary of the risk of bias ratings for each included study and Table S1 summarizes demographic and baseline psychological characteristics of individual study samples by assigned sleep manipulation.

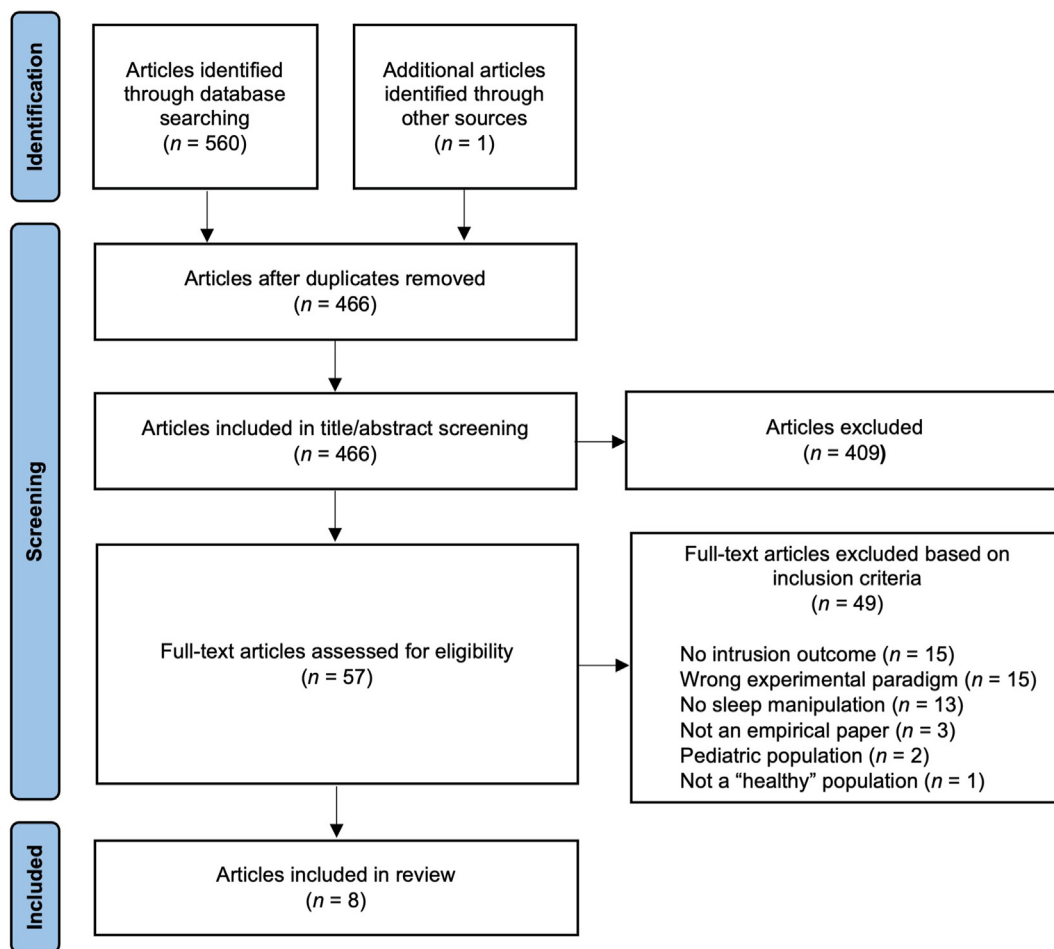


Fig. 1. PRISMA flow chart of the search process and exclusion of articles.

3.2. Meta-analysis

Fig. 2 depicts a forest plot of the meta-analysis comparing intrusive memory frequency in a sleep group to a wake group across all eight included studies. The summary effect size was significant in the direction whereby sleep after exposure to the experimental trauma reduced intrusive memory frequency relative to wakefulness ($g = 0.29$, 95% CI: 0.02 to 0.56, $p = 0.04$) with low heterogeneity ($I^2 = 0.26$; Q test $p = 0.122$). While the funnel plot illustrated in Fig. 3 is suggestive of publication bias due to asymmetry around the pooled effect estimate, Egger's test for asymmetry was non-significant ($p = 0.47$). Notably, the power of Egger's test to detect asymmetry is lower when fewer than 10 studies are included in a meta-analysis [55].

4. Discussion

The present study systematically and quantitatively evaluated whether sleep in the early aftermath of exposure to an experimental traumatic event plays a role in later frequency of trauma-related intrusive memories. A total of eight empirical studies that (1) utilized an analogue trauma film paradigm, (2) directly manipulated sleep duration after exposure to the traumatic film using a between-groups design, and (3) assessed film-related intrusive memories were synthesized in a meta-analysis. Results from the meta-analysis suggest that sleep – compared to wakefulness – reduces the frequency of intrusive memories at a small-

sized effect (Hedge's $g = 0.29$), indicating an overall protective effect of sleep. The results of this meta-analysis support the idea that early sleep after trauma plays a beneficial role in processing these events.

These results generally align with findings from naturalistic studies that have been conducted on the role of early sleep after traumatic event exposure. Measuring sleep immediately after real-life traumatic events is challenging, since many trauma survivors are in a heightened state of distress, experiencing significant physical pain, taking medications, or awaiting emergency care in the middle of the night – all of which pose challenges for researchers attempting to recruit study participants, impact the individual's motivation to participate in a research study, and can compromise an individual's capacity to provide informed consent [56]. However, several studies have found that sleep disturbances including insomnia symptoms – indexed retrospectively in the weeks or months post-exposure – are consistently associated with later development of more general intrusive re-experiencing symptoms of PTSD [57–59]. One study found that difficulties initiating and maintaining sleep were specifically associated with more frequent intrusive memories [60]. While there are, of course, considerable differences between experimentally manipulating an individual's sleep duration and observing naturally occurring sleep disturbances after a traumatic event, the results of this meta-analysis are in line with naturalistic studies highlighting the importance of sleep in the early aftermath of trauma exposure.

Table 1
Characteristics and main results of included studies.

Study	% F	N	Sleep group	Wake group	Trauma stimulus	Intrusion assessments	Sleep assessment	Main results
Porcheret et al., 2015 [36]	69	42	Nighttime sleep at home	TSD in lab	15 m clip compilation	Intrusion diary, IES-R	None	TSD → fewer diary intrusions on days 1 and 2 post-trauma. TSD → lower IES-R scores on day 1 post-trauma.
Kleim et al., 2016 [37]	100	65	Nighttime sleep at home	TSD or daytime wake at home	12 m film scene	Intrusion diary	PSG	Nighttime sleep → fewer diary intrusions on days 3, 6, and 7 post-trauma.
Woud et al., 2018 [38]	71	48	90 m daytime nap in lab	Daytime wake in lab	20 m clip compilation	Intrusion diary, IES-R intrusion subscale	PSG	Nap → fewer diary intrusions across 6 days post-trauma. Nap → lower scores on IES-R intrusion subscale on day 7 post-trauma.
Sopp et al., 2019 [41]	66	41	Nighttime sleep in lab	Partial sleep deprivation in lab	30 m picture stories	In-lab intrusion triggering task	PSG	Nighttime sleep → fewer intrusions during intrusion triggering task on day 1 post-trauma.
Porcheret et al., 2019 [39]	54	50	Nighttime sleep at home	TSD at home	15 m clip compilation	Intrusion diary	Actigraphy	No significant group differences found with complete sample. <i>Additional analysis:</i> Nighttime sleep > 6 h in sleep group (n = 23) → fewer diary intrusions across 7 days post-trauma (relative to < 10 m of sleep in TSD (n = 12) group).
Zeng et al., 2021 [40]	69	60	Nighttime sleep at home	TSD in lab	14 m clip compilation	Intrusion diary, IES-R	None	Nighttime sleep → fewer diary intrusions on days 2, 3, 4 and 5 post-trauma. No significant differences in IES-R scores on day 8 post-trauma.
Wilhelm et al., 2021 [43]	100	55	90 m daytime nap in lab	Daytime wake in lab	12 m film scene	Intrusion diary, IES-R	PSG	No significant differences in diary intrusions across 7 days post-trauma. No significant differences in IES-R scores on day 7 post-trauma.
Sopp et al., 2021 [42]	81	75	Nighttime sleep at home or in lab	Daytime wake at home	45 m picture stories	In-lab intrusion triggering task	PSG	No significant differences in intrusions during intrusion triggering task on day 1 post-trauma.

Note: IES-R = Impact of Event Scale - Revised; PSG = polysomnography; TSD = total sleep deprivation.

Importantly, however, there are numerous limitations to the current study and to the reviewed studies that merit discussion here. First, only a small sample of studies were available for inclusion in the present review. Therefore, meta-analytic results should be interpreted with caution. We were particularly underpowered to detect publication bias, which was suggested by the shape of the funnel plot of study effect sizes (Fig. 3) and can inflate meta-analytic estimates. Second, the small number of studies on this topic precluded examination of potential effect size moderators, including the type of sleep manipulation (e.g., adding a daytime nap versus eliminating a night of sleep), setting (i.e., at home versus in the laboratory), analogue trauma stimulus type and measures included to assess sleep and intrusive memories. Third and most importantly, it is unclear how well these findings can be

said to generalize to the real world due to (a) inclusion of only healthy adults and (b) the use of the trauma film paradigm. By limiting our study population to healthy adults, we sought to isolate the specific effects of sleep and sleep loss on intrusive memory formation and reduce the potential for confounding variables. For example, many original study authors excluded individuals with a history of trauma exposure and who endorsed related intrusive re-experiencing PTSD symptoms; we wanted to examine the effects of sleep and sleep loss – not prior trauma exposure or PTSD status – on intrusive memory formation with this initial quantitative estimate. As noted previously, the trauma film paradigm is advantageous in that it allows researchers to use a standardized experimental protocol to directly manipulate peritraumatic processes and then examine their effects on intrusive memory

Table 2
Risk of bias across included studies.

Study	Bias		Performance		Detection	Attrition	Reporting	Other
	Item	Sequence generation	Allocation concealment	Blinding of Ps/ personnel	Blinding of outcome	Incomplete outcome data	Selective reporting	Other problems
Porcheret et al., 2015 [35]		Low	Low	Unclear	Unclear	Low	Low	Low
Kleim et al., 2016 [36]		Low	Low	Unclear	Unclear	Unclear	Low	High
Woud et al., 2018 [37]		Low	Low	Low	Unclear	Low	Low	Low
Sopp et al., 2019 [40]		Low	Low	Low	Unclear	Low	Low	Low
Porcheret et al., 2019 [38]		Low	Low	Unclear	Unclear	Low	Low	Unclear
Zeng et al., 2021 [39]		Low	Low	Low	Low	Low	Low	Low
Wilhelm et al., 2021 [42]		Low	Low	Unclear	Unclear	Low	Low	Low
Sopp et al., 2021 [41]		Low	Unclear	Unclear	Unclear	Low	Low	Low

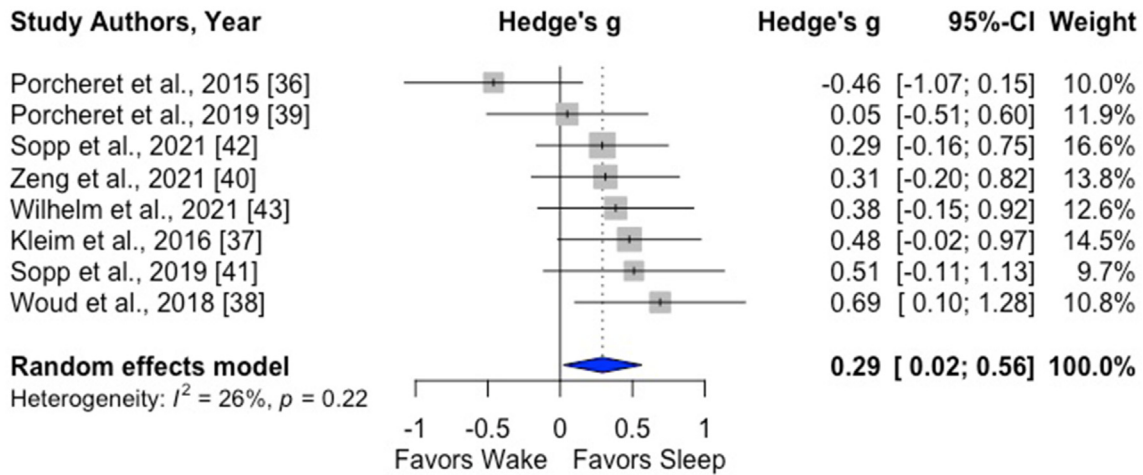


Fig. 2. Forest plot of the meta-analysis comparing intrusive memory frequency in a sleep group to a wake group. Note: Positive g values represent a reduction in intrusive memory frequency in the sleep group as compared to the wake group; negative g values represent an increase in intrusive memory frequency in the sleep group relative to the wake group. Squares represent effect sizes for each study; size of squares indicates weight to the summary effect size based on sample size. Error bars represent a 95% confidence interval. Diamond represents summary effect size.

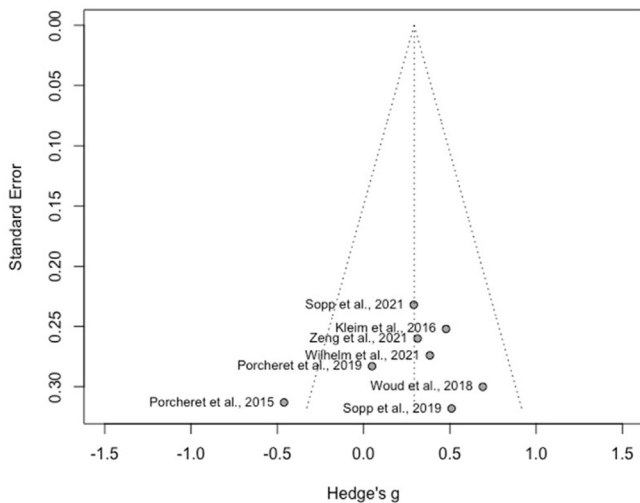


Fig. 3. Funnel plot of the effect sizes comparing intrusive memory frequency in a sleep group to a wake group. Note: Standard error of the effect estimate (y-axis) indexes study size.

formation, but it is not clear whether the results generalize to exposure to actual traumatic events. The trauma film paradigm has been shown to produce intrusive memories, but not necessarily *persistent* intrusive memories. As discussed previously, emotional memory processing is thought to unfold slowly over time and across multiple nights of sleep (e.g. Ref. [21]), which likely contributed to the rapid decline in intrusive memory frequency across days that was reported in several included studies [36,39,40]. Future research efforts should attempt to take a dedicated, step-wise approach to better understand the time course of intrusive memory formation and evolution (for a broader review of this issue in emotional memory processing, see Ref. [61]). In summary, while the trauma film paradigm offers researchers a clean experimental paradigm for manipulating processes that occur shortly after traumatic events, innovation that focuses on creating more ecologically and clinically valid paradigms is an important future direction for this line of work.

This growing body of work generally underscores the importance of obtaining sufficient sleep quantity/quality in the early aftermath of trauma exposure. These findings have particularly important potential implications for clinical practice, especially for individuals who are at predictably greater risk for experiencing posttraumatic stress (e.g., first responders, military personnel, emergency room staff). Our results suggest that encouraging or facilitating sleep in the early aftermath of exposure to a distressing event may aid in the prevention of intrusive re-experiencing symptoms as compared to remaining awake. The current review highlights the need for further research on the relative effects of sleep and wakefulness after traumatic events in these at-risk populations, and more research is needed to determine the optimal timing, duration, and methods of sleep interventions in the wake of a traumatic event. Nevertheless, the results of this meta-analysis support the idea that sleep plays a beneficial role in the processing of traumatic events and raises some exciting possibilities for future sleep-focused early intervention efforts in the wake of traumatic experiences.

Declaration of competing interest

The authors have no conflicts of interest to declare.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.smr.2023.101768>.

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