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The Effect of Cognitive Activity on Sleep Maintenance in a Subsequent Daytime Nap

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Cinzia Arzilli[a], Mariangela Cerasuolo[b], Francesca Conte[b], Valentina Bittoni[a], Claudia Gatteschi[a], Benedetta Albinni[b], Fiorenza Giganti[a], and Gianluca Ficca[b]

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ABSTRACT

Background/Objective: The aim of this study is to assess the effects of a learning task on the characteristics of a subsequent daytime nap. *Participants and Methods*: Thirty-eight subjects were administered a control nap (C) and one preceded by a cognitive training session (TR). *Results*: Relative to C, TR naps showed significantly increased sleep duration with decreased sleep latency, as well as significantly increased sleep efficiency due to reduced awakening frequency. Meaningful trends were also found toward an increase of Stage 2 sleep proportion and a reduction of Stage 1 sleep, percentage of wake after sleep onset (WASO), and frequency of state transitions. *Conclusions*: Our results indicate that presleep learning favors sleep propensity and maintenance, offering the possibility to explore planned cognitive training as a low-cost treatment for sleep impairments.

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Pioneering Feinberg's research proposed that sleep can be affected by wake "content" (Feinberg, 1974). While the classical sleep regulation model (Borbély, 1982) explains sleep characteristics (namely, slow-wave activity) as a function of wake *duration*, Feinberg focused on wake *intensity* (i.e., quantity and quality of physical and cognitive activity). This alternative view received support by studies, in rats, showing relevant sleep changes after experimentally induced increases in cerebral metabolic rate during wake (Campbell & Feinberg, 1996a, 1996b; Feinberg & Campbell, 1993).

Later on, the idea that wake quality influences sleep has been strengthened by an extensive literature showing significant sleep changes after presleep learning sessions. The main experimental paradigm used to detect these modifications is the comparison between a habitual control sleep episode and one preceded by a learning session. In this kind of design, the sleep variables responsible for memory enhancement are expected to show specific increases during posttraining sleep, reflecting their role in the consolidation of memories (Peigneux, Laureys, Delbouck, & Maquet, 2001).These hypothesized postlearning increases have actually been documented for several sleep features. As for nighttime sleep, increases in sleep stage duration, such as REM (e.g., De Koninck, Lorrain, Christ, Proulx, & Coulombe, 1989) and Stage 2 sleep (Meier-Koll, Bussmann, Schmidt, & Neuschwander, 1999), and in sleep microstructural features, namely spindle activity (e.g., Fogel, Smith, & Cote, 2007; Tamaki, Matsuoka, Nittono, & Hori, 2009), sharp-wave ripple activity (e.g., Eschenko, Ramadan, Molle, Born, & Sara, 2008; Molle, Eschenko, Gais, Sara, & Born, 2009), REM density (e.g., Smith & Lapp, 1991) and P-waves density (Datta, 2000), were found after administration of different learning tasks. Also, in nap studies, enhancements of spindle activity were found after learning of unrelated words lists (Ruch et al., 2012; Schmidt et al., 2006). In a study by Ruch et al. (2012), training on a declarative task before a nap also resulted in an increase in delta activity and slow oscillations in Stage 2 sleep compared to a control nap.

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The majority of these studies focused on posttraining changes of discrete sleep components or events. Surprisingly, very few studies have instead assessed the effect of learning on sleep continuity, stability, and organization, given the growing evidence on the role of these parameters for effective sleep-dependent consolidation processes (see Conte & Ficca, 2013 for a review). Evidence on posttraining increases of these parameters would have meaningful clinical implications, since they appear to be relevant determinants of both subjective (Åkerstedt, Hume, Minors, & Waterhouse, 1994) and objective sleep quality (Bonnet, 1985, 1989).

Improvements in night sleep initiation and maintenance have been observed after a computerized cognitive training program in insomniac elderly adults (Haimov & Shatil, 2013); also, declarative learning was shown to increase sleep continuity (indexed by awakenings frequency), stability (i.e., sleep states transitions and arousals frequency), and organization (amount of uninterrupted sleep cycles and time spent in cycles) in healthy young (Mango, Albinni, Conte, Giganti, & Ficca, 2016) and elderly individuals (Conte, Carobbi, Errico, & Ficca, 2012). However, research extending these findings to daytime sleep is still lacking.

Furthermore, a general limitation of this literature concerns ecological validity. Indeed, in everyday life individuals are seldom engaged in the artificial tasks (often purely declarative or procedural) such as those employed in experimental research (Conte & Ficca, 2013).

Aim of this study is to address these issues by investigating the effects of an ecological cognitive task (a word game requiring the activation of multiple cognitive processes) on an afternoon nap, with special regard to objective sleep quality. A crossover design has been adopted, comparing sleep characteristics of a control nap with those of a nap preceded by a learning session, in a group of healthy adults.

Methods

Participants

Thirty-eight young adults (F = 23, M = 15; age range: 19–30 years; mean age: 22.1 ± 2.4 years) were recruited among university students. Participants were screened through a brief ad hoc interview to collect general demographic data and information on medical condition and health habits.

Inclusion criteria were: age 18–30 years; absence of any relevant somatic or psychiatric illness; no sleep apnea or respiratory disorders symptoms; no complaints of sleep disturbances, daytime sleepiness, or sleep-wake rhythm disruptions; no history of drug or alcohol abuse; limited caffeine (no more than 150 mg caffeine per day, corresponding to about three cups of espresso or one cup of American coffee) and alcohol (no more than 250 ml per day) consumption; afternoon nap propensity (assessed through a subjective 5-point scale: only subjects scoring ≥ 3 were included); being unfamiliar with the Ruzzle game (occasional players were included only if their score did not exceed 500 in a test round).

The local Ethical Committee approved the research protocol and all participants signed a consent form.

Procedure

Each subject underwent three afternoon nap recordings (approximately at 2 P.M.) at the sleep laboratory. An adaptation nap was followed by two conditions: (a) control nap, that is, a normal nap with 2-hr maximum time in bed (C); (b) posttraining nap, with the same maximum time in bed but preceded by a learning task (TR). The order of conditions was balanced between subjects in a randomized way.

For each participant, the interval between recordings was between 3 and 7 days. During the 3 days preceding each session, subjects were requested to complete a detailed sleep log to verify the

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regularity of their sleep–wake habits. Also, they were requested to maintain daily activities as habitually as possible and to avoid cognitively engaging activities (such as reading, playing cards, etc.) on recording days. In order to make sure that these conditions were met, we asked subjects to fill a short ad-hoc diary on daily activities. On the days scheduled for recording, the subject arrived at the sleep laboratory approximately at 13:00 and the experimenter proceeded to electrode montage. In C, subjects went to bed immediately after that, while in TR the training session was administered before bedtime.

To control for fatigue levels, a Visual Analogue Scale (VAS, 0 cm = not at all tired and 10 cm = very tired) for fatigue (Hewlett, Dures, & Almeida, 2011) was administered in both conditions immediately before lights off.

In the TR condition, retest was performed 15 min after awakening to allow sleep inertia dissipation (Signal, van den Berg, Mulrine, & Gander, 2012).

Polysomnographic recordings were performed following standard techniques (Rechtschaffen & Kales, 1968), through a multichannel recorder (Galileo EB Neuro).

Cognitive task

Training consisted in an ecological cognitive task, constructed as a slightly modified version of the interactive word game Ruzzle; an ad hoc software was created in order to have exactly the same stimuli for all subjects. Thirty Ruzzle rounds were randomly selected from the original game. These were classified in three levels of difficulty (easy, medium, difficult) according to their maximum global score (lower maximum scores corresponding to greater difficulty). Twenty-two rounds were randomly selected from the three groups and assigned to the four phases of the training scheme to obtain a balanced amount of easy, medium, and difficult rounds (Figure 1).

In each round, the player has 2 minutes to form (by touching an iPad screen) as many words as possible with the 16 letters available in the 4 × 4 grid. The final score of each round depends on the number of words identified, on word length, and on the use of the colored letters (6 per round) which allow the player to multiply the value of the words containing them (Figure 2).

In this way, the game triggers the simultaneous activation of several cognitive functions (semantic and procedural motor memory, working memory, planning, decision making).

Each training session lasted approximately 40 min and was carried out according to the following scheme (Figure 1):

(1) *baseline assessment*, consisting of 3 consecutive rounds, followed by a 2-min break;
(2) *training phase*, consisting of 5 trials, each made up of 2 consecutive rounds followed by a 1.5-min pause and with a final 5-min break;

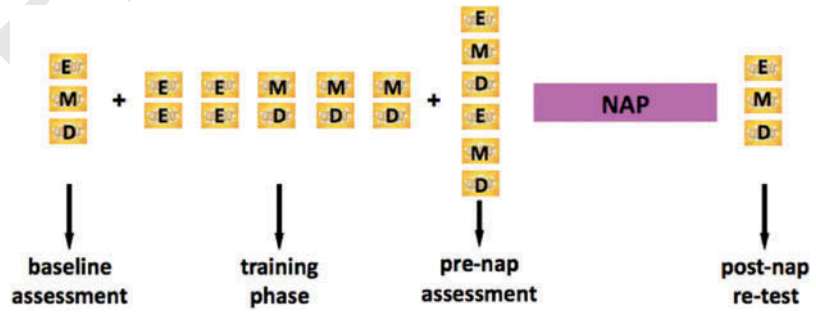

Figure 1. Training session scheme and post-nap retest. The different phases are highlighted with the number of game rounds composing them. Each yellow box represents a game round and the letter it contains indicates the level of difficulty: "E" for easy, "M" for medium, "D" for difficult.

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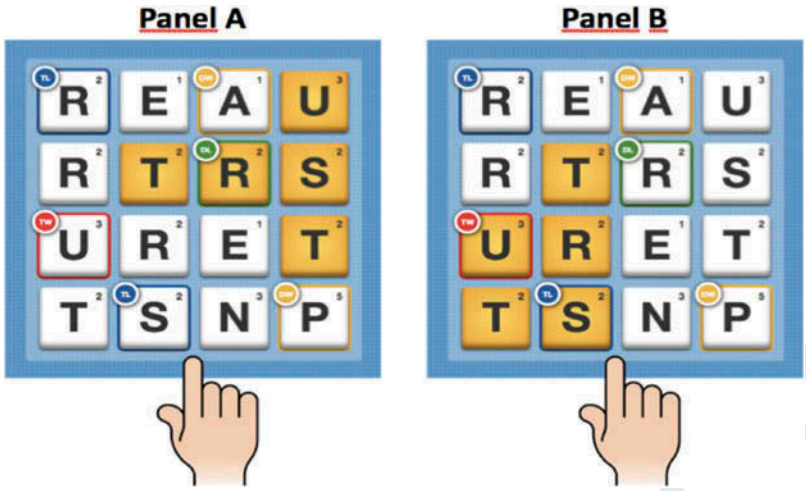

Figure 2. Example of a game grid. The two panels show an example of how the same word can be composed with different colored letters, whose particular properties determine different final scores. In Panel A, the score achieved for the word "trust" is lower than the one achieved in Panel B: in fact, in Panel A, the letter "R" score is doubled (DL = Double Letter), whereas in Panel B the letter "S" score is tripled (TL = Triple Letter) and, also, the whole word score is tripled (TW = Triple Word).

(3) *pre-nap assessment*, consisting of 6 consecutive rounds, during which subjects are instructed to try to achieve the highest global score and the highest possible number of words.

At retest upon awakening, subjects were administered another 3 consecutive rounds (*post-nap retest*).

Two measures, at pre-nap and post-nap assessments, were included in data analysis: (a) average global score (W score) and (b) average words percentage (W% score), that is, the percentage of detected words over the total available words.

Sleep measures

Sleep recordings were visually scored according to standard criteria (Iber, Ancoli-Israel, Chesson, & Quan, 2007) by an expert technician, blind to the study conditions. To verify scoring reliability, 10 randomly selected sleep recordings were also scored by another technician. Interrater agreement was 93.3%.

Classical sleep variables considered in the study were: Sleep Period Time (SPT, i.e., total amount of time in minutes from the first appearance of Stage 1 sleep to final awakening), Total Sleep Time (TST, i.e., total time spent in sleep states, expressed in minutes), Sleep Onset Latency (SOL), Sleep Efficiency (SE, i.e., percentage of TST over Time in Bed), sleep stage proportions, percentage of Wake After Sleep Onset (WASO) over SPT.

Objective sleep quality was also addressed through an additional set of variables (see Conte et al., 2012 for exact definitions) concerning sleep continuity (awakenings frequency and duration), sleep stability (state transitions and arousals frequency), "Functional Uncertainty" (FU) periods frequency and duration, percentage of Time spent in Functional Uncertainty over SPT (TFU%), and sleep organization (sleep cycles number and mean duration, Total Cycle Time [TCT], TCT%).

Data analysis

Statistical analysis was performed using the Statistical Package for Social Sciences (SPSS version 16.0). Due to nonnormal distribution of variables, nonparametric statistics was selected.

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To compare C and TR sleep variables and assess Ruzzle performance changes from pre-nap to post-nap assessment in TR, we used Wilcoxon's signed rank test—one-tailed, for directed hypotheses assuming (a) an improvement of sleep continuity and stability measures in TR, and (b) a better Ruzzle performance at post-nap recall.

Following statistical guidelines to correct for multiple testing without running a too high risk of Type II Error (see, for example, Benjamini & Hochberg, 1995), we applied to sleep measures and fatigue analyses an adapted Bonferroni procedure: the conventional alpha value ($p \leq .05$) was divided by four, that is, by the number of relevant sleep "dimensions" addressed in our research ("sleep classical measures," "sleep continuity," "sleep stability," "sleep organization" (Conte et al., 2012)). Therefore, significance was eventually set at $p \leq .0125$.

The alpha level was maintained at $p \leq .05$ for the analyses concerning W Score and W% Score.

Pre-nap VAS scores at C and TR were compared through Wilcoxon's signed rank test (two-tailed) in order to control for fatigue levels. Spearman's correlation was then performed to check for possible correlations between fatigue and sleep measures both at C and TR.

Results

Quantitative sleep variables

Compared to C, TR displayed a significant increase of SPT, TST, and SE, and a reduction of SOL. An increase of Stage 2 sleep percentage, as well as a decrease of Stage 1 sleep percentage and WASO%, were also found, though proving nonsignificant at the adjusted alpha level of .0125. SWS and REM sleep proportions displayed no change (Table 1).

Sleep continuity

In the TR condition, a significant decrease emerged for the total frequency of awakenings per hour of TST (C: 7.54 ± 4.69 vs. TR: 5.44 ± 3.49, Wilcoxon's $z = -2.407$, $p = .008$). A notable reduction in TR was also found for the frequency of short (C: 5.29 ± 4.25 vs.TR: 3.89 ± 2.94, Wilcoxon's $z = -1.587$, $p = .05$) and long awakenings (C: 2.25 ± 1.98 vs. TR: 1.55 ± 1.57, Wilcoxon's $z = -2.168$, $p = .015$), although statistical significance did not survive Bonferroni correction. No differences emerged, instead, for awakenings mean duration (min; C: 9.33 ± 19.99 vs. TR: 2.98 ± 3.69, Wilcoxon's $z = -1.411$, ns).

Sleep stability

The frequency of state transitions showed a decrease in TR (C: 23.93 ± 9.32 vs. TR: 21.41 ± 8.71, Wilcoxon's $z = -1.588$, $p = .05$), though its significance was not maintained after multiple testing correction. All other sleep stability measures displayed no change: frequency of arousals (C: 5.1 ± 3.2

Table 1. Quantitative sleep variables (Mean ± *SD*) in the Baseline (BL) and Training (TR) conditions.

	BL	TR	Wilcoxon's *z*	*p* value
Sleep Period Time (min)	89.5 ± 31.5	101.7 ± 23.7	−2.602	**.004**
Total Sleep Time (min)	67.9 ± 29.7	84.9 ± 28.6	−3.858	**< .001**
Sleep Onset Latency (min)	16.5 ± 12.7	12.4 ± 12.5	−2.884	**.002**
Stage 1 (%)	32.6 ± 15.1	27.5 ± 14.2	−1.835	**.033** #
Stage 2 (%)	44.1 ± 16.4	47.4 ± 14.9	−1.835	**.033** #
SWS (%)	17.4 ± 15.5	20.7 ± 17.7	−.675	.249
REM (%)	5.9 ± 8.6	5.6 ± 7.3	−.228	.410
Wake After Sleep Onset (%)	22.45 ± 19.6	16.93 ± 16.7	−2.038	**.021** #
Sleep Efficiency (%)	55.6 ± 24.1	69.2 ± 22.6	−3.966	**< .001**

Note. Significant *p* values are in bold. #Nonsignificant after Bonferroni correction for multiple testing (see Methods section).

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vs. TR: 5.06 ± 2.74, Wilcoxon's z = .000, ns), frequency of FU periods per hour of SPT (C: 2.38 ± 3.53 vs. TR: 1.88 ± 1.23, Wilcoxon's z = –.033, ns), mean duration (min) of FU periods (C: 4.25 ± 2.14 vs. TR: 4.11 ± 1.67, Wilcoxon's z = –.545, ns), and TFU over SPT percentage (C: 16.53 ± 11.51 vs. TR: 15.23 ± 11.79, Wilcoxon's z = –.641, ns).

Sleep organization

No sleep cycles measures displayed significant differences between C and TR: number of cycles (C: 0.39 ± 0.82 vs. TR: 0.45 ± 0.64, Wilcoxon's z = −1.000, ns), cycle mean duration, in minutes (C: 12.35 ± 5.57 vs. TR: 12.73 ± 6.92, Wilcoxon's z = –.140, ns), TCT (C: 14.56 ± 8.68 vs. TR: 5.10 ± 8.04, Wilcoxon's z = –.687, ns), TCT% (C: 5 ± 9.48 vs. TR: 5.07 ± 7.8, Wilcoxon's z = –.260, ns).

Cognitive performance

A significant learning effect was found for W% scores (pre-nap: 7.9 ± 3.6 vs. post-nap: 8.5 ± 3.5, Wilcoxon's z = −2.181, p = .015). W scores, instead, showed no differences between pre- and post-nap assessments (pre-nap: 555.5 ± 333.8 vs. post-nap: 554.6 ± 331.7, Wilcoxon's z = –.087, ns).

Fatigue

Fatigue resulted significantly higher in the TR condition compared to C (C: 3.9 ± 1.7 vs. TR: 5.5 ± 1.8, Wilcoxon's z = −3.158, p = .002). However, no significant correlation was found between fatigue and any sleep measure.

Discussion

Our study further supports the hypothesis that quality of waking, namely an intensive cognitive activity performed before sleep, significantly affects subsequent sleep features. Moreover, it extends previous results (Conte et al., 2012; Haimov & Shatil, 2013) to a more ecological type of learning, using a complex cognitive task that requires the activation of multiple memory systems, thus resembling real-life learning.

In agreement with previous findings of ours on night sleep in elderly subjects after cognitive manipulation (Conte et al., 2012), our main finding is the recompacting effect exerted by presleep training on the subsequent nap; after the cognitive task, indeed, the sleep episodes, besides being longer, were also less fragmented and more consolidated than the control naps, as expressed by the increase of sleep efficiency and the decreased frequency of awakenings and sleep state transitions.

From the methodological point of view, here we would like to highlight that (a) visual sleep inspection was chosen since we considered it the best approach to investigate this specific set of variables; (b) the rather conservative statistical approach we decided to adopt (Bonferroni correction for multiple testing), while preventing the risk of Type I Error, increases the risk of Type II Error: therefore, we believe it is important not to overlook those meaningful results (especially the one concerning sleep stability), which did not survive that kind of correction but displayed relevant trends; (c) the observed changes could be successfully detected thanks to our choice of using a nap model, since baseline naps in our sample proved to be, as it might be expected from the literature, much less efficient (Bianchi, Wang, & Klerman, 2012; Kanady, Drummond, & Mednick, 2011) and stable (Dinges, 1992) than night sleep. Of course, our choice also implies a limitation concerning external validity, in that it remains to verify whether our findings could be extended to night sleep (especially when fragmented or curtailed in the frame of clinical insomnia).

The relevance of our results is linked to the importance of sleep continuity and stability as indexes of both objective and subjective sleep quality. In fact, numerous studies have shown the detrimental effects of sleep fragmentation on the effectiveness of both basic and higher cognitive functions in

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subsequent wake (see Stepanski, 2002 for a review); furthermore, though subjective sleep quality was not investigated in our protocol, the perception of "good sleep" also appears to rely significantly on a continuous and stable sleep episode (Kecklund & Akerstedt, 1997; Laffan, Caffo, Swihart, & Punjabi, 2010).

As for the mechanisms sustaining the observed recompacting effect on sleep, supported by the decrease in frequency of awakenings and state transitions, the postsleep improvement of W/% scores suggests that posttraining sleep changes may be specifically reflecting ongoing memory reprocessing during sleep. In particular, the reduction of sleep fragmentation and instability appears consistent with the sequential hypotheses (Ambrosini & Giuditta, 2001; Ficca & Salzarulo, 2004; Stickgold, Whidbee, Schirmer, Patel, & Hobson, 2000), proposing the close interaction between NREM and REM states, rather than their absolute amount, as the main requirement for memory consolidation, and implying that any disturbances of this interaction might be detrimental. In other terms, it is through the increase of continuity and stability that sleep in TR would enable the unfolding of undisturbed NREM-REM sequences, essential requirements for the effective memory consolidation and reshaping of material learned at bedtime. In our study we did not find, in posttraining sleep, an increase of sleep organization (i.e., number and duration of NREM-REM cycles), that would also be predicted by the sequential hypothesis. However, this result is not particularly surprising since, in brief daytime sleep episodes, the average number of completed sleep cycles is too low to allow detection of significant sleep cycle variables changes (Ficca, Axelsson, Mollicone, Muto, & Vitiello, 2010).

Also, the present evidence is in agreement with previous findings from our group obtained on nighttime sleep through administration of a word-pairs task (Conte et al., 2012) and a theatrical monologue (Mango et al., 2016) and with several other studies indicating the importance of sleep continuity in memory consolidation (Dang-Vu, McKinney, Buxton, Solet, & Ellenbogen, 2010; Rolls et al., 2011; Tartar et al., 2006; van Liempt, Vermetten, Lentjes, Arends, & Westenberg, 2011).

However, the hypothesis of specific learning-dependent sleep changes should be further corroborated by a comparison with a wake condition and, possibly, through a nighttime sleep paradigm allowing for sufficient variance to perform correlation analyses between sleep parameters and performance measures.

Since TR was characterized by higher levels of bedtime fatigue, we cannot actually rule out that this variable might have had an impact on the observed sleep changes. However, no correlation was found between fatigue and sleep measures either in C or TR, nor did we find any increase in SWS, which is the sleep variable generally believed to be affected by fatigue associated with cognitive load (Horne & Walmsley, 1976). Anyway, in order to better address the possible role of this factor, future studies should compare the learning condition with an active control condition (i.e., a task requiring the same cognitive effort without triggering specific memory processes).

Results from this study reveal interesting applicative implications for clinics and psychosocial medicine, calling into question the commonplace tenet that presleep cognitive activity hinders sleep propensity and sleep quality by increasing psychophysiological arousal (see, e.g., Higuchi, Motohashi, Liu, & Maeda, 2005; Wuyts et al., 2012). Although we cannot rule out that the subjects were significantly aroused by the quite engaging task, we found a reduction of sleep latency and awakenings. Hence, it may be speculated that, when learning processes are triggered, sleep-related mechanisms are able to counteract arousal effects and to improve both sleep propensity and sleep maintenance. Again, the abovementioned issue of external validity does not allow us to generalize these results to sleep episodes other than a nap: this is why we are currently applying this very same research protocol to look for possible similar sleep changes in posttraining night sleep.

In conclusion, our data suggest that planned cognitive training should be further explored as a strategy to improve sleep quality in healthy populations. Also, being in agreement with previous findings on older adults with insomnia (Haimov & Shatil, 2013), and in light of the increasing importance of nonpharmacological interventions for sleep disturbance, presleep learning sessions could be proposed as a low-cost and easily accessible alternative treatment, or as a complementary strategy in standard therapies, for sleep-disordered populations.

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