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SHORT REPORT

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Music cue during slow wave sleep improves visuospatial memory consolidation

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Summary

The active system consolidation theory assumes that sleep between encoding and retrieval promotes memory consolidation. In the present study, we cued new memories during slow-wave (SWS) or rapid eye movements (REM) sleep stages by presenting an instrumental music stimuli that had been previously presented during a learning session. In a within-subjects design, 18 participants slept for three nonconsecutive nights (cue during SWS, cue during REM, and no cue during control night) and were trained in a visuo-spatial memory task. The administration of cue during SWS produced better memory accuracy in comparison with REM and the control condition.

KEYWORDS

memory consolidation, music cueing, REM, SWS, TMR

1 | INTRODUCTION

It has been proposed that sleep between encoding and retrieval promotes memory consolidation (e.g., Rudoy et al., 2009). Rasch et al. (2007) requested participants to perform an object-location task while a rose (or vehicle) odour was presented during the learning session. While a re-exposure to the same odour during slow wave sleep (SWS) improved memory consolidation, no improvement was found in the normal sleep condition (i.e., no cue exposure during sleep), or with the cue representation during rapid eye movement (REM) sleep (Rasch et al., 2007), in line with the active system consolidation theory (Rasch & Born, 2013). The re-exposure to the cue during SWS should trigger hippocampal activity, favouring the hippocampus–cortex dialogue and the consolidation of memories in the long-term system (Rasch & Born, 2013). The paradigm supporting this theory is known as targeted memory reactivation (TMR; Hu et al., 2020) for which several types of cues are used (Schouten et al., 2017), including auditory stimuli. In the classical TMR paradigm, several sounds are used in association with stimuli (e.g., cat-meow; Rudoy et al., 2009), whereas Gao et al. (2020) presented classical music (e.g., Vivaldi) for the experimental condition and white noise for the control condition during a learning session and SWS stage, confirming the importance of re-exposure to the music cue during SWS (Gao et al., 2020). However, Gao et al. (2020) did not provide the re-exposure to a continuous music cue during REM, given that REM sleep plays a complementary role in the processing of cued memories (Lewis et al., 2018; Tamminen et al., 2017). Although Hu et al. (2020) do not report any TMR effect on memories for REM or wakefulness, in the present study we decided to compare the exposure of the same continuous music cue during SWS and REM (with a control condition of silence). Thus, our study could clarify the impact of memory replay during REM, giving further insight into the literature of TMR effect with continuous auditory cues (instrumental music), with possible educational implications, as suggested by Gao et al. (2020). In line with the study by Rasch et al. (2007), it should be expected that only the presentation of the music cue during the SWS should result in an improvement of memory performance in the subsequent recall phase.

2 | MATERIALS AND METHODS

2.1 | Participants

The participation was voluntary, by filling out an online survey on the Qualtrics Platform. From a dataset of 108 participants, 18 (9 females) healthy individuals (22.23 ± 2.01 years) were recruited after being checked for the absence of sleep–wake problems (at Mini-Sleep Questionnaire, sleep factor score ≤16 and wake factor score ≤14; Natale et al., 2014), for intermediate-types score (at reduced Morningness-Eveningness Questionnaire, 11 ≤ score ≤ 18; Natale, 1999), and for the absence of anxious-depressive traits (a score < 50 at State–Trait Anxiety Inventory and Zung Self-Rating Depression Scale; Innamorati et al., 2006; Pedrabissi & Santinello, 1989). The selected participants did not take any medication. Written informed consent was collected from all participants and the research protocol was approved by the Bioethics Committee of the University of Bologna (protocol number 0250478 of 17/10/2022). Participants received a gift card as compensation for their time.

2.2 | Memory task

Participants had to perform a visuospatial memory task adopted by Rasch et al. (2007). The task was presented via computer and consisted of 15 colour card-pairs. A total of 30 grey squares (cards back) appeared on the computer screen, arranged in a checkerboard pattern (5 × 6 matrix). The goal was to find the same card as the one that was turned over first. Three different versions of the task were used, two of which were those of Rasch et al. (2007) and one ad-hoc created for this experiment. The difference was related to card-pairs, although the categories of cards (e.g., animals, or vehicles) remained constant between these versions. The order of the versions was balanced between participants and experimental conditions. The general accuracy in detecting the pairs was measured.

2.3 | Polysomnography

An adaption night was scheduled 7 days before the experimental nights. Each participant slept for 3 nights in the sleep laboratory with 7 days between each night. Sleep monitoring was conducted following the American Academy of Sleep Medicine guidelines (Berry et al., 2020). Scalp electrodes were attached according to the international 10–20 system at six locations: frontal (F3 and F4), central (C3 and C4), occipital (O1 and O2), and each was referenced to the contralateral mastoid (A1 and A2). Left and right electrooculogram, mentalis and sub-mentalis were also acquired.

2.4 | Music apparatus

Continuous instrumental music stimuli were administered using a stereo loudspeaker system placed at a distance of 1.2 m from the computer during the learning phase and positioned at a distance of 1.2 m (85° angle) from the *nasion* during sleep. The instrumental music cues were original, including piano, oboe, and string accompaniment. Using MIRtoolbox (Lartillot et al., 2008), the acoustical parameters were 0.083 and 0.074 for global energy, 40 and 60 bpm for tempo, 0.492 and 0.321 for mean brightness, and 3618.27 and 1704.45 Hz for spectral centroid.

During both learning phase and sleep, these music cues lasted 10 min and were administered by the experimenter. The acoustic cue was administered at the onset (six consecutive epochs of delta waves) of SWS or at the appearance of the first eye movements during the third REM stage. The stimulation was stopped whether participant transitioned out from SWS or REM, and was re-administered when a stable SWS or REM stage was detected. The mean loudness of music stimuli was 50 dB during the learning phase and 30 dB during sleep. The lower loudness during sleep re-exposure was aimed to avoid awakening.

2.5 | Procedure

Each participant arrived at the sleep laboratory at 21:30. The learning phase of the memory task was administered. The first card of each pair was presented for 1 s followed by the presentation of both cards for 3 s. The next card-pair was presented after 3 s. All 15 pairs were presented twice. The learning sessions ended when at least 60% of correct answers was reached. Scalp electrodes were positioned after this task and participants went to sleep at around 23:30. Four sleep nights were assessed: adaptation, silence, cue during SWS, or cue during REM. The order of the experimental conditions and music cues were counterbalanced across participants. Spontaneous awakening was expected in the morning, otherwise the participant was awakened at 7:30. The recall phase was provided after the awakening. No music was played during the recall. The percentage of card-pairs correctly recalled (recall accuracy) was calculated.

3 | RESULTS

All participants were included except one, whose sleep quality during nights in the laboratory was extremely poor, with difficulties in cue administration and data analysis. The StatSoft was used for analysis.

The repeated measures ANOVA did not show any condition effect on sleep parameters (Table 1).

As regards the learning phase, no condition differences for the number of trials needed to reach the requested accuracy level (silence: 3.41 ± 1.90; SWS: 2.94 ± 1.50; REM: 2.41 ± 1.40; $F_{2,32} = 2.45$, $p = 0.10$, $\eta^2_p = 0.13$) and memory accuracy ($F_{2,32} = 0.15$, $p = 0.86$, $\eta^2_p = 0.01$). A session (learning and recall) × condition (silence, cue during SWS and cue during REM) repeated measures ANOVA was performed on recall accuracy (see also Supplementary Materials in Table S1). A Session effect was obtained ($F_{1,16} = 10.37$; $p = 0.0053$, $\eta^2_p = 0.39$), suggesting higher accuracy in learning (72.7 ± 10.37%)

TABLE 1 Mean and standard deviation for each sleep parameter considered in the three conditions: silence, slow wave sleep (SWS), and REM sleep. TST (total sleep time, in minutes); SO (sleep onset latency, in minutes); WASO (wake after sleep onset, in minutes); SE% (sleep efficiency, i.e., the ratio between total sleep time and time in bed × 100); N1%, N2%, N3% and REM% (percentage of each sleep stage)

	Silence	SWS	REM	$F_{2,32}$	p	η^2_p
TST	436.4 ± 38.8	447.8 ± 39.9	433.1 ± 33.1	1.2	0.32	0.07
SOL	13.6 ± 9.1	17.9 ± 14.3	14.7 ± 10.2	1.4	0.25	0.08
WASO	19.2 ± 27.4	24.7 ± 25.1	16.5 ± 11.6	0.8	0.44	0.05
SE%	93.5 ± 6.3	91.6 ± 6.8	93.5 ± 3.6	0.9	0.41	0.05
N1%	4.67 ± 3.5	6.1 ± 4.2	5.24 ± 3.1	0.9	0.41	0.06
N2%	51.6 ± 6.4	52.24 ± 7.7	51.26 ± 7.5	0.3	0.75	0.02
N3%	23.5 ± 7.3	20.8 ± 8.1	22.4 ± 6.8	2.7	0.08	0.14
REM%	20.1 ± 3.7	20.7 ± 3.9	20.9 ± 5.6	0.3	0.75	0.02

TABLE 2 Memory recall accuracy (mean and standard deviation, expressed in percentage) in the learning and recall phases as well as their difference for each experimental condition.

	Learning	Recall	Difference	Accuracy
Silence	71.7 ± 8.2	64.6 ± 11.2	−7.1 ± 14.3	91.20 ± 19.30
SWS	72.5 ± 10.2	71.3 ± 10.6	−1.2 ± 9.4	99.20 ± 14.00
REM	73.7 ± 12.7	63.9 ± 13.9	−9.8 ± 8.3	86.70 ± 11.90

than in the recall phase (66.6 ± 11.9%). No condition effect was found ($F_{2,32} = 0.81$; $p = 0.45$, $\eta^2_p = 0.05$). The interaction was significant ($F_{2,32} = 3.62$; $p = 0.038$, $\eta^2_p = 0.18$) (Table 2). Planned comparisons showed a significant difference for cue in REM ($t_{16} = 4.87$; $p = 0.0001$; higher accuracy in learning than in recall phase), a tendency towards significance for the silence condition ($t_{16} = 2.05$; $p = 0.057$), and no difference for the cue in SWS ($t_{16} = 0.50$; $p = 0.62$). Also, we found better accuracy (defined by [performance during recall × 100/performance during learning]) in the SWS condition ($F_{2,32} = 3.98$, $p = 0.028$, $\eta^2_p = 0.20$) than that in the REM condition ($t_{16} = 3.14$; $p = 0.006$, Cohen's $d = 1.49$), but not compared with the silence condition ($t_{16} = 1.85$; $p = 0.08$, Cohen's $d = 0.59$). No significant comparison was found between silence and REM conditions ($t_{16} = 0.89$; $p = 0.39$, Cohen's $d = 0.28$) (Table 2).

4 | DISCUSSION

In the present study, we assessed the effect of the re-exposure to a continuous instrumental music cue during SWS or REM sleep on visuospatial memory, in line with the active system consolidation theory (Rasch & Born, 2013). The results showed that the exposure to the music cue during the SWS sleep produced better memory recall in the morning confirming that the reactivation of acquired neuronal representations related to visuospatial task improved memory consolidation (Rasch & Born, 2013). In addition, our result extends, due to the comparison with REM and silence conditions, the findings provided by Gao et al. (2020), using an instrumental music cue. However, both SWS and subsequent REM sleep can play complementary roles in consolidating memory traces (Lewis et al., 2018; Tamminen et al., 2017). The present study can give further insights into the literature of TMR effect with continuous instrumental music used as a cue, with possible educational implications as suggested by Gao et al. (2020). Delivering an acoustic stimulation, as that used in the present study, could be an effective intervention for memory consolidation (Stanyer et al., 2022).

4.1 | Limitations and future directions

The small sample size limits our results and further studies should replicate the study with a higher sample size. In addition, our sample was composed of young adults only. Finally, we used a TMR paradigm and, additionally, we did not take into consideration the presentation of vehicle music during sleep.

5 | CONCLUSION

In sum, our results are in line with the active system consolidation theory. Future studies should address the effects of TMR in educational and clinical settings.

AUTHOR CONTRIBUTIONS

Marco Fabbri: Writing – original draft; methodology; investigation. **Miranda Occhionero:** Investigation; writing – review and editing. **Lorenzo Tonetti:** Writing – review and editing; data curation; investigation. **Marco Costa:** Software; writing – review and editing; investigation. **Federica Giudetti:** Data curation; writing – review and editing; investigation. **Bjoern Rasch:** Writing – review and editing; supervision. **Vincenzo Natale:** Supervision; formal analysis; methodology; writing – review and editing; conceptualization.

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CONFLICT OF INTEREST STATEMENT

None.

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 can be found online in the Supporting Information section at the end of this article.

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