

Supplementary Material

	LIST A	LIST B	LIST C
1	ACCROC	EMEUTE	BOUBOU
2	ANGINE	EMIR	SIROP
3	DUVET	VERROU	EBENE
4	ATOLL	EPERON	GACHIS
5	BEBE	CUMIN	APACHE
6	FLECHE	BERET	JAMBON
7	BIJOU	EBENE	ABAQUE
8	BONBON	ETOUPE	LEVAIN
9	COMPAS	FAISAN	BOTTIN
10	DEGAT	FAUCON	OZONE
11	ECHINE	BOUBOU	NOUGAT
12	ECUEIL	DECES	JUDAS
13	EMAIL	APACHE	BERET
14	ENDIVE	BEGUIN	FAISAN
15	EPONGE	BOTTIN	DECES
16	FLEAU	ABAQUE	BEGUIN
17	GISANT	OFFRE	LAITUE
18	GUIDON	AGENCE	EMIR
19	HENNE	MANDAT	EPERON
20	HUMUS	JAMBON	OFFRE
21	INDICE	GOUJAT	CUMIN
22	INTRUS	LEVAIN	VERROU
23	JUMENT	GACHIS	FAUCON
24	KEPI	NOUGAT	ETOUPE
25	LIGNEE	HACHIS	TUERIE
26	LILAS	ICONE	EMEUTE
27	MARAI	LAITUE	GUENON
28	NOUNOU	JUDAS	PHILO
29	OSIER	GUENON	HACHIS
30	RACHAT	OZONE	TAMPON
31	PACHA	TUERIE	PHOBIE
32	PANTIN	PHILO	GOUJAT
33	PONEY	VOMI	ICONE
34	RAFFUT	TAMPON	AGENCE
35	REJET	SENAT	ONGLET
36	RONDIN	PHOBIE	OVAIRE
37	RAGOUT	ONGLET	VOMI
38	SILLON	OVAIRE	RANCON
39	VAUDOU	SIROP	MANDAT
40	TAUDIS	RANCON	SENAT

Table S1. Words used to constitute learning and interfering word pairs (see the main text).

Stimuli are unrelated French words, neutral, two-syllabic. Word pairs are, for each

participant, randomly tagged at the beginning of the session as “to be reactivated” or “no reactivation”

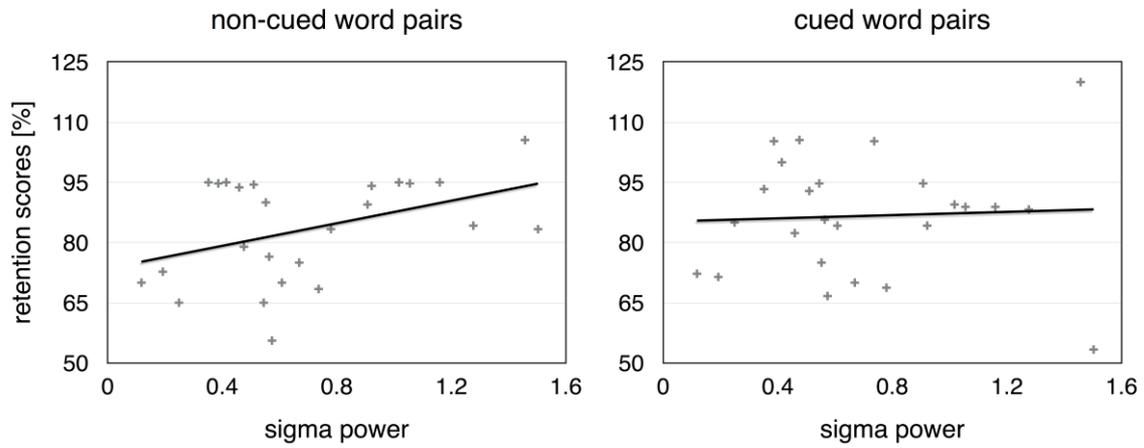


Fig. S1. Correlation between mean sigma power over N2 sleep periods on central electrodes (C3 and C4) and memory retention for uncued (left, $p < .05$) and cued (right, $p > .8$) word pairs. p -Value threshold after correction for multiple comparisons is $p = .025$

Additional analyses: Evoked-related potentials (ERPs)

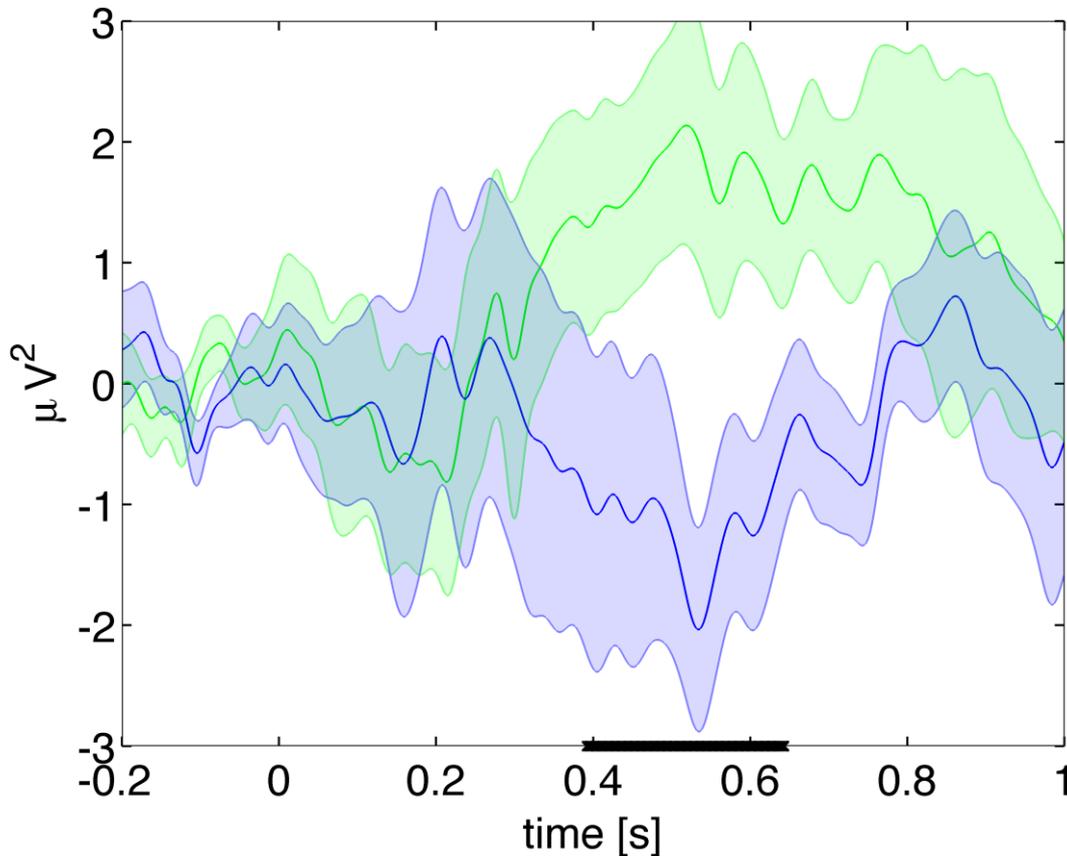


Fig. S2. Grand average of the evoked-related potentials (band-pass filter: 0.9–30 Hz) of the representative electrode FP1 for the first (in green) and second (in blue) words of the pair. Onset of auditory stimuli was set at $t = 0$. Shaded error bars represent the standard error. The black bold line at the bottom indicates the time window for which the difference between both ERPs was significant

As a supplementary analysis, we computed ERPs as done in a prior study (Schreiner and Rasch, 2015; Schreiner et al., 2015). EEG data were referenced to the averaged left and right mastoids and band-pass filtered (frequency range: 0.1–30 Hz). Data were epoched from 200 ms before stimulus onset (for both the first and second words of the pair) until 1 s after onset. Resulting segments were then visually inspected and removed if contaminated by artifacts, and corrected with respect to the 200-ms baseline preceding the onset of words. Finally, segments were averaged across participants. Because no group effect was found for both retention scores and time–frequency analyses (all $p > .1$), participants from the Reactivation

and Interference groups were collapsed. For each of the four electrodes (FP1, FP2, C3, and C4) separately, we computed signal amplitude differences between the first and second words of each pair using non-parametric tests. For each time bin, we calculated Monte Carlo estimates of the significance probabilities using a permutation method corrected for multiple comparisons by clustering across time bins [as implemented in FieldTrip (Oostenveld et al., 2011); 1,000 permutations, paired comparisons, $\alpha = 0.05$, cluster $\alpha = 0.05$]. ERPs' differences were found between the first and second words in left frontal and central electrodes (FP1: 436–632 ms; C3: 479–639 ms). To ensure that the differences in ERPs between the first and second words were not driven by slow sleep oscillations, we computed the same analyses using a different band-pass filter (0.75–30 Hz) and found similar results for both frontal electrodes (FP1: 391–643 ms; FP2: 425–568 ms). At each electrode, the negativity peak was visually located around 550 ms (see *Fig. S2*).

Independently, similar analyses were conducted to assess ERP differences in the target (second word of the pair) between the Reactivation and Interference groups. No significant effects were evidenced.

Additional discussion: ERPs' effects

The negative component N550 is known in the literature to be related to evoked K-complexes (Crowley et al., 2002; Colrain, 2005; Ibáñez et al., 2009). Increased negativity in the N550 evoked by the second word of the pair might thus represent an increase in evoked K-complexes. K-complexes are usually known to be affected by stimulus probability but are diminished rather than increased when stimuli are less frequent or less expected (Colrain, 2005). Considering that the second word of the pair is expected when the first one is displayed, this is in contradiction with our results. It has also been shown that K-complexes are more frequent after auditory stimulation of a conditioned tone with a shock (Beh and Barrat, 1965), which would relate K-complexes to the salience and cognitive processing of stimuli. Also, the role of K-complexes still remains a matter of debate. It is unclear whether it represents a physiological correlate of arousal or, in contrast, serves as a protective mechanism against cortical arousals (e.g., Forget et al., 2011; for a review, see Colrain, 2005). For example, signs of arousals (such as increases in α and β activities) were observed when auditory stimulation during sleep was not followed by a K-complex (Bastien et al., 2000). In contrast, when an evoked K-complex was elicited, there was no sign of arousals, in line with the assumption that K-complexes protect against cortical arousals. Also, Schreiner et al.

(2015) found an increased negativity (between 800 and 1,200 ms after the cue onset) more pronounced for vocabulary gained during the stimulation (i.e., not remembered before but correctly reported after sleep with TMR) than for losses (i.e., correctly reported before but not after sleep with TMR). In this context, they proposed that enhanced negativities after auditory stimulation might relate to long-term memory formation. Finally, Schabus et al. (2012) showed that when tones are presented during sleep spindles, as compared during the absence of sleep spindles, there is an increase in the N550 response. Considering the results of our time–frequency analyses suggesting that the presentation of the first word triggered spindling activity, the second word of the pair would occur during the presence of a spindle which might explain, based on the Schabus et al.’s (2012) study, why an increased N550 response was observed.

Additional analyses: Direct comparison of memory retention between the Nap and Wake conditions

To directly compare retention scores, we performed the analyses separately in the Reactivation and Interference groups (since effects are expected in opposite directions). Thus, 2×2 repeated measures ANOVAs were computed with within-subject factor TMR (Cued vs. Uncued) and between-subjects factor Condition (Nap vs. Wake). The ANOVA computed in the Reactivation group disclosed a main effect of TMR [$F(1, 26) = 18.0, p < .001$], a main effect of Condition [$F(1, 26) = 18.5, p < .001$], and an interaction effect between the TMR and Condition factors [$F(1, 26) = 7.9, p < .01$]. Post-hoc t -tests in the Reactivation group show that participants are better in the Nap condition as compared with the Wake condition ($t = 4.3, p < .001$) and have better retention for cued items as compared with uncued items ($t = 15.5, p < .001$). For uncued word pairs, retention scores do not differ between the Nap and the Wake conditions ($t = -1.58, p = .13$), whereas retention of cued word pairs is higher in the Wake than in the Nap conditions ($t = -4.5, p < .001$; see *Fig. S3*). Also, cued items are better recalled than uncued items in the Wake condition only [$t(13) = 5.3, p < .001$].

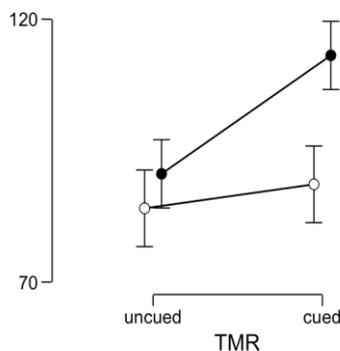


Fig. S3. Reactivation group

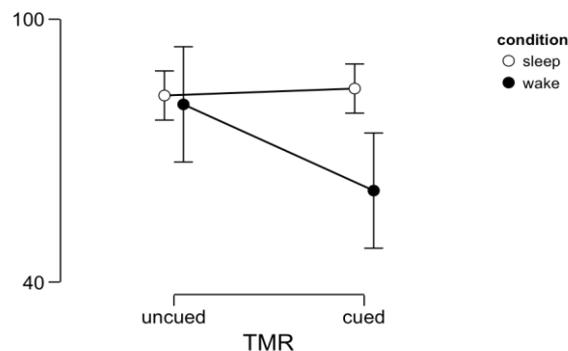


Fig. S4. Interference group

The ANOVA computed in the Interference group disclosed a trend for a main effect of TMR [$F(1, 23) = 3.1, p = .09$], no main effect of condition [$F(1, 23) = 1.6, p = .2$], and a significant interaction effect between TMR and Condition factors [$F(1, 23) = 4.3, p = .04$]. Post-hoc t -tests in the Interference groups show that for uncued word pairs, retention scores do not differ between the Nap and Wake conditions ($t = 0.2, p = .8$), whereas retention of cued word pairs is decreased in the Wake as compared with the Nap condition ($t = 2.1, p = .04$; see *Fig. S4*). Also, recall for cued items is significantly lower than for uncued items in the Wake condition only [$t(13) = -2.3, p = .04$].

Hence, our results show that memory retention is not globally (i.e., independently of cueing) improved in the nap as compared with the wakefulness condition, and confirm that sleep–wake effects are restricted to the cued items. Nonetheless, it should be kept in mind that timing differed between experimental conditions. Indeed, as mentioned in the Methods section, the time interval between the pre- and post-TMR recalls was approximately 2 hr (90-min nap + 30 min for sleep inertia) in the Nap condition, whereas it was around 20 min (15 min of the TMR procedure + 5 min of turnaround time) in the Wake condition.

Thus, we cannot preclude the fact that retention scores would have dropped to lower levels than in the Nap condition in a situation in which the retention time would have been equated between the Nap and Wake conditions.

References

- Bastien LH, Ladouceur C, and Campbell KB (2000). EEG characteristics prior to and following the evoked K-complex universitg laval. *Can J Exp Psychol* 54(4):255–265.
- Beh HC and Barrat PEH (1965). Discrimination and conditioning during sleep as indicated by the electroencephalogram. *Science* 147:1470–1471.
- Colrain IM (2005). The K-complex: a 7-decade history. *Sleep* 28(2):255–273. Available at: <http://www.ncbi.nlm.nih.gov/pubmed/16171251>
- Crowley K, Trinder J, and Colrain IM (2002). An examination of evoked K-complex amplitude and frequency of occurrence in the elderly. *J Sleep Res* 11(2):129–140. doi:10.1046/j.1365-2869.2002.00293.x
- Forget D, Morin CM, and Bastien CH (2011). The role of the spontaneous and evoked K-complex in good-sleeper controls and in individuals with insomnia. *Sleep* 34(9):1251–1260. doi:10.5665/SLEEP.1250
- Ibáñez AM, Martín RS, Hurtado E, and López V. (2009). ERPs studies of cognitive processing during sleep. *Int J Psychol* 44(4):290–304.
- Oostenveld R, Fries P, Maris E, and Schoffelen J-M (2011). FieldTrip: open source software for advanced analysis of MEG, EEG, and invasive electrophysiological data. *Comput Intell Neurosci* 2011:156869. doi:10.1155/2011/156869
- Schabus M, Dang-Vu TT, Heib DPJ, Boly M, Desseilles M, Vandewalle G, Schmidt C, Albouy G, Darsaud A, Gais S, Degueldre C, Balteau E, Phillips C, Luxen A, and Maquet P (2012). The fate of incoming stimuli during NREM sleep is determined by spindles and the phase of the slow oscillation. *Front Neurol*, 3:40. doi:10.3389/fneur.2012.00040
- Schreiner T, Lehmann M, and Rasch B (2015). Auditory feedback blocks memory benefits of cueing during sleep. *Nat Commun* 6:8729. doi:10.1038/ncomms9729
- Schreiner T and Rasch B (2015). Boosting vocabulary learning by verbal cueing during sleep. *Cereb Cortex* 25(11):4169–4179. doi:10.1093/cercor/bhu139