Sleep-related Attentional and Interpretive Bias In Insomnia: A Systematic Review and Meta-analysis.

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Systematic Review

Keywords: Selective Attention, Insomnia, Cognitive Bias, Monitoring, Attentional Bias, Interpretive Bias, Sleep, Review

Posted Date: March 22nd, 2022

DOI: https://doi.org/10.21203/rs.3.rs-1467002/v1

Sleep-related attentional and interpretive bias in insomnia: a systematic review and meta-analysis.

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For submission to: Clinical Psychology Review
Number of Tables: 5
Number of Figures: 7

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Abstract:
Prominent cognitive models of insomnia have emphasized the notion that the disorder is in part maintained by cognitive biases of attention and interpretation for sleep-related "threat" cues which may be internal or external in nature. We present the first systematic review of the sleep-related attention and interpretive bias literature that includes meta-analytic calculations for each respective construct. Literature search identified N=21 attentional bias and N=8 interpretive bias studies that met pre-defined inclusion/exclusion criteria. Seventeen of the twenty-one reviewed attention bias studies compared normal sleeping controls and poor sleepers/insomnia patients. Based on a random effects model, meta-analytic data based on the standardized mean differences of attentional bias studies determined the weighted pooled effect size (17 studies, N=922) to be moderate at .60 (95% CI: 0.26 to 0.93). Furthermore, seven of eight sleep-related interpretive bias studies examined normal sleeping controls and poor sleepers/insomnia patients in sleep-related interpretive bias. Meta-analytic data determined the weighted pooled effect size (7 studies, N=577) to be moderate at .44 (95% CI: 0.19 to 0.69). Based on the outcomes, disorder congruent attentional and interpretive biases appear to be a tentative feature of insomnia. However, despite statistical support for this notion, the absence of longitudinal data limits causal inference concerning the relative role of these biases in the development and maintenance of insomnia. Methodological factors pertaining to the task design, sample population and stimuli are discussed in relation to variation in study outcomes. Finally, we discuss the next steps moving forward to advance the understanding of sleep-related attentional and interpretive bias in insomnia.

Keywords: Poor Sleep; Insomnia; Cognitive Bias; Attentional Bias; Interpretive Bias

Highlights:
- Sleep-related cognitive biases are a key feature of cognitive models of insomnia.
- This is the first meta-analysis of both sleep-related attention and interpretative bias in insomnia.
- Most studies evidence such biases based on cross-sectional data.
- The absence of longitudinal data limits determination of directional causality and interaction between attention and interpretation.
- Study limitations are noted, suggestions are provided for researchers moving forward.

1. Introduction

Insomnia is a prevalent sleep disorder affecting up to 30% of the adult general population (American Academy of Sleep Medicine, 2005; Espie et al., 2012; Morin et al., 2006) and 10% of adults at disorder level (Espie et al., 2012; Morin et al., 2006). It is characterised by difficulty with sleep initiation, maintenance and/or early morning awakening, and accompanied by significant impairment to daytime functioning. Insomnia is associated with diminished quality of life (Kyle et al., 2010; Olfson et al., 2018; Rosenberg, 2021), physical and mental exhaustion, disturbed mood, concentration and memory, deficits in socioemotional functioning (Baglioni et al., 2010; Espie et al., 2012), and psychiatric distress (Riemann, 2007). Due to the significant personal burden it imparts, insomnia has recently been recognised as a public health concern.

Attentional bias refers to the phenomenon whereby certain psychiatric populations exhibit excessive attentional allocation towards emotional stimuli related to the symptom experience of their condition compared to non-condition-related information (Harvey et al., 2004; Pennebaker, 1982). Similarly, an interpretive bias involves the tendency to interpret ambiguous stimuli in a manner which is consistent with the concerns of their disorder (Ree & Harvey, 2006). Several theoretical cognitive models have been put forward to explain the mechanisms underlying the development and maintenance of insomnia (e.g., Espie, 2002; Espie et al., 2006; Harvey, 2002). Emphasized in these models is the notion that insomnia is in part maintained by an attentional bias (often described as *selective attention*) for sleep-related 'threat' cues which may be internal (i.e., bodily sensations) or external (i.e., environmental noises) (Espie et al., 2006; Harvey, 2002). The models propose that such 'threats' may be the product of sleep-specific anxiety, which is generated by dysfunctional beliefs about sleep and worry about the potential consequences of sleep loss on daytime functioning. Driven by this anxious state, attentional resources are preferentially allocated to the processing of sleep-related threat cues. Once detected, such cues may be interpreted in an insomnia-consistent manner, serving to further increase physiological arousal, distress, and negative thoughts concerning sleep and daytime function: a vicious thought cycle that is partly maintained by the sleep-related attentional bias (Harvey, 2002).

While a previous narrative review (Harris et al., 2015) cautiously suggests biased attention for sleep-related threat information to be a likely feature of insomnia based on individual effect sizes, the sleep-related interpretive bias literature remains to be systematically examined. Since this first review, conducted in April 2014, the number of empirical studies examining sleep-related attentional biases have approximately doubled. To that end, the present study sought to systematically review both the sleep-related attentional and interpretive bias and insomnia literature by providing an evaluation of study quality, synthesis of methodological features and a meta-analytic calculation for each form of bias.

2. Method

The protocol for this review was pre-registered in the International Prospective Register of Systematic Reviews (PROSPERO) database (CRD42020207416) and the Preferred Reporting Items for Systematic Reviews and Meta-analysis (PRISMA) (Moher et al., 2009) was followed as guidance for the searching and reporting. Searches were performed by UA. UA and JS independently screened titles and abstracts. Hand searches were carried out by UA and JS on the reference lists of the included studies with the full texts of any new studies screened against the inclusion exclusion criteria. Each full text was screened for quality by UA, JS and MG. Results were synthesised by UA, MG and JS. The meta-analyses were conducted by UA.

2.1 Literature search strategies

The following databases were searched for research articles from all years until the 7th of September 2020: Web of Science; PubMed; Scopus; PsychINFO; and ScienceDirect. The following string of Boolean terms were used for searching the title and abstract of articles: ("sleep" OR "insomnia") AND ("attention bias" OR "attentional bias" OR "interpretive bias" OR "interpretation bias" OR "cognitive bias"). An updated search, performed on the 15th January 2022, was conducted using the same approach, with the dates filtered between 7th of September 2020 and January 2024.

2.2 Study inclusion and exclusion criteria

Where the title of an article contained "sleep", "insomnia", "attention", "attentional", "interpretation", "interpretive" and/or "bias", and the abstract involved a reaction-time based assessment of attentional bias to sleep-related information, the full text article was reviewed and further assessed for inclusion in the review. Conference abstracts, case studies, narrative reviews, opinion papers, discussions, and duplicates were omitted. The inclusion criteria for the studies were as follows: i) insomnia or poor sleeper samples (as identified through validated questionnaire); ii) use of a computerised visual attention allocation/reaction-time based attentional bias task (e.g., Stroop, dot-probe, eye-tracking) or paper/computerised interpretive bias task (e.g., Insomnia Ambiguity task; IAT); adult samples, i.e., participants ≥ 18 years old; and iv) published in peer-reviewed journals. The following exclusion criteria was applied: i) studies that did not use a computerised/reaction-time based measure of attentional bias or paper/computerised interpretive bias task; ii) studies that measured neuropsychiatric functioning, but not sleep-related attentional bias using sleep-specific stimuli; iii) studies not published in the English language; iv) systematic reviews and editorials; and v) grey literature.

2.3 Data extraction and quality assessment

Authors UA, MG and JS assessed the quality of the included studies independently using standardized quality assessment criteria (Kmet et al., 2004). This criterion focuses on the extent to which design, conduct, and analyses minimize errors and biases of quantitative research. Here, appraisal involves assessing 14 items on a three-point rating scale. Three items (relating to blinding of the investigators to treatment) were removed as this was not deemed applicable to the present review. A global score between 0-23 was calculated for each study, enabling comparisons across studies, where higher scores indicate greater quality (see Appendix A1 for the full scale).

2.4 Statistical analyses

Jamovi (The Jamovi Project, 2021) was used to conduct statistical analyses of the data. A random-effects model was implemented, which assumes that individual studies vary in their average effect sizes, and therefore heterogeneity is to be expected (Field, 2003). Although random effects models have less statistical power than

fixed effects models, results may be generalised to similar studies not included in the actual analysis (Rosenthal, 1995). In this analysis, the standardised mean difference (Hedges' adjusted g) was used. Both Cochrane's Q and the I2 statistic were used to assess study heterogeneity. In the former, a significant result is indicative of heterogeneity. In the latter percentages of 25, 50, and 75% are indicative of low, medium and high heterogeneity (Huedo-Medina et al., 2006). A forest plot of overall effect sizes against the standard error of the effect size for each study is presented. The significance of the pooled *d* is determined with a Z test.

3. Results

3.1 Results of the literature review

The initial database search yielded 3693 potentially relevant studies (Web of Science = 156, PubMed = 73, SCOPUS = 139, PsychINFO = 2271, and ScienceDirect = 1054). After reading the titles and abstracts of these studies, and excluding duplicates, *N* = 40 articles were accessed in full and considered for inclusion in the review. Examination of full texts led to the exclusion of 11 studies (see Figure 1). Following the updated search in January 2022 yielding 585 potentially relevant studies, an additional (*N* = 1) study was included. The final sample consisted of 29 studies which fulfilled the inclusion criteria (see Fig. 1). Twenty-one of these studies examined sleep-related attentional bias, whereas 8 examined interpretive bias. *N* = 17 of the 21 attentional bias studies included a comparison between poor sleepers or insomnia patients and normal sleepers. *N* = 7 of the 8 interpretive bias studies included group comparison. Tables 1 (attentional bias) and 2 (interpretive bias) summaries key details for each reviewed study. Quality ratings for each study are provided in the appendix (Tables A2 and A3).

Insert Tables 1 & 2

3.1.1 Quality assessment

Quality scores ranged from 16 to 22 for attentional bias studies and 20 to 22 for interpretive bias studies (*M* = 3.47). As such, most of the available evidence appears to be of moderate quality. All studies (*n* = 29 relied on cross-sectional data, preventing the assessment of directional causality. Most studies provided a detailed hypothesis (*n* = 19), whereas few conducted a power calculation or indicated whether sufficient power was achieved (*n* = 4).

3.2 Sleep-related attentional bias

3.2.1 Attentional bias tasks and stimuli

Out of the 21 studies examining sleep-related attentional bias, 18 adopted a single attentional bias paradigm: five studies used the emotional Stroop task (EST; Barclay & Ellis, 2013; Lundh et al., 1997; Spiegelhalder et al., 2018; Taylor et al., 2003; Zhou et al., 2018), six used the dot-probe (Akram et al., 2018; Jansson-Fröjmark et al., 2012; MacMahon et al., 2006; Spiegelhalder et al., 2010; Takano et al., 2018; Zheng et al., 2018), two used the induced change blindness (flicker) paradigm (Jones et al., 2005; Marchetti et al., 2006), three examined visual attention using eye-tracking (Akram et al., 2018; Beatie et al., 2017; Woods et al., 2013), one used the Posner paradigm (Woods et al., 2009), and one used a Single-Target Implicit Association Test (Koranyi et al., 2017). Another examined spatial filtering following a visual probe task (Giganti et al., 2017). Four used a combination of two attentional bias tasks: two studies used the EST, and a mixed modality (visual–auditory) task (Spiegelhalder et al., 2008; Spiegelhalder et al., 2009), one study used both the emotional Stroop and dot-probe task (Spiegelhalder et al., 2010), another combined dot-probe and the N-back task (Takano et al., 2018).

Studies used different types of stimuli (e.g., words, pictures) in their attentional bias tasks. Ten out of the 21 attentional bias studies used word stimuli, ten used pictorial stimuli, and two used both (Takano et al., 2018; Spiegelhalder et al., 2010). Some studies (Barclay & Ellis, 2013; Koranyi et al., 2017; Lundh et al., 1997; MacMahon et al., 2006; Taylor et al., 2003; Spiegelhalder et al., 2008, 2009, 2010, 2018; Zhou et al., 2018) reported that the words were matched for either length, number of syllables, or frequency of use. Barclay and Ellis (2013) selected sleep-related words without affective connotation, although validation details were not specified. The sleep-related words in MacMahon et al. (2006), Takano et al. (2018), Taylor et al. (2003), Spiegelhalder et al. (2008, 2009, 2010, 2018), Woods et al. (2013) and Zhou et al. (2018) were developed from Wicklow and Espie's (2000) qualitative research on pre-sleep thought content in poor sleepers. Zhou et al. (2018) reported translating these words into Chinese, which were checked by an individual with a doctorate in English. Lundh et al. (1997) and Koranyi et al. (2017) did not document the process of selecting the sleep-related words used in their study.

Spiegelhalder et al. (2008, 2009, 2010) used non-validated pictures of bedroom-related stimuli. The pictorial stimuli in Jansson-Fröjmark et al.'s (2012) dot-probe study were selected from the Internet whereby inclusion was based on: likelihood of inducing a certain level of valence and arousal, matching of the type of situations in the two pairs of images, matching of age and gender in the two images, similar qualitative aspects (e.g., lighting and background), and identical size. Zheng et al. (2018) replicated this procedure to gather the pictorial stimuli for their study. In both studies using the flicker paradigm (Jones et al., 2005; Marchetti et al., 2006), sleep-related items were chosen based on the judgement of 60 people asked to list five objects related to “going to bed to sleep”. The twelve most frequent objects were photographed to create a single image of these items. Woods et al. (2009) used images of alarm clocks (displaying sleep-related times) to represent clock monitoring based on subjective reports of sleep-relatedness (Bearpark, 1994; Harvey, 2002, Tang et al., 2007). Takano et al. (2018) used a series of sleep-related (e.g., alarm clock, bed) and garden-related images (e.g., barbeque grill) based on object categories adapted from Jones et al. (2005). Beattie et al. (2017) used photographs of indoor scenes comprised of bedrooms, living rooms and kitchens which were either taken by the authors themselves or gathered from an internet search. Finally, Akram et al. (2018a, 2018b) used previously validated (Akram et al., 2018c) sleep-related facial stimuli depicting tiredness as their pictorial stimuli.

3.2.2 Meta-analysis calculations for attentional bias studies

The meta-analysis analysis was conducted using the MAJOR plugin for the Jamovi (Jamovi 1.6, R 4.0) statistical analysis package. Specifically, we used the standardized mean difference of attentional bias scores as the outcome measure (see Table 3). A random-effects model was fitted to the data. The amount of heterogeneity (i.e., T^2), was estimated using the Hedges' estimator (Hedges, 1985). In addition to the estimate of T^2, the Q-test for heterogeneity (Cochran, 1954) and the I^2 statistic are reported. In case any amount of heterogeneity was detected (i.e., $T^2 > 0$, regardless of the results of the Q-test), a prediction interval for the true outcomes was provided. Tests and confidence intervals were computed using the Knapp and Hartung method (Hartung & Knapp, 2001; Inthout et al., 2014). Studentized residuals and Cook's distances were used to examine whether studies may be outliers and/or influential in the context of the model (Cook, 1979). Studies with a studentized residual larger than the $100 \times (1 - 0.05/[2 \times k])^{th}$ percentile of a standard normal distribution were considered potential outliers (i.e., using a Bonferroni correction with two-sided $\alpha = 0.05$ for k studies included in the meta-analysis). Studies with a Cook's distance larger than the median plus six times the interquartile range of the Cook's distances were considered influential. The rank correlation test and the regression test,

using the standard error of the observed outcomes as predictor, were used to check for funnel plot asymmetry.

Insert Table 3

A total of k = 17 studies (insomnia/poor sleeper N = 447, controls N = 475), and thirty-five variables were included in the analysis. The observed standardized mean differences ranged from -0.893 to 3.565, with most estimates being positive (71%). The estimated average standardized mean difference based on the random-effects model was: \hat{\mu} = 0.60 (95% CI: 0.26 to 0.93). Therefore, the average outcome differed significantly from zero (t(34) = 3.63, p < .001). According to the Q-test, the true outcomes appear to be heterogeneous (Q(34) = 228.07, p < 0.001, T^2 = 0.91, I^2 = 90.70%). A 95% prediction interval for the true outcomes is given by -1.370 to 2.563. Hence, although the average outcome is estimated to be positive, in some studies the true outcome may in fact be negative (e.g., where attentional disengagement was evidenced). An examination of the studentized residuals revealed that none of the studies had a value larger than ± 3.19 and hence there was no indication of outliers in the context of this model. According to the Cook's distances, two studies (Marchetti et al., 2006: induced change blindness (ICB); Zhou et al., 2018: EST, Interference Index, Sleep Positive) could be overly influential. The regression test indicated funnel plot asymmetry (p = .0003) but not the rank correlation test (p = .112). See Figure 2 for funnel plot.

Insert Figure 2

3.2.3 Summary of attentional bias outcomes

This section provides an overview of each study by task.

3.2.3.1 Dot-probe task

The dot-probe (or Visual Probe) task is commonly used to determine the extent to which attention is drawn towards and held by personally relevant, emotionally negative ('threat') visual stimuli over emotionally neutral stimuli. The task involves the presentation of stimuli pairs (either words or pictures) in the upper or lower part of the computer screen. Each stimuli pair contains an emotionally negative member and an emotionally neutral member. Following the offset of these cues, a probe (a dot or asterisk) appears in either the upper or lower part of the screen, replacing one of the images or words. Here, participants must, for each trial, specify the position of the probe by pressing the corresponding key as quickly as possible. The distribution of attention is shown by the speed of response to probes that replace emotionally neutral stimuli relative to probes that replace the locus of emotionally negative stimuli. Indices of vigilance and disengagement may also be calculated. The vigilance index is calculated by subtracting the mean reaction time for threat stimuli from the mean reaction time for neutral stimuli. Likewise, to calculate the disengagement index, the mean reaction times for neutral trials are subtracted from the mean reaction time for trials where the probe replaced neutral stimuli. Faster responses for the vigilance index and slower responses on the disengagement index depict greater attentional bias to threat information.

Dot-probe example Figure 3

MacMahon and colleagues (2006) used a dot-probe task to compare sleep-related attentional bias outcomes between individuals with primary insomnia, delayed sleep phase syndrome (DSPS: a circadian rhythm sleep disorder with no presumed cognitive pathway) and normal sleepers. Subjects with DSPS acted as a second

control group to account for physiological sleep onset difficulties unattributed to cognitive processes. It was found that individuals with insomnia displayed greater vigilance for sleep-related words (relative to neutral words) compared to those with DSPS and normal sleepers. Using the same task with sleep-related images (i.e., bedrooms) and neutral control images (i.e., kitchen, living rooms), Spiegelhalder and colleagues (2010) found no group differences between controls and insomnia patients on the sleep interference index. Likewise, Takano and colleagues (2018) did not find evidence of any relationships between poor sleep, pre-sleep cognitive arousal and attentional bias scores when employing pictorial stimuli of the same nature.

Jansson-Frömark and colleagues (2012) used sleep-related images portraying fatigue/malaise (e.g, person sat on bed holding their head) and neutral images (e.g., person in office smiling on a telephone) to compare attentional bias indices (i.e., vigilance vs disengagement) amongst individuals with insomnia and good sleepers. Rather than increased vigilance, insomnia was characterised by disengagement difficulties whilst observing sleep-related images, compared to normal sleepers. The authors propose that the use of stimuli pertaining to daytime fatigue/malaise rather than night-time cues (which may trigger conditioned arousal) may account for the lack of vigilance effect. More recently, Akram and colleagues (2018) examined whether individuals with insomnia exhibit an attentional bias for sleep-specific (vs. neutral) faces depicting tiredness. Here, individuals with insomnia displayed decreased rather than increased vigilance towards sleep-related cues when compared with normal sleepers. In addition, like Jansson-Frömark and colleagues (2012), those with insomnia presented difficulty in disengaging attention away from sleep-related images (i.e., tired faces).

Zheng and colleagues (2018) determined that individuals with insomnia were more likely to exhibit an attentional bias following the induction of a negative mood state (i.e., autobiographical recall of poor sleep), relative to a neutral control mood state (i.e., reading recall). Specifically, when assigned to receive the negative mood induction to completing a dot-probe task comprised of images (general threat, sleep positive, sleep negative), an overall bias (i.e., regardless of image content) emerged amongst those in the insomnia group.

3.2.3.2 Emotional Stroop task

The EST typically involves the presentation of threat (i.e., disorder-relevant) information and emotionally neutral words printed in colour, and participants are instructed press a correspondingly coloured response key as quickly as possible whilst ignoring the semantic meaning of the word. The salience of the disorder-relevant word is proposed to consume attentional resources, thereby impairing task performance (MacLeod, 1986). Accordingly, slower responses to disorder-relevant words suggest an attentional bias (or Stroop interference). Lundh and colleagues (1997) were the first to utilise the EST to examine attentional bias in insomnia. In this study, both primary insomnia patients and controls responded more quickly when presented with sleep-related, relative to, physical threat and neutral words (i.e., no differential reaction times). However, the authors failed to calculate the critical measure of attentional bias (i.e., Stroop interference index). Therefore, these outcomes were calculated for the purpose of the current review, by subtracting reaction times for neutral words from reaction times for sleep-related words where greater scores indicate an attentional bias for sleep-related threat. This calculation revealed that insomnia participants in Lundh's study (1997) evidenced a greater degree of sleep-related attentional bias relative to controls (4.80 ± 03.38 vs. 3.85 ± 0.65, d = .35).

Emotional Stroop example Figure 4

Spiegelhalder and colleagues (2008) used the EST alongside a mixed modality paradigm to examine sleep-related attention bias amongst patients with primary insomnia and good sleepers. Sleep experts were also included as an additional control group, consisting of staff at a sleep disorders clinic, to control for frequency of concept usage. Whilst no difference in sleep interference was observed between insomnia patients and healthy sleep controls, greater sleep interference emerged in the insomnia group compared to the sleep expert group. No group differences in attentional bias were observed on the mixed modality task. The authors suggest that sleep-related attention bias may be due to altered emotional distinctions in emotional, cognitive or procedural processing rather than differences in frequency of concept use. Using the same EST, a follow up study (Spiegelhalder et al., 2010) demonstrated that patients with insomnia presented a significant sleep-related attentional bias when compared with healthy controls. Again, using the EST, Spiegelhalder and colleagues (2009) demonstrated that both poor sleep quality and sleepiness were associated with a bias for sleep-related words. Interestingly, an interaction between sleep quality and sleepiness demonstrated that the extent of bias was reduced when poor sleep was related to increased sleepiness, and when greater sleep quality was associated with reduced sleepiness. These outcomes may reflect the notion, as described in the Attention-Intention-Effort (AIE) model of insomnia (Espie et al., 2006), that physiological craving for sleep induces sleep-related attentional bias. In addition, the experience of sleepiness may comfort poor sleepers, who may ordinarily be threatened by increased arousal. This may explain greater EST performance in the co-occurrence of poor sleep quality and increased sleepiness (Spiegelhalder et al., 2009).

Barclay and Ellis (2013) compared sleep interference between poor and good sleepers using non-affective sleep-related words (e.g., dream, pillow), neutral words (e.g., chord, table) and non-specific threat words (e.g., dread, panic). Rather than examining attentional bias scores, the authors compared mean reaction times to each word type. No group differences emerged when examining response times to sleep-related words. However, further within-group analysis determined that poor sleepers displayed longer response latencies to sleep-related words compared to non-specific threat words. Here, personally relevant (sleep-related) threats appeared to hamper performance, whereas non-specific threats accelerated performance. The authors suggest that sleep might have been particularly salient for both groups given that the experiment was conducted in the evening and that poor sleepers may be consumed by sleep specific stimuli, yet highly adapted to generally threatening cues (Barclay & Ellis, 2013). As the authors failed to calculate the critical measure of attentional bias (i.e., Stroop interference index), this was calculated for the purpose of the current review. Like Lundh and colleagues (1997), the outcomes indicate the Barclay and Ellis (2013) evidenced a greater degree of sleep-related attentional bias relative to controls (11.42 ± 0.48 vs. 0.19 ± 18.69, d = .88).

More recently, two studies have examined the relationship between brain reactivity and selective attention towards sleep-related words amongst individuals with insomnia. Zhou and colleagues (2018) used the EST whilst recording event-related potentials (ERP) in participants with insomnia disorder and good sleepers to examine attentional bias towards sleep-negative, sleep-positive and sleep-unrelated neutral words. Here, compared to good sleepers, the insomnia group elicited greater interference for sleep-positive words, and a marginally significant (p = .051) interference effect for sleep-negative words. Moreover, ERP data in the insomnia group demonstrated that sleep-negative words provoked higher amplitudes of P1 and N1 components relative to sleep-positive and neutral control words. These results provide further evidence for a relationship between insomnia and sleep-related attentional bias, and uniquely indicate that insomnia may be associated with enhanced selection and processing of sleep-related information early in the attentional system. Spiegelhalder and colleagues (2018) used Functional Magnetic Resonance Imaging to examine brain reactivity to sleep-related words in insomnia patients and good sleepers. Here, patients with chronic insomnia

did not differ from good sleeper controls in terms brain reactivity to sleep-related words. Furthermore, completion of the EST outside the scanner failed to evidence any group differences in sleep-related attentional bias.

3.2.3.3 Induced Change Blindness (flicker) task

The flicker task examines a concept known as Induced Change Blindness (ICB), where, when a single change has been made to a visual scene, and the method of this change has not been revealed, it is often more difficult to ascertain this change than expected (Rensink, 2002; Simons, 2000). In essence, the flicker task is a form of 'spot the difference' task, where a change is made to pictorial stimuli, and the participant is required to detect this change. Further, a single part of pictorial stimuli is altered between sequentially recurrent brief presentations (known as flickers) until the change is identified. The number of flickers surpassed before the change has been identified acts as the measure of response latency. Moreover, faster response latencies are considered to suggest an increased attention bias.

Flicker example Figure 5

Jones and colleagues (2005) used the ICB flicker task to examine the presence of an attentional bias towards bedroom objects in good, moderate, and poor sleepers. Three image sets were used as stimuli: the original stimulus (OS), sleep-related change stimulus (CS-S: teddy bear, pyjamas, pillow, alarm clock, hot water bottle, hand cream, slippers) and neutral changed stimulus (CS-N: rucksack, journal, files, ink bottle, paper tray, umbrella, gloves). The CS-S was made by removing one of the pair of slippers, and the CS-N by removing one of the pair of gloves. It emerged that, compared with good sleepers, poor sleepers displayed quicker change detection latencies for sleep-related relative to neutral changes, thus, demonstrating a sleep-related attention bias. Moderate sleepers were also quicker to identify the sleep-related changes compared to good sleepers. Using the same task and stimuli, a following study by the same group (Marchetti et al., 2006) assessed sleep-related attentional bias in individuals with insomnia, delayed sleep phase syndrome and good sleepers. Again, those with insomnia were quicker to identify the sleep-related change compared the DSPS and good sleeper groups, and significantly quicker than the neutral change. Together, these findings support the notion of an attentional bias towards sleep-related images in insomnia.

3.2.3.5 Eye-tracking paradigms

Advancing the sleep-related attentional bias literature, several studies have examined the gaze behaviour of individuals with insomnia while observing sleep-related words and images (Akram et al., 2018; Beattie et al., 2017; Woods et al., 2013). Woods and colleagues (2013) were the first to compare the gaze behaviour of good sleepers and individuals with insomnia who observed a series of sleep-positive, sleep-negative, and neutral words. Regardless of word type, participants with insomnia were slower to fixate on target words and subsequently remained fixated for less time relative to good sleepers. Individuals with insomnia were also slower in discriminating between target and distractor words compared to good sleepers. Both groups demonstrated longer first fixations on positive and negative sleep-related words compared to neutral, however this effect was more prominent amongst the insomnia group. Although the authors failed to provide evidence for a sleep-related attentional bias, the outcomes may be reflective of a more general impairment in discriminating and maintaining attention. Expanding on words as stimuli, Beattie and colleagues (2017) compared normal sleepers and individuals with insomnia symptoms in their attentional allocation to sleep-related items in natural scenes, by recording eye movements during free-viewing of bedrooms. Groups did not differ in the amount of time taken to locate bed regions, and the total number of fixations made during

each trial. However, the insomnia group presented a greater number of fixations on bed regions and once fixated, remained there for a longer duration when compared to normal sleepers (Beattie et al., 2017). When presented with a series of sleep-neutral face pairs, Akram and colleagues (2018) found that individuals with insomnia spent more time fixating on and observing sleep-related (i.e., tired) rather than neutral faces, when compared to normal sleepers. These outcomes support the notion of a sleep-related attentional bias for faces depicting tiredness in insomnia.

Insert Table 4 – Eye-tracking Variables

3.2.3.6 Other methodologies

Using a modified Posner paradigm (Posner, 1980: see Figure 6), Woods and colleagues (2009) examined differences between individuals with insomnia and good sleepers in their vigilance and disengagement towards times presented on an alarm clock (e.g., 02:00). Compared with controls, individuals with insomnia presented longer responses on invalid trials (stimulus appears in the opposite box of the target), demonstrating delayed disengagement. Whilst no group differences in valid trials (stimulus presented in the same box as the target) emerged, those with insomnia were significantly slower on invalid trials relative to valid trials. Here, the salience of the alarm clock appears to capture the attention of those with insomnia, providing suggestive evidence of sleep-associated monitoring of external environmental cues as highlighted in cognitive models of insomnia (c.f., Harvey, 2002). In another study, Baglioni and colleagues (2014) examined whether insomnia patients exhibit altered amygdala responses to sleep-related images when compared to good sleepers. During fMRI recordings, the authors found that insomnia patients evidenced increased amygdala activity whilst viewing images of people lying awake and visibly frustrated in bed at night, compared to good sleepers. This result suggests the presence of sleep-related reactivity and, by extension, sleep-related attentional bias, in insomnia

Koranyi and colleagues (2017) used a single-target implicit association test to examine affective responses towards the bed amongst a sample of good sleepers and insomnia patients. In this study, participants indicated the appropriate affective valance of positive and negative words, whilst classifying sleep-related words (e.g., bed, pillow, blanket) into a target category of 'bed'. Insomnia patients revealed significantly stronger negative affective response towards sleep-related words when compared to good sleepers. Giganti and colleagues (2017) used a modified visual prime task to determine whether undergraduate students with and without insomnia differed in their vocal categorisation (i.e., "old" or "new") of neutral (real life objects) and sleep-related (i.e., bed, lamp, pyjamas) images. Whilst implicit memory was unaffected by sleep, participant responses were influenced by the nature of observed stimuli. Independent of priming, the insomnia group recognized sleep-related images at lower spatial frequencies (indicating an attentional bias) relative to controls. Combined, these outcomes support the notion of a sleep-related attentional bias amongst individuals with insomnia, which according to the authors may be driven by a state of cognitive hyperarousal as described by cognitive models (Espie et al., 2006; Harvey, 2002).

Using a modified n-back task, Takano and colleagues (2018) examined the relationship between subjective sleep quality and difficulties in updating working memory for sleep-related stimuli, as a potential mechanism underlying pre-sleep cognitive arousal. In this study, members of the general population determined the content of sequential 1-back and 2-back image presentations as being either sleep-related (i.e., bedroom objects) or non-sleep-related (i.e., garden objects). Sleep quality was not related to sleep-interference on each n-back task. Whilst cognitive and somatic arousal were similarly unrelated to sleep-interference on the 1-back

task, pre-sleep arousal was related to reduced interference by sleep-related stimuli in maintaining non-sleep-related information. These outcomes suggest that pre-sleep arousal may be accompanied by greater efficiency in processing sleep-related information alongside less distraction by a sleep-related distractor when processing non-sleep-related information.

3.3 Sleep-related interpretive bias

3.3.1 Interpretive bias tasks and stimuli

Five of 8 studies examining interpretive bias in insomnia used the Insomnia Ambiguity Task (IAT), developed by Ree and colleagues (2006). Here, a series of ambiguous sentences are each followed by two possible interpretations, one insomnia-consistent and another which is insomnia-inconsistent. For example, *Sam knew how long it would take him to fall asleep: slow* (insomnia-consistent), or *fast* (insomnia-inconsistent). Participants are instructed to choose between the insomnia-consistent and inconsistent ending for each sentence. The IAT was initially validated by Ree and colleagues (2006), where items were rated and verified by six independent judges to ensure that interpretations accompanying each sentence were equally probable, and that one interpretation of each ambiguous sentence was insomnia-consistent whilst the other was not. The remaining studies comprised of: individually programmed face-morph tasks for each participant in the study to examine how individuals with insomnia and controls interpret the extent of their own facially expressed tiredness (Akram et al., 2016); resolving a series of scenarios describing the consequences of poor sleep, and non-sleep-related activities in either a benign or negative manner (Courtauld et al., 2017); and choosing between answering sleep-related or eating-related questions (Takano et al., 2018).

3.3.2 Effect size calculations for interpretive bias studies

The same methodological approach used to calculate the sleep-related attentional bias effect size was used to determine the sleep-related interpretive bias calculation (as described in section 3.2.2).

Insert Table 5

A total of $k = 7$ studies were included in the analysis. The observed standardized mean differences ranged from 0.149 to 0.834, with most estimates being positive (100%). The estimated average standardized mean difference based on the random-effects model was: \hat{\mu} = 0.44 (95% CI: 0.19 to 0.69). Therefore, the average outcome differed significantly from zero ($t(6) = 4.331$, p = .005). According to the Q-test, there was no significant amount of heterogeneity in the true outcomes ($Q(6) = 9.85$, $p = .130$, $T^2 = 0.01$, $I^2 = 18.60\%$). A 95% prediction interval for the true outcomes is given by 0.09 to 0.80. Hence, even though there may be some heterogeneity, the true outcomes of the studies are generally in the same direction as the estimated average outcome. An examination of the studentized residuals revealed that one study (Akram et al., 2021; IAT) had a value larger than ± 2.69 and may be a potential outlier in the context of this model. According to the Cook's distances, one study (Akram et al., 2021; IAT) could be overly influential. Neither the rank correlation nor the regression test indicated any funnel plot asymmetry ($p = .773$ and $p = .416$, respectively). See Figure 6 for the funnel plot.

Insert Figure 6

3.3.3 Summary of interpretive bias outcomes

An interpretive bias can be observed when people disproportionately make a threat-congruent inference in response to an ambiguous and open-ended situation (Gerlach et al., 2020). In the context of psychiatric

disorders, the greater tendency to make a disorder congruent, rather than a neutral, interpretation of ambiguous stimuli serves as the critical measure of interpretive bias. (Ree & Harvey, 2006). A growing number of studies have examined and confirmed the presence of a sleep-related interpretive bias amongst poor sleepers and individuals with insomnia symptoms using an insomnia ambiguity task (IAT; Ellis et al., 2010; Gerlach et al., 2020; Ree & Harvey, 2006; Ree et al., 2006).

Ree and Harvey (2006) first examined the notion of sleep-related interpretive bias amongst students either meeting the DSM-IV-TR criteria for insomnia (APA, American Psychiatric Association, 2004) or who were characterised as normal sleepers. In the study, participants read insomnia and anxiety (general threat) related ambiguous sentences and made a lexical decision about the nature of pseudo or insomnia consistent, general threat consistent and general threat inconsistent words which followed. The median lexical decision time in response to target words consistent with insomnia interpretation of the preceding sentence were subtracted from response time to target words unrelated to the sentence to create an index of speeding to insomnia consistent information, which served as the critical measure of interpretive bias. Whilst no evidence of a sleep-related interpretive bias emerged, greater reports of sleepiness predicted a general bias towards threatening interpretations. In a further study, Ree and colleagues (2006) compared poor and normal sleepers in their responses to a paper-based version of the Insomnia Ambiguity Paradigm. After observing a series of ambiguous scenarios, participants gave an open-ended and forced-choice interpretation of the scenario. Open responses consisted of the first explanation for the scenario which came to mind, whereas forced-choice interpretations consisted of a neutral explanation which was paired with either an insomnia or anxiety related explanation. These findings suggest that poor sleepers exhibit a bias towards interpreting ambiguous situations in a threat-related manner, whether insomnia or anxiety related. These outcomes have since been replicated in several studies sampling poor sleepers (Akram et al., 2021; Ellis et al., 2010; Gerlach et al., 2020). In poor and normal sleeping students, Ellis and colleagues (2010) examined whether sleep-related questionnaire assessments elicit a priming effect which accentuate interpretive bias outcomes. Here, participants completed the IAT (as used by Ree et al., 2006) either before or after completing a series of sleep-related questionnaires. Irrespective of priming, poor sleepers displayed a greater tendency to interpret ambiguous sentences as insomnia consistent rather than insomnia inconsistent. Overall, subjects who were primed endorsed more insomnia consistent interpretations, and relative to normal sleepers this effect was more prominent amongst poor sleepers. These findings suggest that poor sleepers may be more easily activated by sleep-related cues, which may heighten a pre-existing tendency to interpret ambiguous scenarios in an insomnia consistent manner.

Courtauld and colleagues (2017) employed a reaction-time task assessing biased expectations amongst individuals who were categorised as experiencing either high or low insomnia symptoms. Subjects resolved a series of scenarios describing the consequences of poor sleep, and non-sleep-related activities in either a benign or negative manner. Here, the time response difference between resolving negative and benign scenarios provided an index of expectancy bias. Individuals presenting insomnia symptoms were significantly faster in resolving sleep-related scenarios in a negative, rather than benign, manner when compared with controls. However, groups did not differ in their pattern of resolving non-sleep-related scenarios. These outcomes support the notion of a sleep-specific expectancy bias to operate in those experiencing insomnia symptoms. Using a modified version of the pay per-view task, Takano and colleagues (2018) examined whether the experience of poor sleep was related to greater preference for sleep-related topics. In this study, members of the general population were offered a choice between answering sleep-related or eating-related questions. Each option was associated with a variable amount of economic reward which meant that

participants would in some cases face conflict between gaining economic reward and their intrinsic preference for a specific question type. The authors found that subjective reports of poor sleep quality were associated with forgoing greater amounts of reward to have an opportunity to answer sleep-related (as opposed to than eating-related) questions. Despite the negative consequences, the results indicate that poor sleeping individuals appear to voluntarily engage in sleep-related thinking. This motivation toward sleep-related information appears to be consistent with the intention and effort pathways in the Attention-Intention-Effort model (Espie et al., 2006), and according to the authors may explain why people continue to worry about their sleep(lessness).

Akram et al. (2016) examined whether individuals with insomnia display an interpretive bias, such that they misperceive facial attributes of tiredness in a disorder-consistent manner. Here, when compared with normal sleepers, individuals meeting the DSM-5 diagnostic criteria for insomnia disorder displayed an interpretive bias in that they misperceived their own face as appearing more tired than they physically were, confirming symptoms of their disorder (i.e., they interpret information about themselves as being consistent with the presence of a sleep deficit; Akram, 2016). Questionnaire studies have likewise found that individuals displaying symptoms of insomnia display a greater propensity to interpret their cutaneous features (i.e., skin, hair, nails) in a manner which is consistent with the presence of a sleep deficit (Gupta et al., 2015; Oyetakin-White et al., 2015). Whereas follow-up work determined the relationship between insomnia symptoms and perception of cutaneous features to be mediated by greater reports of sleep-related monitoring on awakening (Akram, 2017).

Possible mediational factors underlying the relationship between disorder-consistent processing of sleep-related information and insomnia have only recently been examined from an experimental approach (Akram et al., 2021; Gerlach et al., 2020; Zheng et al., 2018). Gerlach and colleagues (2020) evidenced a positive relationship between pre-sleep worry and poor sleep quality with an increased tendency to choose sleep-related interpretations of ambiguous sentences when using the IAT. However, regression analyses determined suggestive evidence that these outcomes were mediated by trait anxiety but not any objectively determined parameters of sleep continuity (Gerlach et al., 2020). Recently, Akram and colleagues (2021) examined possible mechanisms underlying the relationship between sleep-related interpretive bias and insomnia using the IAT (Ree et al., 2006). Specifically, the role of sleep-associated monitoring, sleep preoccupation, sleep anticipatory anxiety and generalized anxiety. After excluding those reporting a co-occurring physiological sleep disorder, the insomnia symptom group, as determined by the Sleep Condition Indicator questionnaire, demonstrated greater levels of sleep-related Interpretive bias scores compared with normal sleepers. When controlling for task response time, the time at which participants were tested, sleepiness, sleep-associated monitoring, sleep preoccupation, sleep anticipatory anxiety and generalized anxiety, only monitoring on awakening predicted sleep-related interpretive bias. Multiple mediation modelling confirmed that sleep-associated monitoring on awakening mediated the relationship between interpretive bias and insomnia symptoms.

4. Discussion

The aim of this review was to systematically identify studies that examined the extent to which sleep-related attentional and interpretive biases are present in individuals presenting with poor sleep, insomnia symptoms, or insomnia disorder when compared to good sleeper controls. Based on the outcomes of this review we tentatively conclude that sleep-related cognitive biases of attention and interpretation appear to be a key feature of insomnia. More specifically, 17 of the 21 reviewed studies directly compared sleep-related

attentional bias between controls and poor sleepers/insomnia patients demonstrating small to large effect sizes. The majority (14 out of 17) of these studies provided statistical support for the presence of sleep-related attentional bias. Based on a random effects model, meta-analytic data based on the standardized mean differences of attentional bias studies determined the weighted pooled effect size to be moderate, with most estimates being positive (71%). Furthermore, seven of eight studies examined group differences in sleep-related interpretive bias between controls and poor sleepers/insomnia patients demonstrating small to moderate effect sizes. The majority evidenced an interpretive bias to be present in those with disturbed sleep (Akram et al., 2016, 2021; Ellis et al., 2010; Gerlach et al., 2020; Ree et al., 2006). Based on a random effects model, meta-analytic data based on the standardized mean differences of interpretive bias studies determined the weighted pooled effect size (to be moderate., with most estimates being positive. Overall, the results of this review support the presence of sleep-related attentional and interpretive biases in insomnia. Whilst the attentional bias effect size should be taken with caution given a degree heterogeneity identified in the meta-analyses (Higgins et al., 2003), heterogeneity typically emerges in epidemiological meta-analyses which pertain to sleep (Li et al., 2018).

4.1 Relationships Between Attention, Interpretation & Perception

Harvey's (2002) cognitive model of insomnia suggests that selective attention increases the likelihood that people with insomnia will notice ambiguous sleep-related cues, which are subsequently interpreted in a negative manner consistent with the symptom experience of insomnia. As a result, sleep-related interpretive biases may further increase pre-existing arousal and anxiety concerning sleep, thus perpetuating the sleep disturbance in a cyclical manner. Likewise, Espie's (2006) AIE pathway proposes that selective attention precedes and leads to sleep intention and sleep effort, culminating in the reduced automaticity of normal sleep. Here, like Harvey's (2002) model, selective attention is considered to perpetuate the experience of cognitive and somatic sleep-related arousal during the pre-sleep period and throughout the day (Espie et al., 2002). With that in mind, recent work demonstrates heightened pre-sleep cognitive and somatic arousal to be associated with both increased sleep-related attentional (Takano et al., 2018) and interpretive bias (Akram et al., 2021; Gerlach et al., 2020) outcomes in poor sleepers. In individuals exhibiting symptoms of insomnia, greater sleep-related interpretive bias outcomes have been associated with greater levels of sleepiness, anxiety and preoccupation about sleep and sleep-related monitoring on awakening and throughout the day (Akram et al., 2021). In this study, only increased monitoring for insomnia-consistent cues on awakening predicted increased sleep-related interpretive bias scores amongst those experiencing insomnia symptoms (Akram et al., 2021). Together, these outcomes confirm that whilst sleep-related interpretive biases are characteristic of the insomnia experience, the extent of bias appears to be mediated by pre-sleep worry and the extent of monitoring for sleep-related cues that confirm poor sleep on awakening (Akram et al., 2021; Gerlach et al., 2020). Certainly, the combination of pre-sleep arousal at night and morning examination of internal bodily sensations and physical appearance for signs of poor sleep may perpetuate negatively toned cognitive activity described in cognitive models of the disorder (Espie et al., 2006; Harvey, 2002).

Cross-sectional survey data finds that sleep-associated monitoring on awakening (but not throughout the day) mediates the relationship between negative interpretations of cutaneous body image and insomnia symptoms (Akram, 2017). Similarly, qualitative interviews amongst individuals with insomnia highlighted the role of monitoring of the internal and external bodily environment upon awakening as a means of assessing the extent of poor sleep obtained (Akram et al., 2018; Semler & Harvey, 2004). Here, the presentation of sleep-related attentional bias led to negative self-appraisal (i.e., interpretive bias). Internally, the body was perceived as sore, heavy and unrefreshed, whereas externally, attention was focused on facial appearance

(i.e., heavy eyes, poor complexion). Relatedly, Semler and Harvey (2005) found that promoting sleep-misperception upon awakening using false feedback about the quality of sleep obtained served to subsequently alter the perception of daytime deficits in those with insomnia. Using a within subjects' design, on days following false feedback suggesting poor sleep, the authors found that negatively toned cognitive activity, sleepiness, sleep-related attentional bias, and use of safety behaviours were all greater compared to days when false positive feedback was received (Semler & Harvey, 2005). More recently, partial replication employing a between subjects' design amongst individuals with insomnia where sham sleep feedback (positive vs negative) was delivered using actigraphy (Gavriloff et al., 2018). The suggestion of poor sleep and daytime performance appeared to again prompt greater reports of daytime dysfunction and increased fatigue relative to those receiving positive feedback. However, no differences in attentional bias were observed (Gavriloff et al., 2018). Therefore, the period immediately following awakening appears to be crucial in relation to the attentional processing of sleep-related stimuli in those with insomnia, facilitating the likelihood of disorder-consistent interpretation and the subsequent (mis)perception of daytime impairments. To that end, if the emerging sleep-related attentional bias on awakening was to be eliminated, this would theoretically: reduce the tendency for those with insomnia to interpret ambiguous cues in a way which confirms poor sleep, eliminating two key maintaining factors of the disorder; and circumvent the exacerbation of additional perpetuating factors highlighted in cognitive models (Espie et al., 2006; Harvey, 2002) of the disorder (i.e. sleep-related arousal, misperception of daytime deficit, behavioural sleep effort).

Another key question concerning the sleep-related attentional and interpretive bias literature remains the relative roles of psychological and physiological features of insomnia in predicting the presence of cognitive biases of information processing in this population (Spiegelhalder et al., 2009). Studies have found no bias of attention towards sleep-related stimuli amongst individuals with delayed sleep phase syndrome (MacMahon et al., 2006; Marchetti et al., 2006) which suggests that, alone, a physiological sleep disturbance is not enough to cause an attentional bias in terms of disorder specific information processing (Ellis et al., 2013). This proposition is supported by research demonstrating that normal sleepers appear to maintain a stable bias of attention towards sleep-related stimuli using the EST over a period of 36 hours of sustained wakefulness (Sagaspe et al., 2006). Together these findings indicate that an attention bias towards sleep-related stimuli amongst those with insomnia may predominantly occur due to the psychological processes as outlined in cognitive models of insomnia.

4.2 Cortical Activity and Cognitive Bias

The observation of brain reactivity in response to the sleep-related stimuli may provide a timeline of cognitive bias whilst providing insight into the relative roles of vigilance and disengagement, and threat versus craving amongst those with insomnia (Baglioni et al., 2014; Kim et al., 2017; Spiegelhalder et al., 2018; Zhou et al., 2018). Baglioni and colleagues (2014) found that, compared to normal sleeping controls, individuals with insomnia show greater levels of amygdala reactivity during fMRI recordings in response to free viewing of sleep-related images. In people with insomnia, event-related potential (ERP) data showed evidence that negatively valanced sleep-related words presented during an EST yielded higher amplitudes of P1 and N1 components in the occipital region, relative to sleep-positive and sleep-unrelated words (Zhou et al., 2018). This effect was not observed amongst normal-sleeping controls. Here, P1 and N1 represent early ERP components which reflect the automatic sensory process in response to external stimuli (Naatanen et al., 1982). More specifically, the observation of higher P1 and N1 amplitudes infers evidence of early cortical vigilance towards negative sleep-related words (Zhou et al., 2018). Interestingly, this study failed to evidence greater amplitudes of later ERP components (i.e., N2 or P3) which would be required to shift attentional

allocation away from sleep-related words. This latter outcome falls in line with the many studies which suggest that difficulties in disengaging from sleep-related stimuli are a prominent feature of insomnia (Akram et al., 2018; Barclay et al., 2013; Jansson-Fröjmark et al., 2012; Lundh et al., 1997; MacMahon et al., 2006; Spiegelhalder et al., 2008, 2010; Woods et al., 2009; Zhou et al., 2018). At present, interpretation of this data should be considered preliminary when accounting for the limited number of studies examining brain reactivity and attentional bias in insomnia, and the emergence of null outcomes (Spiegelhalder et al., 2018). Indeed, Spiegelhalder and colleagues (2018) failed to evidence differences between insomnia patients and controls in relation to attentional bias outcomes or cortical activity in response to the presentation of sleep-related words when using the EST and free-viewing tasks. Kim et al. (2017) evidenced that the precentral, prefrontal, and posterior cingulate cortex areas in the brain of insomnia patients exhibited greater activation in response to the free viewing of sleep-related images but not neutral images when compared with normal sleepers. The precentral cortex of insomnia patients is known to elicit increased connectivity to the amygdala (Huang et al., 2012) and sensory cortices (Killgore et al., 2013; Zhao et al., 2015), and might be related to hyperarousal of the psychomotor system in the context of sleep-related anxiety in insomnia (Kim et al., 2017). In relation to the current context, the neural processing of sleep-related stimuli may serve to accentuate the hyperarousal of precentral cortical activity amongst those with insomnia. The most novel outcome pertains to the normalised brain reactivity following the successful completion of Cognitive Behavioural Therapy for Insomnia (CBTi). As per the AIE model (Espie et al., 2006), which proposes that attentional bias precedes sleep intent and behavioural sleep efforts, these outcomes further highlight the potential therapeutic role of targeting sleep-related cognitive biases, possibly as an adjunct to CBTi (Espie et al., 2006; Harvey, 2002).

4.3 Methodological Influence

4.3.1 Task & Stimuli

The variation in sleep-related cognitive bias outcomes may partly stem from methodological differences pertaining to the task and stimuli used. Indeed, when examining group differences (insomnia/poor sleeper vs. control) in attentional bias, eye-tracking paradigms employing a free viewing task consistently yielded moderate to large effect sizes, specifically when using pictorial stimuli (Akram et al., 2018; Beattie et al., 2017) relative to words (Woods et al., 2013). With reaction time as the critical measure of attentional bias, the pictorial flicker task reliably yielded large between group effects (Jones et al., 2005; Marchetti et al., 2006). Whilst the EST has previously been considered the least sensitive task in the context of sleep-related attentional bias (Harris et al., 2015), this observation was partly based on some studies opting to analyse only the raw reaction time scores rather than the more appropriate calculation of interference effects (Barclay et al., 2013; Lundh et al., 1997). As such, for the purpose of the current review, we chose to calculate and include only the Stoop interference scores where necessary. Specifically, five (Barclay et al., 2013; Lundh et al., 1997; Spiegelhalder et al., 2008, 2010; Zhou et al., 2018) of six (Spiegelhalder et al., 2018) studies evidenced group differences (insomnia/poor sleeper vs. control) in Stroop interference when processing sleep-related information with moderate to large effects. Apart from one study (Zheng et al., 2018), the dot-probe task appears to reliably evidence group differences in attentional bias for sleep-related words and images with moderate to large effect sizes (Akram et al., 2018; Jansson-Fröjmark et al., 2012; MacMahon et al., 2006; Spiegelhalder et al., 2010). Three studies calculated vigilance and disengagement indices (Akram et al., 2018; Jansson-Fröjmark et al., 2012; Zheng et al., 2018), whereas the remaining studies calculated task interference as the critical measure of attentional bias (MacMahon et al., 2006; Spiegelhalder et al., 2010). Here, the presence of a sleep-related attentional bias appears largely attributable to difficulties in orienting attention towards, and disengaging attentional resources from, the spatial location of insomnia salient stimuli (Akram et al., 2018; Jansson-Fröjmark et al., 2012; MacMahon et al., 2006; Spiegelhalder et al., 2010). Difficulties in

disengaging attention from sleep-related stimuli were also observed using the Posner task (Woods et al., 2009).

As previously mentioned, most of the research to date confirms the presence of a sleep-related interpretive bias amongst poor sleepers and individuals when compared to normal sleeping controls. Here, studies opting to analyse responses to forced choice questions yielded moderate to large effects (Akram et al., 2021; Ellis et al., 2010; Gerlach et al., 2020; Ree & Harvey, 2006) relative to reaction time tasks which yielded mostly small to moderate effects (Coultard et al., 2017; Ree et al., 2006).

4.3.2 Control Variables

Disorder-consistent cognitive biases of attention and interpretation have been well established amongst individuals presenting anxiety and depression (Mogg & Bradley, 2005; Mogg et al., 1995; Peckham et al., 2010; Van Brockstaele et al., 2014). Given the prevalence of co-occurring symptoms of anxiety and depression in people experiencing poor sleep or insomnia (c.f., Alvaro et al., 2013), most sleep-related cognitive bias studies have controlled for psychiatric symptoms in pre-screening or statistical analysis. This is to ensure that the presence of any emerging cognitive bias is driven by the experience of insomnia, rather than comorbid factors. In the reviewed studies, symptoms of anxiety and/or depression were either: statistically controlled for (Akram et al., 2018a; Akram et al., 2021; Gerlach et al., 2019; Koranyi et al., 2017; Ree et al., 2006; Takano et al., 2018); assessed with no need to control for symptoms (Akram et al., 2016; Baglioni et al., 2014); assessed but not controlled for (Akram et al., 2018b; Woods et al., 2010; MacMahon et al., 2006; Courtauld et al., 2017; Beattie et al., 2017) or; controlled for using anxious and sleep-related stimuli (Ree & Harvey, 2006). Many studies excluded participants based on the presence of psychiatric symptoms at the pre-screening stage (Jones et al., 2005; Marchetti et al., 2006; Jansson-Fröjmark et al., 2012; Spiegelhalder et al., 2010, 2018; Giganti et al., 2017; Woods et al., 2008; Zhou et al., 2018). Other studies failed to examine symptoms of anxiety and depression (Barclay & Ellis, 2013; Ellis et al., 2010; Spieglhalder et al., 2008, 2009; Takano et al., 2018). Few studies have controlled for other sleep-disorder symptoms or sleep-related variables (e.g., chronotype, daytime sleepiness, sleep-related arousal) which may possibly influence perceptual judgments when observing sleep-related stimuli (Akram et al., 2021; Gerlach et al., 2019; Jansson-Fröjmark et al., 2012; 2019; MacMahon et al., 2006; Marchetti et al., 2006; Spiegelhalder et al., 2010, 2018).

4.3.3 Sample, Population & Design

Data from a total of *N* = 1499 participants were included in this review, *N* = 922 from attention bias studies with a mean sample size of 60.10, and *N* = 277 from interpretive bias studies with a mean sample size of 96.75. Overall, studies included in this review were comprised of rather small sample sizes ranging from 31 to 192 participants. Despite some diversity in study location, sampling was disproportionately limited to the United Kingdom (*N* = 13) and Germany (*N* = 8). Few studies were conducted in the rest of Europe (*N* = 2), the United States (*N* = 2), Australia (*N* = 1) or China (*N* = 1). All studies collected cross-sectional data. Moreover, a disproportionate number of Caucasian female participants was observed, and several of the included studies restricted their sample to include only students (Courtauld et al., 2017; Ellis et al., 2010; Giganti et al., 2017; MacMahon et al., 2006; Ree & Harvey, 2006; Takano & Raes, 2018; Takano et al., 2018; Woods et al., 2009, 2013; Zhou et al., 2018).

Most sleep-related attentional bias studies (15 of 21) sampled individuals meeting the DSM-5 diagnostic criteria for insomnia and normal sleepers. Here, nine studies drew from the clinical population of insomnia

patients, whereas the remaining used diagnostic screening of students and/or the general population to identify the presence of insomnia. Two of the 8 interpretive bias studies sampled individuals meeting the DSM-5 diagnostic criteria for insomnia (Akram et al., 206; Ree et al., 2006), with the remaining studies using questionnaire measures to determine insomnia symptoms.

4.4 Suggestions for Future Work

Moving forward, we offer suggestions for future researchers to consider which may improve and expand on the sleep-related cognitive bias literature whilst providing a greater understanding of cognitive models of insomnia. The priority however should involve addressing the limitations discussed above (i.e., sample size, cross-sectional design).

4.4.1 Mediating Factors

As discussed, the exploration of potential mediational factors fundamental to the sleep-related cognitive bias and insomnia relationship has only recently begun in the context of interpretive bias outcomes (Akram et al., 2021 Gerlach et al., 2020; Zheng et al.,2019). In a recent theoretical perspective, we propose candidate factors that may play a crucial role in addressing moderating questions such as “when,” “for whom” and “under which” conditions are sleep-related attentional biases evident in individuals characterized by insomnia (Akram et al., 2018d). More specifically, the relative role(s) of: the 5HTTLPR polymorphism and brain reactivity; valance of mood state; sleep-related worry; and misperception of sleep and daytime impairment have been suggested (Akram et al., 2018d).

4.4.2 Methodological Approach

Moving forward from reaction time assessments of attentional bias, which can be considered an indirect measure of attention, several studies have used eye-tracking paradigms to examine selective attention in insomnia (Akram et al., 2018d; Beattie et al., 2017; Woods et al., 2013). Here, visual attention can be continuously recorded throughout stimuli presentation to determine where individuals with insomnia direct and fixate their gaze, providing anobjective and direct assessment of attention (Eizenman et al., 2003; Godjin & Theeuwes, 2003; Marks et al., 2014). Likewise, recent advances using virtual reality environments have significantly improved the proximity and salience of disorder congruent stimuli when assessing attentional bias in individuals experiencing anxiety (Urech et al., 2015; Yuan et al., 2018), depression (Camacho-Conde et al., 2021; Voinescu et al., 2021) and body image disturbance (Porras-Garcia et al., 2019). Certainly, virtual reality paradigms could improve the ecological assessment of cognitive bias in insomnia. For example, expanding on images of the bedroom, participants may be exposed to an immersive bedroom environment.

Future work should focus on the integration of sleep-related attentional and interpretive biases measures (Harris et al., 2015) to identify the relative contribution of each cognitive process to insomnia. Future reaction time tasks may be paired with eye-tracking, virtual reality or EEG paradigms with a focus on capturing the relationship between initial attention allocation to sleep-related cues and the subsequent influence on perceptual judgments (i.e., interpretation bias). This approach would also allow a greater understanding of how sleep-related cognitive biases are characterised in the context of vigilance and disengagement.

4.4.3 Attentional Bias Modification

Deploying attentional bias modification (ABM) paradigms immediately prior to nocturnal sleep-onset may be used to reduce the extent of sleep-related attentional bias in insomnia, and therefore, lead to an associated reduction in symptom severity (Clarke et al., 2016; Milkins et al., 2016). Here, attentional avoidance of

negative sleep-related information is facilitated using a modified dot-probe task where the target location always follows the placement of neutral (i.e., location opposite sleep-related) stimuli. Following repeated exposure over consecutive days, this paradigm may 'train' an individual's attention away from negative information related to their specific condition and towards more neutral information (Hallion & Russo, 2011). The immediate effects of ABM appear to be most prominent when implemented just before the event which is perceived as threatening to the population (Amir et al., 2008). In the context of sleep, poor sleepers completing ABM immediately before attempting sleep reported improved sleep quality, reduced pre-sleep arousal, and reduced sleep onset latency relative to alternative nights where a control task was completed (Clarke et al., 2016; Milkins et al., 2016). Expanding on this research, Lancee et al. (2017) evidenced no therapeutic effect of ABM amongst those meeting diagnostic criteria for insomnia. However, this study delivered ABM in the evening between 7 and 11 pm, rather than the individuals immediate period before sleep, where biased attention may be more prominent (Milkins et al., 2016). Whilst this work appears promising, further studies are required to determine the efficacy of ABM amongst individuals with insomnia.

5. Conclusions

Theoretical models of insomnia highlight the crucial role of sleep-related attentional and interpretive biases in the development and maintenance of the disorder (Espie et al., 2006; Harvey, 2002). Based on the outcomes of this meta-analysis and systematic review, disorder congruent attentional and interpretive biases appear to be tentative features of the disorder. Indeed, most studies analysed in this review lend statistical support for this notion, with moderate and comparable effects for both sleep-related attentional and interpretive biases. Our findings highlight methodological factors pertaining to the task design, sample population and stimuli used, which may influence the variation in study outcomes. Due to a degree of heterogeneity among studies alongside the absence of any longitudinal data, we are still unable to infer any causal influence on the development and maintenance of insomnia (Harris et al., 2015). Therefore, we suggest that future researchers seek to clarify the presence of these cognitive biases in insomnia using experimental designs, whilst also examining the role of potential mediating and moderating factors.

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Tables

Table 1
Outcomes and characteristics of reviewed studies examining sleep-related attentional bias.

Study	Sample & Design	Group allocation	Key measures	Task characteristics	Main outcomes	Attention bias and sleep associations
Dot-probe						
MacMahon et al. (2006)	N = 63: PI = 21 (14 female, 23.6ys), DSPS = 22 (10 female, 21.8ys), GS = 20 (11 female,28.2ys). Between-subjects	DSM-IV, ICSD-R criteria for ID and DSPS; PSQI>6, actigraphy.	PSQI for presence and severity of sleep disturbance (mean score PI = 9.8; GS = 2.6; DSPS = 7.4),	Dot-Probe: 20 sleep, 20 matched neutral words, 60 neutral non-sleep-related words. DV — sleep interference index.	Sleep interference index: PI = 3.9ms ± 9.4, DSPS = 1.1ms ± 8.3, GS = −2.5ms ± 9.7. PI > DSPS = GS d (PI-GS) = .67 d (DSPS-GS) = .40 d (PI-DSPS) = .32	SSS and PSQI scores did not correlate with AB scores
Spiegelhalder et al. (2010)	N = 60: PI = 30 (20 female, 46.9ys), C = 30 (21 female, 48.3ys). Between-subjects	DSM-IV-TR, physical and psychiatric examination, PSG on 22 PIs.	PSG. PSQI (mean score PI = 13.3; C = 3.9). SSS (mean score PI = 2.9; C = 1.8).	Dot-Probe: 20 sleep-related, 120 control pictures. DV — sleep interference index	Sleep interference index: PI = 8.9ms ± 30.5, C = −7.6ms ± 41.6. PI = C (p = .085) d (PI-C) = .45	AB scores significantly Positively associated with PSG sleep parameters (TST, SE, SWS) and negatively associated with number of awakenings.
Jansson-Fröjmark et al. (2012)	N = 42: PI = 21 (17 females, 50.2ys) NS=21 (17 females, 50.4ys). Between-subjects	PI: diagnostic interview using DSISD and ICSD. ISI (required score PI > 15), PRIME-MD to exclude co-morbid sleep and psychiatric disorder. NS: SLEEP-50, DSISD, PRIME-MD.	ISI (mean score PI = 21.3; NS = 3.1). ESS (mean score PI = 7.7; NS = 6.7).	Dot-Probe: 20 threatening pictures (fatigue/malaise), 80 neutral pictures. DVs — Vigilance index, Disengagement index, Overall bias (=vigilance − disengagement index).	PI: Vigilance index= 4.5ms ± 39.9, Disengagement index= −20.8ms ± 38.3, Overall bias index= 25.3ms ± 56.7. NS: Vigilance index= 0.6ms ± 18.3, Disengagement Index = 9.5ms ± 27.4, Overall bias index = −8.9ms ± 32.0. PI > NS on Disengagement and Overall bias indices. PI=NS on Vigilance index. Vigilance index: d (PI-NS) = .13 Disengagement index: d (PI-NS) = .91 Overall bias index: d (PI-NS) = .74	Anxiety and depression (HADS) were not associated with overall bias, disengagement, and vigilance.
Akram et al. (2018)	N = 82: ID = 41 (65% female, 28.0ys); NS = 41 (67% female, 25.3ys). Between-subjects	DSM-5 criteria, SLEEP-50 to exclude for co-morbid sleep disorder symptoms	SSS to control for sleepiness (mean score ID = 2.83; NS = 2.23).	Dot-probe: 12 tired and 12 neural faces. N=96 tired-tired face pairs; N=96 neutral-neutral face pairs. DVs — Vigilance and disengagement indices.	ID: Vigilance index = -27.6 ± 67.0, Disengagement index= 30.9 ± 73.9. NS: Vigilance index = -2.4 ± 10.7, Disengagement index = 0.8 ± 12.8. Vigilance: ID > NS Disengagement: ID < NS Vigilance index: d (ID-NS) = .53 Disengagement index: d (ID-NS) = .57	No relationship between sleepiness and attentional bias indices. Anxiety (HADS) was related to disengagement from sleep-related stimuli in the insomnia group and was subsequently controlled for in analyses.
Takano et al. (2018)	N = 61: (50 female, 22.2ys) PS = 28 GS = 33. Correlational	PSQI (required score PS>5).	PSQI, PSAS: No group data.	DV – Correlations between PSQI, PSAS-C and PSAS-S with task outcomes (dot probe, bias score; 1-back, switch to sleep score; 2-back, interference by sleep).	Dot-probe: PSQI, r = .04; PSAS-C, r = -.01; PSAS-S, r = .11. 1-back task:, PSQI, r = -.04; PSAS-C, r = -.00; PSAS-S, r = -.14.2-back task: PSQI, r = -.26; PSAS-C, r = -.33*; PSAS-S, r = -.39*.	Sleep-interference scores (RT) for the 2-back task was negatively correlated with PSAS-C (r=−0.33, p=0.025) and PSAS-S (r=−0.39, p=0.006) but not PSQI. No other correlations between bias outcomes and sleep.
Zheng et al. (2018)	N = 65: ID = 31 (71% female, 19.55ys) GS = 34 (64% female, 19.50ys) Unprimed subjects analysed for current review: ID = 17 GS = 15	DSM-5 criteria, PSQI (required score PS>5).	PSQI	Dot probe: sleep-related positive and negative, and neutral images. Group vs Priming conditions. DV – Vigilance and maintenance indices for sleep negative and positive stimuli amongst those who were not primed.	ID: Sleep positive, Vigilance index, = 13.32 ± 39.82, Maintenance index= -7.22 ± 55.01; Sleep negative = Vigilance index, = 12.79 ± 68.35, Maintenance index= -8.97 ± 65.98 GS: Vigilance index = Sleep positive, Vigilance index, = 6.95 ± 38.19, Maintenance index= 1.23 ± 23.63; Sleep negative = Vigilance index, = 21.30 ± 35.33, Maintenance index= -0.94 ± 39.80	No correlations observed between attentional bias indices and emotional state.
Emotional Stroop						
Lundh et al. (1997)	N=40: PI=20 (16 females, 46.4ys), C=20 (16 females, 45.5ys). Between-subjects	Screening in Sleep Disorders Unit in Hospital.	-	Stroop, 6 stimulus groups: sleep, sleep control, physical threat, physical control, colour words, and groups of five Xs.	RT: PI=68.0ms ± 15.7, C = 69.3ms ± 14.4. Sleep interference: PI = −4.80ms ± 3.38, C = −3.95ms ± 0.65. PI = C*	No association between sleep interference index and anxiety (STAI-S) or depression (BDI).

				DV — sleep interference index.	d* (PI-C) = .88	
Spiegelhalder et al. (2008)	N = 60: PI = 20 (12 female, 40.6ys) SE=20 (12 female, 38 ys) C=20 (12 female, 38.6ys) Between-subjects	DSM-IV criteria for primary insomnia. Physical and psychiatric examination.	PSQI to assess sleep quality (mean scores PI = 10.8; SE = 4.3; C = 2.6).	Stroop: 20 sleep-related, 60 neutral words. DV — sleep interference index.	Sleep interference index: PI=3.8ms ± 15.4, SE=−8.7ms ± 15.7, C=−1.9ms ± 14.8. PI > SE PI = C d (PI-C) = .38 d (PI-SE) = .80 d (C-SE) = .45	-
Spiegelhalder et al. (2009)	N = 104 good sleepers (51 female, 28.0ys). Correlational	-	PSQI to assess sleep quality (mean score = 4.4). SSS to assess sleepiness level (mean score = 2.7).	Stroop: 20 sleep-related, 60 neutral words. DV — sleep interference index	PSQI and SSS had significant positive impact on AB scores (t=2.83, P=.01; t=2.16, P=.05, respectively). PSQI x SSS interaction had negative impact on AB, t= −2.79, P<.01. Multiple linear regression: f2 = .09	-
Spiegelhalder et al. (2010)	N = 60: PI = 30 (20 female, 46.9ys), C = 30 (21 female, 48.3ys) Between-subjects	DSM-IV-TR, physical and psychiatric examination, PSG on 22 PIs.	PSG, PSQI (mean score PI = 13.3; C = 3.9), SSS (mean score PI = 2.9; C = 1.8).	Stroop: 10 sleep-related, 30 neutral words. DV — sleep interference index.	Sleep interference index: PI = −0.6ms ± 19.7, C = −11.4ms ± 22. PI > C d (PI-C) = .52	AB scores did not correlate with PSG sleep parameters (TST, SE, SWS).
Barclay et al. (2014)	N = 107: (66 females, 33.2 ys) - PS (n = 42), GS (n = 65). Between-subjects	PSQI (required score PS>5).	PSQI to assess sleep quality (mean scores PS = 8.57; GS = 3.66).	Stroop: 20 non-affective sleep-related, 20 neutral, 20 non-specific threat words. DV — sleep RTs.	Sleep RTs: PS = 723.4ms ± 172.6, GS = 713.2ms ± 166.3. Sleep interference index: PS = 11.42 ± 0.48, NS = 0.19 ± 18.69. d* (Interference) = .88	-
Spiegelhalder et al. (2018)	N=55: PI=20 (10 female, 42.6ys); GS=35 (21 female, 40.0ys. Between-subjects, correlational	DSM-IV-TR, and psychiatric examination for PI, RDC criteria for GS.	PSG, PSQI (mean score PI = 10.4; GS=1.8), ISI (mean score PI = 14.7; GS=2.3), DBAS (mean score PI = 4.7 ; GS =2.3), ESS (mean score PI =7.6; GS = 6.8), SSS (mean score PI = 2.3; GS = 2.2), PSAS-S (mean score PI = 12.1; GS = 10.3), PSAS-C (mean score PI = 19.2; GS = 13.4), GSES (mean score PI = 7.0; GS = 1.1).	Stroop: 10 sleep-related and 20 neutral control words. DV – RTs and attentional bias index.	RT: PI = 802ms ± 112, GS = 772ms ± 80. Attentional bias index: PI = 4.6ms ± 20.4, GS = 4.5ms ± 28.7. d = .00	Exploratory analyses did not show any significant correlations between brain reactivity/selective attention to sleep-related words and questionnaire scores/PSG parameters.
Zhou et al. (2018)	N=31: ID=16 (11 female, 23.4ys); GS=15 (10 female, 21.1ys). Between-subjects	DSM-V Criteria for Insomnia Disorder following diagnostic telephone interview.	PSQI (mean score PI = 12.55; GS = 3.94)	Stroop: 26 sleep-negative, 26 sleep-positive, 52 sleep-unrelated neutral words. DV - sleep-negative, 26 sleep-positive, neutral RTs.	RT: Sleep Negative, PI = 680ms ± 131, GS = 593 ± 88; Sleep Positive, PI = 681ms ± 136, GS = 589 ± 86; Sleep Neutral, PI = 668ms ± 129, GS = 600 ± 101. ID < GS for sleep-negative and sleep-positive words.	ERP data indicated that sleep-negative words elicited higher amplitudes of P1 and N1 components.
Flicker (ICB)						
Jones et al. (2005)	N = 192 (32.1 years): PS = 64 MS = 64 GS = 64 Between-subjects	PSQI (required score PS.>5. MS score = 4-5. GS score = 0–2). Retrospective, random allocation.	PSQI for sleep quality.	Flicker: A picture (original stimulus) with sleep-related (slippers), or neutral (gloves) change detection. DV — change detection latency (number of flickers).	Number of flicker cycles to detect sleep-related change: PS=14.5 ± 8.5, MS=15.5 ± 9.1, GS=23.1 ± 7.6. Number of flicker cycles to detect neutral change: PS=21.9 ± 12.1, MS=18.4 ± 10.9, GS=16.5 ± 6.8. PS < GS, MS < GS, PS = MS. Sleep-related versus neutral change detection latencies across groups: d (PS-GS) = 1.58 d (PS-MS) = .43 d (MS-GS) = 1.09	No significant effect of depression (BDI) on change detection latencies (sleep or neutral stimuli).
Marchetti et al. (2006)	N = 90: PI = 30 (16 female, 22.5 years) DSPS = 30 (14 female, 22.7ys) GS = 30 (15 female, 23.2ys) Between-subjects	DSM-IV, ICSD-R criteria for PI and DSPS. PSQI (required score PI > 6, GS < 5). Actigraphy, sleep diary (TST and SOL recorded).	PSQI for sleep quality (mean score PI = 9.5; GS = 2.6; DSPS = 4.8).	Flicker: A picture (original stimulus) with either a sleep-related (a teddy bear), or neutral (a mug) change to be detected. DV — change detection Latency.	Number of flicker cycles for detecting sleep-related change: PI = 4.7 ± 2.1, DSPS = 9.7 ± 3.5, GS = 12.4 ± 3.0. Number of flicker cycles for detecting neutral change: PI = 18.2 ± 1.64, DSPS = 11.2 ± 3.14, GS = 12.3 ± 3.10. PI < DSPS < GS Sleep-related versus neutral change detection latencies across groups:	-

					d (PI-GS) = 5.37 d (PI-DSPS) = 4.44 d (DSPS-GS) = .50	
Posner						
Woods et al. (2009)	N = 44: PI = 22 (11 female, 24.4ys) NS = 22 (11 female, 23.7ys) Between-subjects	ICSD-2, DSM-IV, MEQ-RF, PSQI (required score PI > 6, NS < 5).	PSQI (mean score PI = 10.8; NS = 3.0), MEQ-RF, actigraphy, sleep diary (TST and SOL recorded) to confirm diagnosis of PI and rule out circadian rhythm sleep disorders.	Posner: sleep-related Night-time clock images (e.g., 02:00). DV — response times on valid vs invalid trials.	RT valid trials: PI=523ms ± 130, NS = 584ms ± 102. PI = NS; RT invalid trials: PI=689.76ms ± 154.59, NS=590.55ms ± 108.58. PI > NS. Valid trials: d* (PI-NS) = .52 Invalid trials: d* (PI-NS) = .74	-
Eye-tracking						
Woods et al. (2013)	N=41: PI=21 (49% female, 22ys) GS=20 (51% female, 24ys) Between-subjects	DSM-IV criteria for PI, PSQI, ISI, DBAS, SPS, MEQ.	PSQI (mean score PI = 10.4; GS=1.8), ISI (mean score PI = 14.7; GS = 2.3), DBAS (mean score PI =85.4; GS =54.2), SES (mean score PI =10.0; GS =2.5), MEQ (mean score PI =1.4; GS =1.3).	Lexical word task: 26 sleep-positive, 26 sleep-negative, 26 neutral words and corresponding pseudo words for each. DV – visual attentional allocation to sleep vs. neutral words. Differences in discrimination time, home in to target time, first fixation onset and duration.	Discrimination time: PI (vs. GS) were slower, regardless of word type. Home in to target: PI (vs. GS), no differences. FFO: PI (vs. GS) took longer to fixate on target, regardless of word type. FFD: PI (vs. GS), no differences. Discrimination time: Sleep negative, d = .56, Sleep positive, d = .71. Home in to target: Sleep negative, d = .52, Sleep positive, d = .48. FFO: Sleep negative, d = .06, Sleep positive, d = .08. FFD: Sleep negative, d = .37, Sleep positive, d = .37.	-
Beattie et al. (2017)	N = 41: IS = 20 (13 female, 23ys) NS=20 (15 female, 22ys) Between-subjects	PSQI (required score IS > 6), ISI (required score IS > 7)	PSQI (mean score IS = 11.2; NS = 3.3), ISI (mean score IS = 15.0; NS = 2.7), MEQ (mean score IS = 40.6; NS = 48.8).	48 photographs of indoor scenes, 12 of bedrooms (sleep-related stimuli), living rooms and kitchens respectively. Free viewing of stimuli. DV – total number of fixations, first fixation onset, % of fixations landing on bed region, retention time on bed region, number of revisits to bed region.	Total fixations (bed region): IS=147ms ± 18, NS=150ms ± 17; IS = NS. FFO (bed region): IS=50ms ± 11, NS=51ms ± 13; IS = NS % of fixations on bed region: IS=85.4%s ± 12.6, NS=77.8% ± 12.2; IS = NS. Retention for bed region: IS=698ms ± 274, NS=549ms ± 150; IS > NS. Revisits to bed region: IS=0.51 ± .25, NS=0.54 ± .25; IS = NS. Total fixations (bed region): d = .17 FFO (bed region): d = .71 % of fixations on bed region: d = .61 Retention for bed region: d = .67 Revisits to bed region: d = .12	Subjective reports of anxiety and depression were not related to any of the eye tracking measures.
Akram et al. (2018)	N = 40: ID = 20 (85% female, 25ys) NS = 20 (74% female, 23ys) Between-subjects	DSM-V Criteria for Insomnia Disorder, Diagnostic screening interview and questionnaire	ISI (mean score ID = 14.8; NS=4.2)	Free viewing of tired-neutral (i.e. threat-neutral) face pairs. Eyes, nose and mouth regions analysed. DV – differences (Group x Face x Region) in first fixation onset [FFO] and duration [FFD], total fixation [TFD] and gaze duration [TGD].	Tired Eyes: FFO, ID=680ms ± 62, NS=687ms ± 62. FFD, ID=121ms ± 10, NS = 100ms ± 10. TFD, ID=739ms ± 93, NS=542ms ± 93. TGD, ID=788ms ± 97, NS=594ms ± 97. d (FFO) = d (FFD) = d (TFD) = d (TGD) =	-
Other						
Spiegelhalder et al. (2008)	N = 60 PI = 20 (12 female, 40.6ys) SE = 20 (12 female, 38ys) C = 20 (12 female, 38.6ys) Between-subjects	DSM-IV, physical and psychiatric examination.	PSQI (mean scores PI = 10.8; SE = 4.3; C = 2.6).	Mixed modality: 20 sleep-related, & 60 control pictures. Deep/high sounds played. Responses given with right (high sound) or left (deep sound) fingers whilst looking at pictures. DV — sleep interference.	Mixed Modality: Sleep interference index: (PI=−4.3ms ± 36.3, C=−4.2ms ± 23.1, SE = −5.8 ± 33.2). PI = SE = C EST: (PI=3.8 ± 15ms, C=1.9 ± 14.8ms, SE = -8.7 ± 15.7). PI > SE = C	-

					d (PI-C) = .00 d (PI-SE) = .04 d (C-SE) = .06	
Spiegelhalder et al. (2009)	N = 104 good sleepers (51 female, 28.0ys). Correlational, within-subjects	-	PSQI (mean score = 4.4). SSS (mean score = 2.7).	Mixed modality (as above)	RT=455 ± 113ms. No significant impact of PSQI, SSS, or PSQI x SSS on AB scores. Multiple linear regression: f2 = .01	-
Baglioni et al. (2014)	N = 60: ID = 22 (915 female, 41ys) GS = 38 (21 female, 40ys) Between-subjects, correlational	DSM-V Criteria for Insomnia Disorder, Screening in Sleep Disorders Unit in Hospital, PSG on all participants.	PSG, PSQI (mean score IS = 11.2; NS = 3.3), DBAS-16 (mean score IS = 15.0; NS = 2.7), MEQ (mean score IS = 40.6; NS = 48.8), GSES (mean score IS = 5.9; NS = 1.2), PSAS-S (mean score IS = 11.1; NS = 10.2), PSAS-C (mean score IS = 17.9; NS = 13.4), ESS (mean score IS = 8.0 ; NS = 6.7).	fMRI analysis of amygdala activity whilst viewing images of people lying awake and visibly frustrated in bed at night.	Significantly greater amygdala activity in ID vs. GS whilst observing insomnia-related stimuli (t=2.10). Lower activation (ID vs. GS) whilst observing unrelated stimuli (t= -.464).	No correlations between objective measures of sleep recorded before the task and amygdala activity during the observation of insomnia related stimuli in ID or GS.
Giganti et al. (2017)	N=43: ID=23 (22ys) GS=20 (23ys) Between-subjects,	Short clinical interview (no details) and the SDQ, ISI and PSQI. Inclusion criteria for the insomnia group were: SDQ; ISI > 7; PSQI > 4.	PSQI (mean score IS=8.3; NS=3.2), ISI (mean score IS=12.1; NS=3.3), SDQ (no data), MEQ (mean score IS=46.8; NS=44.6).	Visual Priming Task: 88 images (44 sleep-related, 44 neutral: 50% old and 50% new). DV –Differences in the spatial filtering of verbal image detection and priming scores.	People with insomnia identified sleep-related stimuli at lower spatial filtering compared with neutral ones (P < 0.01), whereas good sleepers identified neutral stimuli at lower spatial filtering compared with sleep-related ones (P < 0.01)	Significantly smaller effect scores in the insomnia group indicating stronger affective responses towards sleep-stimuli in those with insomnia.
Koranyi et al. (2017)	N = 44: ID = 22 (21 female, 58ys) GS = 22 (14 female, 55ys) Between-subjects, correlational	ICSD-3 criteria for insomnia disorder, PSQI and ISI.	PSQI (mean score ID = 14.4; NS = 4.7), ISI (ID = 18.7; NS = 3.2), HADS (ID = 7.5; GS = 3.4).	Single-Target Implicit Association Test: Positive and negative affective words and sleep-related words. DV – sleep RTs for ST-IAT.	No mean scores provided. ST-IAT: (ID=0.13 ± 0.20; GS=0.29 ± 0.29). ID < GS: Indicating stronger automatic negative affective responses towards the bed in those with insomnia. d (ID-GS) = .64	-

Note: "=", ">" and "<" symbols represent equality or the direction of inequality of sleep-related attentional bias between insomnia patients/poor sleepers and healthy sleepers based on statistical significance. AB—attentional bias; AI—acute insomnia; APSQ—Anxiety and Preoccupation with Sleep Questionnaire; BDI—Beck Depression Inventory; BNSQ—Basic Nordic Sleep Questionnaire; C—control; CA—cognitive arousal; DBAS—Dysfunctional Beliefs and Attitudes about Sleep; DFSAS—Daytime Functioning and Sleep Attribution Scale; DSM-IV—Diagnostic Statistical Manual of Mental Disorders, 4th edition; DSM-IV-TR—Diagnostic Statistical Manual of Mental Disorders, 4th edition, Text Revision; DSM-5 — Diagnostic Statistical Manual of Mental Disorders, 5th edition; DSID — Duke Structured Interview for Sleep Disorders; DSPS — Delayed Sleep Phase Syndrome; DV — Dependent Variable; ES — effect size; ESS — Epworth Sleepiness Scale; ERP - Event-related potential; FIRST — Ford Insomnia Response to Stress Test; GS — good sleepers; HADS — Hospital Anxiety and Depression Scale; ICSD — International Classification of Sleep Disorders; ID - Insomnia Disorder based on DSM-5 classification; ISI — Insomnia Severity Index; MEQ — Morningness–Eveningness Questionnaire; MS—moderate sleepers; NS—normal sleepers; PI—primary insomnia; Prime-MD—Primary Care Evaluation of Medical Disorders; PS—poor sleepers; PSAS—Pre-Sleep Arousal Scale; PSG—polysomnography; PSQI—Pittsburgh Sleep Quality Index; RT —reaction time; SDQ - Sleep Disorders Questionnaire ; SCL-90R—Symptom Checklist; SE—sleep expert; ST-IAT, Single Target Implicit Association Test; SLEEP-50 —a screening questionnaire of 50 items assessing a variety of sleep disorders; SOL—sleep onset latency; SPS—Sleep Preoccupation Scale; SSS —Stanford Sleepiness Scale; STAI — State-Trait Anxiety Inventory; TST — total sleep time; VAS — visual analogue scale; WASO — wake after sleep onset; YS – age in years; Effect size (* RTs, not interference index).

Table 2
Outcomes and characteristics from reviewed studies examining sleep-related interpretive bias.

Study	Sample size & design	Group allocation	Key measures	Task characteristics	Main outcomes	Interpretive bias and sleep association
Ree & Harvey (2006)	N = 78: PI = 40 NS = 38 Between-subjects	DSM-IV-TR (IDI) and ISI >8 for PI;ISI <9 and DSM-IV-TR (IDI) for NS.	ISI (mean score PI=15.0; NS=4.9), SSS (PI=3.3; NS=2.9), BDI (PI=8.9; NS=5.2), STAI-S (PI=36.9; NS=34.1); STAI (PI=44.5; NS=37.0).	Modified Insomnia Ambiguity Task (IAT). Ambiguous sentences are followed by an insomnia consistent or anxiety consistent word that is paired with an insomnia-inconsistent interpretation. DV – IAT Scores (i.e. reaction time for insomnia consistent responses).	RT: Insomnia/general threat consistent pairs (PI = 66 *ms* ± 71; NS =5 4 *ms* ± 88); Insomnia/general threat inconsistent pairs (PI = 77 *ms* ± 62; NS = 57 *ms* ± 78). PI > NS on speeding to insomnia words following insomnia sentences.	Whilst no evidence of a sleep-related interpretive bias emerged, greater reports of sleepiness predicted a general bias towards threatening interpretations.
Ree et al. (2006)	N = 78: PS = 34 NS = 41 Between-subjects	ISI > 7 for PS; ISI < 9 for NS; STAI ≥41 for high anxious; STAI < 41 for low anxious..	ISI (mean score PS=11.76; NS=2.98), SSS (no means reported), STAI (no means at group level reported).	IAT. DV – IAT Scores, Anxiety Interpretation Scores (AAT Scores)	IAT Scores: Low anxious (PS = 14.00 ± 2.83; NS = 12.09 ± 2.66); High anxious (PS = 14.50 ± 3.87; NS=13.28 ± 3.39). AAT Scores: Low anxious (PS = 12.50 ± 3.52; NS = 9.83 ± 3.69); High anxious (PS = 12.60 ± 3.72; NS=11.33 ± 3.69). Total scores were calculated based on the mean IAT scores regardless of the anxiety group (PS = 14.25 ± 4.77; GS = 12.69 ± 4.36).	-
Ellis et al. (2010)	N = 108: PS=59 GS=59 Between-subjects	ISI >7 for PS; ISI < 8 for GS; Priming or non-priming condition.	ISI (no means reported), DBAS (no means reported).	IAT DV – IAT Scores	IAT Scores: Primed (PS = 17.54 ± 4.54; GS = 13.63 ± 4.40); unprimed (GS = 14.52 ± 3.48; NS = 12.90 ± 3.76). PS > NS when primed PS = NS unprimed Total scores were calculated based on the mean IAT scores regardless of the priming condition (PS = 16.03 ± 4.01; GS = 13.27 ± 4.08).	-
Akram et al. (2016)	N = 40: PI=20 NS=20 Between-subjects	DSM-V, Diagnostic screening questionnaire	HADS, VAS measuring self-reported tiredness.			Correlational analyses indicated no significant associations between measures of anxiety, depression and self-reported tiredness with misperception scores (all $p > 0.05$), suggesting that these factors did not influence interpretations.
Coultard et al. (2017)	N = 70: CSI = 40 C = 30 Between-subjects	ISI (required score CSI >14, C <6).	PSQI (*M* = CSI = 10.1; C = 4.5), ASPQ (CSI = 58.4; C = 27.7), DASS-21-A (CSI = 14.5; C = 5.7), DASS-21-D (CSI = 16.0; C = 6.6), DASS-21-S (CSI = 22.6; C = 8.6).	DV — response time to resolve sleep-related and unrelated sentences in a benign or negative (disorder-consistent) manner.	RT – Sleep-related scenarios: negative response (CSI = 2673ms ± 1061; C = 2976 *ms* ± 1883), benign response (CSI = 3539 *ms* ± 1269; C = 3004ms ± 1461). Sleep-unrelated scenarios: negative response (CSI = 2065ms ± 715; C = 1955 *ms* ± 741), benign response (CSI = 2245 *ms* ± 704; C = 2274 *ms* ± 1037). CSI > C on sleep-related expectancy bias	-
Takano et al. (2018)	N = 58 Correlational	n/a	PSQI (*M* = 5.5), BDI-II (9.7).	Modified Pay Per View Task: Presentation of sleep-related or eating-related words that were associated with variable amounts of reward, followed by a sleep or eating-related statement that varied in degree of dysfunctionality. Participants were required to rate the applicability of the statement to themselves. DV – Self applicability, choice frequency of 'sleep' averaged across conditions.	PSQI scores were significantly related to the self-applicability of sleep-related statements ($r = .59$). PSQI scores were significantly related to the choice frequency of 'sleep' averaged across conditions ($r = .28$).	Poorer sleep quality (PSQI) predicted greater likelihood of foregoing a higher reward in order to have the opportunity to rate sleep (relative to eating-related) questions.
Gerlach et al. (2020)	N = 76 Correlational	n/a	PSQI (*M* = 5.87), PSAS-S (10.93), PSAS-C (14.1), sleep diary and actigraphy (TST, SOL and SE) recorded respectively.	IAT (adapted into German language) DV – Relationships between IAT Scores, pre-sleep worry scores, and subjective and objective sleep.	IAT Scores: IAT scores were independently related to PSQI ($r = .25$), PSAS-C ($r = .31$) and STAI ($r = .40$) scores. Regression analyses found STAI scores to mediate the relationship between sleep and IAT scores.	No significant associations between objective measures of sleep continuity and interpretive bias.

Akram et al (2021)	N = 76: ISY = 34 NS = 42 Between-subjects	SCI ≥17 = ISY, ≤16 = NS	SCI (mean score IS = 10.4; NS = 34.5), APSQ, (mean score ISY=55.0; NS = 28.6), SAAQ, (mean score IS = 25.7; NS = 18.4), SSS (mean score ISY = 3.6; NS = 2.5).	IAT. DV – IAT Scores	IAT Scores: IS = 17.63 ± 4.33; NS = 13.69 ± 4.92. IS > NS	-

Note: "=", ">" and "<" symbols represent equality or the direction of inequality of sleep-related attentional bias between insomnia patients/poor sleepers and healthy sleepers based on statistical significance.

APSQ — Anxiety and Preoccupation with Sleep Questionnaire; C — control; CSI — clinically significant insomnia symptoms; DBAS — Dysfunctional Beliefs and Attitudes about Sleep; DSM-IV — Diagnostic Statistical Manual of Mental Disorders, 4th edition; DSM-IV-TR — Diagnostic Statistical Manual of Mental Disorders, 4th edition, Text Revision; DSM-5 — Diagnostic Statistical Manual of Mental Disorders, 5th edition; DV — Dependent Variable; ES — effect size; GS — good sleepers; HADS — Hospital Anxiety and Depression Scale; ICSD — International Classification of Sleep Disorders; IDI — Insomnia Diagnostic Interview; ID — Insomnia Disorder based on DSM-5 classification; ISI — Insomnia Severity Index; IS — Insomnia Symptoms; MEQ — Morningness–Eveningness Questionnaire; MS — moderate sleepers; NS — normal sleepers; PI — primary insomnia; Prime-MD — Primary Care Evaluation of Medical Disorders; PS — poor sleepers; PSAS — Pre-Sleep Arousal Scale; PSG — polysomnography; PSQI — Pittsburgh Sleep Quality Index; RT — reaction time; SAAQ — Sleep Anticipatory Anxiety Questionnaire; SCI — Sleep Condition Indicator; SLEEP-50 — a screening questionnaire of 50 items assessing a variety of sleep disorders; SSS — Stanford Sleepiness Scale; STAI — State-Trait Anxiety Inventory; VAS — visual analogue scale; YS — age in years.

Table 3

Forest plot of overall effect sizes for individual studies examining attentional bias, ordered by publication date

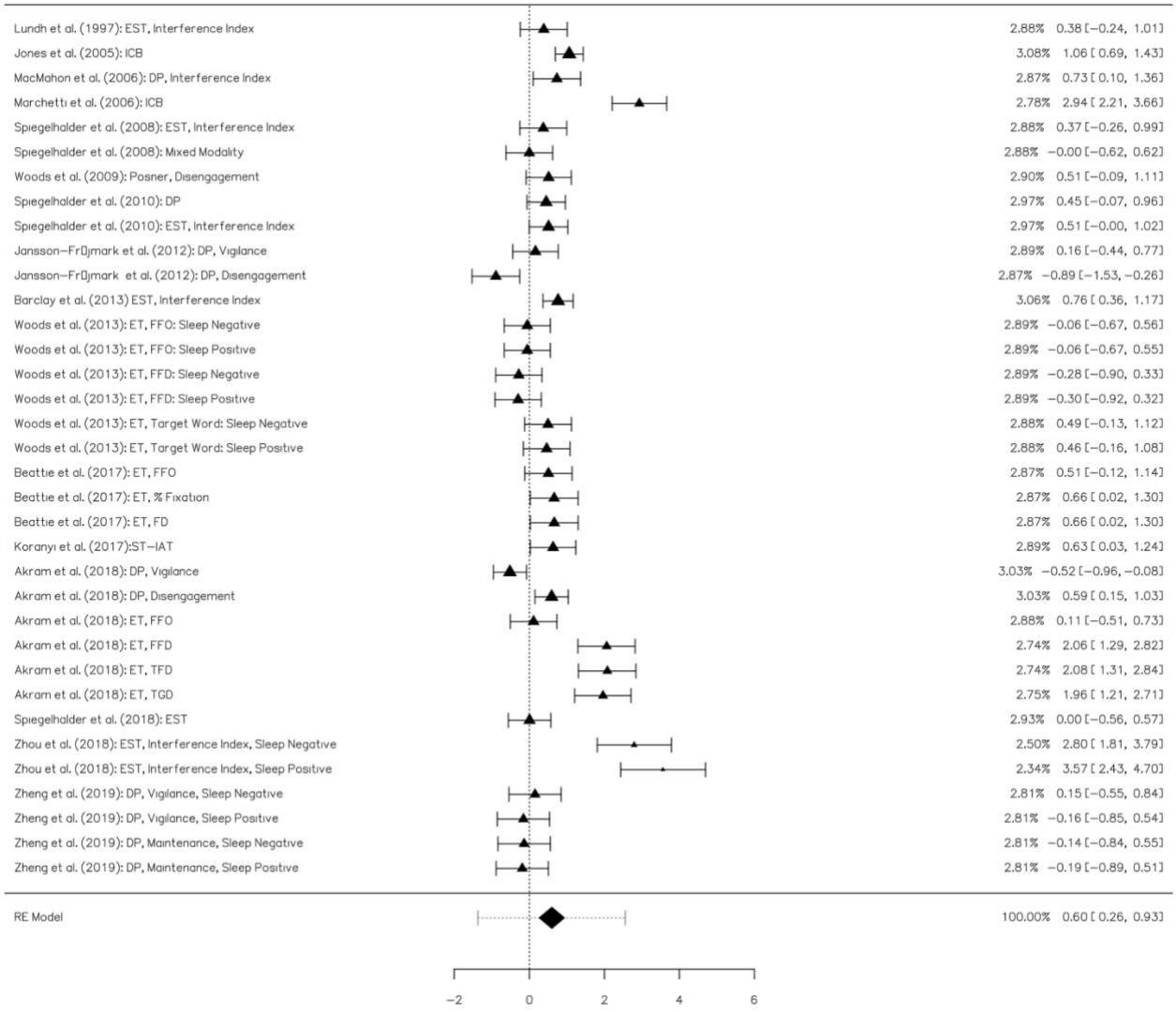
	Insomnia/Poor Sleepers		Control Groups		Cohens *d*
Study	Mean	Total N	Mean	Total N	
Lundh et al. (1997): EST, Interference Index*	4.80 ± 3.38	20	3.85 ± 0.65	20	0.35
Jones et al. (2005): ICB$^{\nabla}$*	-14.5 ± 8.5	64	-23.1 ± 7.6	64	1.07
MacMahon et al. (2006): DP, Interference Index*	3.9 ± 9.4	21	-2.5 ± 7.6	20	0.75
Marchetti et al. (2006): ICB$^{\nabla}$*	4.7 ± 2.1	30	12.4 ± 3.0	30	2.97
Spiegelhalder et al. (2008): EST, Interference Index	3.8 ± 15.4	20	-1.9 ± 14.8	20	0.38
Spiegelhalder et al. (2008): Mixed Modality	-4.3 ± 36.3	-	-4.2 ± 23.1	-	0.00
Woods et al. (2009): Posner, Disengagement$^{\nabla}$ *	523 ± 130	22	584 ± 102	22	0.52
Spiegelhalder et al. (2010): DP*	8.9 ± 30.5	30	7.6 ± 41.6	30	0.04
Spiegelhalder et al. (2010): EST, Interference Index*	−0.6 ± 19.7	-	−11.4 ± 22	-	0.52
Jansson-Fröjmark et al. (2012): DP, Vigilance$^{\nabla}$	4.5 ± 39.9	21	0.6 ± 18.3	21	0.13
Jansson-Fröjmark et al. (2012): DP, Disengagement*	-20.8 ± 38.3	-	9.5 ± 27.4	-	0.91
Barclay et al. (2013) EST, Interference Index*	11.42 ± 0.48	42	0.19 ± 18.69	65	0.88
Woods et al. (2013): ET, FFO: Sleep Negative$^{\nabla}$	261 ± 358	21	240 ± 362	20	0.06
Woods et al. (2013): ET, FFO: Sleep Positive$^{\nabla}$	256 ± 348	-	236 ± 331	-	0.06
Woods et al. (2013): ET, FFD: Sleep Negative*	1662 ± 928	-	1927 ± 909	-	0.29
Woods et al. (2013): ET, FFD: Sleep Positive*	1646 ± 943	-	1932 ± 922	-	0.31
Woods et al. (2013): ET, Target Word: Sleep Negative	2039 ± 1051	-	1627 ± 454	-	0.51
Woods et al. (2013): ET, Target Word: Sleep Positive	1816 ± 568	-	1586 ± 393	-	0.47
Beattie et al. (2017): ET, FFO$^{\nabla}$	1131 ± 340	20	1326 ± 411	20	0.52
Beattie et al. (2017): ET, % Fixation*	19.4 ± 6.2	-	16.2 ± 2.6	-	0.67
Beattie et al. (2017): ET, FD*	698 ± 274	-	549 ± 150	-	0.67
Koranyi et al. (2017): ST-IAT$^{\nabla}$	0.13 ± 0.20	22	0.29 ± 0.29	22	0.64
Akram et al. (2018): DP, Vigilance$^{\nabla}$	-27.6 ± 67.0	41	-2.41 ± 10.66	41	0.53
Akram et al. (2018): DP, Disengagement*	30.9 ± 73.9	-	0.78 ± 12.79	-	0.57
Akram et al. (2018): ET, FFO$^{\nabla}$	680 ± 62	20	687 ± 62	20	0.11
Akram et al. (2018): ET, FFD*	121 ± 10	-	100 ± 10	-	2.10
Akram et al. (2018): ET, TFD*	739 ± 93	-	542 ± 93	-	2.12
Akram et al. (2018): ET, TGD*	788 ± 97	-	594 ± 97	-	2.00
Spiegelhalder et al. (2018): EST	4.6 ± 20.4	20	4.5 ± 28.7	30	0.00
Zhou et al. (2018): EST, Interference Index, Sleep Negative*	11.69 ± 6.86	16	-7.72 ± 6.64	15	2.88
Zhou et al. (2018): EST, Interference Index, Sleep Positive*	12.65 ± 6.70	-	-11.44 ± 6.45	-	3.66
Zheng et al. (2019): DP, Vigilance, Sleep Negative (Unprimed)$^{\nabla}$	12.79 ± 68.35	17	21.30 ± 35.33	15	0.16
Zheng et al. (2019): DP, Vigilance, Sleep Positive (Unprimed)$^{\nabla}$	13.32 ± 39.82	-	6.95 ± 38.19	-	0.16
Zheng et al. (2019): DP, Maintenance, Sleep Negative (Unprimed)	-8.97 ± 65.98	-	-0.94 ± 39.80	-	0.15
Zheng et al. (2019): DP, Maintenance, Sleep Positive (Unprimed)	-7.22 ± 55.01	-	1.23 ± 23.63	-	0.20

Heterogeneity: $Tau^2 = 0.91$; $H^2 = 10.76$, df = 34 (P = 0.001); $I^2 = 91\%$

Note: ∇ = Reverse scored

Test for overall effect: Z = 3.63 (P < 0.001)

Weight %, Std. Mean Difference, 95% CI



Note: DP, Dot-probe; EST, Emotional Strop test; ET, Eye-Tracking; ICB, Induced Change Blindness; FFO, First Fixation Onset; FFD, First Fixation Duration; TFG, Total Gaze Duration; TFD, Total Fixation Duration; TGD, Total Gaze Duration; ST-IAT, Single Target Implicit Association Test.

Table 4
Definition of eye-tracking variables

First Fixation Onset (FFO)	The amount of time elapsed before the first fixation landed within a target interest-region.
First Fixation Duration (FFD)	The time between the start of the first fixation which landed within the interest region until this fixation oriented elsewhere
Total Fixation Duration (TFD)	The total duration of all fixations made within each interest region.
Total Gaze Duration (TGD)	The total summation of the fixations' duration that landed within the interest region.
Total Number of Fixations	The total number of fixations that occur during an interval of time that land within the target interest region.
% Fixations	The percentage of fixations made within the target interest region during an interval.

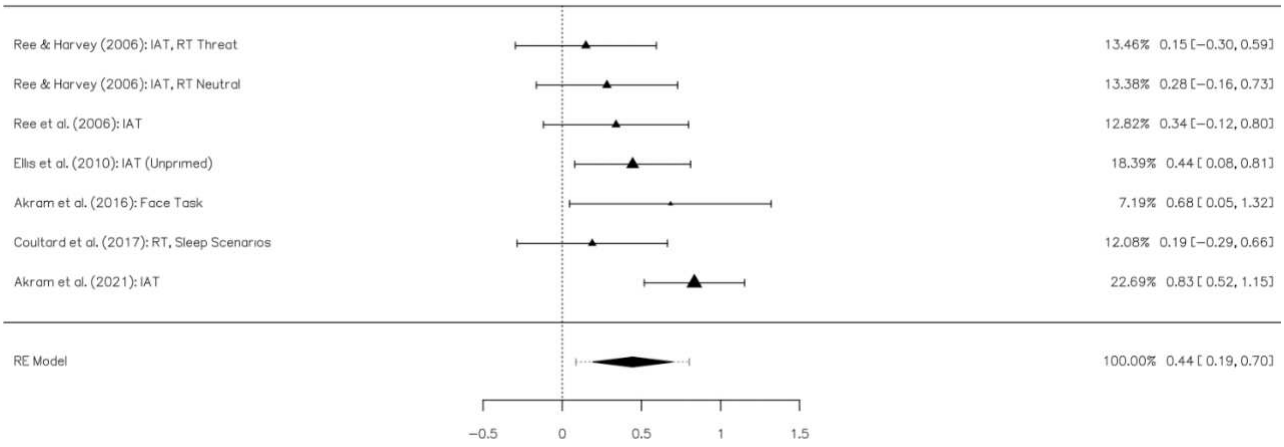
Table 5

Forest plot of overall effect sizes for individual studies examining interpretative bias, ordered by publication date

	Insomnia/Poor Sleepers		Control Groups		Cohen's *d*
Study	*M*	Total N	*M*	Total N	
Ree & Harvey (2006): IAT, RT Threat	66 ± 71	40	54 ± 88	38	0.15
Ree & Harvey (2006): IAT, RT Neutral	77 ± 62	40	57 ± 78	38	0.28
Ree et al. (2006): IAT	14.25 ± 4.77	34	12.69 ± 4.36	41	0.34
Ellis et al. (2010): IAT (Unprimed)	14.52 ± 3.48	31	12.90 ± 3.76	29	0.45
Akram et al. (2016): Face Task	28.75 ± 79.70	20	-19.80 ± 57.71	20	0.70
Coultard et al. (2017): RT, Sleep Scenarios$^{\nabla}$	2673 ± 1061	30	2976 ± 1883	40	0.19
Akram et al., (2021): IAT	17.63 ± 4.33	67	13.69 ± 4.92	109	0.85

Heterogeneity: $Tau^2 = 0.01$; $H^2 = 1.23$, df = 6 (P = 0.13); $I^2 = 19\%$ Note: ∇ = Reverse scored

Test for overall effect: Z = 4.33 (P < 0.005)



Note: RT, Reaction Time; IAT, Insomnia Ambiguity Paradigm

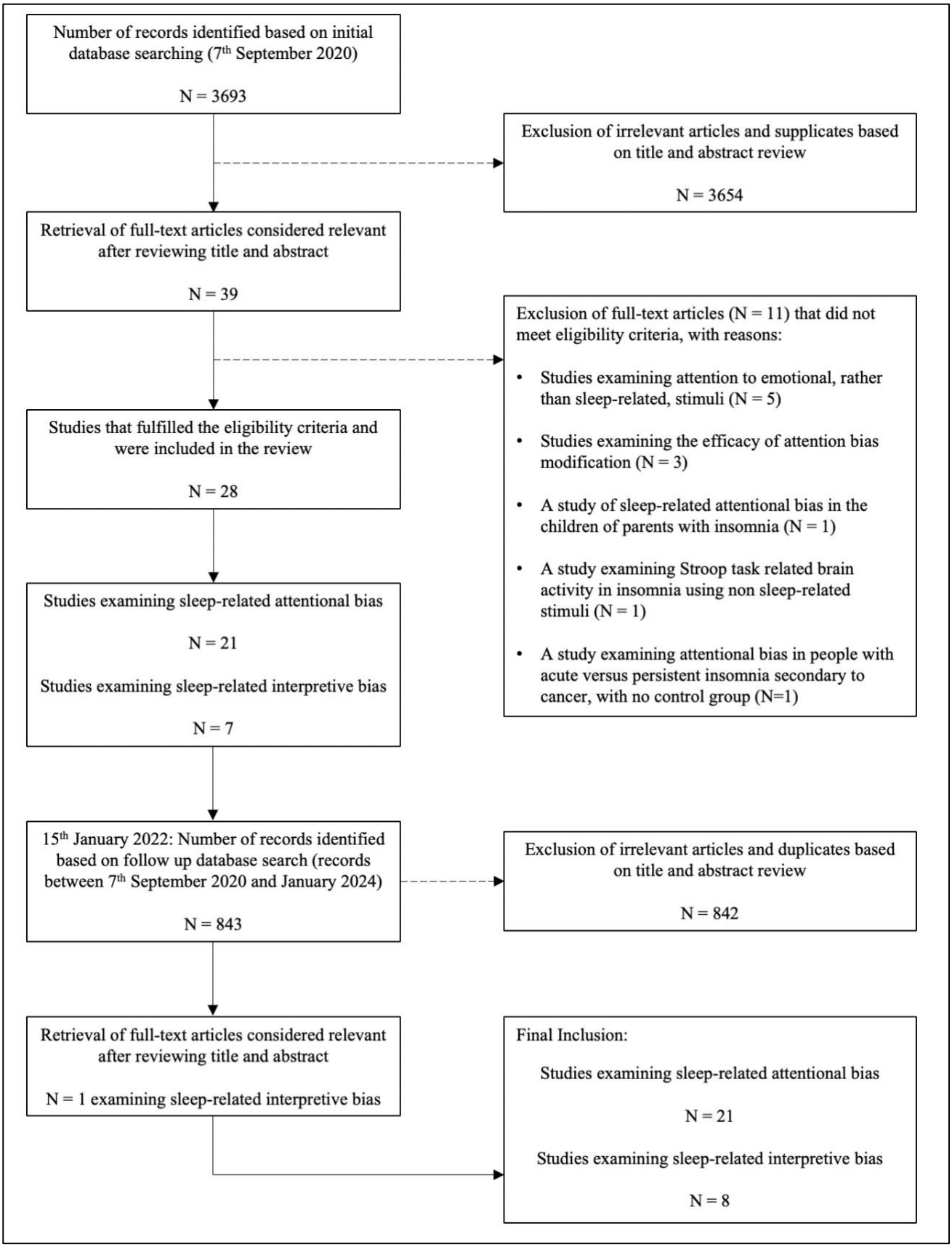


Figure 1. Flowchart presenting the literature search and study selection strategies

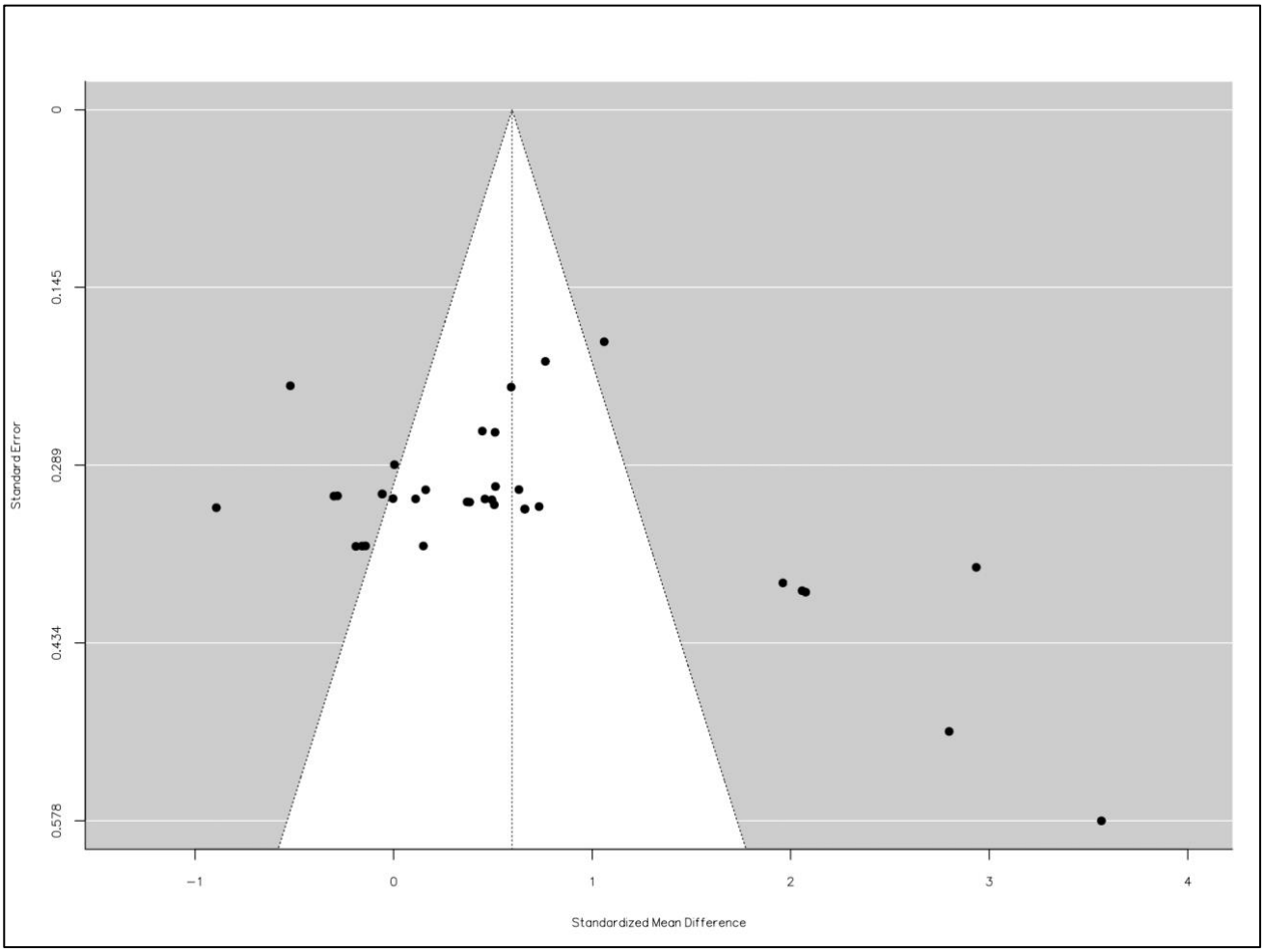


Figure 2. Funnel plot of meta-analytic effect sizes for sleep-related attentional bias. Vertical line on pooled effects of mean standardised difference.

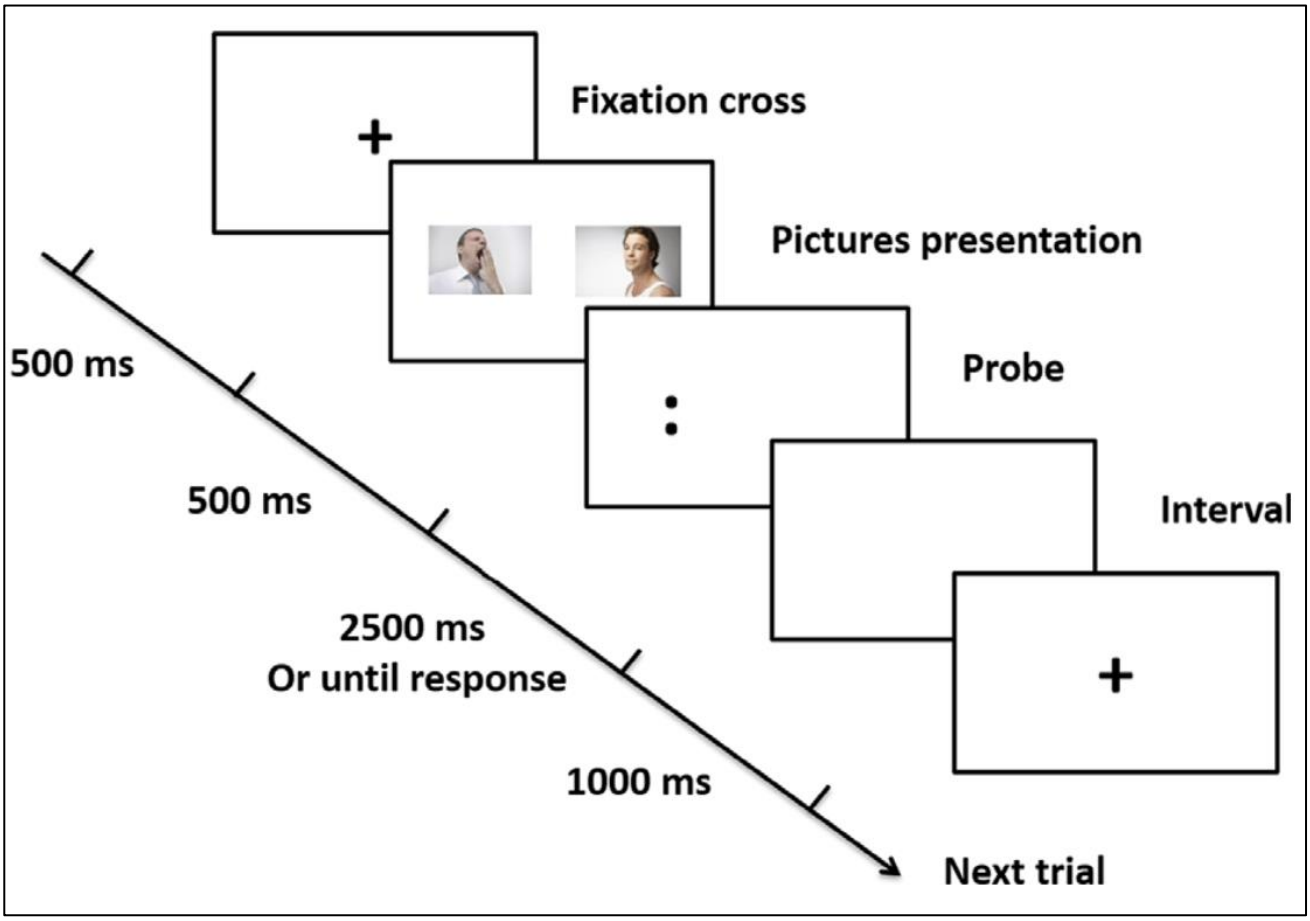


Figure 3. Dot-probe task trial. Trials initially start with a fixation crossing the middle of the computer screen. Pairs of emotional and neutral stimuli (words or images) are then presented horizontally. After the words disappear a dot-probe (large dot) subsequently appeared either on the right or left position. This remains on the screen until a keyboard response is made or the trial times-out. Participants are required to press a corresponding key, indicating the position of the probe, as quickly and as accurately as possible. After an interval, the next trial begins. The vigilance index is calculated by subtracting the mean reaction time for sleep-related stimuli from the mean reaction time for neutral stimuli. In contrast, the mean reaction time for neutral trials were subtracted from the mean reaction time for trials where the dots replaced neutral stimuli in the presence of sleep-related stimuli to calculate the disengagement index. [Example from Jansson-Fröjmark et al. (2012)].

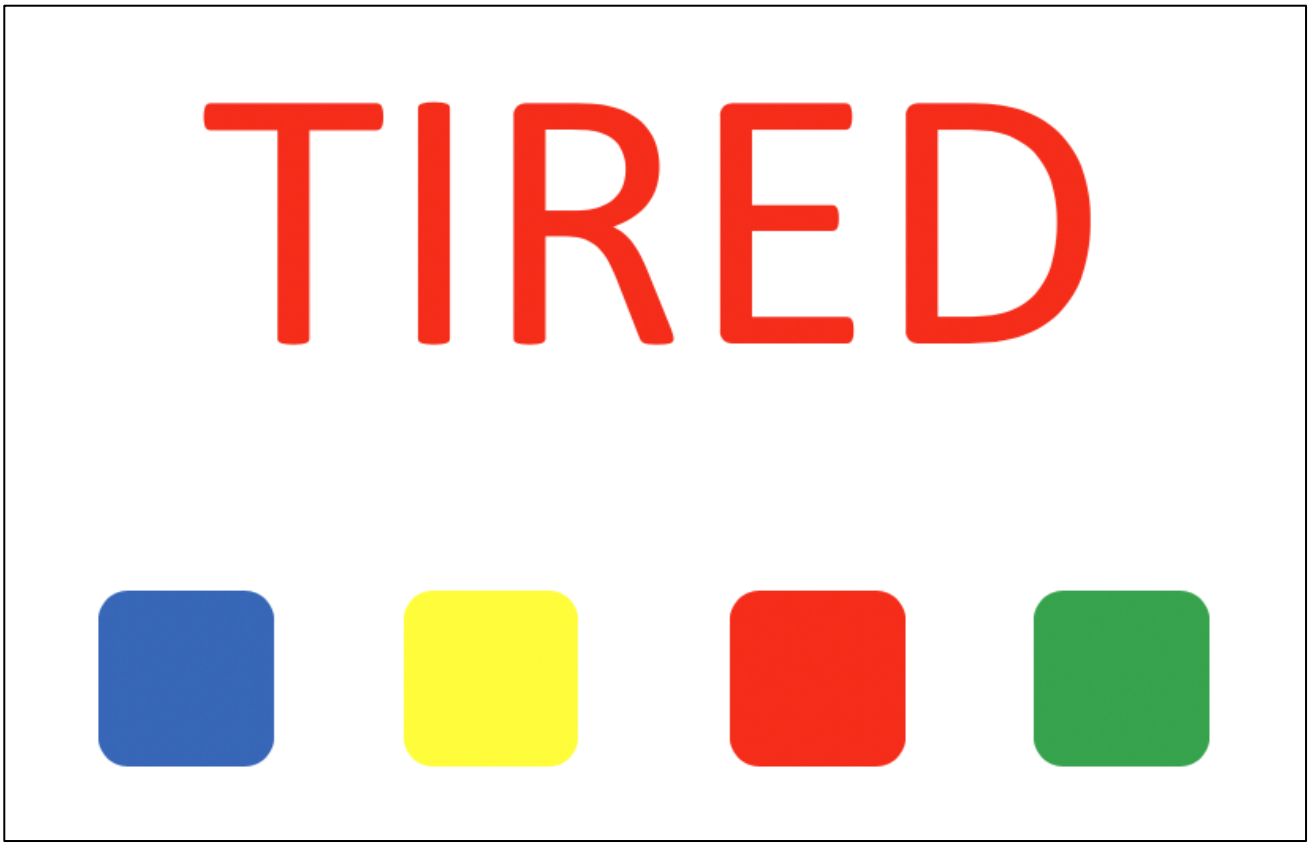


Figure 4. Emotional Stroop Task: The EST involves presenting participants with neutral and threatening words in different colours. Participants are required to press a correspondingly coloured response key as quickly as possible. Longer response latencies to threatening words are considered to suggest an increased attention bias (or Stroop interference). Due to the content of the threatening word expending attentional resources, performance on the task is subsequently impaired (MacLeod, 1986). Higher (positive) interference index scores indicate attentional bias towards emotionally salient material. [Example trial created by author].

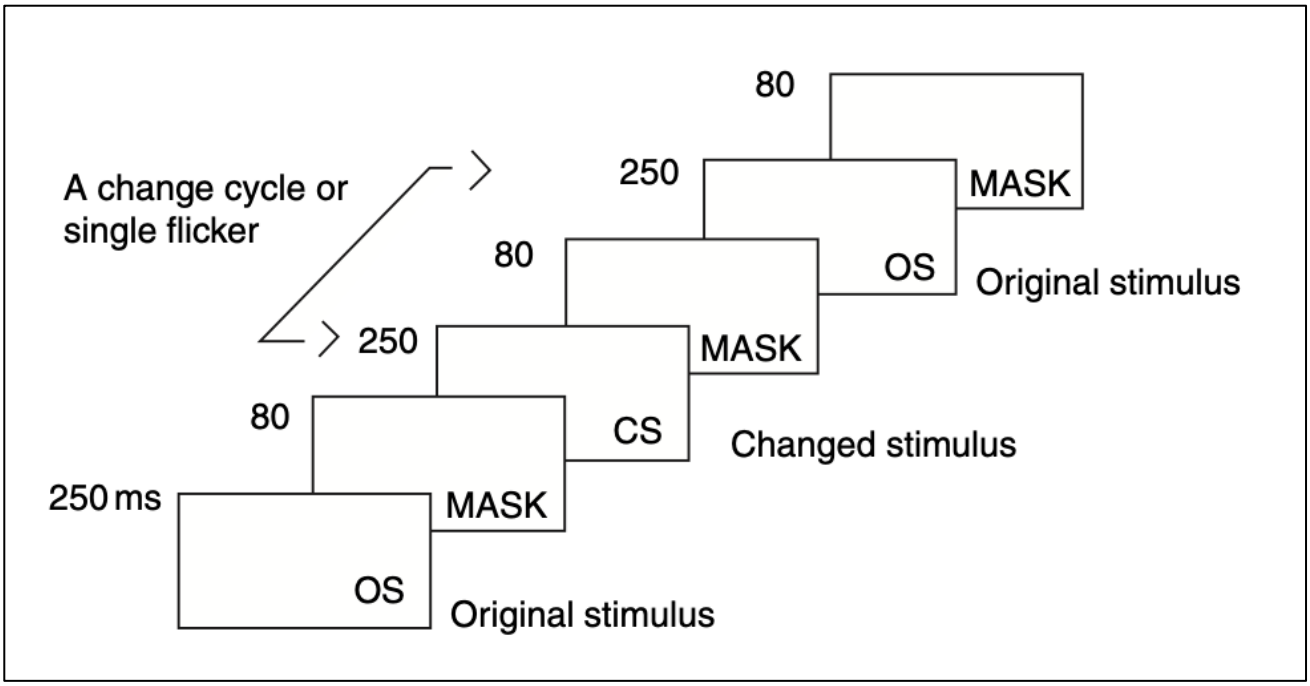


Figure 5. The flicker task examines a concept known as 'induced change blindness' (ICB), where, when a single change has been made to a visual scene, and the method of this change has not been revealed, it is often more difficult to ascertain this change than expected (Rensink, 2002; Simons, 2000). In essence, the flicker task is similar to a 'spot the difference' task, where a change is made to pictorial stimuli, and the participant is required to detect this change. Further, a single part of pictorial stimuli is altered between sequentially recurrent brief presentations (known as flickers) until the change is identified. The number of flickers surpassed before the change has been identified acts as the measure of response latency. Moreover, faster response latencies are considered to suggest an increased attention bias. [Example trial from Marchetti et al., 2006].

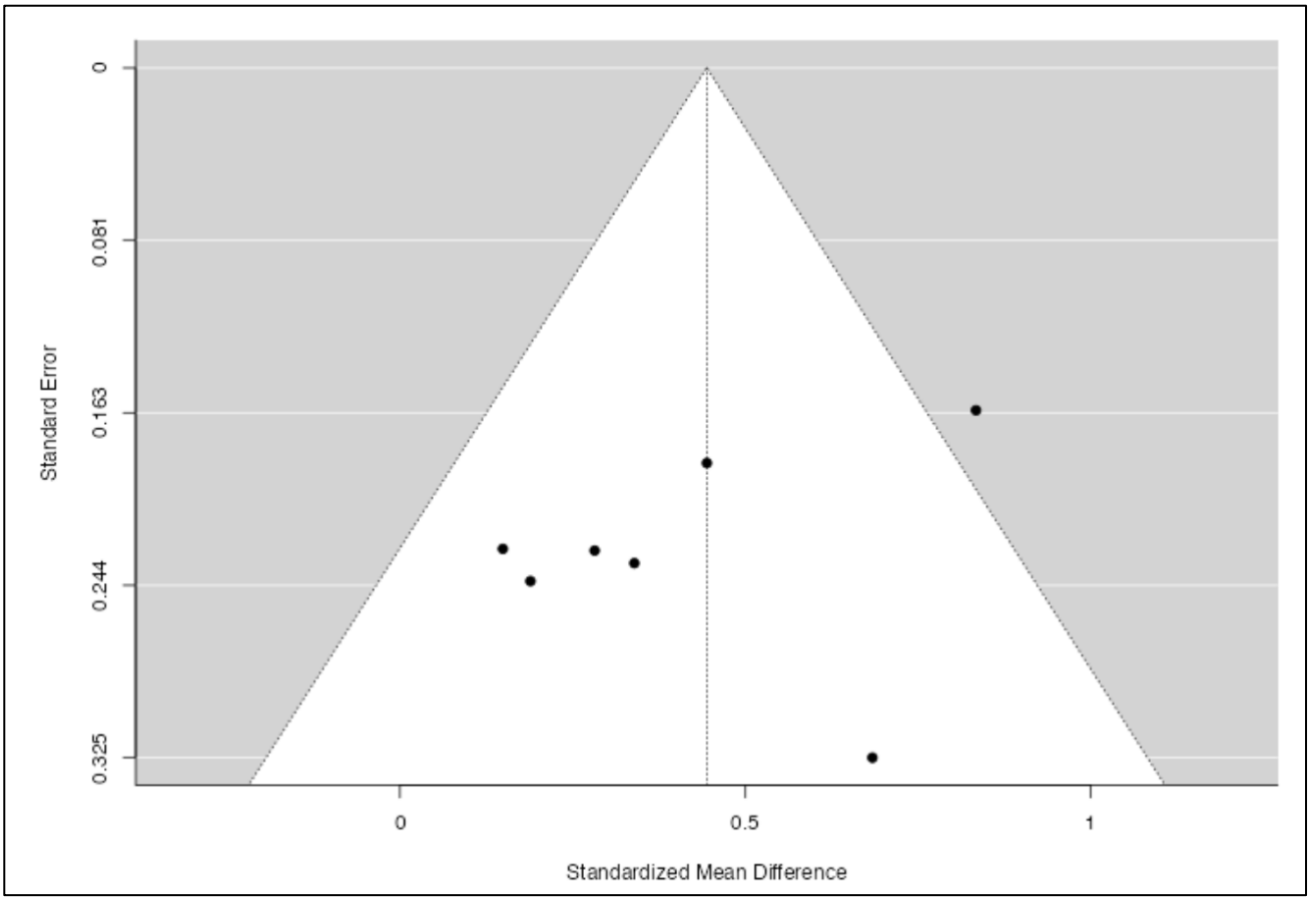


Figure 6. Funnel plot of met-analytic effect sizes for sleep-interpretive bias. Vertical line on pooled effects of mean standardised difference.

Appendix - Supplementary Information and Data

A1 Quality rating checklist example

Criteria Study:		**YES (2)**	**PARTIAL (1)**	**NO (0)**	**N/A**
1	Question / objective sufficiently described?				
2	Study design evident and appropriate?				
3	Method of subject/comparison group selection or source of information/input variables described and appropriate?				
4	Subject (and comparison group, if applicable) characteristics sufficiently described?				
5	If interventional and random allocation was possible, was it described?	Not Applicable			N/A
6	If interventional and blinding of investigators was possible, was it reported?				
7	If interventional and blinding of subjects was possible, was it reported?				
8	Outcome and (if applicable) exposure measure(s) well defi ned and robust to measurement / misclassification bias? Means of assessment reported?				
9	Sample size appropriate?				
10	Analytic methods described/justified and appropriate?				
11	Some estimate of variance is reported for the main results?				
12	Controlled for confounding?				
13	Results reported in sufficient detail?				
14	Conclusions supported by the results?				
	Total Score (max 22):	XX			

A2 & A3 – Quality ratings

Table A1
Attentional bias quality ratings

Study	UA Rating	JS Rating	MG Rating	Mean Rating
Akram et al. (2018a)	21	20	20	20.33
Akram et al. (2018b)	20	20	20	20.00
Baglioni et al. (2014)	21	20	21	20.66
Barclay et al. (2012)	17	19	19	18.33
Beattie et al. (2017)	19	20	20	19.66
Giganti et al. (2017)	16	20	20	18.66
Jansson-Fröjmark et al. (2012)	22	20	20	20.33
Jones et al. (2005)	22	19	20	20.33
Koranyi et al. (2017)	18	19	18	18.33
Lundh et al. (1997)	19	17	18	18.00
MacMahon et al. (2006)	22	20	20	20.66
Marchetti et al. (2006)	21	20	20	20.33
Spiegelhalder et al. (2008)	19	20	19	19.33
Spiegelhalder et al. (2009)	18	20	19	19.00
Spiegelhalder et al. (2010)	19	20	19	19.33
Spiegelhalder et al. (2018)	22	20	20	20.66
Takano et al. (2018)	22	21	21	21.33
Woods et al. (2009)	20	20	20	20.00
Woods et al. (2013)	20	18	18	18.66
Zhou et al. (2018)	19	20	20	19.66
Zheng et al. (2019)	18	20	18	18.66

Note: Quality scores range between 0-22.

Table A2
Interpretive bias quality ratings

Study	UA Rating	JS Rating	MG Rating	Mean Rating
Ree & Harvey (2006)	20	20	20	20.00
Ree et al. (2006)	20	20	20	20.00
Ellis et al. (2010)	20	20	20	20.00
Akram et al. (2016)	20	20	20	20.00
Coultard et al. (2017)	20	20	20	20.00
Takano et al. (2018)	21	21	20	20.66
Gerlach et al. (2020)	21	21	21	21.00
Akram et al. (2021)	21	20	20	20.33

Note: Quality scores range between 0-22.