Learning new vocabulary during deep sleep

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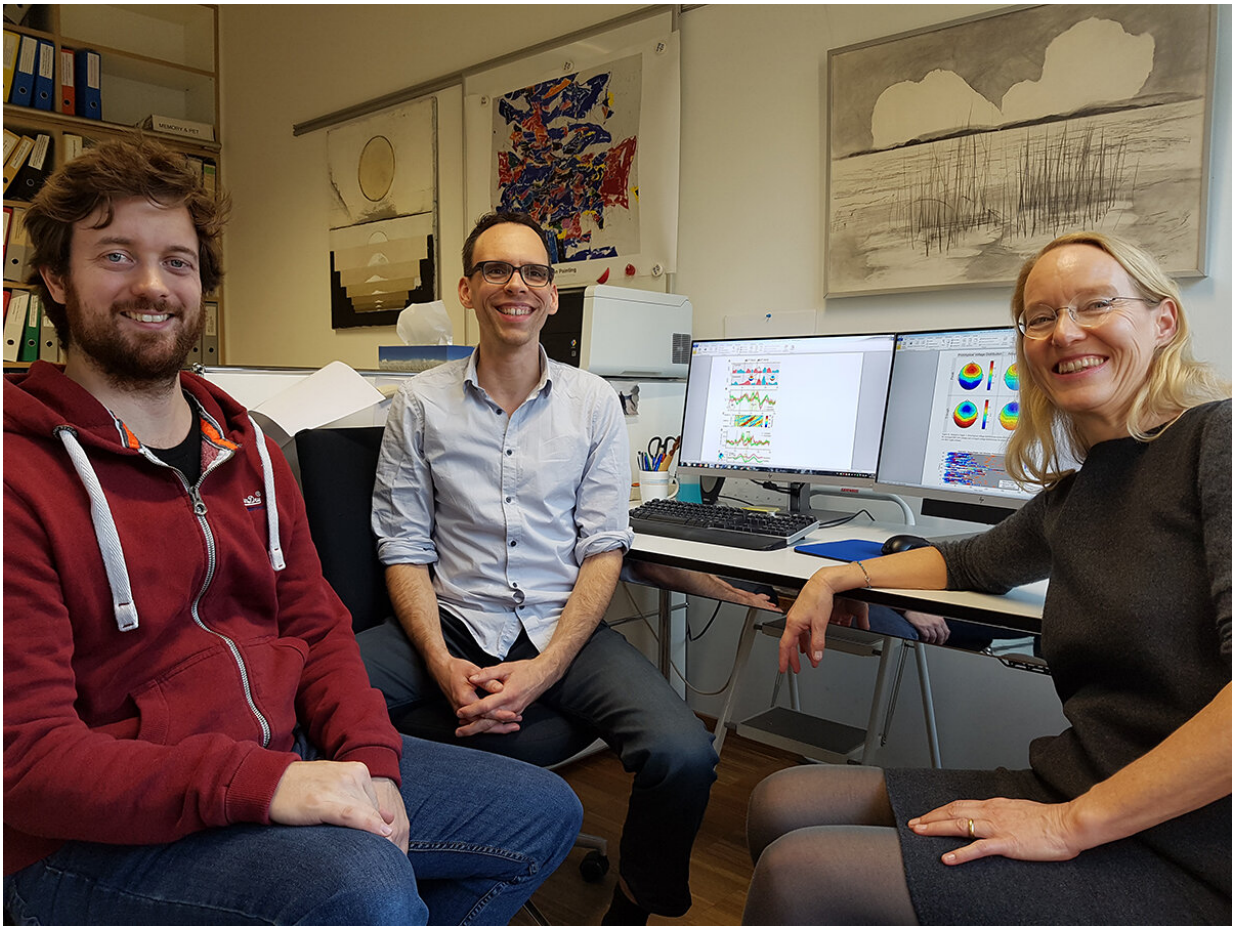


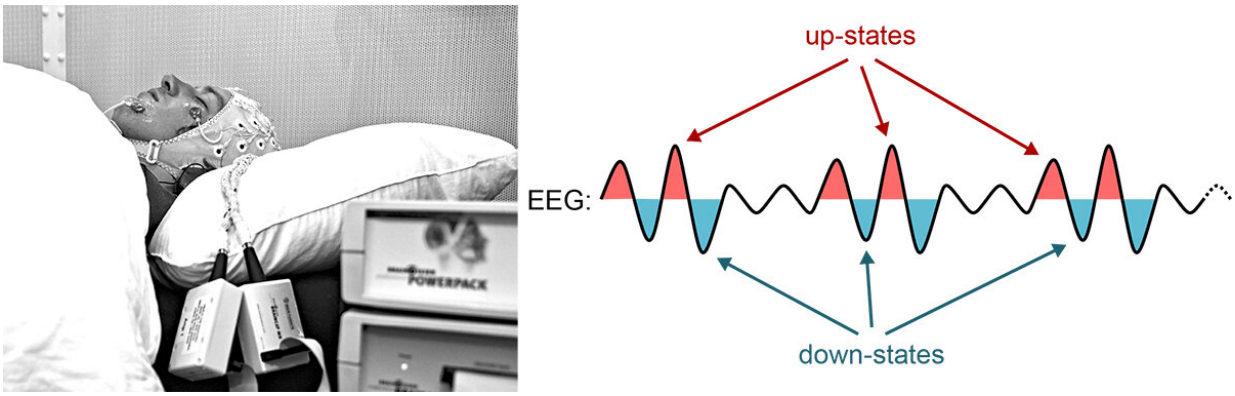
From left to right: Marc Züst, Simon Ruch and Katharina Henke. Credit: Tom Willems, University of Bern

Sleeping is sometimes considered unproductive time. Could the time spent asleep could be used more productively—e.g., for learning a new

language? To date, sleep research has focused on the stabilization and consolidation of memories formed during wakefulness. However, learning during sleep has rarely been examined. There is considerable evidence for a recapitulation by replay in the sleeping brain of wake-learned information. The replay during sleep strengthens the still fragile memory traces and embeds the newly acquired information in the preexisting store of knowledge.

If replay during sleep improves the storage of wake-learned information, then the initial processing of new information should also be feasible during sleep, potentially carving out a memory trace that lasts into wakefulness. This was the research question of Katharina Henke, Marc Züst and Simon Ruch at the University of Bern, Switzerland. These investigators show for the first time that new foreign words and their translations could be associated during a midday nap with associations stored into wakefulness. Following waking, participants could reactivate the sleep-formed associations to access word meanings when represented with the formerly sleep-played foreign words. The hippocampus, a brain structure essential for wake-associative learning, also supported the retrieval of sleep-formed associations. The results of this experiment are published open access in the scientific journal *Current Biology*.

The research group examined whether a sleeping person is able to form new semantic associations between played foreign words and translation words during the brain cells' active states, the so-called "up-states." When we reach deep sleep stages, our brain cells progressively coordinate their activity. During deep sleep, the brain cells are commonly active for a brief period of time before they jointly enter into a state of brief inactivity. The active state is called up-state and the inactive state down-state. The two states alternate about every half-second.



Left panel: In the sleep laboratory, the electrical activity of the brain is recorded using electroencephalography (EEG). Right panel: During deep sleep, slow oscillatory high-amplitude waves emerge in the EEG. These waves are generated by the brain cells' rhythmic alternation between highly active phases (red: "up-states") and passive phases (blue: "down-states"). Credit: Simon Ruch/Marc Züst, University of Bern

Semantic associations between sleep-played words of an artificial language and their German translations words were only encoded and stored if the second word of a pair was repeatedly played (two, three or four times) during an up-state. E.g., when a sleeping person heard the word pairs "tofer = key" and "guga = elephant," then after waking, they were able to categorize with better-than-chance accuracy whether the sleep-played foreign words denominated something large ("Guga") or small ("Tofer"). "It was interesting that language areas of the brain and the hippocampus—the brain's essential memory hub—were activated during the wake retrieval of sleep-learned vocabulary, because these brain structures normally mediate wake learning of new vocabulary," says Marc Züst, co-author of the paper. "These brain structures appear to mediate memory formation independently of the prevailing state of consciousness—unconscious during deep sleep, conscious during wakefulness."

Besides its practical relevance, this new evidence for sleep learning challenges current theories of sleep and theories of memory. The notion of sleep as an encapsulated mental state in which we are detached from the physical environment is no longer tenable. "We could disprove the idea that sophisticated learning is impossible during deep sleep," says Simon Ruch, co-author. The current results underscore a new theoretical notion of the relationship between memory and consciousness that Katharina Henke published in 2010 (*Nature Reviews Neuroscience*). "In how far and with what consequences deep sleep can be utilized for the acquisition of new information will be a topic of research in upcoming years," says Katharina Henke.

More information: *Current Biology* (2019). DOI: 10.1016/j.cub.2018.12.038

Katharina Henke. A model for memory systems based on processing modes rather than consciousness, *Nature Reviews Neuroscience* (2010). DOI: 10.1038/nrn2850

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