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RESEARCH ARTICLE

False memories formation is increased in individuals with insomnia

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Summary

Previous studies suggest that sleep can influence false memories formation. Specifically, acute sleep loss has been shown to promote false memories production by impairing memory retrieval at subsequent testing. Surprisingly, the relationship between sleep and false memories has only been investigated in healthy subjects but not in individuals with insomnia, whose sleep is objectively impaired compared to healthy subjects. Indeed, this population shows several cognitive impairments involving prefrontal functioning that could affect source monitoring processes and contribute to false memories generation. Moreover, it has been previously reported that subjects with insomnia differentially process sleep-related versus neutral stimuli. Therefore, the aim of the present study was to compare false memories production between individuals with insomnia symptoms and good sleepers, and to evaluate the possible influence of stimulus category (neutral versus sleep-related) in the two groups. The results show that false memories are globally increased in participants reporting insomnia symptoms compared to good sleepers. A reduction in source monitoring ability was also observed in the former group, suggesting that an impairment of this executive function could be especially involved in false memories formation. Moreover, our data seem to confirm that false memories production in individuals with insomnia symptoms appears significantly modulated by stimulus category.

KEYWORDS
Deese–Roediger–McDermott (DRM) paradigm, false memory, insomnia disorder, sleep-related stimuli

1 | INTRODUCTION

Previous studies report that false memories can be influenced by sleep (for a review see Conte & Ficca, 2013; Landmann et al., 2014). Among the first to investigate the relationship between sleep and false memories, Diekelmann, Born, and Wagner (2010), Diekelmann, Landolt, Lahl, Born, and Wagner (2008) showed that sleep-deprived individuals produce more false memories at morning re-test compared to participants in an undisturbed sleep condition. The authors specified that this effect could be mainly linked to an impaired memory retrieval process. In fact, acute sleep loss can affect several cognitive functions related to prefrontal activity that are essential to accurate recall from long-term memory (Durmer & Dinges, 2005; Frenda & Fenn, 2016).

Most of the available studies on sleep and false memories have been conducted on healthy subjects exposed to experimental sleep deprivation (see Diekelmann et al., 2008, 2010 or restriction e.g. Lo, Chong, Ganesan, Leong, & Chee, 2016), while clinical samples have been neglected. As there is growing acceptance that the nature and severity of the cognitive consequences of these experimental sleep interventions differ from those reported in chronic sleep disorders (Shekleton, Rogers, & Rajaratnama, 2010), we intended to assess the effect of chronically disturbed sleep on false memories production.

Insomnia is a sleep disorder characterised by subjective complaints of non-restorative sleep and of difficulties in initiating and/or maintaining sleep, accompanied by decreased daytime functioning, which persist in time (American Psychiatric Association, 2013). Objective sleep impairments are also often reported in this population, such as changes in sleep architecture (i.e. reduction in slow-wave sleep and rapid eye movement [REM] sleep duration) compared to healthy subjects (Baglioni et al., 2014). Moreover, individuals with insomnia show several cognitive impairments that could contribute to false memories generation. It has been observed that they perform more poorly than good sleepers on complex cognitive tasks depending on the efficiency of the prefrontal cortex, e.g. in tests assessing working memory (e.g. retention and manipulation of previously acquired information), problem solving, information processing, and selective attention (for a review see Fortier-Brochu, Beaulieu-Bonneau, Ivers, & Morin, 2012).

Other factors are likely to modulate the effects of disordered sleep on false memories production. For instance, an important one could be the nature of the administered stimuli. Indeed, several studies report that individuals with insomnia preferentially focus their attention on stimuli that are related to sleep, which appear to them more salient than neutral ones (Espie, Broomfield, MacMahon, Macphee, & Taylor, 2006; Harvey, 2002). This phenomenon is known as "attentional bias" and has been previously observed in this population through specific cognitive tasks, such as the Stroop task (Spiegelhalder, Espie, Nissen, & Riemann, 2008; Zhou et al., 2018), the dot probe task (MacMahon, Broomfield, & Espie, 2006), priming tasks (Giganti et al., 2017), and eye-tracking paradigms (Woods, Scheepers, Ross, Espie, & Biello, 2013). Overall, these studies suggest that sleep-related stimuli induce a higher activation in individuals with insomnia relative to good sleepers, leading the former to respond differently to these stimuli. For instance, it has been observed that individuals with insomnia, compared to good sleepers, show slower reaction times for sleep-related stimuli at the Stroop task (Spiegelhalder et al., 2008; Zhou et al., 2018) and that they recognise these stimuli at lower spatial frequencies in a priming task (Giganti et al., 2017). Instead, the effect of stimulus category has not yet been investigated in tasks based on semantically associated items, such as the Deese–Roediger–McDermott paradigm (DRM; Roediger & McDermott, 1995).

A complementary hypothesis has been sometimes put forward (e.g. Williams, Mathews, & MacLeod, 1996) that the attentional bias may reflect the way in which "experts" react to their expertise-related stimuli when performing specific tasks. A few studies actually show that experts generally produce higher rates of false memories for words that are related to the domain of their expertise compared to non-experts (Baird, 2003; Castel, McCabe, Roediger, & Heitman, 2007). This finding is attributed to the stronger semantic activation occurring in experts: in the case of DRM word lists, expertise would increase the number and strength of associations between expertise-related terms and enhance the spreading activation to include the non-presented critical words.

In light of this literature, the investigation of the effects of stimulus category in a DRM task in individuals with insomnia, who may be considered "experts" and strongly activated by the theme of sleep (Espie et al., 2006; Harvey, 2002), appears particularly interesting.

The first aim of the present study was to assess whether chronic poor sleep quality in subjects with insomnia affects false memories production. To this end, we compared performance at the DRM paradigm (Roediger & McDermott, 1995) between a group of individuals showing insomnia symptoms and one of good sleepers. In light of literature on the attentional bias described in people with insomnia (Giganti et al., 2017; Harris et al., 2015), we also evaluated the possible effect of stimulus category by comparing performance at neutral and sleep-related word lists included in the DRM task. Finally, considering the association between false memories production and executive functioning (e.g. Leding, 2012; Peters, Jelicic, Verbeek, & Merckelbach, 2007), as well as the observed impairments of these functions in insomnia (for example see Haimov, Hanuka, & Horowitz, 2008; Joo et al., 2013), we assessed in both groups working memory, inhibitory control and source monitoring ability, the latter being considered as especially linked to false memories formation (Mitchell & Johnson, 2000).

2 | METHODS

2.1 | Participants and procedure

A total of 80 potential participants were approached at university sites (i.e. lecture halls, library, etc.) and asked to complete a set of screening questionnaires: the Pittsburgh Sleep Quality Index (PSQI; Italian version from Curcio et al., 2013), Insomnia Severity Index (ISI; Italian version from Castronovo et al., 2016), Sleep Disorder Questionnaire (SDQ; Violani, Devoto, Lucidi, Lombardo, & Russo, 2004), Beck Depression Inventory II (BDI-II; Italian version from Sica & Ghisi, 2007), and Beck Anxiety Inventory (BAI; Italian version from Sica & Ghisi, 2007) described in detail below. In addition, they were administered a semi-structured interview at the sleep laboratory, conducted by a licensed psychologist who had received specific training, in order to assess general medical condition and health habits, presence of psychiatric disorders and sleep disorders. The presence of clinical insomnia was specifically addressed by means of the semi-structured interview (Morin, 1993).

Based on scores at the screening instruments and on the interview, 53 university students were recruited for the study and included in either the "good sleep group" (GS Group, $n = 28$) or the "insomnia group" (IN Group, $n = 25$). Inclusion criteria common to

both groups were: absence of any relevant somatic or psychiatric disorder; absence of clinically significant depression and anxiety symptoms (BDI-II score ≤29; BAI score ≤25); no history of drug or alcohol abuse; absence of sleep disorders (other than insomnia for the IN Group) and of any sleep apnea or respiratory disorder symptom; having a regular sleep–wake pattern (e.g. individuals with irregular study or working habits such as shift-working were excluded); no use of psychoactive medication or alcohol at bedtime. In addition, for inclusion in the IN Group, participants had to score ≥5 at the PSQI, ≥8 at the ISI and to be classified as presenting "clinically significant insomnia" at the SDQ; further, they had to fully meet Diagnostic and Statistical Manual of Mental Disorders, fifth edition (DSM-5) criteria for Insomnia Disorder, as verified through the interview. Finally, inclusion in the GS Group was based on: PSQI score <5, ISI score <8, being classified as a "good sleeper" at the SDQ, and absence of any sleep disorder as also verified through the interview.

The two groups did not differ for age, gender distribution, circadian preference (measured through the reduced version of the Morningness–Eveningness Questionnaire; Italian version from Natale, Esposito, Martoni, & Fabbri, 2006) and daytime sleepiness (measured through the Epworth Sleepiness Scale; Italian version from Vignatelli et al., 2003). Instead, as expected, significant between-group differences emerged in several habitual sleep features assessed through the PSQI, such as bedtime, sleep duration and sleep onset latency, as well as in PSQI global scores (Table 1).

Participants were requested to complete a sleep diary on the day of the DRMs testing session, in order to control that they performed the task after a night of sleep that was representative of their habitual sleep. In Table 2 we report the sleep measures of the night before the administration of the memory task in both groups.

All selected participants were individually invited to the sleep laboratory, where they were administered the DRM paradigm (Roediger & McDermott, 1995).

On separate days, a subsample of 17 participants from the IN Group (eight males and nine females; mean [*SD*] age of 24.5 [2.2] years) and 21 from the GS Group (eight males and 13 females; mean [*SD*] age of 24.1 [2.2] years) were again invited individually to the sleep laboratory where they were administered a set of cognitive tests to evaluate executive functioning and source monitoring ability. Table 3 lists demographic characteristics, circadian preference, daytime sleepiness and habitual sleep features of the subsample. All testing sessions (both the DRM and the executive functioning tasks) were performed in the morning, between 11:00 a.m. and 1:00 p.m., by an experimenter who was blind to the study group.

There was no money or credit compensation for participating in the study.

The study design was submitted to the Ethical Committee of the Department of Psychology, University of Campania "L. Vanvitelli", which approved the research (code 22/2020) and certified that the involvement of human participants was performed according to acceptable standards.

2.2 | Screening instruments

1. The PSQI (Italian version from Curcio et al., 2013), a self-report questionnaire evaluating subjective sleep quality in the past month. It is composed of 19-items grouped into seven subscales: Subjective Sleep Quality, Sleep Latency, Sleep Duration, Habitual Sleep Efficiency, Sleep Disturbances, Use of Sleep Medication and Daytime Dysfunctions due to sleepiness. The PSQI total score ranges from 0 to 21, with higher scores indicating sleep difficulties and lower sleep quality. The cut-off score of ≥5 is adopted to discriminate between good and bad sleepers.

TABLE 1 Age, gender distribution, circadian preference, daytime sleepiness, habitual sleep features and sleep quality in the insomnia group (IN Group) and good sleep group (GS Group)

Variable	IN Group	GS Group	Statistical test
Age, years, mean (*SD*)	25.16 (4.34)	24.10 (3.17)	$U = 278.50$, $p = 0.19$
Gender, male/female, *n*	13/12	11/17	$\chi^2 = 0.86$, $p = 0.862$
MEQr score, mean (*SD*)	13.00 (2.61)	14.54 (3.18)	$U = 245.00$, $p = 0.06$
ESS score, mean (*SD*)	7.64 (2.82)	6.32 (3.28)	$U = 253.00$, $p = 0.11$
Habitual bedtime, hh:mm, mean (*SD*)	00:32 (00:52)	23:32 (00:59)	$U = 91.50$, $p = 0.001$
Habitual rise time, hh:mm, mean (*SD*)	08:08 (01:04)	07:32 (01:23)	$U = 182.50$, $p = 0.233$
Habitual sleep duration, hh:mm, mean (*SD*)	06:27 (00:59)	07:41 (00:48)	$U = 78.50$, $p < 0.001$
Habitual sleep onset latency, hh:mm, mean (*SD*)	00:25 (00:13)	00:11 (00:05)	$U = 116.00$, $p < 0.001$
PSQI global score, mean (*SD*)	8.16 (2.26)	3.21 (0.87)	$U = 0.000$, $p < 0.001$

ESS, Epworth Sleepiness Scale; GS Group, good sleep group; IN Group, insomnia group; MEQr, Morningness–Eveningness Questionnaire (reduced version); PSQI, Pittsburgh Sleep Quality Index.

Habitual bedtime, rise time, sleep duration and sleep onset latency were collected through the PSQI. Mann–Whitney *U* is reported for between-groups comparisons for all variables except gender. Results of the chi-squared test are reported for differences in gender distribution.

TABLE 2 Sleep features of the night preceding the DRM task session in the insomnia group (IN Group) and good sleep group (GS Group)

Variable	IN Group	GS Group	Statistical test
Bedtime, hh:mm, mean (*SD*)	00:42 (00:47)	23:46 (00:55)	$U = 85.50$, $p = 0.003$
Rise time, hh:mm, mean (*SD*)	07:50 (01:01)	07:48 (00:51)	$U = 219.50$, $p = 0.98$
Sleep duration, hh:mm, mean (*SD*)	06:47 (01:01)	07:52 (01:06)	$U = 0.004$, $p = 0.004$
Sleep onset latency*	3 (i.e. "≥15 min")	2 (i.e. "10 min")	$U = 202.00$, $p = 0.010$
Number of awakenings, mean (*SD*)	1.2 (1.18)	0.53 (0.83)	$U = 235.50$, $p = 0.025$
Rise time latency*	2 (i.e. "10 min")	1 (i.e. "5 min")	$U = 206.00$, $p = 0.019$

Sleep features were collected through sleep logs. Mann–Whitney *U* is reported for between-groups comparisons for all variables. An asterisk (*) indicates median values. Prior night's sleep onset latency was obtained through the question: "How long did it take you to fall asleep last night?" ("<5 min", "5 min", "10 min", "≥15 min"). Rise time latency was obtained through the question: "How long did it take you to rise from bed after this morning's awakening?" ("<5 min", "5 min", "10 min", "≥15 min").

TABLE 3 Age, gender distribution, circadian preference, daytime sleepiness, habitual sleep features and sleep quality in participants of the subsample

Variable	IN Group	GS Group	Statistical test
Age, years, mean (*SD*)	24.53 (2.18	24.10 (3.56)	$U = 143.00$, $p = 0.31$
Gender, male/female, *n*	8/9	8/13	$\chi^2 = 0.310$, $p = 0.578$
MEQr score, mean (*SD*)	12.82 (2.51	14.52 (3.61)	$U = 127.50$, $p = 0.136$
ESS score, mean (*SD*)	8.35 (3.58	6.57 (3.52)	$U = 119.00$, $p = 0.08$
Habitual bedtime, hh:mm, mean (*SD*)	00:36 (00:49	23:21 (00:40)	$U = 27.50$, $p < 0.001$
Habitual rise time, hh:mm, mean (*SD*)	07:51 (01:14	07:23 (00:51)	$U = 87.00$, $p = 0.305$
Habitual sleep duration, hh:mm, mean (*SD*)	06:22 (00:59	07:39 (00:48)	$U = 33.50$, $p = 0.001$
Habitual sleep onset latency, hh:mm, mean (*SD*)	00:27 (00:14	00:10 (00:04)	$U = 41.00$, $p < 0.001$
PSQI global score, mean (*SD*)	8.35 (3.58	3.19 (0.98)	$U = 0.000$, $p \leq 0.001$

ESS, Epworth Sleepiness Scale; GS Group, good sleep group; IN G, insomnia group; MEQr, Morningness–Eveningness Questionnaire (reduced version); PSQI, Pittsburgh Sleep Quality Index.

Habitual bedtime, rise time, sleep duration and sleep onset latency were collected through the PSQI. Mann–Whitney *U* is reported for between-groups comparisons for all variables except gender. Results of the chi squared test are reported for differences in gender distribution.

2. The ISI (Italian version from Castronovo et al., 2016), assessing the severity of insomnia symptoms during the previous 2 weeks. Based on the scores, subjects are classified into four categories: (a) no clinically significant insomnia (score 0–7); (b) subthreshold insomnia (8–14); (c) clinical insomnia – moderate severity (score 15–21); (d) clinical insomnia – severe (22–28).
3. The SDQ (Violani et al., 2004) is a self-rating questionnaire with 27 items evaluating the presence of different sleep problems in the last month. The first three questions concern symptoms of insomnia, while the others investigate the presence of excessive sleepiness, sleep apnea, parasomnias, and snoring. A subsequent set of questions investigates the duration, frequency, and consequences of the sleep problem, and is used for the evaluation of the severity of the sleep disturbances reported. The SDQ permits the classification of subjects into three main categories: subjects who do not complain of any sleep disorder; subjects who report the occurrence of subthreshold insomnia and subjects with clinically significant insomnia.
4. The BDI-II (Italian version from Sica & Ghisi, 2007) assesses the severity of depressive symptoms. It comprises 21 items and the total score ranges from 0 to 63, with higher scores indicating more severe depressive symptoms. Particularly, scores 0–13 represent minimal depression, scores 14–19 mild depression, scores 20–28 moderate depression, and scores 29–63 severe depression symptoms.
5. The BAI (Italian version from Sica & Ghisi, 2007), a self-report instrument assessing the presence and severity of anxiety symptoms in the past week. It comprises 21 items measuring the intensity of common somatic and cognitive symptoms of anxiety through a Likert scale ranging from 0 (Not at all) to 3 (Severely – it bothered me a lot). The score range is 0–63, with higher scores indicating more severe anxiety symptoms: specifically, a total score of 0–7 is considered to index minimal severity, 8–15 mild, 16–25 moderate, and 26–63 severe.

2.3 | False memories task

In the classical DRM paradigm (Roediger & McDermott, 1995), an immediate free recall test is administered on a list of words that are semantically associated to an unstudied critical word (e.g. "ink", "paper", "school", all related to "pen"). This task reliably produces high rates of false memories for unstudied critical lures (Roediger & McDermott, 1995).

In order to highlight the possible effect of stimulus category, here we adopted, as in Baird (2003), a reduced version of the DRM paradigm (Roediger & McDermott, 1995) consisting in the presentation of four-word lists made up of 15 words each. Indeed, as observed in a recent meta-analysis (Newbury & Monaghan, 2019), the length of the lists rather than their number appears to significantly affect false recall rates (with longer lists producing greater false recall).

The sleep-related list used in this study (i.e. the one corresponding to the unpresented lure "sleep") was created ad hoc in Italian following the method used by Iacullo and Marucci (2016), due to the absence of any such standardised list in Italian. Thus created, the list was preliminarily presented to 30 university students (21 females and nine males; mean [*SD*] age of 24.10 [4.06] years), not enrolled in the present study, to assess the false recall rate for it (which was 27%). Then, we selected from Iacullo and Marucci (2016) the three lists showing the most similar false recall rates. The selected lists, corresponding to the lures "flag", "pen", and "river", all showed a false recall rate of 21%. Furthermore, in order to test possible differences between our sleep-related list and the neutral one, 25 individuals (16 females and nine males; mean [*SD*] age of 25.88 [3.23] years), who were not enrolled in the main study, were asked to rate on a 1–5 Likert scale the sleep-relatedness, familiarity, activation and valence of each word belonging to the two lists, as well as their respective critical lures. Comparisons between the two lists revealed no significant difference for familiarity ($t = -1.00$, $p = 0.33$), activation ($t = 0.57$, $p = 0.57$) or valence (which was judged as neutral for both lists; $t = -1.31$, $p = 0.20$), whereas a significant difference emerged for sleep-relatedness ($t = -17.6$, $p \leq 0.001$).

As in Roediger and McDermott (1995) and Iacullo and Marucci (2016), the words in each list were presented in order of associative strength with the unpresented lure (from strongest to weakest).

As for task administration, the experimenter read the lists aloud with an interval of 20 s between lists. Participants were instructed to memorise the words as accurately as possible and were informed that they would be tested on them later. The "flag" and "river" lists (List 1 and 4, respectively), here used to control for primacy and recency effects as in Baird (2003), were presented to all participants as the first and last list of the set, respectively. The order of presentation of the "pen" and "sleep" lists (List 2 and 3, respectively), instead, was balanced between subjects (Baird, 2003).

After the "river" list was presented, participants performed the free recall test. Specifically, they were requested to write down on a blank piece of paper as many words as possible from all the presented lists. They were allotted 5 min for recall. In order to hold recall time constant between subjects, participants were instructed to continue thinking about the words for the whole allotted time.

2.4 | Executive functioning tasks

For the assessment of executive functioning we employed classical tasks that measure the main executive components (e.g. Denckla, 1994; Miyake et al., 2000): specifically, working memory was evaluated through the Working memory subtests of the Wechsler Adult Intelligence Scale, fourth edition (WAIS-IV; Wechsler, 2008) and inhibitory control was tested through the Stroop task (Stroop, 1935). In addition, we created an ad hoc task aimed to evaluate source monitoring ability, which is deemed to be specifically linked to false memories formation (Mitchell & Johnson, 2000).

1. Working memory subtests of the WAIS-IV (Wechsler, 2008), including the Digit Span subtest (made up of three increasingly difficult tasks: digit span forwards, backwards, and sequencing) and the Arithmetic subtest (requiring to perform mental arithmetic problems): taken together, performance at these tasks provides the Working Memory Index (WMI), a global measure of the ability to attend to information presented verbally, manipulate it in short-term memory, and then formulate a response. The tests were administered according to the standard procedure reported in the WAIS-IV manual.
2. Stroop Colour and Word Test (Stroop, 1935): here we adopted a computerised version of the task developed on the Open Sesame software (version 3.3.8). The stimuli consisted of the words "red," "green," "yellow" and "blue" presented at the centre of a black computer screen in one of the four colours. The colour of the word displayed corresponded to its meaning in 50% of the trials (congruent condition), whereas in the remaining 50% of the trials word colour and meaning were different (incongruent condition). Subjects had to indicate, as soon as possible, the colour of the text by pressing a key on the keyboard corresponding to the effective colour of the text. Subjects performed a short training phase consisting of 24 trials in order to familiarise with the task and afterwards they performed the task including 240 trials.
3. Source Monitoring task: a computerised Source Monitoring Task (see Supporting Information) was included to evaluate the ability to discriminate between different sources of information. We developed this task from Nienow and Docherty (2004), who originally evaluated internal source monitoring ability, that is the ability to discriminate between two internal sources of information. According to the classification of source monitoring's types proposed by Johnson, Hashtroudi, and Lindsay (1993), we extended the original task in order to test External Source Monitoring (i.e. the ability to discriminate between two externally derived sources of information) and Reality Monitoring ability (i.e. the ability to discriminate between internal and external information sources). Therefore, our task included three different subtests: Internal Source Monitoring (I-SM), External Source Monitoring (E-SM) and Reality Monitoring (RM-SM). Tasks presentation was counterbalanced between subjects.

2.5 | Data analysis

Outcome measures of the DRM task were: number of false memories, i.e. total number of falsely recalled critical lure words; number of veridical memories, corresponding to the total number of words

correctly recalled from the original word lists; number of intrusions, representing the total number of recalled words not corresponding to studied items or to the critical lure words. Only performance at the two experimental lists ("pen" and "sleep" lists) were included in data analysis, as the first and last lists ("flag" and "river" lists) were used to control for primacy and recency effects (as in Baird, 2003). Veridical memories were significantly more numerous for lists one and four compared to lists two and three (lists one and four: mean [*SD*] 11.64 [2.58] versus lists two and three: mean [*SD*] 9.98 [3.18]; Wilcoxon's *Z*: 878.00; $p < 0.001$; ES:0.624), confirming the presence of primacy and recency effects.

Concerning executive functioning, the outcome measures were: digit span scores, arithmetic scores and the WMI obtained from the WAIS-IV subtests, as well as number of correct responses, number of errors and response times (ms) for the Stroop task. Finally, Table 4 displays outcome variables considered for the source monitoring task.

Due to non-normal distribution of the data, we employed non-parametric statistics. Cardinal variables were compared between the IN and GS groups through the Mann–Whitney *U* test. Within-subject comparisons were performed through the Wilcoxon signed-rank test. Finally, Spearman and point-biserial correlation analysis were performed to test the association memory performance, cognitive testing, and source monitoring ability in the whole sample. Spearman correlation was also performed to assess associations between sleep features of the night before the DRM session and DRM performance in the whole sample. The statistical significance level was set at $p \leq 0.05$.

To test the interaction between groups and stimulus type, we analysed the data with a mixed model logistic regression using the statistical software R (version 4.0.3) and the package "lme4". In this analysis, we considered the total number of false memories as dependent variable, the group (GS Group and IN Group) as fixed effect. The random effects were the type of list and participant unique identifier.

We also performed a mediation analysis (using PROCESS macro; SPSS version 27; Hayes, 2018) to test the role of source monitoring ability as mediator of the relationship between sleep quality (i.e. IN Group and GS Group) and the total number of false memories produced. We considered "Group" as independent variable and the total number of false memories as dependent variable. The considered mediator was the source monitoring ability, calculated by summing up all the correct responses to the three source monitoring subtests (i.e. I-SM, E-SM, and RM-SM). We calculated the indirect effect of "Group" on false memories production, through source monitoring ability, quantified as the product of the ordinary least squares (OLS) regression coefficient estimating source monitoring ability from "Group" and the OLS regression coefficient estimating false memories production from source monitoring ability controlling for "Group". A bootstrapping procedure (with 5,000 bootstrap samples) to estimate 95% confidence intervals (CIs) was used. According to Preacher and Hayes (2008), a 95% CI that does not include zero provides evidence of a significant indirect effect.

An a priori power analysis was conducted. Taking into account the sample size of the study and an α level of 0.05, a power analysis based on Mann–Whitney *U* test testified that we were able to detect an effect size equal to $p = 0.717$ (i.e. P represents the effect size index (Trumble, Ferrer, Bay, & Mollan, 2020), in particular, $P(X<Y)$ where X represents random draws from the first probability distribution and Y represents random draws from the other distribution) with a power equal to 0.80.

TABLE 4 Outcome variables of the source monitoring task

Source Monitoring task		
Subtest	**Variable**	**Description**
I-SM	I – correct	The number of words correctly attributed to the internal sources of information
	I – Index 1	The proportion of words correctly identified as "said" out of the total number of words correctly recognised as "old"
	I – Index 2	The proportion of words correctly identified as "thought" out of the total number of words correctly recognised as "old"
E-SM	E – correct	The number of words correctly attributed to the external sources of information
	E – Index 1	The proportion of words correctly identified as from "man" source out of the total number of words correctly recognised as "old"
	E – Index 2	The proportion of words correctly identified as from "women" source out of the total number of words correctly recognised as "old"
RM-SM	RM – correct	The number of words that were correctly attributed to the internal and the external sources of information
	RM – Index 1	The proportion of words correctly identified as from internal source out of the total number of words correctly recognised as "old"
	RM – Index 2	The proportion of words correctly identified as from external source out of the total number of words correctly recognised as "old"

E-SM, external source monitoring subtask; I-SM, internal source monitoring subtask; RM-SM, reality monitoring subtask.

3 | RESULTS

3.1 | False memories task

The IN Group globally produced more false memories ($U = 247.00$; $p = 0.04$; $ES = -0.27$) than the GS Group (Figure 1). No differences emerged between groups in the total number of veridical memories (mean [*SD*] IN Group 9.44 [3.33] versus GS Group 10.36 [2.93]; $U = 284.00$, $p = 0.24$) or in the number of intrusions (mean [*SD*] IN Group 1.24 [1.09] versus GS Group 1.18 [1.02]; $U = 340.50$, $p = 0.86$).

Moreover, the IN Group generated more false memories ($U = 254.00$; $p = 0.04$; $ES = -0.28$; Figure 2) and less veridical memories ($U = 242.500$; $p = 0.05$; $ES = -0.27$; Figure 3) at the sleep-related list compared to the GS Group. Instead, the two groups did not differ neither in the number of false memories (mean [*SD*] IN Group 0.52 [0.51] versus GS Group 0.36 [0.48]; $U = 239.00$, $p = 0.24$) nor of veridical memories (mean [*SD*] IN Group 5.52 [2.48] versus GS Group 5.50 [1.67]; $U = 349.5$, $p = 0.99$) at the neutral list.

As for within-subjects comparisons, the IN Group produced less veridical memories for the sleep-related list compared to the neutral list ($Z = -2.587$, $p = 0.01$; $ES = -0.52$; Figure 3), while no differences between lists emerged in the number of false memories ($Z = -0.378$, $p = 0.71$; Figure 2). The GS Group did not show differences in the number of false memories ($Z = -0.471$, $p = 0.63$; Figure 2) or veridical memories ($Z = -1.81$, $p = 0.10$; Figure 3).

As for the linear regression model, we observed a significant main effect of Group ($F_{1,51} = 5.00$, $p = 0.03$), whereas no significant main effect of list type ($F_{1,51} = 0.04$, $p = 0.84$) nor interaction effect ($F_{1,51} = 0.37$, $p = 0.55$) emerged.

3.2 | Executive functioning tasks

No between-groups differences emerged at the working memory and Stroop tasks (Table 5).

As for source monitoring ability, the IN Group had lower scores in Index 1 at the RM-SM subtest compared to the GS Group ($ES = -0.29$; Table 6), suggesting difficulties in correctly discriminating between internal and external sources of information. There were no other between-groups differences.

The number of false recalls at the sleep-related list showed a negative correlation with the number of correct responses to the Stroop task ($r = -0.355$, $p = 0.03$) and a positive correlation with the number of errors ($r = 0.355$, $p = 0.03$), while the number of veridical recalls for the same list positively correlates with the digit span score ($r = 0.376$, $p = 0.02$) and the WMI of the WAIS-IV ($r = 0.344$, $p = 0.03$). Also, the total number of veridical memories showed a positive correlation with the WMI of the WAIS-IV ($r = 0.352$, $p = 0.03$) and a negative correlation with the total number of errors at the I-SM task ($r = -0.322$, $p = 0.05$). As for the relationship between sleep measures of the night preceding the DRM session and subsequent DRM performance, we observed a positive correlation between the total number of false memories and the number of night awakenings ($r = 0.267$, $p = 0.05$), whereas the total number of veridical memories showed a trend to a significant positive correlation with sleep duration ($r = 0.266$, $p = 0.09$). No other significant correlations emerged.

The results of the mediation analysis revealed a non-significant indirect effect of sleep quality on false memories production through source monitoring ability (point estimate = 0.04, 95% CI −0.085, 0.086).

4 | DISCUSSION

In the present study we investigated false memories production in individuals with insomnia and in good sleepers, assuming that poor sleep quality and its cognitive consequences (see for a review Fortier-Brochu et al., 2012) can render the former more prone to this phenomenon.

As a main result, we observed that the IN Group globally produced more false memories compared to the GS Group, thus supporting an association between sleep quality and false memories production. In light of the literature on cognitive functioning in insomnia disorder, this result is of particular interest. According to the Activation-Monitoring theory (Roediger & McDermott, 1995; Roediger, Watson, McDermott, & Gallo, 2001), during the retrieval phase participants generally rely on a source monitoring process to separate items that were studied from those that were not: in this phase, frontally mediated executive functions are essential to ensure efficient source monitoring and memory accuracy (Johnson, Raye, Mitchell, & Ankudowich, 2012). In this regard, it has been observed that false memories production is increased in healthy subjects after sleep deprivation (Diekelmann et al., 2008, 2010), a procedure that strongly affects prefrontal functioning (Durmer & Dinges, 2005). In subjects with insomnia, previous studies documented diurnal impairment in the same cognitive functions that may help to reject false memories and ensure efficient memory recall, i.e. retention and manipulation of information in working memory, inhibitory control, and cognitive flexibility (Fortier-Brochu et al., 2012).

In our present study, we did not observe significant between-groups differences in most executive tasks. However, it would be hazardous to rule out the presence of executive impairments in insomnia. It might be that the changes in cognitive performance reported in the present population are of a subtler and more situational kind (Fortier-Brochu et al., 2012) and therefore went partially undetected in the classical neuropsychological tasks adopted here. Moreover, the suggested relationship between executive functioning and performance at the DRM paradigm (see e.g. Leding, 2012; Peters et al., 2007) seems to be supported by the correlational analysis. In fact, we observed that the number of false recalls is negatively associated with accuracy at the Stroop task, and, conversely, that the number of veridical memories correlates both positively with the WMI and negatively with accuracy at the source monitoring task.

Additionally, an interesting result comes from the RM-SM subtest of the source monitoring task, at which the IN Group were less

accurate than the GS Group. Importantly, this bias was limited to the RM-SM subtest, which requires participants to discriminate between internally and externally generated stimuli, i.e. the same ability required by the DRM task (while it did not extend to the ability to discriminate between two internal or two external sources). Together with our observation of higher false recall in the IN Group, this finding lends support to the Source Monitoring Framework (SMF) in the explanation of false memories formation (Mitchell & Johnson, 2000) and to the hypothesis that the protective role of executive functioning against false memory is weakened in subjects with insomnia. In fact, according to the SMF, false memories arise from an error of commission, that is when thoughts or images coming from one source (e.g. an external one) are erroneously attributed to another one (e.g. an internal one; Mitchell & Johnson, 2000). The ability to correctly discriminate between two sources of information is linked to the efficiency of executive functioning and especially of memory retrieval processes (Johnson et al., 2012): the latter are strongly modulated by prefrontal functioning and are affected by acute (Durmer & Dinges, 2005; Frenda & Fenn, 2016; Mitchell & Johnson, 2000) and chronic sleep loss, as in the case of individuals with insomnia (Fortier-Brochu et al., 2012). Therefore, in line with the SMF, we may explain our present results by assuming that the IN Group produced more numerous false memories than the GS Group because they are more susceptible to errors of commission as a consequence of their chronic sleep loss.

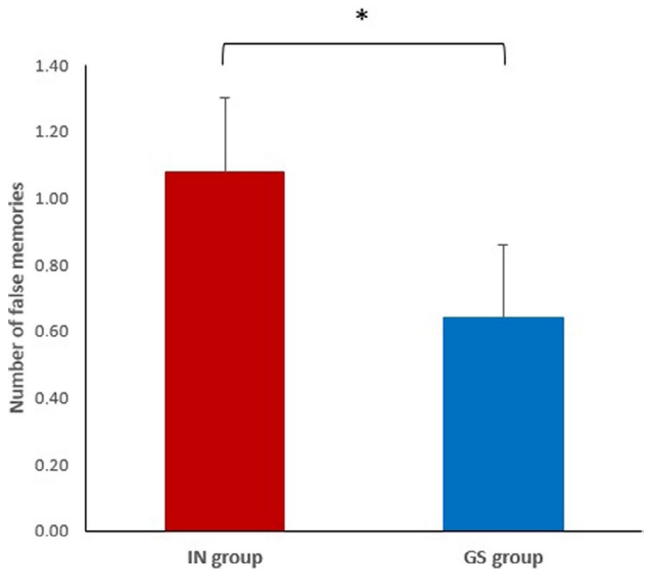

FIGURE 1 Comparison between the insomnia group (IN Group) and good sleep group (GS Group) in the total number of false memories. *$p \leq 0.05$. Error bars represent standard deviations

The data described so far should still be cautiously interpreted for the methodological limitation represented by the limited sample size, possibly accounting for the low magnitude of the finding and the negative results of our mediation analysis. However, taken overall, they encourage to thoroughly consider and further experimentally explore the hypothesis that the efficiency of executive functions, including the crucial source monitoring ability, promotes accurate retrieval and prevents false memories formation (Diekelmann et al., 2008; Peters et al., 2007).

Another interesting finding concerns the influence of stimulus type on DRM performance in the IN Group. In accordance with literature on the attentional bias for sleep-related stimuli in individuals with insomnia (Giganti et al., 2017; Harris et al., 2015), we observed greater false recall at the "sleep" list in the IN Group compared to the GS Group. Indeed, it is known that individuals with insomnia preferentially focus their attention on sleep-related items, considering them more salient and "threatening" than neutral ones (Espie et al., 2006; Harvey, 2002). This phenomenon has been previously

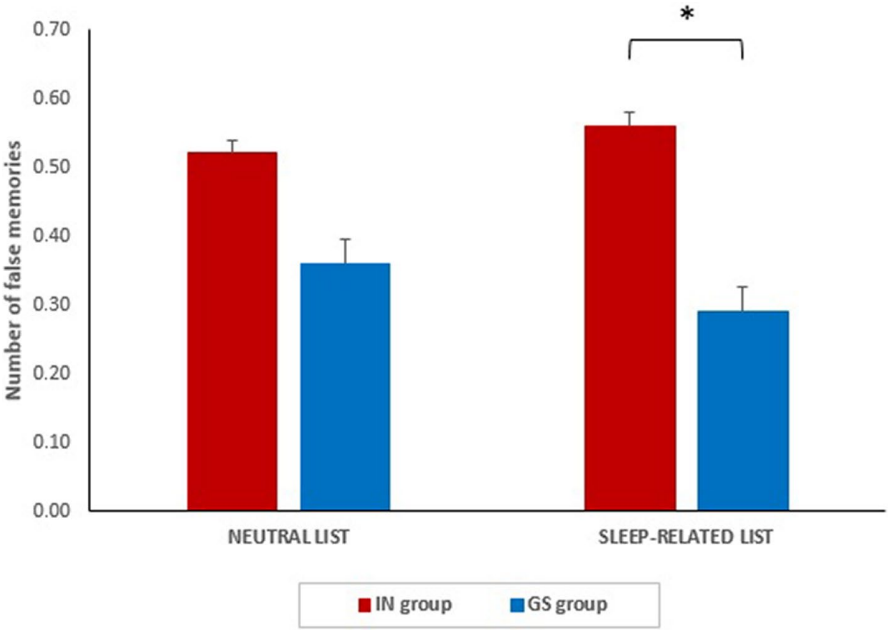

FIGURE 2 Comparison between the insomnia group (IN Group) and good sleep group (GS Group) in the number of false memories for neutral list and sleep-related list. *$p \leq 0.05$. Error bars represent standard deviations

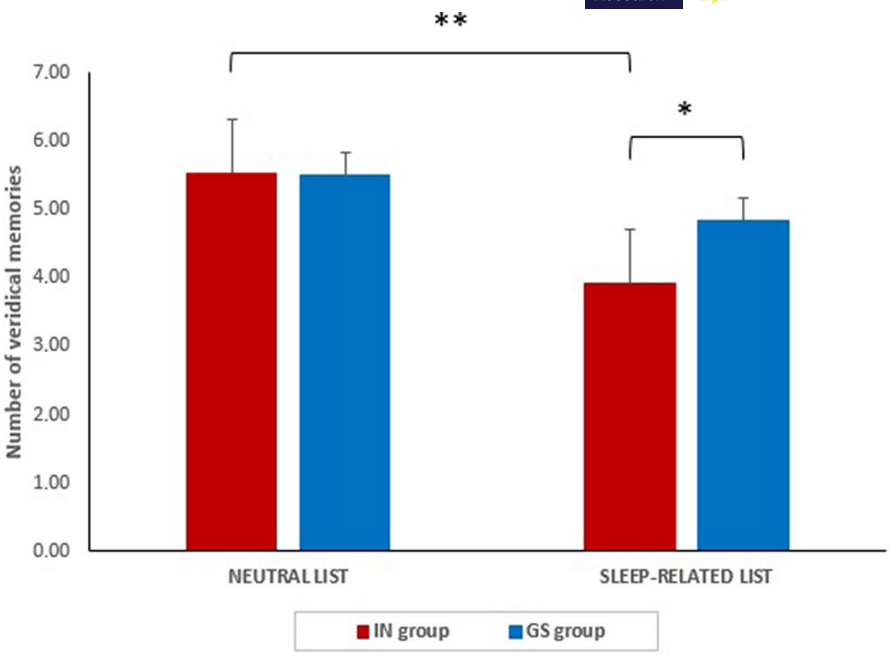

FIGURE 3 Number of veridical memories for neutral list and sleep-related list in the insomnia group (IN Group) and good sleep group (GS Group). $^{*}p \leq 0.05$; $^{**}p \leq 0.01$. Error bars represent standard deviations

TABLE 5 Comparison between the insomnia group (IN Group) and good sleep group (GS Group) in Stroop task and Wechsler Adult Intelligence Scale, fourth edition (WAIS-IV) performance

Task	Variable	IN Group, mean (*SD*)	GS Group, mean (*SD*)	*U*	*p*
Stroop	Stroop – correct responses	230.35 (29.54)	232.20 (25.52)	306.00	0.84
	Stroop – errors	9.65 (29.53)	7.80 (25.52)	363.00	0.85
	Stroop – response times	872.78 (163.26)	851.07 (177.47)	364.00	0.70
WAIS	Digit span subtest	9.71 (3.02)	9.57 (2.38)	322.50	0.87
	Arithmetic subtest	5.00 (3.06)	5.29 (3.28)	324.00	0.78
	Working Memory Index	84.82 (13.72)	85.38 (13.09)	325.50	0.90

TABLE 6 Comparison between the insomnia group (IN Group) and good sleep group (GS Group) in the source monitoring task

Subtest	Variables	IN Group, mean (*SD*)	GS Group, mean (*SD*)	*U*	*p*
I-SM	I – correct	18.64 (3.84)	19.19 (2.73)	166.00	0.61
	I – Index 1	56.18 (5.87)	55.87 (8.07)	177.00	0.83
	I – Index 2	43.82 (5.87)	44.13 (8.07)	177.00	0.82
E-SM	E – correct	18.11 (3.99)	18.38 (2.94)	169.50	0.82
	E – Index 1	55.10 (14.23)	56.14 (13.56)	167.00	0.84
	E – Index 2	44.91 (14.24)	43.85 (13.56)	167.00	0.88
RM-SM	RM – correct	20.52 (2.34)	19.00 (3.11)	125.50	0.43
	RM – Index 1	47.33 (6.22)	54.16 (13.52)	107.50	0.03
	RM – Index 2	51.28 (6.34)	45.65 (13.46)	114.50	0.21

E-SM, external source monitoring subtask; I-SM, internal source monitoring subtask; RM-SM, reality monitoring subtask.

observed through specific cognitive tests (see e.g. Giganti et al., 2017; MacMahon et al., 2006), but had not yet been investigated in a task based on strong semantic associations, such as the DRM paradigm. Previous studies on the DRM task show that, relative to neutral word lists, arousing and negatively valenced lists can promote stronger associative connections between their items, so that the non-presented lures undergo greater activation and their false recall is facilitated at subsequent recovery (Howe, Wimmer, Gagnon, & Plumpton, 2009; Otgaar, Howe, Brackmann, & Smeets, 2016). Therefore, we can explain our present result by assuming that, for our IN Group, items of the "sleep" list were more arousing and negatively valenced compared to the neutral list. Although in our study we did not directly ascertain whether the IN Group actually judged the sleep-related words as more negative and arousing than neutral ones, it has been

previously shown that emotional valence and arousing capacity of sleep-related stimuli strongly differ between subjects with insomnia and good sleepers (Baglioni et al., 2010; Zhou et al., 2018).

Here again, given that the regression model did not show a significant interaction between group and stimulus type, we should take into account, beyond the small sample size, two further limits of our present study: (a) we did not include a specific measure of attentional bias, which would have enabled us to exclude that between-groups differences are due to factors other than stimulus type; (b) we could not analyse fine-grained differences in characteristics of our DRM lists, such as semantic relatedness and forward–backward associative strength between words, that might have played a role.

Surprisingly, we observed that veridical recall at the "sleep" list was impaired in the IN Group, both relative to their own performance at the neutral list and to the GS Group. This result suggests that, in the IN Group, the attentional bias for the sleep-related list has different consequences on false and veridical memories, with an enhancement of false recall paralleling an impoverished veridical recall. Assuming in this group a higher activation driven by the salience of the sleep-list, a better veridical recall (relative both to the neutral list and to the GS Group) for this list could be expected. In fact, previous studies showed that, in subjects with insomnia, the attentional bias generally enhances performance on sleep-related stimuli by locating greater attentional resources on them (see e.g. Giganti et al., 2017; MacMahon et al., 2006). Moreover, studies adopting the DRM paradigm on healthy subjects showed that salient stimuli generally enhance both false memories and veridical recollection of stimuli (Baird, 2003; Castel et al., 2007). However, some authors pointed out that certain stimuli not only promote false memories production but also, in parallel, reduce veridical retrieval (Brainerd, Holliday, Reyna, Yang, & Toglia, 2010). To this regard, adopting the DRM paradigm, Brainerd et al. (2010) observed that stimuli with negative valence generally increase false memories production but, at the same time, can also suppress true memory recollection, explaining this result in light of the Fuzzy-Trace Theory (Brainerd & Reyna, 2002). According to this theory, subjects simultaneously encode two independent traces for each word, respectively the "verbatim trace" (i.e. the trace related to the contextual features of a word and especially linked to veridical memory, corresponding in the DRM paradigm to the "studied words") and the "gist" or "fuzzy" trace (i.e. the trace representing the meaning of an item, preferentially linked to false memories production). The presentation of arousing and negatively valenced stimuli generally leads to strong gist traces but, at the same time, could also interfere with simultaneous processing of verbatim traces, causing lower subsequent hit rates for negative targets (Brainerd et al., 2010). In our present study, the sleep-related word list might have performed in this way. In other words, supposing a high activation driven by the sleep-related list in our IN Group, the triggering of the gist trace "sleep" in this group could have: on one hand, promoted false recall at the sleep-related list; on the other hand, interfered with the processing of verbatim sleep-related traces and consequently impacted the veridical recall of words semantically associated to the gist trace.

Concerning the neutral word list, we did not observe between-groups differences either in the number of false or veridical memories. This result seems to suggest that, in absence of interference such as that linked to sleep-related stimuli, individuals with insomnia have an efficient declarative memory system for words that are semantically related. In fact, as further evidence of this cognitive efficiency, we did not detect between-groups differences in the number of intrusions (i.e. words not belonging to the original word lists and also not semantically related to the critical lure words). It could be the case that the well-documented declarative memory deficits in people with insomnia (Fortier-Brochu et al., 2012) specifically emerge in tasks assessing memory retrieval of semantically *unrelated* words. In other words, the semantic association between stimuli, which generally facilitates their recall (Aka, Phan, & Kahana, 2020; Silberman, Miikkulainen, & Bentin, 2005), would allow sleep-impaired individuals to achieve at the DRM task the same performance as good sleepers.

Because of the limited statistical power and the small effect size, our present results need to be carefully interpreted and require further replications in larger samples. Indeed, as pointed out by Fortier-Brochu et al. (2012), small sample size and low statistical power are a common issue in studies comparing cognitive performance between people with insomnia and good sleepers and may prevent the detection of small group differences. Nevertheless, our present results add to the previous literature on the attentional bias in subjects with insomnia and open to new research question.

In conclusion, our present data show that individuals with insomnia symptoms produce more false memories than good sleepers and point to a relevant role of the attentional bias for sleep-related stimuli in the DRM task in this clinical sample. Although we cannot assert that the increase in false memories production in people with insomnia is due to a widespread impairment of executive functioning, our present results highlight in this population a notable bias in source monitoring ability that could have contributed to their false memories production.

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CONFLICT OF INTEREST

The authors declare no conflicts of interest, no personal financial support and involvement with an organisation with financial interest in the subject matter of the paper.

AUTHOR CONTRIBUTIONS

All authors contributed in a meaningful way to this manuscript. Conceptualisation of the research, SM, FC, SR, GF, and FG; methodology, SM, FC, GG, GF, and F.G; formal analysis, SM, ODR, GG, and FG; investigation, SM and ODR; data curation, SM, GG, and FG; writing – original draft preparation, SM and FG; writing – review and editing, SM, FC, and FG; supervision, FC, GF, and FG; project

administration, GF and FG. All authors have read and agreed to the published version of the manuscript.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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SUPPORTING INFORMATION

Additional supporting information may be found in the online version of the article at the publisher's website.

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