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Pre-sleep arousal can be associated with efficient processing of sleep-related information

Keisuke Takano[a,*,1], Louise Vanden Poel[b,1], Filip Raes[b]

[a] Department of Psychology, Clinical Psychology and Psychotherapy, Ludwig-Maximilians-University Munich, Germany
[b] Center for the Psychology of Learning and Experimental Psychopathology, University of Leuven, Belgium

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ABSTRACT

Background and objectives: Cognitive bias to sleep-related information is thought to be a core feature of sleep disturbances. The bias may enhance pre-sleep arousal, such as excessive worry about sleeplessness, which prevents people from initiating normal sleep onset. The present study focused on (a) attention bias toward sleep-related stimuli and (b) difficulty in updating working memory for sleep-related stimuli as two possible mechanisms underlying pre-sleep cognitive arousal.
Method: Participants ($n = 61$, a community sample) completed a dot-probe task (with sleep-related and matched control word stimuli) and a 1-back and 2-back task (with sleep-related and non-sleep-related pictorial stimuli).
Results: For the dot-probe task, the results showed no significant association between pre-sleep cognitive arousal and sleep-related attention bias. However, the results of the 2-back task suggest that pre-sleep arousal is associated with decreased interference by sleep-related stimuli in maintaining non-sleep-related information. That is, individuals with higher levels of pre-sleep arousal are more efficient at processing sleep-related materials.
Limitations: The non-clinical nature of the sample may limit the clinical implications of the findings.
Conclusions: Although the current results cannot be explained by the extant cognitive theories of insomnia, we offer an alternative explanation based on the idea of worry as mental habit: mental processes that occur frequently (e.g., repetitive thoughts about sleep) require less cognitive resource. Therefore, sleep-related information may be processed easily without consuming much cognitive effort.

1. Introduction

Cognitive models of insomnia (Espie, Broomfield, MacMahon, Macphee, & Taylor, 2006; Harvey, 2002) have highlighted the role of excessive preoccupation with sleep in the development and maintenance of insomnia symptoms. Research has shown increased levels of worry and symptom-focused rumination (e.g., "If I cannot sleep well tonight, I will not be able to concentrate on my work tomorrow.") in individuals with sleep disturbances, compared to good sleepers (Carney, Edinger, Meyer, Lindman, & Istre, 2006; Gross & Borkovec, 1982; Harvey, 2002; Thomsen, Mehlsen, Christensen, & Zachariae, 2003). Such sleep- or insomnia-related cognition is particularly problematic when it occurs in pre-sleeping hours (e.g., Nicassio, Mendlowitz, Fussell, & Petras, 1985), because thinking about sleep (lessness) and the possible consequences of poor sleep, along with general problem-solving and personal issues (self-focusing), are significant predictors of increased sleep latency (Takano, Sakamoto, & Tanno, 2014; Wicklow & Espie, 2000) and nighttime physiological arousal (Takano et al., 2014).

As a possible mechanism underlying excessive worry about sleep, researchers have investigated attention bias toward sleep-related information in individuals with sleep disturbances and clinical levels of insomnia. Studies have suggested that these individuals' attention is easily captured by and/or inefficiently disengaged from sleep-related stimuli (e.g., focusing on a clock to calculate how many hours they have slept; Woods, Marchetti, Biello, & Espie, 2009). One theory proposes that such attention bias could result in excessive monitoring of internal and external cues of sleep, which further triggers worry and rumination about sleeplessness and daytime dysfunctions (Harvey, 2002). Experimental studies have examined this sleep-related attention with various types of cognitive tasks, such as the dot-probe task, Posner task, and change blindness task (for a review, see Harris et al., 2015). Overall, the results support the presence of a sleep-related attentional bias in individuals with sleep disturbances (e.g., Jansson-Fröjmark, Bermås, &

* Corresponding author. Department of Psychology, Division of Clinical Psychology and Psychotherapy, Ludwig-Maximilians-University Munich, Leopoldstr.13, 80802 Munich, Germany.
E-mail address: Keisuke.Takano@psy.lmu.de (K. Takano).
[1] These authors contributed to the current study equally; co-first authorship.

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Kjellén, 2013; Jones, Macphee, Broomfield, Jones, & Espie, 2005; MacMahon, Broomfield, & Espie, 2006; Marchetti, Biello, Broomfield, MacMahon, & Espie, 2006; Woods et al., 2009).

However, sleep-related attention bias seems to be a more fragile phenomenon than initially expected, as more recent studies have failed to replicate attention bias in insomnia and non-clinical poor sleepers (e.g., Spiegelhalder et al., 2010, 2016). Two attention-bias-modification studies also failed to detect attention bias using the dot-probe task (Clarke et al., 2016; Lancee et al., 2017). This is probably because "sleep-related stimuli" is a multi-faceted construct. Sleep-related stimuli were originally developed from an investigation of pre-sleep cognition (MacMahon et al., 2006; Wicklow & Espie, 2000), which included both negatively valenced and emotionally neutral stimuli (e.g., *tired, fatigue, dream, bed*). Although even emotionally neutral sleep-related stimuli can be a target of selective attention (Harris et al., 2015), a recent Stroop study using "non-affective" sleep-related stimuli failed to detect significant differences between good and poor sleepers in response latency to sleep-related words (Barclay & Ellis, 2013). This is a good strategy to control the effect of emotional valence, but the non-affective sleep-related stimuli do not cover "threatening signs" of insomnia (e.g., *exhausted, aroused, restless*). Thus, in the present study, we used the "original" set of sleep-related stimuli (e.g., MacMahon et al., 2006) with matched control stimuli in terms of valence and arousal in the dot-probe paradigm (one of the most widely used attention-bias tasks; cf. Bar-Haim, Lamy, Pergamin, Bakermans-Kranenburg, & van Ijzendoorn, 2007). This stimulus set covers both emotionally negative and neutral materials reflecting the contents of pre-sleep cognitions (Taylor, Espie, & White, 2003; Wicklow & Espie, 2000), which allowed us to determine whether attention is specifically biased to sleep-related threatening information or merely the negative features of those stimuli.

Although attention bias has been a target of many studies examining cognitive (dys)functions in sleep disturbances, other cognitive processes could also be relevant to pre-sleep worry and rumination. Given the persistent nature of insomnia-related cognition, difficulty in updating working memory (WM) is a candidate mechanism to explain the "stickiness" of sleep-related thinking. WM is a cognitive system that allows temporary storage and mental manipulation of information, which must balance two functions that are often in conflict with each other: maintenance and updating (Kessler & Oberauer, 2014; Rac-Lubashevsky & Kessler, 2016). The maintenance function refers to the limited storage capacity of WM, which keeps relevant information actively accessible. Moreover, it prevents the interference from irrelevant internal (e.g., long-term memory) and external (e.g., perceptual) input. The updating function refers to the ability to rapidly manipulate information held in WM when required, by adding new, relevant information and/or discarding information that is no longer relevant (Ecker, Oberauer, & Lewandowsky, 2014; Ecker, Lewandowsky, & Oberaurer, 2014).

Maintenance and updating are two conflicting demands, as they are indicators of stability versus flexibility, respectively. Computational models propose that there is a dynamic and selective input-gating mechanism that regulates the switching between these two functions (e.g., Frank, Loughry, & O'Reilly, 2001; O'Reilly, 2006). When the gate is open, available information can enter WM, thereby allowing rapid updating. When the gate is closed, the current information in WM is maintained, while irrelevant information is prevented from entering. Evidence from previous research shows that switching between the WM functions of maintenance and updating, and therefore opening or closing the gate, results in an increased response time, or "switch cost" (Kessler & Oberauer, 2014, 2015).

Specific biases and impairments in WM updating have been observed in individuals with depression and anxiety, which are also characterized by persistent cognition such as rumination and worry (e.g., Joormann & Gotlib, 2008; Nolen-Hoeksema, Wisco, & Lyubomirsky, 2007; Segal, Kessler, & Anholt, 2015). Experimental studies using emotional n-back tasks, which measure the ability to maintain and update emotional information (e.g., happy and sad faces), have suggested that depressed individuals tend to be slower to disengage from sad stimuli and faster to disengage from happy stimuli in comparison to healthy controls (Levens & Gotlib, 2010). Moreover, those individuals seem to have greater difficulty in removing irrelevant, negative information from WM and this interference is also associated with depressive rumination (Joormann & Gotlib, 2008). Other studies suggest that rumination and worry are associated with general deficits in WM updating that are not limited to emotional processing (e.g., Gustavson & Miyake, 2016; Meiran, Diamond, Toder, & Nemets, 2017). Given the potential role of persistent cognition in sleep disturbances (Espie et al., 2006; Harvey, 2002), it can be hypothesized that pre-sleep worry would be associated with an inability to maintain and update WM particularly for sleep-related information.

In summary, the present study tests the associations between pre-sleep worry and (a) attention bias to sleep-related stimuli, as measured by the dot-probe task, and (b) difficulty updating WM for sleep-related information, as measured by the n-back tasks. For attention bias, we had two (mutually exclusive) hypotheses. If people with higher levels of pre-sleep arousal show a greater attention bias to sleep-related stimuli, we could conclude that sleep-specific attention bias is independent of general emotional factors. However, if sleep-related attention bias is contaminated by emotional factors (and the bias can be attributed to vigilance to negatively valenced stimuli), the dot-probe performance should not correlate with pre-sleep arousal as our sleep-related and control stimuli are matched in valence and arousal. The second hypothesis was that individuals with higher (vs. lower) levels of pre-sleep arousal would significantly differ in their performances on the n-back (1-back and 2-back) tasks. In these tasks, participants are required to maintain and update WM in response to sequential presentation of sleep-related and non-sleep-related pictorial stimuli. Participants were asked to indicate whether the type (sleep-related or non-sleep-related) of stimulus of the current trial was the same as, or different than, that of the n-back trial. For the 1-back task, we predicted that individuals with higher levels of pre-sleep worry would show greater difficulty in removing sleep-related information from their WM. This persistency would be reflected in longer response times and lower accuracy for trials where participants had to switch from a sleep-related (*n-1*st trial) to a control stimulus (*n*-th trial; i.e., switch cost). For the 2-back task, we predicted that individuals with higher levels of pre-sleep worry would show greater interference from a sleep-related stimulus on the *n-1*st trial (reflected in longer response times and lower accuracy) when maintaining control stimuli between the *n-2* and *n*-th trial.

2. Method

2.1. Participants

Sixty-one participants (50 women and 11 men; mean age = 22.2, *SD* = 3.6 years) were recruited from a large sample pool of a university, which covers its students and community living in the city and surrounds. There was no requirement for participation except that participants had to be fluent in Dutch. For their participation, participants received monetary compensation, either 10 or 20 euros, depending on their performance on a decision-making task (see also section 2.5 Procedure).

Although we did not have a good prior for an expected effect size of the n-back tasks, power analysis with G*power (Faul, Erdfelder, Lang, & Buchner, 2007) suggested that the required sample size was $n = 26$–59 to detect a correlation of 0.35–0.50 under alpha = 0.05 and beta = 0.80. We assumed a moderate-to-large effect for the association between pre-sleep arousal and task performances (including the dot-probe and n-back tasks), because a recent review (Harris et al., 2015) suggested that the effect of the sleep-related attentional bias ranges from moderate to large sizes (e.g., $d = .74$ for attention bias measured by the dot-probe task, Jansson-Fröjmark et al., 2013).