

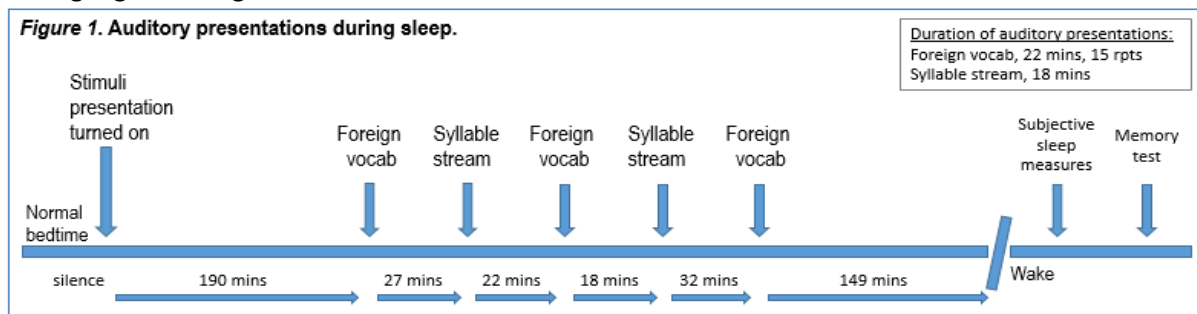
## Can we learn during sleep? An investigation of the extent to which linguistic stimuli can be processed during sleep

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Learning novel semantic information during sleep is an area marked by a longstanding debate. Despite the paucity of recent evidence supporting sleep-learning, products claiming successful overnight acquisition of a foreign language, are sold on the internet. This study investigated participants' ability to learn two types of linguistic stimuli during sleep: 1) Foreign vocabulary (Spanish or French) and 2) a continuous stream of artificial non-sense syllables. Chosen stimuli, explicit vocabulary learning and implicit statistical learning of word boundaries, are considered two key skills in language learning.



Twenty healthy volunteers (9 males; age 24.5±4.2) took part in a single night study. Participants were prepared for ambulatory polysomnography with home recording and overnight stimulus presentation (Figure 1). Foreign vocabulary scores in the morning were compared to baseline the night before. Implicit learning performance was compared to performance on a control stream of syllables. Sleep recordings were scored by raters blind to stimuli presentation using standard criteria, indicating an average sleep efficiency of 86.69%, with stimuli occurring in a variety of sleep stages (Table 1).

Table 1: Mean % of time spent in sleep and wake during stimuli presentation/the entire night.

*	Foreign vocabulary (%)	Syllable stream (%)	Entire night (%)
Wake	27.8	19.4	16.5
Stage 1	12.3	9.7	8.9
Stage 2	42.6	45.7	36.7
Stage 3	3.9	14.2	21.3
REM	13.3	11.4	16.7

Foreign vocabulary learning was partially successful when participants were awake for > 10% of the time during auditory presentations,  $p < .001$  (equivalent to 5 words), but reduced in sleeping participants  $t(6) = 5.28$ ,  $p = .002$  (equivalent to 1.5 words). Performance on the implicit learning task did not improve with nocturnal presentation.

These results suggest that while learning of foreign vocabulary is possible overnight, this is not true of implicit statistical learning. Subgroup analysis indicates only those participants spending >10% awake overnight were able to improve foreign vocabulary, although subjectively these participants did not report significantly disturbed night sleep. These findings may indicate a failure of primary encoding in participants with <10% wake, as the consolidation period was the same for both subgroups.