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Olfactory associative learning during human sleep: Interplay between sleep stages, slow wave oscillations and behavior

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Recent finding suggests that humans can learn novel information during sleep, and that this information can modulate behavior during wakefulness in a sleep stage-dependent manner. Specifically, new associations learned during non rapid eye movement sleep (NREM) had larger and longer lasting influence on behavior than associations learned during rapid eye movement (REM) sleep. NREM sleep, unlike REM sleep, is rich in slow oscillation and these oscillations promote memory consolidation of information previously learned during wakefulness. We set out to test whether slow oscillations are also part of the mechanism underlying olfactory associative learning during sleep. We recorded electroencephalogram (EEG) during partial-reinforcement conditioning in NREM and REM sleep. On reinforced trials (two-thirds of trials), the conditioned stimulus (tone or odor) was paired with an unconditioned stimulus (odor). On non-reinforced trials (one-third of trials), the conditioned stimulus was presented without an ensuing odor, which enabled us to measure learning without the interference of the unconditioned stimulus. We found an increase in slow oscillations (0.5-5Hz) power following the conditioned stimulus offset in non-reinforced trials during NREM sleep, compared to REM sleep and to a control experiment in which the same stimuli were presented in a random order during NREM. Moreover, during NREM the increase in slow oscillations following the conditioned stimulus offset was significantly larger when the conditioned stimulus was previously paired with an unpleasant odor than with a pleasant odor. This difference was not evident during REM sleep. Our results demonstrate that new associations learned during sleep increased slow oscillation activity during NREM sleep but not during REM sleep. Furthermore, the increase in slow oscillations depended on the unconditioned stimulus properties (odor valence). This work suggests a link between sleep stage dependent olfactory associative learning during sleep and slow oscillations.

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