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Effects of pre-sleep cognitive intrusions on subjective sleep and next-day cognitive performance in insomnia

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Abstract

Pre-sleep cognitive intrusions about next-day activities, or proprioceptive and environmental stimuli are thought to trigger insomnia in neurocognitive models. Recent research showed that intrusive cognitions at bedtime may interact with sleep in influencing next-day emotional functioning; their effects on cognitive functioning, however, is largely unknown. We tested the effects of pre-sleep cognitive intrusions on subjective sleep and next-day cognitive performance in 80 participants, either with chronic insomnia or good sleepers. Pre-sleep intrusions were inspected using a validated questionnaire and sleep was assessed with a sleep diary. Cognitive functioning the following morning was measured using task switching paradigm assessing executive functions. Structural equation modelling with manifest variables (i.e., path analysis) shows that pre-sleep cognitive intrusions predicted increased sleep onset latency and wake after sleep onset, and lowered sleep efficiency. Moreover, task switching accuracy was independently predicted by pre-sleep cognitive intrusions in the previous night in those with insomnia but not in controls, beyond the effects of trait anxiety, task switching components, and previous night's sleep. Findings confirm detrimental effects of pre-sleep intrusions on sleep continuity and suggest the presence of links between pre-sleep conscious activity and next-day executive performance in patients with insomnia, with the need to better elucidate potential mediators.

Keywords: sleep, insomnia, intrusive cognitions, repetitive thinking, executive functions

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Insomnia is the most common sleep disorder in the general population (Riemann et al., 2017) and it is among the most expensive neuropsychiatric disorders (Gustavsson et al., 2011) for direct (drugs, psychotherapy) and indirect (e.g., absenteeism, accidents) costs. Diagnostic criteria of insomnia involve difficulties falling asleep (sleep onset latency > 30 minutes), and/or difficulties maintaining sleep (wake after sleep onset > 30 minutes), and/or early awakenings in the morning (1 hour before the desired), accompanied by perceived poor sleep quality and significant daytime social, emotional, and cognitive impairment (American Psychiatric Association, 2013).

Alterations in cognitive arousal systems have been traditionally considered as key exacerbating and maintaining factors of insomnia (Harvey, 2002; Perlis, Giles, Mendelson, Bootzin, & Wyatt 1997). According to the neurocognitive model of insomnia (Perlis et al., 1997), conditioned cortical hyperarousal at bedtime would result in a cascade of cognitive processes deleterious for sleep, such as increased sensory information processing. The experience of negative and uncontrollable thoughts about sleeplessness, proprioceptive or environmental stimuli, or worries and ruminations in the pre-sleep period (pre-sleep cognitive intrusions), is considered a particularly distressing facet of cortical hyperarousal (Nelson & Harvey, 2003). Indeed, Borkovec defined insomnia itself as "the result of an inability to turn off intrusive, affectively-laden thoughts and images at bedtime" (Borkovec, Robinson, Pruzinsky, & DePree, 1983, p. 9). A widely replicated finding is that pre-sleep cognitive intrusions trigger sleep difficulties not only in individuals with insomnia (e.g. Lancee, Eisma, van Zanten, & Topper, 2016; Sella, Cellini, Miola, Sarlo, & Borella, 2018; Wicklow & Espie, 2000), but also in healthy samples (Heath, Johnston, Dohnt, Short, & Gradisar, 2018; McGowan, Behar, & Luhmann, 2016; Syrek, Weigelt, Peifer, & Antoni, 2017; Takano, Sakamoto, & Tanno, 2012; Vannikov-Lugassi & Soffer-Dudek, 2018; Zoccola, Dickerson, & Sumam, 2009), with a specific effect on prolonging sleep onset latency (i.e., the time needed to fall asleep, Harvey, 2000; Harvey, 2005; Heath et al., 2018; Stewart, Gibb,

Strauss, & Coles, 2018; van Egeren, Haynes, Franzen, & Hamilton, 1983). Interestingly, intrusive cognitions and sleep seem to interact in predicting daytime functioning in clinical and non-clinical samples. For instance, individuals with insomnia reporting (daily) cognitive intrusions have higher depression rates compared to both individuals with insomnia without cognitive intrusions and individuals with high trait disposition to cognitive intrusions (trait ruminators and worriers) without insomnia (Kalmbach, Pillai, & Drake, 2018). Additionally, some authors found that sleep problems mediate the relationship between cognitive intrusions (both experienced during the day or in the pre-sleep period), and mood (Borders, Rothman, & McAndrew, 2015; Takano et al., 2012). More recently, in undergraduate students, Vannikov-Lugassi & Soffer-Dudek, (2018), found that pre-sleep cognitive intrusions were associated with poor sleep and next-day dissociative experiences.

It has yet to be investigated, however, whether pre-sleep cognitive intrusions have impact on daytime objective cognitive functioning. It is a robust finding, in fact, that cognitive intrusions interfere with concentration (e.g., Morsella, Ben-Zeev, Lanska, & Bargh, 2010). Moreover, cognitive intrusions have been associated with impairment in executive functions (Bomyea & Amir, 2011; Philippot & Brutoux, 2008; Whitmer & Gotlib, 2012), which are considered as cognitive control functions underpinning the performance on complex cognitive tasks (e.g., cognitive control and set-shifting). Interestingly, executive functions are also among the cognitive processes that seem to be impacted in insomnia (e.g. see Ballesio, Aquino, Kyle, Ferlazzo, & Lombardo, 2019 for a review), and in healthy individuals after experimental sleep curtailment (Lim & Dinges, 2010). Accordingly, it is plausible to hypothesise that pre-sleep cognitive intrusions may not only predict following sleep quality, but also play a role in influencing next-day cognitive performance, and particularly executive functions. This hypothesis also lays on the fact that a core feature of intrusive cognitions is the difficulty in disengaging from intrusive thoughts (Ehring et al., 2011), which can be viewed as a process mirroring executive functions (Cox, Cole, Kramer, & Olatunji, 2018; Ólafsson et al., 2011; Ottaviani, 2018). Recent evidence showed promising results in this direction. For instance, Nota, Schubert, & Coles, (2016) highlighted that short sleep duration and high trait

disposition to cognitive intrusions interacted in determining poorer inhibitory control, a cognitive function often impaired in emotional disorders (e.g. Snyder, 2013; Snyder, Miyake, & Hankin, 2015) and in chronic insomnia (see Ballesio et al., 2019 for a review; Covassin et al., 2011). However, the specific effects of cognitive intrusions experienced in the pre-sleep period on next-day executive functions remain unexplored, as well as the potential differential effects between individuals with insomnia and good sleepers. A clearer understanding of the relationships between pre-sleep cognitive intrusions and daily functioning would be desirable to develop and implement specific treatment strategies targeting night-time and daytime cognitive symptoms of insomnia (e.g., pre-sleep cognitions and daytime executive dysfunction). Therefore, it was our aim to test: 1) whether pre-sleep cognitive intrusions have an effect on subsequent subjective sleep; 2) whether pre-sleep cognitive intrusions and subsequent sleep have an effect on next-day executive performance.

Method

Participants and procedure

The study comprised a total sample of 80 (24.03±3.88, 76.3% females) young adults. Participants were recruited from the student community of Sapienza University of Rome through flyers, online advertisement and announcements during lectures. To reduce sampling bias, the study was presented as investigating the relationships between sleep quality and cognitive functioning. Individuals >18 years old having a chronic insomnia disorder according to DSM-5 criteria (American Psychiatric Association, 2013) were included in the insomnia group. Individuals >18 years old reporting good sleep were included in the good sleep group. Good sleep was defined as the absence of self-reported insomnia symptoms. Severe mental or physical illness as investigated in a clinical interview as well as use of sleep drugs were considered as exclusion criteria for both groups. Moreover, suspect of other sleep problem (sleep apnoea, parasomnia, narcolepsy, circadian rhythm sleep disorders, sleep movement disorders) as assessed with a clinical interview (see below) was a reason for exclusion for both groups. Subjects interested in the study were screened for

insomnia symptoms through questionnaires, and those reporting insomnia symptoms, or those reporting good sleep, were contacted to undergo an in-person intense clinical assessment. The clinical assessment included a semi-structured clinical interview for insomnia that also covers non-sleep related areas (e.g., physical and mental illness, medications, see below) as well as self-report insomnia and anxiety measures (see below). The clinical interview was conducted by two clinical psychologists with expertise in behavioural sleep medicine. At the end of the clinical assessment process, selected participants completed the task switching paradigm to assess executive functions. Executive functions assessment was kept fixed in the morning to control for circadian effects (Blatter & Cajochen, 2007). Participants were asked to abstain from caffeinated beverage and from smoking for the 2 hours prior to executive functions assessment. Subjective sleep of the night prior to executive functions assessment was monitored using self-reported sleep diary. Participants were asked to complete the sleep diary within 30 minutes from the final awakening in the morning. At the end of the executive functions' assessment, participants were retrospectively investigated about pre-sleep cognitive intrusions experienced in the previous night using a validated questionnaire (see below). The study was conducted in accordance with Helsinki Declaration and was approved by the Institutional Review Board of the Department of Psychology, Sapienza University of Rome

Measures

Insomnia measures

The Insomnia Severity Index (ISI; Bastien, Vallières, & Morin, 2001) is a brief self-report instrument measuring the severity of night-time and daytime symptoms of insomnia, with scores of 0-7 in ISI indicating absence of insomnia, scores of 8-14 indicating presence of subclinical insomnia, and scores of 15 or higher indicating clinical insomnia.

The Semi-Structured Clinical Interview for Insomnia (Morin, Savard, Oullet, & Daley, 2003) was used to confirm the diagnosis of insomnia. The interview was administered by two clinical psychologists with certified expertise in behavioural sleep medicine. Areas investigated in the interview are: presence and severity of insomnia, sleep habits, history of sleep problems,

presence and severity of sleep disorders other than insomnia (narcolepsy, circadian rhythm disorders, sleep apnea, restless leg syndrome, parasomnias), presence of physical and mental illness.

The sleep diary in accordance with the Consensus sleep diary (Carney et al., 2012) was used to monitor perceived sleep in the night between pre-sleep intrusions experience and task switching assessment. The diary allowed to collect information about sleep onset latency (SOL), wake after sleep onset (WASO), total sleep time (TST), time in bed (TIB) and to calculate the sleep efficiency index (SEI) as TST/TIB*100 (Carney et al., 2012).

Trait anxiety measure

The State-Trait-Anxiety-Inventory-Y (STAI-Y; Spielberger, 1989) is a widely used 20 items questionnaire assessing trait anxiety. It was employed in light of the well-known association between insomnia and anxiety (Belleville, Cousineau, Levrier, & St-Pierre-Delormeb, 2011), and intrusive thought and anxiety (Ehring et al., 2011).

Pre-sleep cognitive intrusions measure

The Pre-Sleep Cognitive Intrusions Inventory (PCII, Sanavio, 2000), was used to assess pre-sleep intrusive cognitions. The questionnaire assesses the intensity of the experience of several thoughts (worries and ruminations, next-day schedule planning, sleep-focused cognitions) that may occur in bed during the night (i.e., during sleep onset latency or nocturnal awakenings) and has been developed and validated in individuals with insomnia (Sanavio, 1988; Sanavio, 2000). Completers are asked to rate how intense each intrusive thought was during the night prior to assessment from 0 (“not at all”) to 4 (“a lot”). Examples of items include “thinking about problems of my family”, or “thinking about things I must do the next day”, or “thinking about worries I cannot turn away”, or “thinking about the mistakes I might have done during the day”, or “thinking about being sleepless”.

Executive function measure

The Task Switching paradigm, as soon represented in figure 1, was used to assess executive function (Ballesio, Cerolini, Ferlazzo, Cellini, & Lombardo, 2018; Ballesio, Ottaviani, &

Lombardo, 2018; Couyoumdjian et al., 2010; Sdoia & Ferlazzo, 2008). We used the same procedure described in detail in previous studies from our group (Ballesio et al., 2018; Ballesio, Ottaviani, 2018). Three performance indices can be derived from the task: the switch cost, the backward inhibition and the accuracy of the performance (correct responses rate).
Switching from one rule to another implies performance cost, i.e., that we will refer to as switch cost. Also, switching back to a recently executed task is harder than switching back to a less recently executed task. The switch cost index reflects increased mean reaction times (RTs) on the third trial of switching triplets (A-B-A, C-B-A), versus the third trial of repetition triplets (A-A-A). The backward inhibition index reflects slower RTs on the third trial of alternating triplets (A-B-A) versus the third trial of non-alternating triplets sequences (C-B-A) that is due to residual inhibition suffered by the rule A in A-B-A versus C-B-A sequences. Good inhibitory and switching abilities are needed to perform correctly in the task and therefore support accuracy (Davidson, Amso, Cruess Anderson, & Diamond, 2006; Diamond & Kirkham, 2005; Goldin et al., 2014). Therefore, we considered accuracy in the task switching as main outcome of the study. This decision was based on previous literature suggesting a specific impairment in accuracy of the performance rather than reaction-time based indices in insomnia, especially due to hyperarousal (Edinger, Means, & Krystal, 2013; Fortier-Brochu & Morin, 2014; see also Shekleton, Rogers, & Rajaratnam, 2010 for a review). In total, 54 triplets were presented. Trial errors were excluded from the calculations of the two indices. In addition, RTs exceeding ±2 standard deviations from the mean were not included in the calculations.

Analytic approach

As a first step, descriptive statistics of the study variables were examined on the overall sample. Thus, applying criteria and procedures described above, we determined the quasi-experimental groups (controls vs. subjects with chronic insomnia).

Aim 1: Effects of pre-sleep cognitive intrusions on subjective sleep

In order to examine the effect of cognitive intrusions on subjective sleep, we tested a a structural equation model with manifest variables (i.e., path analysis), positing the direct impact of pre-sleep cognitive intrusions (scores on PCII) on four variables collected from the sleep diary, i.e., sleep onset latency (SOL), wake after sleep onset (WASO), total sleep time (TST), and sleep efficiency index (SEI), which were modelled as interrelated distal outcomes. Moreover, PCII was controlled for scores on STAI-Y in order to remove individual differences attributable to trait anxiety from cognitive intrusions. Model fit with observed data was evaluated by means of widely used fit indices adopting a multifaceted approach (see Kline, 2016): 1) Chi-square (χ^2, if not significant for $p < .05$, the model fits perfectly the data); 2) Root Mean Square Error of Approximation (RMSEA, Steiger, 1990); 3) Comparative Fit Index (CFI, Bentler, 1990) and Tucker-Lewis Index (TLI, Tucker & Lewis, 1973); 4) Standardized Root Mean Square Residual (SRMR, Hu & Bentler, 1999). Values ≤ .05 for the RMSEA, ≥ .95 for CFI and TLI, and ≤ .05 for SRMR were established as indicative of good fit. Finally, we also tested for potential indirect effects of STAI-Y on sleep diary variables by interpreting the 95% confidence interval based on 1,000 bootstrap replications (Williams & MacKinnon, 2008) around the point estimate.

Aim 2: Effects of pre-sleep cognitive intrusions and sleep on next-day task switching performance

In order to evaluate whether pre-sleep cognitive intrusions have an effect on next-day executive performance, we adopted a multi-group approach. We tested simultaneously on the two quasi-experimental groups (controls vs. subjects with chronic insomnia) a structural equation model with manifest variables (i.e., path analysis) were PCII directly affected the accuracy of performance in the executive function task. As for the previous model, PCII was controlled for STAI-Y, while also the direct effect of STAI-Y on accuracy of performance was specified. Moreover, the accuracy of performance was controlled for the other two indices of the task switching paradigm (i.e., backward inhibition and switch cost) and for the sleep diary variables (i.e., SOL, WASO, TST and SEI). Also in this case, the sleep diary variables were posited as oblique. In a first step of the multi-

group model, all structural paths (both direct effects and covariances) were constrained to equality across quasi-experimental groups. Thus, we examined modification indices in order to evaluate (one by one) whether equality constraints on model parameters hold across the two groups (Millsap & Kwok, 2004). After releasing equality constraints as suggested by modification indices, the fit of the less restrictive model was contrasted with the fully constrained model by means of the $\Delta\chi^2_{(\Delta df)}$ (Scott-Lennix & Lennox, 1995) and ΔCFI (Cheung & Rensvold, 2002). If the fully constrained model fit significantly worse than the model where some equality constraints were released (i.e., $\Delta\chi^2$ is significant for $p > .01$ and $\Delta CFI \geq .01$), one can conclude that some effects are significantly different between the groups. Finally, we examined the indirect effect of STAI on the accuracy of performance within the multi-group framework, in order to detect potential moderated mediation effects.

Results

Descriptive statistics

Descriptive statistics of the study variables are soon summarized in Table 1. As it can be noted, some variables showed nontrivial positive skewness (i.e., SOL, WASO and SEI), while others showed non-ignorable negative skewness values (i.e., TTS and accuracy of performance). STAI-Y and PCII were extremely reliable in terms of internal consistency on the present sample (STAI-Y $\alpha = .93$ and PCII $\alpha = .96$), as well as for the ISI ($\alpha = .91$). STAI-Y and PCII were strongly and positively correlated, and they were both significantly and positively associated with SOL (and vice versa). PCII was also significantly and positively related to WASO and negatively with the accuracy of performance in the switching task. SOL and WASO were also significantly and negatively related with TTS. A strong negative correlation was observed among switch cost and accuracy of performance. Finally, the continuous score of ISI was strongly and positively correlated with PCII and slightly less with STAI-Y. Moreover, ISI showed a moderate positive correlation also with SOL and WASO, and weak negative correlations with TTS and the accuracy of performance.

Quasi-experimental groups

Relying on the cut-offs of the ISI proposed by Bastien et al., (2001) and confirmed in the clinical assessment, fifty individuals were classified as clinically relevant for insomnia (mean age 23.12± 3.82 years, 74% females) and thirty good sleepers (mean age 25.53±3.56 years, 78.9% females). No gender differences were found between controls and clinically relevant group (χ^2 = .01, p = .95). Finally, no differences in age were found in relation to gender ($F_{(1,76)}$ = .10, p = .75), quasi-experimental group membership ($F_{(1,76)}$ = 3.53, p = .06), and their interaction ($F_{(1,76)}$ = .83, p = .36).

Pre-sleep cognitive intrusions predict following sleep

Since some variables were substantially skewed, standard errors of model parameters and the χ^2 of the first path analytic model were estimated with the robust maximum likelihood (MLR, see Muthén & Muthén, 1998-2017), which provides an asymptotically equivalent χ^2 to the Yuan-Bentler T2* test statistic (i.e., $YB\chi^2$, see Yuan & Bentler, 2000). Some missing data on the sleep diary variables (specifically, one missing data point on SOL, nine on WASO, and seven both on TST and SEI) were found. For ascertaining their nature, the Little's (1988) MCAR test was performed on the variable used for the model. The MCAR test evaluates the null hypothesis that such missing data points were completely missing at random. Since it was not significant (Little's MCAR $\chi^2_{(df=10)}$ = 5.48, p = .86), we can conclude that the observed missingness occurred completely at random. For this reason, missing data were handled using the full information maximum likelihood approach (FIML, Arbuckle, 1996) for modelling purposes. The fit of the tested model was excellent: $YB\chi^2_{(N=80,\ df=4)}$ = 3.34, p = .50; RMSEA = .00, CFI = 1.00, TLI = 1.03, SRMR = .03. Noteworthy, this model does not fit the data worse than the partial mediation model where all effects of STAI-Y on sleep diary variables were specified[1]. Figure 2 displays structural coefficients in a completely standardized metric. As can be noted, almost half of the total variability

[1] Since this model is saturated (i.e., it has zero degrees of freedom) and the $YB\chi^2$ in our substantive model is not statistically different from zero, we can conclude that our substantive (full mediation) model depicted in Figure 2 does not fit the data worse than the partial mediation (saturated) model.

of PCII scores was attributable to trait anxiety. After controlling for this component, PCII exerts a positive and significant impact on SOL and WASO, while a weak negative effect was found in relation to SEI. No significant effect of PCII on TST was detected. Moreover, STAI indirectly affects SOL (bootstrapped standardized coefficient = .23, 95% C.I. .13–.35), WASO (bootstrapped standardized coefficient = .17, 95% C.I. .05–.32) and SEI (bootstrapped standardized coefficient = -.10, 95% C.I. -.27–-.02), while no indirect effect of STAI-Y on TST was detected. In light of these results, we can argue that the impact of trait anxiety on SOL, WASO and SEI is totally mediated by PCII (MacKinnon, 2008). Overall, this model explained the 12% of variability for SOL, the 7% for WASO and the 3% for SEI.

Pre-sleep cognitive intrusions predict next-day task switching performance

Also in this case, the multi-group path analytic model was estimated with MLR and the FIML approach was used to handle missing data, which were limited to those described in previous paragraph. As a first step, we constrained all structural coefficients (i.e., the direct effect of STAI-Y on PCII, the direct effect of PCII, backward inhibition, switch cost and the four sleep diary variables on accuracy on task switching performance, as well as the six covariances among the sleep diary variables) to be equal across control and clinical groups. This model fit the data poorly: $YB\chi^2_{(ng1=30,\ ng2=50;\ df=57)} = 76.12$, $p < .05$; RMSEA = .09, CFI = .83, TLI = .91, SRMR = 31. On the basis of modification indices, we released the equality constraints on three effects (i.e., the direct effects of PCII, SOL and switch cost on accuracy of performance). After releasing these constraints, model fit improved significantly: $YB\chi^2_{(ng1=30,\ ng2=50;\ df=57)} = 57.92$, $p = .33$; RMSEA = .04, CFI = .97, TLI = .98, SRMR = 11. The statistical comparison with the fully constrained model yielded the following results: $\Delta YB\chi^2_{(\Delta df=3)} = 12.80$ with $p < .05$, and ΔCFI = .14. Thus, the model with the three released constraints is retained as the best fitting.

Please insert Figure 3 here

Figure 3 shows the final model estimates in a completely standardized metric. As it can be noted, the effect of STAI-Y on PCII was strong and very similar across groups. With regards to the

effect of PCII on accuracy of performance, the effect was statistically significant only for the clinical group, while the effect of switch cost on accuracy of performance was significantly higher in the clinical group than for controls. SOL had a significant (positive) impact on performance only for the control group. Finally, the indirect effect of STAI-Y on the accuracy of performance was significant for the clinical group (bootstrapped standardized coefficient = -.16, 95% C.I. -.27– -.05) but not for controls (bootstrapped standardized coefficient = -.07, 95% C.I. -.20– 19), suggesting that the indirect effect of STAI-Y on the accuracy of performance is moderated by the quasi-experimental grouping variable. Thus, while the direct effect of trait anxiety on the accuracy of performance is not significant for both groups, its specific indirect effect was significant only in the clinical group. Overall, this model explained the 26% of variance of PCII scores and the 19% of accuracy of performance in the control group and, respectively, 21% and 54% for the clinical group.

Discussion

The first aim of this study was to test the effects of pre-sleep cognitive intrusions on subjective sleep. Consistently with previous findings (Heath et al., 2018; Sella et al., 2018; Syrek et al., 2017; Takano et al., 2012; Vannikov-Lugassi & Soffer-Dudek, 2018; Wicklow & Espie, 2000; Zoccola et al., 2009), we found that higher pre-sleep intrusions were associated with poorer sleep, and specifically with longer time needed to fall asleep and night-time wake, and lower sleep efficiency in both individuals with insomnia and good sleepers. Importantly, we found that these relationships remained significant controlling for the effects of trait anxiety, which resulted also indirectly associated with poorer sleep, confirming robust literature on anxiety and sleep disturbance (see Belleville et al., 2011 for a review). Interestingly, pre-sleep cognitive intrusions did not affect total sleep time, suggesting a specific impact on sleep continuity rather than sleep duration, therefore supporting the conceptualisation of pre-sleep intrusions as a robust maintaining factor of insomnia.

The second aim of this study was to explore whether pre-sleep cognitive intrusions may predict, besides following sleep, next-day performance on an executive function task. This hypothesis was based on literature showing that intrusive cognitions and repetitive thinking are longitudinally associated with poor executive functioning in healthy samples (Philippot & Brutoux, 2008; Whitmer & Gotlib, 2012), and that a "core" feature of intrusive cognitions, the difficulty of disengaging from the thought (Ehring et al., 2011), may be considered a process mirroring executive control (the ability to exert control over the onset, the experience and the suppression of the thought).

Present results evidenced that higher cognitive intrusions at bedtime were associated with lower accuracy in the task switching beyond the role of trait anxiety, switch cost and backward inhibition and previous night's sleep in those with insomnia but not in controls. To the best of our knowledge, this is the first investigation providing evidence for a relationship between pre-sleep conscious activity and next-day executive performance in insomnia. As it emerged from path analysis, previous night's sleep was not associated with executive performance the next day; therefore, we did not further investigate the mediation effect of sleep on executive performance. Several factors may explain such results. First, it is possible that habitual sleep habits, rather than only sleep of the night prior to executive function assessment may play a role. For example, Nota et al., (2016) found that sleep duration in the last month interacted with repetitive thinking in influencing executive performance. Moreover, it is possible that intrusive cognitions may not be limited to pre-sleep period but be still ongoing during task implementation, with consequent performance impairment due to several mechanisms including distraction. Consistent with this hypothesis, Ottaviani, Shapiro, & Couyuomdjian, (2013) found that daytime intrusive cognitions during the implementation of a cognitive task were associated with poorer performance (i.e., prolonged reaction times) in unselected individuals. Moreover, it is known that poor sleep may also drive daytime intrusive cognitions (Baker, Baldwin, & Garner, 2015). Unfortunately, we did not collect information about ongoing conscious activity during the task implementation, thus we could

not test this hypothesis. Thus, future studies would benefit from the administration of a measure of state cognitive intrusions prior to task switching assessment. Also, it is possible that both intrusive cognitions and impaired accuracy in the task may reflect a more stable cortical hyperarousal condition; this interpretation would fit the conceptualisation of insomnia as a 24h hyperarousal disorder (Riemann et al., 2010). In fact, there is evidence that hyperarousal in insomnia hinders cognitive functions (Cellini, de Zambotti, Covassin, Sarlo, & Stegagno, 2014; Khassawneh, Bathgate, Tsai, & Edinger, 2017), especially in terms of impaired accuracy of the performance (Edinger et al., 2013). Nevertheless, a recent study provided contrasting results, showing that pre-sleep arousal was associated with a more efficient cognitive performance (Takano, Poel, & Raes, 2018). However, the study included an unselected sample and employed a cognitive task assessing sleep-related information processing in working memory. Thus, it is possible that different paths may link pre-sleep arousal with the executive processing of "hot" (sleep-related content) and "cold" (sleep-independent content) information (Hoffman, Schmeichel, & Baddeley, 2012). Related to this, intrusive cognitions are considered negatively emotionally-toned cognitions (Kuisk, Bertelson, & Walsh, 1989). Because executive performance may vary in function of mood (Chepenik, Cornew, & Farah, 2007; Snyder, 2013), it is possible that emotional experience may mediate the relationship between pre-sleep intrusions and next-day executive performance. That is, intrusive cognitions may drive negative emotion which in turn may predict poor executive function. In fact, cognitive intrusions include the perceived intrusiveness and uncontrollability of the thought, i.e., the inability to control the onset of the thought that is therefore perceived as unwanted, unproductive and emotionally unpleasant (Ehring et al., 2011; Kuisk et al., 1989; Ottaviani, Medea, Lonigro, Tarvainen, & Couyuomdjian, 2015). Similarly, it is plausible that trait disposition to perseverative thinking besides that captured by the STAI-Y may play a key role (Stewart et al., 2018; Tousignant, Taylor, Suvak, & Fireman, 2019). Specifically, it is possible that rumination and worry, which both share the characteristic of intrusiveness, are both relevant in insomnia (Carney, Edinger, Mejer, Lindman, & Istre, 2006; Lancee et al., 2016) and are both associated with executive functions

(Yang, Cao, Shields, Teng, & Liu, 2016), may moderate the association between pre-sleep intrusions and executive performance (by increasing the effects of pre-sleep intrusions on performance in those with high trait disposition to perseverative thinking). Further studies are needed to explore cognitive-emotional factors underlying this relationship. Particularly needed are studies involving electrophysiological and psychophysiological measures that may ascertain the impact of hyperarousal on cognitive performance.

Confirming robust literature on executive impairments in anxiety (see Snyder et al., 2015 for a review), we also found that trait anxiety indirectly predicted accuracy in the task switching, with a moderated mediation effect. Interestingly, this effect was significant in those with insomnia only, likely due to the high association between insomnia and anxiety symptoms (Baglioni, Spiegelhalder, Lombardo, & Riemann, 2010).

Surprisingly, we found that, in good sleepers, higher SOL was associated with higher accuracy in the task switching. This result is apparently counterintuitive. However, in a recent study Ballesio et al., (2018) reported that good sleepers tended to perform slightly better in the task switching after a night of disturbed sleep compared to their habitual sleep. In that study, authors argued that the engagement in this challenging task with increased cognitive efforts in order to compensate the deficits may have resulted in a more efficient performance. This interpretation also fits well our present results. Therefore, further investigation of compensatory effects in good sleepers are needed.

Limitations

Our main hypothesis was directional (pre-sleep cognitions as predictor of cognitive performance) and theory-driven. However, although we asked participants to retrospectively provide information on previous night conscious activity, we employed a quasi-experimental design with the cross-sectional measurement of the independent variable (pre-sleep intrusions) and dependent variable (executive functions). An ecological momentary assessment of ongoing conscious activity would ideally be more appropriate (Ottaviani et al., 2015). However, this type of

design would lead further concerns when used in the pre-sleep period, as it would likely bring an increase of interference of the experimental design on both sleep and personal experience, increasing the levels of arousal. For this reason, pre-sleep intrusions are usually assessed retrospectively (Heath et al., 2018). In this frame, future studies may benefit from including a retrospective assessment of previous night pre-sleep intrusions upon awakening. For instance, sleep diaries could be adapted in order to include a specific section assessing pre-sleep intrusions in the previous night. Moreover, an opposite direction of the relationships between the variables under study may also theoretically be possible, as executive functions have been shown to predict repetitive intrusive cognitions in insomnia (Ballesio et al., 2018). Supporting this opposite direction, switching abilities has been suggested to mediate the relationship between poor sleep and repetitive thinking, at least in non-clinical samples (Cox et al., 2018). It is not explored yet whether these patterns are applicable in insomnia patients. Similarly, as we were interested in investigating the effects of pre-sleep intrusions on behavioural outcomes, we considered trait anxiety as a control measure in order to remove individual differences attributable to trait anxiety from cognitive intrusions. However, it must be noted that recent research on unselected participants considered poor sleep as a prospective predictor of state anxiety (Cox, Sterba et al., 2018). Finally, the relatively small sample may have impacted our results. Thus, longitudinal studies dismantling these association with larger samples are strongly needed to advance the knowledge in this field.

Conclusions

Pre-sleep cognitive arousal and daytime functional impairment are common in individuals suffering of insomnia. This study provides first evidence for a role of pre-sleep cognitive intrusions in influencing daytime cognitive performance in insomnia. Future research is needed to consolidate these results and overcome the limitations of the present study. Specifically, it is strongly suggested to assess intrusive cognitions upon awakening and prior to executive functions assessment.

Further studies investigating the potential mediators (e.g., cognitive and physiological arousal, emotional experience) and moderators (e.g., age) of the association between pre-sleep

intrusions and executive performance are warranted. Also, studies examining the opposite direction of this relationship, i.e., the effects of executive control functions on intrusive cognitions, are needed to further advance the field. Future studies investigating the determinants of daytime cognitive impairments in insomnia should consider role of pre-sleep conscious activity. Moreover, future studies would benefit from considering the role of habitual sleep patterns on executive functions. Finally, clinical trials, testing the effects of behavioural treatments targeting pre-sleep intrusive cognitions (such as bedtime writing, Scullin, Krueger, Ballard, Pruett, & Bliwise, 2018) on sleep and daytime executive performance are warranted.

Declaration of interest

The authors have no conflict of interest to disclose.

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Table 1
Descriptive Statistics of the Study Variables

	M	SD	Skewness	Kurtosis	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.
1. STAI-Y	47.16	11.61	-.09	-.70	*.93*									
2. PCII	71.54	42.62	.26	-.97	.66**	*.95*								
3. SOL	25.28	24.84	1.85	4.05	.32**	.35**	–							
4. WASO	20.41	34.49	2.88	9.75	.23	.26*	.16	–						
5. TTS	387.56	76.30	-1.05	1.28	-.16	-.09	-.26*	-.27*	–					
6. SEI	93.14	46.96	5.44	31.69	-.19	-.15	-.12	-.20	.17	–				
7. Accuracy of Performance	51.30	4.55	-3.39	13.16	-.13	-.26*	.08	.01	.08	-.10	–			
8. Backward Inhibition	11.88	134.97	.44	.77	.02	-.04	-.01	-.01	.04	-.03	-.13	–		
9. Switch Cost	156.99	149.97	1.19	2.02	-.12	-.03	.09	-.06	-.10	.19	-.47**	.10	–	
10. ISI	9.53	6.71	-.09	-1.39	.58**	.73**	.42**	.35**	-.26*	-.19	-.25*	-.05	.03	.91

Note. STAI-Y = State-Trait-Anxiety-Inventory-Y (Trait Anxiety); PCII = Pre-Sleep Cognitive Intrusions Inventory; SOL = Sleep onset latency; WASO = Wake after sleep onset; TST = Total sleep time; SEI = Sleep efficiency index; ISI = Insomnia Severity Index. ** p <.01; * p< .05. Cronbach's alpha coefficients of STAI-Y, PCII and ISI are reported in italics along the principal diagonal.

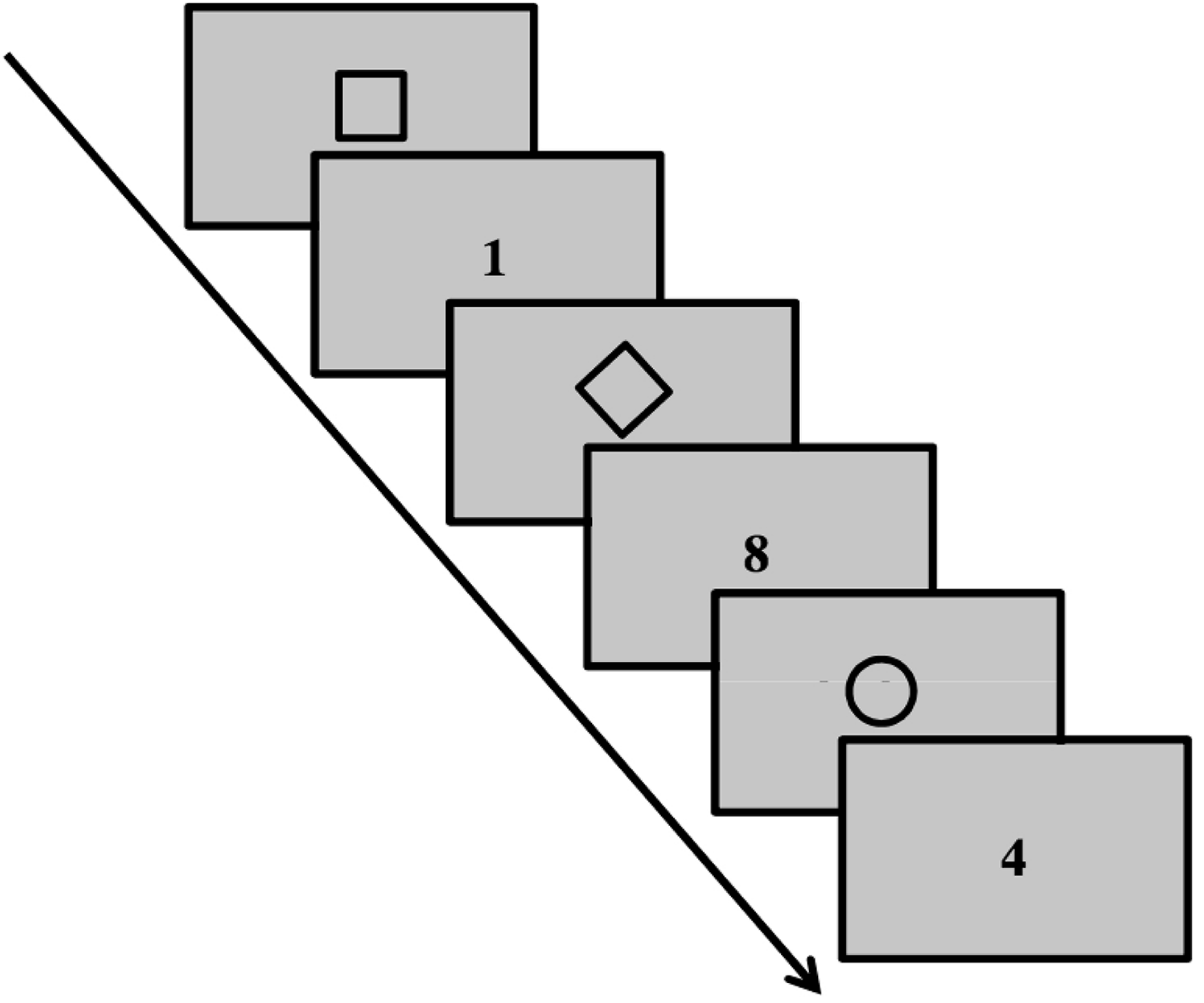

Figure 1

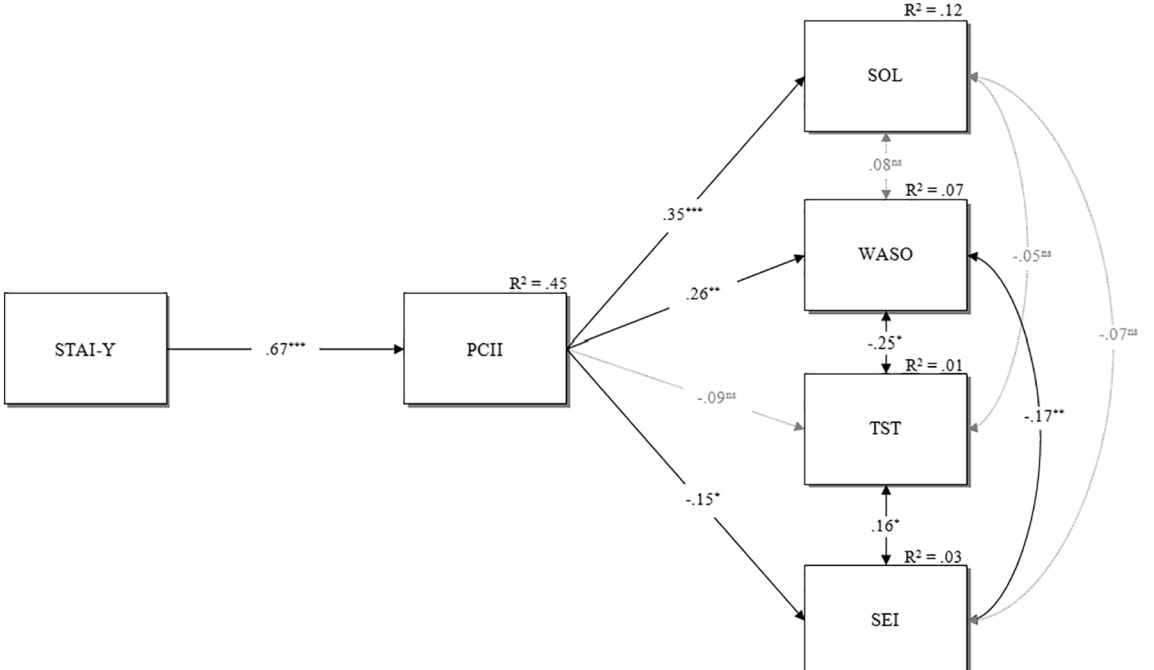
STAI-Y
.67***
PCII
R² = .45
.35***
.26**
-.09ns
-.15*
SOL
R² = .12
WASO
R² = .07
TST
R² = .01
SEI
R² = .03
.08ns
-.25*
.16*
-.05ns
-.07ns
-.17**

Figure 2

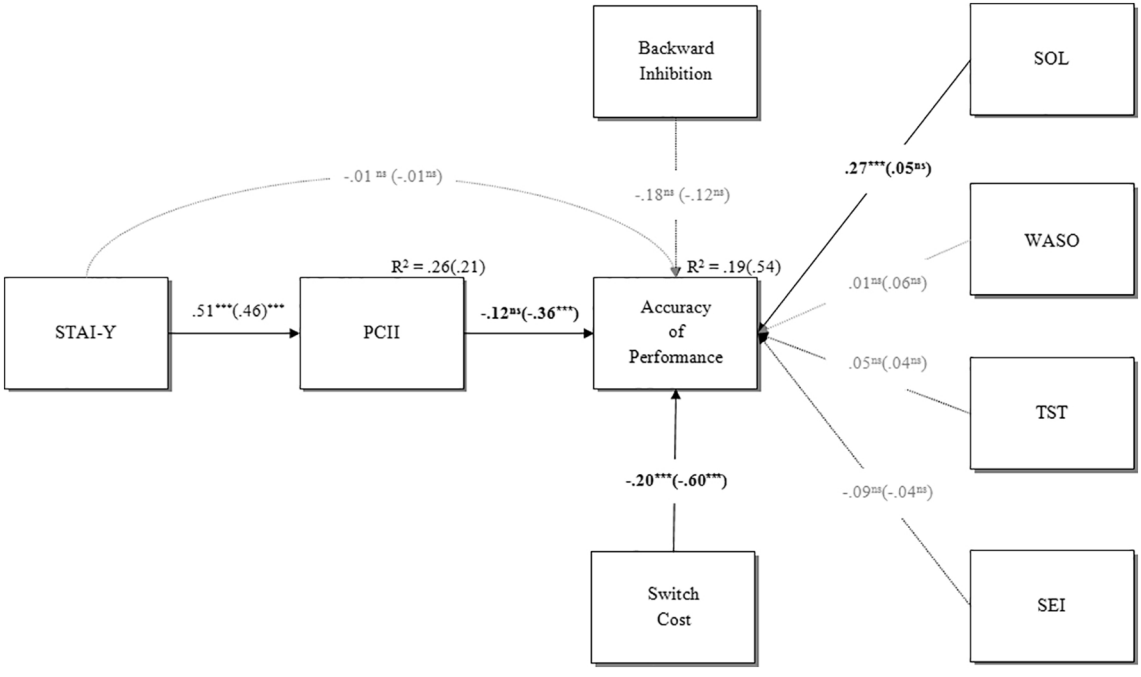
Backward Inhibition
SOL
-.01 ns (-.01ns)
-.18ns (-.12ns)
.27***(.05ns)
WASO
R2 = .26(.21)
R2 = .19(.54)
.01ns(.06ns)
STAI-Y
.51***(.46)***
PCII
-.12ns(-.36***)
Accuracy of Performance
.05ns(.04ns)
TST
-.20***(-.60***)
-.09ns(-.04ns)
Switch Cost
SEI

Figure 3