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Insomnia-related interpretational bias is associated with pre-sleep worry

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Abstract

Cognitive models of insomnia highlight the role of biased cognition in sleep-related information, which is proposed to underlie pre-sleep worry, which in turn results in both subjective and objective sleep deficits. To test this hypothesis, the current study investigated interpretational bias, which is a tendency to interpret ambiguous stimuli in a threat-related (here: insomnia-related) manner. We specifically hypothesized that interpretational bias would be associated with (a) pre-sleep worry and (b) poor subjective and objective sleep. Interpretational bias was measured using the ambiguous scenario task, in which participants (n = 76, community sample) were presented with two types of scenarios (insomnia and anxiety related) that could be alternatively interpreted in a neutral manner. Participants additionally completed questionnaires to assess global sleep quality and pre-sleep worry, which were followed by 1-week sleep assessments (via diaries and actigraphy) to estimate specific, daily subjective and objective sleep parameters. The results showed that insomnia-related (but not anxiety-related) interpretational bias was positively associated with pre-sleep worry as well as overall sleep quality. However, these associations could be explained by general trait anxiety. We also found no connection to specific subjective or objective parameters of daily sleep, such as sleep onset latency. These findings support the cognitive-hyperarousal mechanism, where biased cognition (together with trait anxiety) underlies pre-sleep worry. The association with overall sleep quality, but not with specific, daily subjective or objective sleep parameters, may suggest that interpretational bias is specifically relevant for how individuals judge and describe their sleep quality.

KEYWORDS
cognitive arousal, cognitive bias, insomnia, interpretational bias, pre-sleep worry, sleep quality

1 | INTRODUCTION

Cognition plays an important role in the development and maintenance of insomnia. Researchers have focused on the cognitive-hyperarousal mechanism, in which people with insomnia symptoms tend to experience excessive and uncontrollable worry about their poor sleep quality (also referred to as cognitive arousal in the literature; Nicassio, Mendlowitz, Fussell, & Petras, 1985). Worry, then, typically triggers excessive levels of effort and intention to sleep (Espie, Broomfield, Macmahon, Macphee, & Taylor, 2006) and activates the

central nervous system by enhancing emotional distress (Harvey, 2002; Harvey, Tang, & Browning, 2005). This cognitive, emotional and/or physiological hyperarousal impedes the normal initiation of sleep. Indeed, empirical research has shown that worry and symptom-focused rumination are associated with sleep disturbances (e.g., Carney, Harris, Moss, & Edinger, 2010; Ellis, Mitchell, & Hogh, 2007). Furthermore, pre-sleep worry about sleeplessness and the possible consequences of poor sleep are known to be a good predictor of, for example, increased sleep onset latency (Wicklow & Espie, 2000; Wuyts et al., 2012).

As a possible mechanism underlying sleep disturbances, cognitive models of insomnia have suggested biased cognition toward sleep-related information (Espie et al., 2006; Harvey, 2002). For example, some studies have suggested that the attention of poor sleepers is more likely to be captured by internal and external cues of sleep than is the attention of good sleepers (Harris et al., 2015). This form of selective attention is thought to cause, for example, excessive clock monitoring (i.e., watching a clock to know how many minutes they have spent sleeping; Woods, Marchetti, Biello, & Espie, 2009), and to further trigger worry about sleeplessness and daytime dysfunctions (e.g., Macmahon, Broomfield, & Espie, 2006; however, see Spiegelhalder et al., 2018 for null findings on attention bias). Another form of biased cognition is interpretational bias, which can be observed when people make an inference and deduce a conclusion on an ambiguous and open-ended situation. Interpretational bias has been extensively studied in regard to depression and anxiety; studies typically found that individuals with these disorders interpret ambiguous situations negatively (e.g., scrambled sentences and ambiguous scenarios; Hirsch, Meeten, Krahé, & Reeder, 2016). In the context of insomnia, Ree, Pollitt, and Harvey (2006) investigated how normal and poor sleepers interpret ambiguous scenarios, either in a threat-related (i.e., insomnia or anxiety related) or neutral manner. They have found that poor sleepers tend to interpret ambiguous scenarios in a more insomnia- and anxiety-related manner than do normal sleepers (cf. Ellis, Gardini, & Hogh, 2010; Ree & Harvey, 2006). In accordance with these findings, another experimental study found that individuals with insomnia misperceived their own morphed faces as appearing more tired than they actually were, which is also a form of biased interpretation and confirms the symptoms of their disorder (Akram, Ellis, Myachykov, & Barclay, 2016). These findings support the prediction of the cognitive models that biased cognition would cause individuals to detect threatening (or sleep-related) cues and subsequently associate those cues with sleep difficulties (e.g., interpret a pale face as an indication of sleeplessness). This becomes a source of sleep-related worry and rumination that perpetuates sleep disturbances (Harvey et al., 2005; Ree et al., 2006). However, to the best of our knowledge, this direct link between biased sleep-related cognition and worry has not yet been examined. Therefore, the current study aimed to establish this association, particularly in regard to insomnia-consistent interpretational bias.

Individuals with subjective sleep disturbances often overestimate sleep-onset latency (SOL) and underestimate total sleep time (TST) relative to objective measures of polysomnography or actigraphy (for a review, see Harvey & Tang, 2012). This misperception of sleep is a hallmark of insomnia-related cognition. Individuals are convinced that they have substantially less sleep and worse daytime performances than they do in reality, thereby triggering dysfunctional safety behaviours to compensate for their perceived lack of sleep (e.g., Harvey, 2002). Importantly, sleep misperception is observed not only in people who have real (physiological) sleep deficits, but also in individuals whose objective sleep parameters are within the normal range (e.g., McCall & Edinger, 1992). The phenomenological similarity between interpretational bias and sleep misperception leads to the hypothesis that people with interpretational bias may "interpret" their subjective sleep quality as poor, even when there is no objective impairment. In addition, it is known that pre-sleep worry is associated with an overestimation of SOL and underestimation of TST relative to objective measures of sleep (Takano, Boddez, & Raes, 2016; Tang & Harvey, 2004). Hence, the second goal of the present study was to explicitly test whether interpretational bias is related to objectively or subjectively measured sleep disturbances.

In summary, the current study investigated cognitive processes that have been identified by cognitive models of insomnia. We first tested the positive association between interpretational bias and pre-sleep worry. Interpretational bias was measured using the ambiguous scenario task (AST; Ree et al., 2006), in which participants are presented with ambiguous scenarios related to either insomnia or anxiety that could be alternatively interpreted in a neutral manner. We assessed anxiety-consistent as well as insomnia-consistent interpretational bias to determine whether pre-sleep worry is specifically associated with a bias for insomnia-related information or with interpretational bias in general. Second, we tested the association between interpretational bias and subjective and objective measures of sleep. Upon completion of the AST, participants undertook sleep assessments at home using actigraphy and by keeping a sleep diary. We predicted that insomnia-consistent interpretational bias would be associated with subjective estimates of sleep parameters (i.e., longer SOL and shorter TST) and poorer overall evaluation of sleep, whereas this bias would have smaller or even null associations with objective estimates of sleep on actigraphy.

2 | METHOD

2.1 | Participants

Eighty-five participants were recruited via social network services and flyers distributed at LMU Munich. Participants were included in the present study if they were (a) 18 – 30 years old, (b) fluent in German and (c) did not have a physiological disorder that prevented them from performing the experimental tasks or sleep assessments. Based on these criteria, five participants had to be excluded. Furthermore, two participants only wore an actigraph for one or two nights, data from one participant were lost due to incorrect operation of the software and one participant did not complete the baseline assessment. Therefore, the final sample consisted of 76

participants (66 women) with a mean age of 22.64 (*SD* = 3.01) years. The rational for targeting a non-clinical population is that biased cognition is thought to be a transitional state in the development of insomnia that is characterized by a serious objective sleep deficit (Espie et al., 2006). Therefore, we assumed that insomnia-related bias is most likely observed in subclinical individuals who have not yet developed chronic symptoms but have some complaints about sleep.

The sample size was determined based on the effect sizes observed in Ree et al. (2006). The effect sizes (for the differences in interpretational bias between poor and good sleepers) were d = 0.70 and 0.78 for forced-choice and open-ended responses of the AST, respectively. Our power analysis (with G*power; Faul, Erdfelder, Lang, & Buchner, 2007) estimated a required sample size of *n* = 54–68 to detect the sizes of the effects based on the assumptions of alpha = 0.05 and power = 0.80.

2.2 | Measures

2.2.1 | Pittsburgh Sleep Quality Index (PSQI)

The PSQI (Buysse, Reynolds, Monk, Berman, & Kupfer, 1989; Riemann & Backhaus, 1996) was used to assess participants' subjective sleep difficulties over the past 4 weeks. The PSQI consists of 18 items (excluding co-sleeping items), which are combined into seven subscales: sleep duration, sleep disturbances, sleep latency, daytime dysfunction, sleep efficiency, sleep quality and sleep medication. The subscales are scored on a 4-point scale. A global score with a possible range of 0 to 21 is obtained by adding the subscores; higher scores indicate worse overall sleep quality. The PSQI global score exhibited moderate internal consistency in the current sample (Cronbach's α = 0.51).

2.2.2 | Pre-sleep arousal scale (PSAS)

The PSAS (Gieselmann, de Jong-Meyer, & Pietrowsky, 2012; Nicassio et al., 1985) was used to assess pre-sleep arousal in general (not specific to the previous night). This scale consists of two subscales: cognitive arousal as an index for pre-sleep worry (e.g., "Worry about falling asleep") and somatic arousal (e.g., "Heart racing, pounding or beating irregularly"). Each subscale consists of eight items, which are rated on a 5-point scale (1 = not at all; 5 = extremely); higher values indicate higher cognitive and somatic arousal. Both subscales exhibited good internal consistency in the current data (α = 0.69 and 0.91, respectively).

2.2.3 | State-Trait Anxiety Inventory (STAI)

The STAI (Laux, Glanzmann, Schaffner, & Spielberger, 1981; Spielberger, Gorsuch, & Lushene, 1970) was used to assess trait anxiety. The STAI consists of 20 items referring to general feelings of stress, worry and discomfort. Each item is rated on a 4-point scale; a high total value indicates higher levels of trait anxiety. In the current sample, the internal consistency was moderate (α = 0.88).

2.3 | Sleep diary

Daily subjective sleep parameters were measured using a sleep diary (Carney et al., 2012). Every morning, upon awakening, participants completed a sleep diary via an online platform. Included in these entries were questions about the following aspects of the previous night´s sleep: (a) the duration of time to fall asleep in minutes (i.e., SOL), (b) the number of hours spent sleeping (i.e., TST) and (c) the overall quality of sleep (SQ). These questions are rated on a 5-point scale (1 = very poor; 5 = very good). All diary entries made after 17:00 hours were excluded from the analysis to avoid possible contamination by memory bias. On average, participants completed the diary for 6.75 (*SD* = 0.64) nights.

2.4 | Actigraphy

Objective sleep parameters were measured via actigraphy. Participants wore an actigraph (wGT3X-BT; ActiGraph, Pensacola, FL, USA) on their non-dominant wrist for seven consecutive days following the laboratory assessment (the questionnaires and the AST). Physical activity was recorded with a sampling rate of 30 Hz and aggregated in 1-min epochs. The sleep–wake cycle was defined by the Cole-Kripke algorithm (Cole, Kripke, Gruen, Mullaney, & Gillin, 1992). Although actigraphs sometimes misinterpret physical movements during sleep as being awake and motorless awaking as sleeping, actigraphy has been shown to be consistent with polysomnography (> 80% accuracy; Ancoli-israel et al., 2003; Cellini, Buman, McDevitt, Ricker, & Mednick, 2013). Furthermore, actigraphy maintains ecological validity, as participants do not have to sleep in unfamiliar settings such as a sleep laboratory (cf. the first night effect; e.g., Byun, Kim, Moon, Motamedi, & Cho, 2019). In the current study, valid actigraphy data were obtained for participants for an average of 6.24 (*SD* = 1.03) nights, after excluding nights with large inconsistencies in in-bed and out-of-bed times (> 0.5 hr) between sleep diary and actigraphy.

2.5 | Ambiguous scenario task

The stimuli were adapted from an earlier study (Ree et al., 2006) and included 27 ambiguous scenarios for each of the insomnia and anxiety versions. When translating the scenarios into German, we dropped three items from the insomnia version and five items from the anxiety version because they were not sufficiently ambiguous in the German translation (some of the German words do not have double meanings to make a scenario ambiguous: e.g., a father's "urn" on a mantelpiece). Two extra scenarios were created to replace the omitted items; therefore, the final set of scenarios consists of 24 items for each version.

Insomnia- and anxiety-related scenarios were presented in a quasi-random order; that is, the insomnia-related and anxiety-related

scenarios were intermixed in a single block. Interpretational bias was assessed both in an open-ended and in a forced-choice response form. For each scenario, participants were first instructed to write down their initial interpretation of the situation (i.e., open-ended responses). They were explicitly informed that the scenarios can be interpreted in several ways, and to simply describe how they would interpret each scenario in the provided text box. Subsequently, two possible interpretations of the same scenario were displayed: a neutral interpretation and a threat-related interpretation that referred either to insomnia or to anxiety. Participants were instructed to indicate which interpretation was more likely to be true (i.e., forced-choice responses). The following is an example scenario with insomnia-related and neutral response options:

Fogginess made it difficult for Julie to get going in the morning.

- Response option a: Her drowsiness made it difficult to get going.
- Response option b: The weather made it difficult to get going.

The open-ended responses were coded as either threat consistent or threat inconsistent by two of the authors (FG and GW), independently. A response was coded as insomnia consistent when it had sleep keywords referring to sleep problems, sleeping pills or concerns/worry about sleep. Several participants did not describe the situation but only paraphrased the presented sentence; these were coded as insomnia inconsistent even when a "sleep keyword" was present. Similarly, open-ended responses on the anxiety version of the AST were coded as anxiety consistent versus anxiety inconsistent by the independent raters. Based on participants' open-ended responses, we found that one anxiety-related scenario was not sufficiently ambiguous. Therefore, this scenario was excluded from the analyses. On average, inter-rater reliability for the open-ended responses was good ($\kappa = 0.86$ and agreement rate = 94% for all ratings across both versions of the AST).

2.6 | Procedure

Participants were invited to the laboratory individually, although up to two participants were tested simultaneously. All participants provided written informed consent after having received explanations about the study protocol. In the laboratory, participants answered several questionnaires, including the PSQI, PSAS and STAI. Afterwards, they completed the following computer tasks: the AST, the dot-probe task (Macmahon et al., 2006) and the pay-per-view task (Takano & Raes, 2018). The latter two tasks are not reported here as these are out of the scope of the current study. The task order was randomized across participants. On the following day, we began monitoring participants' sleep using actigraphy and sleep diaries; this lasted for seven consecutive days. After completing the sleep assessment, participants were once again invited to the laboratory to be given monetary compensation of 30€ or 40€. The amount given was determined based on the participant's performance in the pay-per-view task. The study protocol was approved by the ethical committee of the Department of Psychology, LMU Munich.

2.7 | Statistical analyses

To ensure the unifactor structure of both AST versions (even after translation and adaptation to the German language), we first performed exploratory factor analyses on the responses to the AST. Second, we conducted a series of correlation and regression analyses to test the hypothesized associations between interpretational bias, pre-sleep worry and both subjective and objective sleep estimates. Specifically, we used hierarchical multiple regressions to test (a) whether the associations can be uniquely attributed to pre-sleep worry even after controlling for general trait anxiety and (b) whether the associations are unique to subjective (versus objective) estimates of the sleep parameters.

3 | RESULTS

3.1 | Descriptives

Table 1 describes the means and *SD*s of the assessed variables. In the current sample, 34 (45%) participants exhibited clinically significant sleep disturbances (above the cut-off of 5 in the PSQI global score; Buysse et al., 1989). Although it is already known that students tend to have more sleep problems than older individuals (e.g., Lund, Reider, Whiting, & Prichard, 2010), it is noteworthy that the prevalence rate in the sample study is higher than in the general population.

3.2 | Factor analyses on the AST items

Given that we made several modifications to the items of the AST due to language differences, we performed exploratory factor analyses on the responses of all versions of the AST (insomnia and anxiety related; forced choice and open ended). This allowed us to test the (uni)factor structure of the AST items and to select items that are internally consistent with each insomnia- and anxiety-consistent interpretation. Because both forced-choice and open-ended responses were dummy coded, we first estimated polychoric correlations. These were then submitted to factor analyses, assuming a unifactor structure. The results suggest that around half of the items were loaded on a single latent factor within each version of the AST (see Table A1 and A2). Therefore, we selected the items that had good factor loadings (> 0.30) for both the forced-choice and open-ended response types. This item selection resulted in 11 items for the insomnia AST and six items for the anxiety AST, which were then used to score insomnia- and anxiety-consistent interpretational bias in the following analyses.[1]

[1]Because of this large reduction in items, we repeated the same analyses with all items that were included in the ASTs. We found that the results were overall unchanged; e.g., pre-sleep worry was significantly positively associated with insomnia-consistent interpretational bias ($r = 0.32$ for forced-choice and $r = 0.26$ for open-ended responses), but not with anxiety-consistent bias ($r = 0.06$ for forced-choice and $r = 0.06$ for open-ended responses). Trait anxiety showed significant correlations with all these measures of bias with $rs = 0.26 - 0.31$.

TABLE 1 Descriptive statistics and correlations ($n = 76$)

Variables	*M*	*SD*	Range	1	2	3	4	5	6	7	8	9	10	11	12
1. PSQI	5.87	2.35	1 – 13	–											
2. PSAS SOM	10.93	3.30	8 – 24	0.20	–										
3. PSAS COG	14.1	6.56	7 – 34	0.56*	0.44*	–									
4. STAI-T	39.67	9.00	28 – 63	0.44*	0.48*	0.46*	–								
5. Acti SOL (min)	6.28	2.55	2.7 – 16.7	0.17	0.24*	0.35*	0.17	–							
6. Acti TST (hr)	7.26	0.89	4.8 – 11.0	−0.19	−0.02	−0.12	0.00	−0.23*	–						
7. Diary SOL (min)	17.52	14.50	1.6 – 85.7	0.23*	0.04	0.30*	0.00	0.24*	0.07	–					
8. Diary TST (hr)	7.46	0.70	5.6 – 8.9	−0.36*	0.02	−0.22	−0.11	−0.08	0.68*	−0.18	–				
9. Diary Qual	2.75	0.52	1.3 – 3.9	−0.28*	−0.07	−0.23*	−0.33*	0.07	−0.08	−0.22	0.16	–			
10. AST INS (FC)	6.21	2.45	1 – 11	0.25*	0.14	0.31*	0.40*	0.19	−0.03	0.20	−0.10	−0.32*	–		
11. AST INS (OE)	4.86	2.44	0 – 10	0.21	0.08	0.29*	0.35*	0.22	−0.12	0.13	−0.19	−0.22	0.82*	–	
12. AST ANX (FC)	1.84	1.19	0 – 6	0.20	−0.08	0.03	0.25*	0.06	0.16	0.11	−0.03	−0.19	0.32*	0.19	–
13. AST ANX (OE)	2.45	1.36	0 – 6	0.19	0.11	−0.02	0.27*	0.05	0.17	0.14	0.07	−0.14	0.33*	0.28*	0.67*

Abbreviations: PSQI, Pittsburgh Sleep Quality Index; PSAS SOM (COG), Pre-sleep Arousal Scale Somatic (Cognitive) subscale; STAI-T, State-Trait Anxiety Scale – Trait; Acti SOL, TST, actigraphy estimations of sleep onset latency and total sleep time; Diary SOL, TST, estimates on sleep diary; Diary Qual, rating on overall quality of sleep; AST INS, ANX (FC, OE), ambiguous scenario task for insomnia- or anxiety-consistent interpretational bias (forced-choice or open-ended responses).

*$p < .05$.

3.3 | Correlations

Forced-choice and open-ended responses were moderately-to-highly correlated with each other for both the insomnia- and anxiety-related AST (Table 1). These two types of responses showed similar patterns of correlations with sleep and anxiety variables. Consistent with previous findings, insomnia-related interpretational bias was positively correlated with the PSQI score, indicating a link between stronger interpretational bias and worse global sleep quality. Note that the correlation reached statistical significance only for the forced-choice but not for the open-ended responses, although we did not see a substantial difference in the magnitude between these two correlations. General pre-sleep arousal also showed a positive correlation with insomnia-related interpretational bias, although this correlation was statistically significant only for cognitive arousal (i.e., pre-sleep worry) but not for somatic arousal. Neither the PSQI nor PSAS scores were significantly associated with anxiety-related interpretational bias. The STAI was the only measure that was significantly correlated with both insomnia- and anxiety-related interpretational bias.

3.4 | Regressions

To clarify whether pre-sleep worry has a unique effect on insomnia-related interpretational bias over and above trait anxiety, we performed two-step hierarchical multiple regression analyses. In the first step, we entered the two PSAS scores into a model that predicted either forced-choice or open-ended responses in the AST. Subsequently, the STAI score was added to the regression model. The results revealed a significant effect of cognitive arousal in the first step, which was, however, dissolved when adding the STAI in the second step (Table 2). These findings suggest that the association between pre-sleep worry and insomnia-related interpretational bias can be explained by trait anxiety. We also performed similar multiple regression analyses on anxiety-consistent interpretational bias, which revealed a significant effect of the STAI but not PSAS. These results imply that individuals with higher levels of pre-sleep worry are more prone to interpret an ambiguous situation in an insomnia-related (but not anxiety-related) manner; however, this tendency can be attributed to trait anxiety in general.[2]

To test the associations between interpretational bias and specific subjective and objective sleep parameters (based on the collected sleep diary and actigraphy data), another set of multiple regression analyses was performed. Each interpretational bias was predicted by SOL and TST estimates of the sleep diary and actigraphy data. The regression models also included the daily overall subjective sleep quality as a predictor. The results indicated that only daily, overall subjective sleep quality is associated with insomnia-related interpretational bias (for forced-choice responses; see Table 3). Neither the subjective nor the objective estimates of SOL

[2]As Ree et al. (2006) found a significant interaction between sleep disturbances and trait anxiety in predicting interpretational bias, we also tested the moderation effect of the STAI on the association between the PSAS and interpretation bias. However, the results showed no significant interactions for forced-choice or open-ended responses (*ps*> 0.42).

TABLE 2 Regressions predicting insomnia-consistent interpretational bias by pre-sleep arousal and trait anxiety (n = 76)

	Estimates	*SE*	*t*	*p*	95% CI	Fit
IV: AST Insomnia (Forced choice)						
Step 1						R^2 = 0.095
PSAS Som	0.01	0.09	0.07	0.94	[−0.18, 0.19]	
PSAS Cog	0.11	0.04	2.46	0.02	[0.02, 0.21]	
Step 2						R^2 = 0.189
PSAS Som	−0.09	0.09	0.92	0.36	[−0.27, 0.10]	
PSAS Cog	0.07	0.05	1.53	0.13	[−0.02, 0.16]	
STAI-T	0.10	0.03	2.89	0.01	[0.03, 0.17]	
IV: AST Insomnia (Open end)						
Step 1						R^2 = 0.084
PSAS Som	−0.04	0.09	0.45	0.66	[−0.23, 0.14]	
PSAS Cog	0.12	0.05	2.49	0.02	[0.02, 0.21]	
Step 2						R^2 = 0.163
PSAS Som	−0.13	0.09	1.33	0.19	[−0.32, 0.06]	
PSAS Cog	0.08	0.05	1.63	0.11	[−0.02, 0.17]	
STAI-T	0.09	0.04	2.59	0.01	[0.02, 0.16]	

Abbreviations: AST, ambiguous scenario task; PSAS Som (Cog), Pre-sleep Arousal Scale - Somatic arousal (Cognitive arousal).

TABLE 3 Regressions predicting insomnia-consistent interpretational bias by sleep diary and actigraphy estimates (n = 76)

	Estimates	*SE*	*t*	*p*	95% CI	Fit
IV: AST Insomnia (Forced choice)						R^2 = 0.154
Acti SOL	0.18	0.12	1.59	0.12	[−0.05, 0.41]	
Acti TST	0.00	0.46	0.01	0.99	[−0.90, 0.91]	
Diary SOL	0.01	0.02	0.63	0.53	[−0.03, 0.05]	
Diary TST	−0.09	0.57	0.16	0.87	[−1.24, 1.05]	
Diary quality	−1.47	0.55	2.67	0.01	[−2.58, −0.37]	
IV: AST Insomnia (Open end)						R^2 = 0.127
Acti SOL	0.22	0.12	1.86	0.07	[−0.02, 0.45]	
Acti TST	0.02	0.46	0.05	0.96	[−0.90, 0.95]	
Diary SOL	0.00	0.02	0.05	0.96	[−0.04, 0.04]	
Diary TST	−0.51	0.58	0.88	0.38	[−1.67, 0.65]	
Diary quality	−1.01	0.56	1.81	0.07	[−2.13, 0.10]	

Abbreviations: AST, ambiguous scenario task; Acti, actigraphy; Diary, sleep diary; SOL, sleep onset latency; TST, total sleep time.

and TST were associated with the insomnia-related interpretational bias. Furthermore, we estimated similar regression models predicting anxiety-related interpretational bias, which showed that none of the diary and actigraphy parameters was associated with this bias. These results suggest that insomnia-consistent interpretational bias is only associated with the overall evaluation of poor-quality sleep, and not with the estimates of individual sleep parameters.

3.5 | Interpretational bias and differences between subjective and objective sleep parameters

To explicitly test whether interpretational bias is associated with a misperception of sleep (i.e., over- or underestimation of sleep parameters), we also examined the correlations with the difference scores between the subjective and objective sleep parameters of the SOL and TST. We found no significant correlations for the SOL differences: r = 0.17 and 0.10 with insomnia-related interpretational bias (forced choice and open ended, respectively); r = 0.10 and 0.13 with anxiety-related interpretational bias. However, the TST difference score showed a small negative correlation with anxiety-related interpretational bias for forced-choice (r = −0.24, p = .03), but not for open-ended, responses (r = −0.16). The correlation with insomnia-related interpretational bias was not significant for the forced-choice or open-ended responses: r = −0.07 and −0.04. These findings suggest that interpretational bias is not related to biased estimations of individual sleep parameters.

4 | DISCUSSION

Cognitive models of insomnia predict that biased cognition is the basis of pre-sleep worry about sleeplessness, which arouses autonomic nervous activity and emotional distress, and thus prevents the normal initiation of sleep. We specifically tested whether insomnia-consistent interpretational bias is associated with (a) pre-sleep worry and (b) perceived or real deficits of sleep. First, as predicted, the results showed that insomnia-consistent interpretational bias is positively associated with pre-sleep worry. Second, we replicated previous findings regarding the association between insomnia-consistent interpretational bias and global subjective sleep disturbances measured by the PSQI (Ellis, Gardani, & Hogh, 2010; Ree et al., 2006). Third, this bias is not related to either subjective or objective estimates of SOL and TST; rather, this bias is significantly associated with participants' overall evaluations of daily sleep quality.

The replicated association between the AST and PSQI highlights the robustness of interpretational bias among individuals with subjective sleep disturbances. Pre-sleep worry (PSAS cognitive arousal) was also found to be associated with this interpretational bias. Furthermore, this association seems to be domain specific, as pre-sleep worry was not significantly correlated with anxiety-related interpretational bias. These findings fit the model's prediction that the biased cognition "fuels" pre-sleep worry, increasing arousal and anxiety, and thus contributing to sleep disturbances (Ree et al., 2006). However, worry had no effect on interpretational bias after controlling for trait anxiety. Thus, although the association may be attributed to general anxiety, it is not specific to sleep-related (or insomnia-related) worry. Given the moderate correlation between the PSAS and STAI, there is a significant amount of overlap in individuals with pre-sleep worry and those with trait anxiety. It appears that anxious individuals tend to interpret ambiguous situations in a threat-related manner: this phenomenon is not limited to insomnia, but also applies to anxiety and threats in general. Thus, if individuals exhibit general trait anxiety, they are likely to also exhibit insomnia-related interpretational bias.

Contrary to our hypothesis, interpretational bias was not related to the (mis)perception of sleep. More specifically, neither a perceived nor real (objective) state of sleep correlates with the extent of interpretational bias. Instead, interpretational bias is associated with overall daily sleep quality (over a 1-week period). These results suggest that the bias may be related to the cognitive processes involved in integrating pieces of information about perceived sleep (e.g., SOL and TST) to judge the overall quality of one's sleep. It is possible that people with sleep disturbances have dysfunctional beliefs about sleep (e.g., I have to have 8 hr sleep to function well during the day; Morin, Vallières, & Ivers, 2007), which make them feel that their sleep is insufficient even when they have an objectively sufficient amount of sleep (e.g., 7 hr) and correctly estimate the hours spent sleeping. This speculation should be tested in future research to better understand how individuals judge overall quality of sleep while holding such irrational beliefs, as well as how interpretational bias is related to this judgement process and creates a sense of sleeplessness. The non-significant correlations between interpretational bias and (mis)perception of sleep might be due to the non-clinical nature of our sample; indeed, neither the sleep onset latency nor total sleep time (subjective and objective) indicated severe sleep problems in our participants (e.g., mean TST = 7.47 and 7.26 hr for diary and actigraphy estimates, respectively). We therefore agree that a replication of the current findings in a more heterogeneous sample with diverse patterns of sleep (covering clinically significant levels of disturbances) is desirable.

Several limitations need to be further considered when interpreting the present results. First, the non-clinical nature of our sample may limit the clinical implications of these findings. We explicitly targeted a non-clinical (or subclinical) sample, given that sleep misperception is a transient phenomenon between acute and chronic insomnia symptomatology. Nevertheless, a number of studies have suggested that clinical samples with a diagnosis of insomnia may exhibit more prominent cognitive dysfunctions (Vanable, Aikens, Tadimeti, Caruana-Montaldo, & Mendelson, 2000) and biases toward insomnia-related stimuli (Taylor, Espie, & White, 2003). As we did not find any associations between the misperception of sleep and participants' interpretational bias, future research should focus on clinical samples. Second, responses to the AST are known to be primed by the administration of sleep/insomnia questionnaires (Ellis et al., 2010). Because we administered all sleep questionnaires prior to the AST, it should be noted that this may have led to our participants being more prone to interpret the scenarios in an insomnia-consistent manner. Furthermore, it is likely that participants realized that the AST was about insomnia (or anxiety). Knowing the intention of the task may have affected participants' responses, for example, due to social desirability or a self-serving bias. To overcome this issue, a more implicit task (e.g., based on response time) could be used in future research. Fourth, the relatively short period of sleep diary and actigraphy assessment may limit the generalizability of our results. Because we only found null or small correlations between the PSQI and diary/actigraphy estimations, we cannot exclude the possibility that the sleep-assessment week was not typical for some participants. Replication is needed with a longer period for the diary and actigraphy assessments. Fifth, we experienced some difficulty in creating appropriate stimuli for the AST in our local language. Several items were eliminated based on the factor analyses to guarantee the internal consistency of the AST. Although we believe that there is no substantial difference between the German version and the original English version of the AST, particularly in regard to the correlations with insomnia and anxiety measures, caution should be used when comparing the results of the two versions.

In conclusion, this study provides empirical evidence that interpretational bias is associated with pre-sleep worry and an overall evaluation of poor sleep quality. Given the cross-sectional nature of the findings, a prospective study is warranted to establish the causal directions between the hypothesized cognitive processes involved in the cognitive-hyperarousal mechanism. One

interesting direction would be to manipulate interpretational bias via a bias-modification procedure (e.g., Menne-Lothmann et al., 2014), as this may provide information about the cognitive pathways to sleep disturbances as well as have direct implications for clinical intervention.

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

AUTHOR CONTRIBUTIONS

FG, KT and TE designed the study; FG collected the data; FG, KT and GW analysed the data and drafted the manuscript; all authors contributed to the revision of the manuscript and approved the final manuscript.

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APPENDIX

TABLE A1 Factor loadings of items in the ambiguous scenario task for insomnia-consistent interpretation

Item #	Forced choice	Open ended
19	**0.80**	**0.36**
22	**0.72**	**0.63**
10	**0.64**	**0.59**
9	0.61	0.25
24	**0.56**	**0.69**
20	**0.50**	**0.61**
7	**0.50**	**0.35**
12	**0.45**	**0.55**
11	**0.41**	**0.78**
5	0.38	0.12
23	**0.35**	**0.33**
18	**0.35**	**0.38**
16	0.34	0.22
4	**0.34**	**0.47**
21	0.33	0.21
13	0.30	–
1	0.25	−0.02
15	0.18	0.64
2	0.12	0.41
8	0.01	0.02
17	−0.01	−0.19
6	−0.07	0.33
3	−0.25	−0.20
14	−0.26	−0.11

Note: Bold items were used to score insomnia-consistent interpretational bias. Item 13 was constant as all participants had the same score on the open-ended responses. The scenarios and response options can be found in the OSF page: https://osf.io/jbup4/?view_only=252da13ed8f94a9c92c316bb83c1ee68

TABLE A2 Factor loadings of items in the ambiguous scenario task for anxiety-consistent interpretation

Item #	Forced choice	Open ended
13	**1.00**	**0.37**
11	0.79	0.17
8	0.58	−0.11
2	**0.57**	**0.66**
1	**0.56**	**0.38**
6	0.50	0.12
15	**0.49**	**0.34**
10	**0.47**	**0.40**
21	**0.46**	**0.62**
20	0.44	−0.05
22	0.29	0.30
3	0.09	0.67
4	0.01	0.75
7	0.00	0.04
18	−0.06	0.70
17	−0.17	0.65
19	−0.29	−0.17
16	−0.36	0.37
23	−0.38	0.67
24	−0.39	0.11
14	−0.45	0.42
5	–	0.76
12	–	−0.41

Note: Bold items were used to score anxiety-consistent interpretational bias. Items 5 and 12 were constant as all participants made the same responses; Item 9 was excluded from the analyses because of the translational issue.