Accepted Manuscript

I sleep with my Mind's eye open: Cognitive arousal and overgeneralization underpin the misperception of sleep

Keisuke Takano, Yannick Boddez, Filip Raes

PII: S0005-7916(16)30070-2

DOI: [10.1016/j.jbtep.2016.04.007](https://doi.org/10.1016/j.jbtep.2016.04.007)

Reference: BTEP 1229

To appear in: *Journal of Behavior Therapy and Experimental Psychiatry*

Received Date: 16 January 2016

Revised Date: 23 April 2016

Accepted Date: 25 April 2016

Please cite this article as: Takano, K., Boddez, Y., Raes, F., I sleep with my Mind's eye open: Cognitive arousal and overgeneralization underpin the misperception of sleep, *Journal of Behavior Therapy and Experimental Psychiatry* (2016), doi: 10.1016/j.jbtep.2016.04.007.

This is a PDF file of an unedited manuscript that has been accepted for publication. As a service to our customers we are providing this early version of the manuscript. The manuscript will undergo copyediting, typesetting, and review of the resulting proof before it is published in its final form. Please note that during the production process errors may be discovered which could affect the content, and all legal disclaimers that apply to the journal pertain.

I Sleep With My Mind's Eye Open:

Cognitive Arousal and Overgeneralization Underpin the Misperception of Sleep

Keisuke Takano, Yannick Boddez, and Filip Raes

University of Leuven

Author Note

Keisuke Takano, Yannick Boddez, and Filip Raes, Center for Learning and Experimental Psychopathology, University of Leuven, Belgium. Correspondence concerning this article should be addressed to Keisuke Takano, Center for Learning and Experimental Psychopathology, University of Leuven, Tiensestraat 102, Leuven 3000, Belgium. Phone: +32163 26001. Fax: +32163 26099. E-mail: Keisuke.Takano@ppw.kuleuven.be

Abstract

Background and Objectives: Misperception of sleep (e.g., underestimation of sleep time relative to objective measures) is a common feature of insomnia and other psychopathologies. To elucidate the mechanisms underlying this tendency, we examined the role of pre-sleep cognitive arousal and overgeneralization.

Methods: We monitored the sleep of 54 community dwellers (the majority being university students), using actigraphy and a sleep diary for 7 days. Immediately after this period, the participants provided an additional global evaluation of their sleep for the past week. In this global evaluation, participants were asked to estimate their average number of hours of sleep and the duration of time taken to fall asleep (sleep onset latency) across the past seven nights.

Results: Single-night misperceptions (difference between actigraphy and sleep diary estimations) of sleep time and sleep onset latency were significantly associated with pre-sleep cognitive arousal, but not with overgeneralization. In contrast, global misperception of sleep (difference between sleep diary and global estimations) were associated with overgeneralization, but not with cognitive arousal.

Limitations: Our sample mainly consisted of female university students, which limits the generalizability of the results.

Conclusions: Misperception of sleep occurs in two cases: (1) in the case of a single night due to excessive arousal, and (2) in the case of multiple nights due to overgeneralization.

Keywords: sleep perception, cognitive arousal, overgeneralization, actigraphy

I Sleep With My Mind's Eye Open:

Cognitive Arousal and Overgeneralization Underpin the Misperception of Sleep

1. Introduction

The misperception of sleep, namely, the tendency to perceive sleep as wakefulness without objective evidence of sleep disturbances, is a well-known phenomenon observed in individuals with insomnia (Harvey & Tang, 2012). It is operationally defined as an underestimation of total sleep time (TST) and overestimation of sleep onset latency (SOL, i.e., the duration of time taken to fall asleep) relative to the results of objective measures of sleep such as polysomnography (PSG; e.g., Carskadon et al., 1976; Frankel, Coursey, Buchbinder, & Snyder, 1976; Vanable, Aikens, Tadimeti, Caruana-Montaldo, & Mendelson, 2000) and methods such as actigraphy (e.g., Tang & Harvey, 2004a, 2004b; Wicklow & Espie, 2000). The misperception of sleep is argued to be common among people with insomnia as a primary and secondary symptom; for example, patients with depression (Rotenberg, Indursky, Kayumov, Sirota, & Melamed, 2000), post-traumatic stress disorder (Kobayashi, Huntley, Lavela, & Mellman, 2012), and chronic pain (Wilson, Watson, & Currie, 1998) tend to misperceive and exaggerate their sleep problems even when there is no indication of deficits in objectively measured sleep.

Cognitive models of insomnia have proposed that the misperception of sleep plays a central role in the development and persistence of sleep problems (e.g., Espie et al., 2007; Harvey, 2002). According to these theoretical accounts, the perception of insufficient sleep fuels anxious worry about sleeplessness and daytime dysfunctions, which, in combination with high levels of physiological arousal and emotional distress, directly interferes with getting sleep (Harvey, 2002). Furthermore, in order to avoid this sleep-related anxiety, people who believe that they suffer from a lack of sleep tend to engage in irrational “safety behaviors” and establish maladaptive sleep habits (e.g., staying longer in bed, drinking excessive alcohol,

and cancelling appointments to take a nap). Ironically, such attempts to get more sleep actually worsen the quality of their sleep, because they interfere with the normal sleep cycle and disrupt the biological body clock (Harvey, 2002; Morin, 2002). In addition, intervention studies have suggested that correcting the misperception of sleep reduces insomnia symptoms and anxiety about sleeplessness (Tang & Harvey, 2004a; Tang & Harvey, 2006). However, despite the potential importance of the misperception of sleep for our understanding of the development, maintenance, and treatment of sleep disorders, the underlying psychological mechanisms of the misperception of sleep are still largely unknown.

One possible factor that can influence the perception of sleep is cognitive arousal. Indeed, theories suggest that pre-sleep worry distorts the perception of how long it takes to fall asleep, because time tends to be perceived as longer under a high-arousal state (Borkovec, 1982; Harvey & Tang, 2012). Furthermore, it has been argued that excessive cognitive activity and hyperarousal of the central nervous system can blur the distinction between states of sleep and wakefulness, resulting in people even mistaking sleep for wakefulness (Bonnet & Arand, 1992; Perlis, Giles, Mendelson, Bootzin, & Wyatt, 1997; Perlis, Merica, Smith, & Giles, 2001). In line with these suggestions, a number of empirical studies have suggested that manifestations of negative cognitive arousal such as depressive rumination and anxious worry contribute to the perception of poor sleep (Nicassio, Mendlowitz, Fussell, & Petras, 1985; Takano, Iijima, & Tanno, 2012; Thielsch et al., 2015; Thomsen, Mehlsen, Christensen, & Zachariae, 2003), impaired objective sleep (Gross & Borkovec, 1981; Takano, Sakamoto, & Tanno, 2014), or both (Pillai, Steenburg, Ciesla, Roth, & Drake, 2014; Wicklow & Espie, 2000; Zoccola, Dickerson, & Lam, 2009). Other studies have directly examined the discrepancies between subjective and objective estimations of sleep by using PSG or actigraphy measurement and have suggested that worry contributes to the overestimation of SOL and underestimation of TST, relative to the corresponding estimates of objective sleep

measures (Tang & Harvey, 2004b; Tang, Schmidt, & Harvey, 2007; Vanable et al., 2000; Van Egeren, Haynes, Franzen, & Hamilton, 1983).

As has been previously stated, the misperception of sleep is often defined as the single-night discrepancy between objective and subjective estimations of sleep. However, this single-night discrepancy cannot capture the “total picture” regarding the misperception of sleep, because a sense of sleeplessness is often based on an overall evaluation of sleep across several days or weeks. Therefore, in the present study, we also investigated another type of sleep misperception, that is, the estimation bias that occurs when providing a global evaluation of sleep across multiple nights. Although the discrepancy between daily and global estimations of sleep has never been examined before, there is indeed evidence that suggests that such global estimations (often measured as habitual sleep) could be more biased than single-night estimations. Silva et al. (2007) examined sleep in a community sample by using the following three measures of sleep: (a) an objective measurement of sleep by using PSG, (b) a self-report of sleep taken on the morning after PSG administration, and (c) the retrospective recall of habitual sleep. They found that sleep duration in habitual sleep reports was overestimated relative to the sleep duration measured by PSG and the self-reported morning estimations of sleep (see also Biddle, Glozier, Robillard, Hermens, & Hickie, 2015; Lauderdale, Knutson, Yan, Liu, & Rathouz, 2008; Wolfson et al., 2003). The differences between the diary and retrospective reports (i.e., a sleep questionnaire measuring sleep obtained in the week prior to the maintenance of the sleep diary) have also been examined in individuals with insomnia. These individuals tend to underestimate TST and overestimate SOL in retrospective estimations relative to the average of sleep recorded in their sleep diary (Fichten et al., 2005).

It is of particular importance to identify factors that are related to these biased global estimations. First, the global estimation bias can contribute significantly to the vicious cycle

of sleep-related anxiety and irrational behaviors that exacerbate sleep problems. In this regard, these global estimations might be even more crucial than single-night misperceptions, because they tap the long-term negative evaluation of sleep quality. Second, asking respondents to globally evaluate the sleep they have had over the past weeks is a common assessment style in self-report questionnaires such as the Pittsburgh Sleep Quality Index (Buysse, Reynolds, Monk, Berman, & Kupfer, 1989) and Insomnia Severity Index (Bastien, Vallières, & Morin, 2001). Given the wide usage of these questionnaires, it is essential to reveal the factors that might bias the responses to certain items.

In the present study, we investigated whether negative overgeneralization contributes to the global misperception of sleep. When judging the overall quality of sleep, respondents typically aggregate their perceived sleep across multiple nights to provide a single global score such as an “average” sleep time. This aggregation process could be a source of bias. Negative overgeneralization has mainly been studied in relation to depression, in which a single negative experience or failure is generalized across multiple dimensions, occasions, aspects of the self, or even to a global sense of self-inadequacy (Carver, 1998; Carver, Lavoie, Kuhl, & Ganellen, 1988). Because generalized mental representations do not incorporate specific contextual details, people with a tendency to overgeneralize are more likely to feel that they always fail at everything rather than to focus on context-specific difficulties or particularities (Watkins, 2008). We hypothesized that a similar process might occur in retrospective global evaluations of sleep: Individuals with this vulnerability may unjustifiably generalize their experience of a single or few (bad) nights of perceived insufficient sleep and thereby claim that they have had a whole series of bad nights (“I slept badly this entire week”).

Taken together, the misperception of sleep can occur (a) in the case of a biased estimation of sleep parameters for a single night and/or (b) in the case of a biased global

estimation of sleep parameters for multiple nights. To assess the bias in these two cases, we used actigraphy to measure sleep across seven consecutive days to obtain objective sleep measures, and a sleep diary to measure day-to-day perceptions of sleep. At the end of the sleep monitoring, we also asked the participants to provide an overall evaluation of the sleep they had had in the past seven days in order to obtain retrospective global estimations of sleep (i.e., average TST and SOL). Based on these sleep measures, we defined single-night misperception of sleep as the difference between objective (i.e., actigraphy) and subjective (i.e., sleep-diary) estimations in terms of single-night TST and SOL. We also assessed the global misperception of sleep, which was defined as the difference between sleep diary estimations and the retrospective global estimations of TST and SOL. We examined the relation between these two discrepancies, on the one hand, and pre-sleep cognitive arousal and negative overgeneralization, on the other hand. Our specific hypotheses were that (a) the single-night misperception (discrepancy between actigraphy estimations and sleep diary estimations) would be uniquely associated with increased pre-sleep cognitive arousal, and (b) the global misperception (discrepancy between sleep diary estimations and global estimations) would be specifically explained by the tendency to overgeneralize.

2. Method

2.1. Participants

We recruited 60 individuals (7 males and 53 females) from a large sample pool comprising community dwellers and students from the University of Leuven. Participants received a monetary reward (25 euros) at the end of the study. We excluded the data of 6 participants for the following reasons: 2 of the participants did not complete the one-week sleep monitoring; 1 participant did not wear the actigraph for three nights; and for 3 participants, there were large differences between their in-bed and out-bed times as measured by actigraphy and their in-bed and out-bed times as recorded in their sleep diary (>1 hour),

casting doubt on the reliability of their sleep diary reports. Although two participants reported they were taking medication that could influence their sleep (methylphenidate and escitalopram) in the briefing session, we did not exclude their data from the analysis (however, results did not change when doing so). The final sample consisted of 54 participants (7 males and 47 females) with a mean age of 21.8 ($SD = 3.7$) years.

2.2. Measures

2.2.1. Beck Depression Inventory II (BDI-II; Beck, Steer, & Brown, 1996). We assessed the participants' current levels of depressive symptoms using the Dutch version of the Beck Depression Inventory II (van der Does, 2002). The BDI-II is a self-report measure consisting of 21 items describing typical depressive symptoms. Each item was rated on a scale ranging from 0 to 3. The BDI-II showed good internal consistency for the current data ($\alpha = .88$).

2.2.2. Attitudes Toward Self (ATS; Carver, La Voie, Kuhl, & Ganellen, 1988). We assessed the tendency to engage in negative overgeneralization, using the Dutch version of the ATS generalization subscale. This scale consists of seven items describing the tendency to generalize the experience of a single failure to all or many life's experiences, which reduces the person's broader sense of self-worth (e.g., "A single failure can change me from feeling OK to seeing only the bad in myself"; Carver, 1998). Each item was rated on a 5-point scale ranging from (1) *I disagree very strongly* to (5) *I agree very strongly*. The ATS generalization subscale showed good internal consistency for the current data ($\alpha = .86$).

2.2.3. Pittsburgh Sleep Quality Index (PSQI; Buysse et al., 1989). We measured participants' subjective sleep quality for the past month using a Dutch version of the PSQI. The PSQI consists of 19 items that are divided into seven subcomponents of sleep disturbance (i.e., sleep duration, sleep disturbances, sleep latency, daytime dysfunction, sleep efficiency, sleep quality, and medication). Each subcomponent is scored on a scale ranging

from 0 to 3, and the aggregation of the seven scores is used as the global index of subjective sleep quality. The internal consistency of this tool was .75. Using a cut-off score of 5, we identified 26 participants from our sample as having relatively severe sleep problems.

2.2.4. Sleep diary. We asked participants to keep a sleep diary for seven consecutive days. They were asked to record their sleep pattern from the previous night upon waking up every morning. In the diary, participants recorded their (a) in-bed and out-of-bed times; (b) SOL; (c) TST (the total number of hours they slept). We exclusively focused on SOL and TST and not on wake time after sleep onset (WASO) because our sample consisted mainly of university students. It is known that SOL does not vary across different age groups, whereas WASO becomes a more prevalent and typical sleep complaint in older populations (Ohayon, Carskadon, Guilleminault, & Vitiello, 2004).

2.2.5. Pre-sleep Arousal Scale (PSAS; Nicassio et al., 1985). We measured participants' levels of pre-sleep cognitive and somatic arousal, using an adapted version of the PSAS. The instructions and items were modified such that they measured the arousal levels of the "previous night," as opposed to the "general" arousal levels, which is what the original version of the PSAS measures. The PSAS consists of 16 items: eight items measure cognitive arousal (e.g., "Worry about falling asleep") and the other eight items measure somatic arousal (e.g., "Heart racing, pounding, or beating irregularly"). Each item was rated on a 5-point scale ranging from (1) *not at all* to (5) *extremely*. The internal consistency of the PSAS was .83 for the cognitive arousal subscale and .81 for the somatic arousal subscale. The PSAS was bundled with the sleep diary.

2.2.6. Actigraphy. We used an actigraph (wGT3X-BT; ActiGraph, Pensacola, FL) to estimate the objective TST and SOL scores. The wGT3X-BT is a wristwatch-like device containing a sensor to detect the three-dimensional acceleration of limb movements. Physical activity was monitored with a sampling rate of 30 Hz and recorded in 1-minute epochs. An

actigraph was attached to the participants' non-dominant wrist, and they were asked to keep it on for 24 hours, for seven consecutive days. We determined participants' sleep-wake intervals, using software (Actiware 6.11.8; ActiGraph) with the Cole-Kripke algorithm (Cole, Kripke, Gruen, Mullaney, & Gillin, 1992). A previous study comparing the GT3X+ (an old model of the wGT3X-BT) with PSG and another actigraph device has confirmed the validity and reliability of the GT3X+ for estimating sleep-wake patterns (Cellini, Buman, McDevitt, Ricker, & Mednick, 2013). In general, actigraphy shows good consistency with PSG for discriminating sleep and wake epochs (over 90% minute-by-minute agreement rates in healthy adults; for a review, see Ancoli-Israel, Cole, Alessi, Chambers, Moorcroft, & Pollak, 2003) and for estimating SOL and TST ($r_s > .70$; Cole et al., 1992). However, it should be acknowledged as a limitation that actigraphy sometimes misidentifies quiet wakefulness as sleep (Kushida, Chang, Gadkary, Guilleminault, Carrillo, & Dement, 2001) and sleep motor activity as being awake (Short, Gradisar, Lack, Wright, & Carskadon, 2012). The specificity of actigraphy in detecting wakefulness during sleeping hours can be particularly low for individuals with disturbed sleep who tend to lie in bed for long periods of time without body movement (Kushida et al., 2001).

2.2.7. Retrospective global estimations of sleep (follow-up sleep assessment).

After we monitored participants' sleep for one week, they were asked to report the quality of sleep they had had over the past week. Participants responded by providing an average estimation of TST (i.e., "During the past week, how many hours of actual sleep did you get per night"?), SOL (i.e., "During the past week, how long has it typically taken you to fall asleep each night"?). We adapted these items from the PSQI items for TST and SOL. The global estimation of WASO was calculated by multiplying the times and duration.

2.3. Procedure

We invited participants to an individual briefing session during which they were informed about the study protocols. During this session, participants also provided written informed consent and completed the baseline questionnaires, which included the BDI-II, ATS, and PSQI. From the day of the briefing session, participants wore an actigraph and maintained a sleep diary for seven consecutive days. They were prompted to fill in the diary every morning upon waking up¹. After this seven-day sleep monitoring, we invited participants to the laboratory again, and completed the follow-up sleep assessment. On average, they maintained the sleep diary for 6.7 nights ($SD = 0.8$). The study protocols were approved by the Social and Societal Ethics Committee and by the Medical Ethics Committee of the University of Leuven.

2.4. Statistical Analysis

For the sleep parameters TST and SOL, we defined two bias scores by calculating the differences between the actigraphy and sleep diary estimations (i.e., single-night misperception) and the differences between the sleep diary and global estimations (i.e., global misperception). Before calculating these scores, we calculated the average of the parameters that were measured daily across seven days for all participants. A positive single-night misperception score indicated overestimation in the sleep diary relative to the actigraphy estimations. Similarly, a positive global misperception score indicated overestimation in the global report of sleep had across seven nights relative to the average sleep estimations recorded in the sleep diary.

To analyze the results, we used multiple regression analysis. We estimated regression models, in which a bias score was predicted by arousal and overgeneralization. In the regression models, we controlled for gender differences and depressive symptoms as these two covariates are known to influence general time estimation abilities (e.g., Block, Hancock,

¹ Responses made after 5 pm were excluded, because they were considered as unreliable. Following this criterion, in total four diary entries were excluded from the analyses.

& Zakay, 2000; Msetfi, Murphy, & Kornbrot, 2012). Under the assumption of $\alpha = 0.05$, $\beta = 0.80$, and four predictors of multiple regression, power analysis by G*power (Faul, Erdfelder, Buchner, & Lang, 2009) indicated a sample size of $N = 22\text{--}55$ to be sufficient to detect a moderate-to-strong effect ($f^2 = .15\text{--}.35$) for a single regression coefficient.

3. Results

3.1. Descriptive statistics

The descriptive statistics and correlations are shown in Table 1. On average, participants had 7.5–7.6 hours of TST per night ($SD = 0.9\text{--}1.3$ hours; range = 4.0–11.0 hours) for the actigraphy, sleep diary, and global estimations. There were no significant differences among the TST estimations obtained by the three measurement methods, $F(1.3, 68.0) = 1.33$, $p = .26$. The means for SOL were 11.4–28.0 min ($SD = 8.0\text{--}24.5$ min; range = 0–120 min) for the three measurement methods; one-third to half of the participants reported mild-to-severe onset difficulties (> 15 min; Buysse et al., 1989). The actigraphy SOL estimation was shorter than the sleep diary SOL estimation, $t(53) = 5.95$, $p < .001$, $d_z = 0.81$ (Bonferroni-corrected alpha = .017) and than the retrospective global SOL estimation, $t(52) = 3.79$, $p = .000$, $d_z = 0.52$. In addition, the diary SOL estimation was longer than the global SOL estimation, $t(52) = 2.61$, $p = .011$, $d_z = 0.36$. The sleep estimations obtained by the three measurement methods were moderately to highly correlated with each other for TST and SOL.

The results of all the three measurement methods revealed that cognitive arousal was associated with increased SOL. This was not so for TST, with the only exception that cognitive arousal was associated with decreased TST for the results of the global estimation. Overgeneralization was not correlated with any of the sleep parameters except for TST as estimated by actigraphy, which suggests that individuals with a greater tendency to overgeneralize have a longer sleeping time.

3.2. Misperception of TST

Correlational analysis including all participants showed that the single-night misperception of TST (i.e., the difference between the actigraphy and sleep diary estimations) was negatively correlated with pre-sleep cognitive arousal (Figure 1, Panel A; $r = .57$), but not with overgeneralization (Figure 1, Panel B; $r = -.22$). However, the global misperception of TST (i.e., the difference between sleep diary and global estimations) was significantly correlated with overgeneralization, but not with cognitive arousal (Figure 1, Panels C and D; $r = -.21$ and $-.45$, respectively).

In order to examine the unique effects of cognitive arousal and overgeneralization on the misperception of TST, we estimated regression models in which the single-night or global misperception was predicted by cognitive arousal and overgeneralization. The results (Table 2) extend the findings of the correlational analyses, revealing significant unique associations between single-night misperception and cognitive arousal, and between global misperception and overgeneralization. In line with our hypotheses, these results imply that the underestimation of TST for a single night is uniquely associated with increased pre-sleep cognitive arousal, whereas the underestimation of TST across multiple nights is specifically associated with negative overgeneralization.

3.3. Misperception of SOL

Similarly, we examined the association between biases in SOL estimations, on the one hand, and cognitive arousal and overgeneralization, on the other hand. Correlational analyses on all participants showed that single-night misperception was significantly associated with pre-sleep cognitive arousal, but not with overgeneralization (Figure 2, Panels A and B; $r = .56$ and $-.18$, respectively). Global misperception was correlated with neither cognitive arousal nor overgeneralization (Figure 2, Panels C and D; $r = .14$ and $.14$).

Multiple regression analyses showed a significant unique effect of cognitive arousal on single-night misperception (Table 2). Furthermore, the analyses revealed a significant

effect of overgeneralization on global misperception after controlling for depressive symptoms. This significant effect (despite the null correlation) could be a result of suppression effects (e.g., MacKinnon, Krull, & Lockwood, 2000) due to the moderate correlation between depressive symptoms and overgeneralization (Table 1). A previous study has suggested the possibility that individuals with depressive symptoms can estimate time intervals more accurately than those without such symptoms (depressive realism; e.g., Kornbrot, Msetfi, & Grimwood, 2013). However, the tendency to overgeneralize, which characterizes most individuals with depressive symptoms, is specifically associated with a biased (or over) estimation of SOL.

3.4. Pre-sleep Somatic Arousal and Misperceptions of Sleep

We repeated the same multiple regression analyses for pre-sleep somatic arousal. The results showed that in the case of TST estimations, somatic arousal predicted neither single-night, $\beta = -.18$, $t = 1.30$, $p = .20$ nor global misperceptions, $\beta = -.13$, $t = 0.97$, $p = .34$. In the case of SOL estimations, somatic arousal was significantly associated only with single-night misperception, $\beta = .48$, $t = 3.75$, $p = .00$, and not with global misperception, $\beta = .04$, $t = 0.27$, $p = .79$. These results suggest that unlike cognitive arousal, somatic arousal is associated with a single-night discrepancy in the case of SOL, but not in the case of TST.

3.5. Subgroup analysis

Subgroup analysis showed that individuals with higher levels of insomnia symptoms (those scoring > 5 on the PSQI) had a significant correlation between cognitive arousal and single-night misperception, whereas those with lower levels of insomnia symptoms had no such correlation (Table 2). On the other hand, overgeneralization was significantly correlated with single-night misperception of SOL and global misperception of TST only for the low-insomnia group. These results might suggest that the associations between misperception of sleep and cognitive arousal/overgeneralization vary across different levels of insomnia

symptoms. However, it should be noted that the distributions of cognitive arousal and overgeneralization were very different for the high- vs. low-insomnia groups. These two variables, cognitive arousal and overgeneralization, were moderately-to-highly correlated with the PSQI (Table 1), which critically limited the ranges of cognitive arousal and overgeneralization within each group (e.g., 90% of participants in the low-insomnia group had lower cognitive arousal scores than the overall average). Given these biased distributions, the results of the subgroup analysis need to be interpreted with caution and only regarded as preliminary evidence.

4. Discussion

In the present study, we examined the psychological factors that are relevant to the misperception of sleep. Upon monitoring participants' sleep for one week, we found that the discrepancy between actigraphy and sleep diary estimations was uniquely associated with pre-sleep cognitive arousal, whereas the discrepancy between sleep diary and retrospective global estimations was specifically associated with negative overgeneralization.

Our data suggest that individuals who experience higher levels of pre-sleep cognitive arousal tend to estimate TST as shorter and SOL as longer than the objective estimations obtained by actigraphy. These results are consistent with previous findings that negative cognitions are positively correlated with the increased discrepancy between PSG and self-reports of sleep (Vanable et al., 2000; Van Egeren et al., 1983) and with a nap study revealing that the experimental induction of worry contributes to an underestimation of TST and an overestimation of SOL (Tang & Harvey, 2004b). Given that stressor-specific negative thinking is associated with impaired subjective sleep quality (Zoccola et al., 2009), stressful events might be a trigger for cognitive arousal, which in turn influences the perception of sleep. An important way in which the current study extends these earlier findings is that our data were collected in a naturalistic setting wherein the participants continued living their

regular daily lives (cf. Tang et al., 2007). Because sleep at a laboratory is often affected by the unfamiliar environment (e.g., the “first-night effect”; e.g., Ancoli-Israel et al., 2003), the present study provides ecological validity for the relationship between cognitive arousal and the misperception of sleep.

It is important to note that not just sleep diary estimations but also the actigraphy estimations revealed that pre-sleep cognitive arousal was significantly correlated with increased SOL. Manconi et al. (2010) discussed that estimating sleeping hours may be more difficult for poorer sleepers, because such individuals tend to have sleep characterized by more night-to-night variability. This argument may be partly applicable to our data, wherein a more variable SOL (defined as a standard deviation across seven days) was associated with a longer mean SOL, $r = -.84$, although this was not the case for TST, $r = .12$. However, this viewpoint seems to be insufficient because it fails to explain why in the case of SOL, the estimation error is almost invariably in the direction of overestimation (and not underestimation; cf. Manconi et al., 2010).

A possible explanation for the link between cognitive arousal and misperception of sleep is that arousal disrupts the internal biological pacemaker used to perceive duration of time. It is well documented that increased arousal leads the biological pacemaker to emit more pulses in a given time unit (e.g., Zakay & Block, 1997; Droit-Volet & Meck, 2007). Because this pulse emission controls the perceived duration of prospective time² (if the frequency of the pulse emission increases, subjective time passes faster than does real time), high levels of arousal can contribute to the overestimation of time. Although arousal is not the

² Prospective and retrospective timing have been distinguished to explain the difference between the experience of passing time and the sense of temporal duration in hindsight (MacDonald, 2014). In prospective timing, participants are aware that a duration judgment is necessary before the onset of the duration. Prospective timing might be relevant for a sleep diary, in which participants are explicitly instructed beforehand that they will need to estimate their sleep times. On the other hand, in retrospective timing, participants are unaware of the importance of a duration judgment, and they are suddenly asked to estimate the duration of time after the end of the duration. Retrospective timing, which is mainly influenced by long-term memory about event sequences (MacDonald, 2014), might be involved in a one-shot sleep questionnaire that asks participants to report their past sleep status.

sole factor that influences human time perception (e.g., Block, Hancock, & Zakay, 2010), this account appears to readily explain the association between arousal and distorted SOL estimations.

Because assessment of subjective sleep quality largely depends on participants' temporal duration judgment, a number of studies have looked at time-estimation ability in the context of sleep and insomnia. In fact, those studies have failed to find evidence that people with insomnia have a decrement in general time-estimation ability, using various experimental designs such as finger tapping, verbal estimation, and time production (Fichten et al., 2005; Rioux, Tremblay, & Bastien, 2006; Tang & Harvey, 2005). Therefore, it would be reasonable to assume that misperception of sleep in insomnia is a context-specific phenomenon (not a dispositional factor) that would occur specifically under high-arousing conditions. Researchers have argued that patients with insomnia tend to experience increasing levels of arousal as bedtime approaches, because those individuals often have a fear of sleeplessness (Rioux et al 2006; Tang & Harvey, 2005). Thus, inaccurate time estimation might become more evident at the time of sleep onset.

As hypothesized, the discrepancies between daily and global sleep estimations were associated with the tendency to overgeneralize negative experiences. These results suggest that (negative) overgeneralization, wherein a person generalizes the experience of a single negative event or failure to many or all experiences/performances in other areas of his/her life, thereby perceiving a low global or overall sense of personal inadequacy (e.g., Carver et al., 1988), is associated with a bias wherein the person perceives having had insufficient sleep on a single or few nights as having had hardly any nights or no nights of adequate sleep. Because retrospective global estimations of sleep were highly correlated with diary report estimations of sleep, it is plausible that the participants estimated the average (or global) sleep time across seven days on the basis of day-to-day perceptions of sleep. Interestingly, however, there seem

to be individual differences in the way that perceived sleep is aggregated; people with a tendency to overgeneralize negative experiences or evaluations seem to overestimate the bad nights and underestimate the good nights. A finding of particular importance is that our analyses revealed null effects of cognitive and somatic arousal on the global misperception of sleep. Therefore, the bias in the retrospective and global evaluation of sleep appears to be independent of the arousal systems. Even though people were able to report their sleep accurately in their sleep diary, it is still possible that their global estimations of sleep are biased. Because self-report questionnaires such as the PSQI rely on the participants' global ratings, the influence of overgeneralization should be borne in mind when administering such sleep questionnaires.

The results of the subgroup analysis showed significant associations between cognitive arousal and single-night misperception of SOL and TST, but only for individuals with higher levels of insomnia symptoms. Although it is tempting to conclude that cognitive arousal is particularly influential for individuals with insomnia symptoms, these results can be mainly attributed to the unequal distribution of cognitive arousal due to splitting the sample into the low- and high-insomnia groups. The low-insomnia group did not have enough participants with high levels of cognitive arousal, which limited the variability of cognitive arousal and the chance of detecting a significant correlation. Overgeneralization, in turn, had significant correlations with misperception of sleep only for the low-insomnia group. This is an unexpected result, but here also the distribution of overgeneralization was very different for the low- and high-insomnia groups, thus preventing us from drawing strong conclusions about this. Future research needs to investigate the group differences in the associations between misperception of sleep and arousal/overgeneralization in a larger sample to alleviate the distribution biases.

Our study has several limitations, which should be kept in mind when interpreting the findings. First, keeping a sleep diary might have enhanced the accuracy of the retrospective global estimations of sleep in the follow-up assessment. However, it is critical to note that regardless of this possible influence, individuals with the tendency to engage in negative overgeneralization still exhibited biased estimations in their global estimations of sleep. Second, we cannot determine the causal directions between the sleep estimation biases on the one hand, and cognitive arousal and negative overgeneralization on the other hand. It is, for example, still possible that when people perceive that they have had poor sleep, they believe that they were experiencing excessive worry and emotional distress at night, because subjective time progression can influence the hedonic evaluation of an experience (e.g., when time passed faster, the experience must have been more enjoyable; Sackett, Meyvis, Nelson, Converse, & Sackett, 2010). To verify the direction of causality, future research involving the use of a prospective/longitudinal design or experimental methods to manipulate cognitive arousal (e.g., Morin, 2002) and the tendency to overgeneralize (e.g., Raes, Williams, & Hermans, 2009) could be conducted. Third, our sleep-monitoring period (i.e., one week) might be too short to capture clinical levels of sleep problems, given that the diagnostic criteria for sleep disorders specify duration of symptoms lasting at least two weeks (American Academy of Sleep Medicine, 2005). Further research using longer sleep-monitoring periods is needed to allow a more reliable assessment of individual sleep patterns. Fourth, our sample mainly consisted of female university students, which limits the generalizability of the results. It is also noteworthy that approximately half of our sample reported moderate-to-severe sleep problems on the PSQI. Previous studies have already suggested that there is a relatively high prevalence of sleep problems among students compared to other age groups (e.g., Brown, Buboltz, & Soper, 2002). Although we believe that investigating such vulnerable individuals contributes to the face validity of our findings

in the context of sleep problems, replication is warranted with other populations and other age groups. Fifth, we did not control for the usage of alcohol and caffeine, which could influence perception of sleep as well as physiological sleep per se (e.g., Tang & Harvey 2004). Although collecting data about alcohol and caffeine consumption in daily life requires high compliance from participants, it is nonetheless necessary for future studies to test (and control for) the links between (excessive) consumption of arousing substances and misperception of sleep.

In conclusion, this is the first study that provides evidence that the misperception of sleep occurs in two different cases: (a) in the case of estimations for a single night, which is uniquely associated with excessive arousal, and (b) in the case of estimations across multiple nights, which is uniquely linked to the tendency to overgeneralize. It would be interesting if future research examined the misperception of sleep in these two cases in patients with insomnia, as this could provide a complete picture of the mechanisms underlying pathological sleep state misperception.

Acknowledgments

The authors would like to thank Robin Peeters and Els Simillion for their assistance in data collection.

Declaration of interest

The authors declare that there are no conflicts of interest.

Role of Funding Organizations

Keisuke Takano is supported by the Postdoctoral Fellowship for Research Abroad, granted by the Japan Society for the Promotion of Science. Yannick Boddez and Filip Raes are supported by KU Leuven Research Council grant PF/10/005. Yannick Boddez receives additional support from an Interuniversity Attraction Poles grant from the Belgian Science Policy Office (P7/33).

References

- American Academy of Sleep Medicine. (2005). *International Classification of Sleep Disorders: Diagnostic and coding manual (2nd ed.)*. Westchester, IL: Author.
- Ancoli-Israel, S., Cole, R., Alessi, C., Chambers, M., Moorcroft, W., & Pollak, C. P. (2003). The role of actigraphy in the study of sleep and circadian rhythms. *Sleep*, 26, 342–392.
- Bastien, C. H., Vallières, A., & Morin, C. M. (2001). Validation of the Insomnia Severity Index as an outcome measure for insomnia research. *Sleep Medicine*, 2, 297–307. doi:10.1016/S1389-9457(00)00065-4
- Beck, A. T., Steer, R. A., & Brown, G. K. (1996). *Beck Depression Inventory* (2nd ed.). San Antonio, TX: The Psychological Corporation.
- Biddle, D. J., Glozier, N., Robillard, R., Hermens, D. F., & Hickie, I. B. (2015). Accuracy of self-reported sleep parameters compared with actigraphy in young people with mental ill-health. *Sleep Health*. Advance online publication. doi:10.1016/j.sleh.2015.07.006
- Block, R. A., Hancock, P. A. and Zakay, D. (2000). Sex Differences in Duration Judgments: A Meta-analytic Review. *Memory and Cognition*, 28, 1333–1346. doi: 10.3758/BF03211834
- Block, R. A., Hancock, P. A., & Zakay, D. (2010). How cognitive load affects duration judgments: A meta-analytic review. *Acta Psychologica*, 134, 330–343. doi:10.1016/j.actpsy.2010.03.006
- Bonnet, M. H., & Arand, D. L. (1992). Caffeine use as a model of acute and chronic insomnia. *Sleep*, 15, 526–536.
- Borkovec, T. D. (1982). Insomnia. *Journal of Consulting and Clinical Psychology*, 50, 880–895. doi:10.1037/0022-006X.50.6.880
- Brown, F. C., Buboltz, W. C., & Soper, B. (2002). Relationship of sleep hygiene awareness, sleep hygiene practices, and sleep quality in university students. *Behavioral Medicine*, 28, 33–38. doi: 10.1080/08964280209596396

- Buysse, D. J., Reynolds, C. F. 3rd, Monk, T. H., Berman, S. R., Kupfer, D. J. (1989). The Pittsburgh Sleep Quality Index: A new instrument for psychiatric practice and research. *Psychiatry Research*, 28, 193–213. doi:10.1016/0165-1781(89)90047-4
- Carskadon, M. A., Dement, W. C., Mitler, M. M., Guilleminault, C., Zarcone, V. P., & Spiegel, R. (1976). Self-reports versus sleep laboratory findings in 122 drug-free subjects with complaints of chronic insomnia. *American Journal of Psychiatry*, 133, 1382–1388.
- Carver, C. S. (1998). Generalization, adverse events, and development of depressive symptoms. *Journal of Personality*, 66, 609-620. doi: 10.1111/1467-6494.00026
- Carver, C. S., La Voie, L., Kuhl, J., & Ganellen, R. J. (1988). Cognitive concomitants of depression: A further examination of the roles of generalization, high standards, and self-criticism. *Journal of Social and Clinical Psychology*, 7, 350-365. doi: 10.1521/jscp.1988.7.4.350
- Cellini, N., Buman, M. P., McDevitt, E. A., Ricker, A. A., & Mednick, S. C. (2013). Direct comparison of two actigraphy devices with polysomnographically recorded naps in healthy young adults. *Chronobiology International*, 30, 691-698. doi: 10.3109/07420528.2013.782312
- Cole, R. J., Kripke, D. F., Gruen, W., Mullaney, D.J., & Gillin, J. C. (1992). Automatic sleep/wake identification from wrist activity. *Sleep*, 15, 461-469.
- Droit-Volet, S., & Meck, W. H. (2007). How emotions colour our perception of time. *Trends in Cognitive Sciences*, 11, 504-513. doi:10.1016/j.tics.2007.09.008
- Espie, C. A., Broomfield, N. M., MacMahon, K. M., Macphee, L. M., & Taylor, L. M. (2006). The attention-intention-effort pathway in the development of psychophysiologic insomnia: a theoretical review. *Sleep Medicine Review*, 10, 215-245. doi:10.1016/j.smrv.2006.03.002

- Faul, F., Erdfelder, E., Buchner, A., & Lang, A. G. (2009). Statistical power analyses using G*Power 3.1: Tests for correlation and regression analyses. *Behavior Research Methods*, 41, 1149–1160. doi: 10.3758/BRM.41.4.1149.
- Fichten, C. S., Creti, L., Amsel, R., Bailes, S., & Libman, E. (2005). Time estimation in good and poor sleepers. *Journal of Behavioral Medicine*, 28, 537-553. ooi: 10.1007/s10865-005-9021-8
- Frankel, B. L., Coursey, R. D., Buchbinder, R., & Snyder, F. (1976). Recorded and reported sleep in chronic primary insomnia. *Archives General Psychiatry*, 33, 615-623. doi:10.1001/archpsyc.1976.01770050067011
- Gross, R. T., & Borkovec, T. D. (1981). Effects of a cognitive intrusion manipulation on the sleep-onset latency of good sleepers. *Behavior Therapy*, 13, 112-116. doi:10.1016/S0005-7894(82)80054-3
- Harvey, A. G. (2002). A cognitive model of insomnia. *Behaviour Research and Therapy*, 40, 869-893.
- Harvey, A. G., & Tang, N. K. (2012). (Mis)perception of sleep in insomnia: A puzzle and a resolution. *Psychological Bulletin*, 138, 77-101. doi: 10.1037/a0025730
- Kobayashi, I., Huntley, E., Lavela, J., Mellman, T. (2012). Subjectively and objectively measured sleep with and without posttraumatic stress disorder and trauma exposure. *Sleep*, 35, 957-965.
- Kornbrot, D. E., Msetfi, R. M., & Grimwood, M. J. (2013). Time perception and depressive realism: Judgment type, psychophysical functions and bias. *PLoS One*, 8, e71585. doi: 10.1371/journal.pone.0071585
- Kushida, C. A., Chang, A., Gadkary, C., Guilleminault, C., Carrillo, O., Dement, W. C. (2001). Comparison of actigraphic, polysomnographic, and subjective assessment of sleep

parameters in sleep-disordered patients. *Sleep Medicine*, 2, 389-396. doi:

[http://dx.doi.org/10.1016/S1389-9457\(00\)00098-8](http://dx.doi.org/10.1016/S1389-9457(00)00098-8)

MacDonald, C. J. (2012). Prospective and retrospective duration memory in the hippocampus: is time in the foreground or background? *Philosophical Transactions of the Royal Society B Biological Science*, 369, 20140018. doi: 10.1098/rstb.2012.0463

MacKinnon, D. P., Krull, J. L., & Lockwood, C. M. (2000). Equivalence of the mediation, confounding and suppression effect. *Prevention Science*, 1, 173-181. doi: 10.1023/A:1026595011371

Manconi, M., Ferri, R., Sagrada, C., Punjabi, N. M., Tettamanzi, E., Zucconi, M., . . .

Ferini-Stambi, L. (2010). Measuring the error in sleep estimation in normal subjects and in patients with insomnia. *Journal of Sleep Research*, 19, 478-486. doi: 10.1111/j.1365-2869.2009.00801.x.

Mezick, E. J., Wing, R. R., & McCaffery, J.M. (2014). Associations of self-reported and actigraphy-assessed sleep characteristics with body mass index and waist circumference in adults: Moderation by gender. *Sleep Medicine*, 15, 64-70. doi:10.1016/j.sleep.2013.08.784

Morin, C. M. (2002). Contributions of cognitive-behavioral approaches to the clinical management of insomnia. *Journal of Clinical Psychiatry*, 4, 21-26.

Msetfi, R. M., Murphy, R. A., & Kornbrot, D. E. (2012). The effect of mild depression on time discrimination. *The Quarterly Journal of Experimental Psychology*, 65, 632-645. doi: 10.1080/17470218.2011.608908

Nicassio, P. M., Mendlowitz, D. R., Fussell, J. J., & Petras, L. (1985). The phenomenology of the pre-sleep state: The development of the pre-sleep arousal scale. *Behaviour Research and Therapy*, 23, 263-271. doi:10.1016/0005-7967(85)90004-X

- Ohayon, M. M., Carskadon, M. A., Guilleminault, C., & Vitiello, M. V. (2004). Meta-analysis of quantitative sleep parameters from childhood to old age in healthy individuals: developing normative sleep values across the human lifespan. *Sleep*, 27, 1255-1273.
- Perlis, M. L., Giles, D. E., Mendelson, W. B., Bootzin, R. R., Wyatt, J. K. (1997). Psychophysiological insomnia: The behavioural model and a neurocognitive perspective. *Journal of Sleep Research*, 6, 179-188. doi: 10.1046/j.1365-2869.1997.00045.x
- Perlis, M. L., Merica, H., Smith, M. T., & Giles, D. E. (2001). Beta EEG activity and insomnia. *Sleep Medicine Reviews*, 5, 365–376. doi: 10.1053/smr.2001.0151
- Pillai, V., Steenburg, L. A., Ciesla, J. A., Roth, T., & Drake, C. L. (2014). A seven day actigraphy-based study of rumination and sleep disturbance among young adults with depressive symptoms. *Journal of Psychosomatic Research*, 77, 70-75. doi: 10.1016/j.jpsychores.2014.05.004.
- Rioux, I., Tremblay, S., & Bastien, C. H. (2006). Time estimation in chronic insomnia sufferers. *Sleep*, 29, 486-493.
- Rotenberg, V. S., Indursky, P., Kayumov, L., Sirota, P., & Melamed, Y. (2000). The relationship between subjective sleep estimation and objective sleep variables in depressed patients. *International Journal of Psychophysiology*, 37, 291–297. doi:10.1016/S0167-8760(00)00110-0
- Raes, F., Williams, J. M., & Hermans, D. (2009). Reducing cognitive vulnerability to depression: A preliminary investigation of Memory Specificity Training (MEST) in inpatients with depressive symptomatology. *Journal of Behavior Therapy and Experimental Psychiatry*, 40, 24-38. doi: 10.1016/j.jbtep.2008.03.001
- Sackett, A. M., Meyvis, T., Nelson, L. D., Converse, B. A., & Sackett, A. L. (2010). You're having fun when time flies: The hedonic consequences of subjective time progression. *Psychological Science*, 21, 111-117. doi: 10.1177/0956797609354832

- Short, M. A., Gradisar, M., Lack, L. C., Wright, H., & Carskadon, M. A. (2012). The discrepancy between actigraphic and sleep diary measures of sleep in adolescents. *Sleep Medicine*, 13, 378-84. doi: 10.1016/j.sleep.2011.11.005.
- Silva, G. E., Goodwin, J. L., Sherrill, D. L., Arnold, J. L., Bootzin, R. R., Smith, T., ... Quan, S. F. (2007). Relationship between reported and measured sleep times: The sleep heart health study (SHHS). *Journal of Clinical Sleep Medicine*, 2007, 3, 622-630.
- Takano, K., Iijima, Y., & Tanno, Y. (2012). Repetitive thought and self-reported sleep disturbance. *Behavior Therapy*, 43, 779-789. doi: 10.1016/j.beth.2012.04.002
- Takano, K., Sakamoto, S., & Tanno, Y. (2014). Repetitive thought impairs sleep quality: An experience sampling study. *Behavior Therapy*, 45, 67-82. doi: 10.1016/j.beth.2013.09.004
- Tang, N. K. Y., & Harvey, A. G. (2004a). Correcting distorted perception of sleep in insomnia: A novel behavioural experiment? *Behaviour Research and Therapy*, 42, 27-39.
- Tang, N. K. Y., & Harvey, A. G. (2004b). Effects of cognitive arousal and physiological arousal on sleep perception. *Sleep*, 27, 69-78.
- Tang, N. K. Y., & Harvey, A. G. (2006). Altering misperception of sleep in insomnia: Behavioral experiment versus verbal feedback. *Journal of Consulting and Clinical Psychology*, 74, 767-776. doi:10.1037/0022-006X.74.4.767
- Tang, N. K. Y., Schmidt, D. E., & Harvey, A. G. (2007). Sleeping with the enemy: Clock monitoring in the maintenance of insomnia. *Journal of Behavior Therapy and Experimental Psychiatry*, 38, 40-55. doi:10.1016/j.jbtep.2005.07.004
- Thomsen, D. K., Mehlsen, M. Y., Christensen, S., & Zachariae, R. (2003). Rumination—relationship with negative mood and sleep quality. *Personality and Individual Differences*, 34, 1293-1301. doi:10.1016/S0191-8869(02)00120-4
- Van der Does, A.J.W. (2002). *Handleiding bij de Nederlandse bewerking van de BDI-II [Manual of the Dutch version of the BDI-II]*. San Antonio, TX/Lisse, the Netherlands: The

Psychological Corporation/Swets Test Publishers.

Van Egeren, L., Haynes, S. N., Franzen, M., & Hamilton, J. (1983). Presleep cognitions and attributions in sleep-onset insomnia. *Journal Behavioral Medicine*, 6, 217-232. doi:

10.1007/BF00845382

Variable, P. A., Aikens, J. E., Tadimeti, L., Caruana-Montaldo, B., & Mendelson, W. B. (2000).

Sleep latency and duration estimates among sleep disorder patients: Variability as a function of sleep disorder diagnosis, sleep history, and psychological characteristics. *Sleep*, 23, 71-79.

Watkins, E. R. (2008). Constructive and unconstructive repetitive thought. *Psychological Bulletin*, 134, 163-206. doi: 10.1037/0033-2909.134.2.163.

Wicklow, A., & Espie, C. A. (2000). Intrusive thoughts and their relationship to actigraphic measurement of sleep: Towards a cognitive model of insomnia. *Behaviour Research and Therapy*, 38, 679–693. doi:10.1016/S0005-7967(99)00136-9

Wilson, K. G., Watson, S. T., & Currie, S. R. (1998). Daily diary and ambulatory activity monitoring of sleep in patients with insomnia associated with chronic musculoskeletal pain. *Pain*, 75, 75–84. doi:10.1016/S0304-3959(97)00207-8

Wolfson, A. R., Carskadon, M. A., Acebo, C., Seifer, R., Fallone, G., Labyak, . E., Martin, J. L. (2003). Evidence for the validity of a sleep habits survey for adolescents. *Sleep*, 26, 213-216.

Zakay, D., & Block, R. A. (1997). Temporal cognition. *Current Directions in Psychological Science*, 6, 12–16. doi: 10.1111/1467-8721.ep11512604

Zoccola, P. M., Dickerson, S. S., & Lam, S. (2009). Rumination predicts longer sleep onset latency after an acute psychosocial stressor. *Psychosomatic Medicine*, 71, 771–775. doi: 10.1097/PSY.0b013e3181ae58e8

Table 1
Descriptive Statistics and Correlations

	Mean	SD	Range	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.
1. BDI-II	10.0	7.6	0-31	-									
2. PSQI	6.1	3.1	1-16	.52**	-								
3. PSAS Cog	14.5	4.4	8.7-28.0	.37**	.73**	-							
4. PSAS Som	10.4	2.5	8.0-17.9	.32*	.44**	.68**	-						
5. ATS Gen	19.7	5.6	7-32	.58**	.43**	.24	.09	-					
6. TST Acti (hrs)	7.5	0.9	4.3-10.0	.31*	.13	.25	.20	.33*	-				
7. TST SLD	7.6	1.1	4.4-10.7	-.02	-.33*	-.26	-.06	.09	.63**	-			
8. TST GL	7.5	1.3	4.0-11.0	-.16	-.45**	-.32*	-.15	-.09	.49**	.89**	-		
9. SOL Acti (min)	11.4	8.0	3.6-50.3	.15	.22	.34*	.37**	-.07	.04	.00	-.01	-	
10. SOL SLD	28.0	24.5	3.4-112.0	.30*	.38**	.58**	.56**	.10	.27*	-.09	-.12	.62**	-
11. SOL GL	22.6	24.2	0.0-120.0	.16	.33*	.48**	.54**	.19	.28*	.04	-.05	.50**	.81**

Note. $N = 54$, except for TST SLD, TST GL, SOL GL, WASO SLD, and WASO GL ($N = 53$); BDI-II = Beck Depression Inventory II; PSQI = Pittsburgh Sleep Quality Index; PSAS Cog/Som = Pre-sleep Arousal Scale Cognitive/Somatic Arousal Subscale; ATS = Attitude Toward Self Generalization Subscale; TST Acti/SLD/GL = Total sleep time estimated by actigraphy/sleep diary/global estimations; SOL Acti/SLD/GL = Sleep onset latency estimated by actigraphy/sleep diary/global estimations; ** $p < .01$, * $p < .05$.

Table 2

Multiple Regressions Predicting Single-night and Global Misperceptions in TST (Total Sleep Time), SOL (Sleep Onset Latency), and WASO (Wakes after Sleep Onset) due to Cognitive Arousal and Negative Overgeneralization

	Single-night misperception (= Sleep diary – Actigraphy)			General misperception (= Global estimations – Sleep diary)		
	β	t	p	β	t	p
Predicting TST ($N = 53; 52$)						
Gender	.064	0.53	.602	-.106	0.79	.431
BDI-II	-.147	0.98	.330	-.107	0.66	.515
PSAS Cog	-.493	3.76	.001	-.112	0.78	.440
ATS Gen	-.008	0.05	.957	-.364	2.33	.024
Adj R^2	.29			.15		
Predicting SOL ($N = 54; 53$)						
Gender	.126	1.04	.305	-.167	1.24	.220
BDI-II	.137	0.92	.361	-.429	2.62	.012
PSAS Cog	.560	4.28	.000	-.178	1.23	.226
ATS Gen	-.061	0.43	.667	.425	2.71	.009
Adj R^2	.29			.17		

Note. BDI-II = Beck Depression Inventory-II; PSAS Cog = Pre-sleep Arousal Scale, Cognitive Arousal Subscale; ATS Gen = Attitude Toward Self Generalization Subscale. Two participants had missing values in either their sleep diary or global estimations.

Table 3

Correlations between Misperception of Sleep and Cognitive Arousal and Overgeneralization for Individuals with Higher and Lower Levels of Insomnia Symptoms

Type of Misperception	Low insomnia ($N = 28$)		High insomnia ($N = 26^a$)	
	PSAS Cog	ATS Gen	PSAS Cog	ATS Gen
Single-night TST	-.14	.15	-.58**	-.24
Global TST	-.14	-.54**	.04	-.11
Single-night SOL	.25	-.41*	.41*	.05
Global SOL	-.09	.34	-.21	.11

Note: TST = Total Sleep Time; SOL = Sleep Onset Latency. PSAS Cog = Pre-sleep Arousal Scale, Cognitive Arousal Subscale; ATS Gen = Attitude Toward Self Generalization Subscale.

^a $N = 25$ for Single-night SOL and Global SOL; $N = 24$ for Global TST. * $p < .05$, ** $p < .01$.

Figure 1. Single-night and Global Misperceptions of Total Sleep Time as a Function of Cognitive Arousal (Panels A and B) and Overgeneralization (Panels C and D). A positive single-night misperception score (i.e., the difference between actigraphy and sleep diary estimations) indicates that a greater overestimation of sleep was observed in the case of the sleep diary recordings than in the case of the actigraphy measurements. A positive global misperception score (i.e., difference between sleep diary and global estimations) indicates a greater overestimation of sleep in the case of retrospective global estimations than in the case of the sleep diary estimations.

Figure 2. Single-night and Global Misperceptions of Sleep Onset Latency as a Function of Cognitive Arousal (Panels A and B) and Overgeneralization (Panels C and D). A positive single-night misperception score (i.e., difference between actigraphy and sleep diary estimations) indicates that a greater overestimation of sleep was observed in the case of the sleep diary recordings than in the case of the actigraphy measurements. A positive global misperception score (i.e., the difference between sleep diary and global estimations) indicates that a greater overestimation of sleep was observed in the case of the retrospective global estimations than in the case of the sleep diary estimations.

Misperception of sleep is a common feature of insomnia and other psychopathologies.

We identified two cases in which misperception of sleep occurs.

Single-night misperceptions were associated with pre-sleep cognitive arousal.

Global misperceptions of sleep were associated with overgeneralization.