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Sleep your way up ☆

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1. Objectives

Two recent papers of the group of Robert Stickgold at Harvard provide new evidence for the importance of sleep for skill learning. The study of Mednick et al. [1] shows that too much practice on a single day may in fact harm performance on a visual texture discrimination task, unless a daytime nap is scheduled between learning sessions. The amount of slow-wave sleep appears to be critical for the prevention of performance loss. The study of Walker et al. [2] demonstrates the importance of nocturnal sleep, especially stage 2 sleep during the last quarter of the night, for improvement on a simple motor skill task. Both papers, in fact, describe a series of studies that elegantly rule out a number of alternative explanations, including circadian and motivational factors.

2. Study design

Experimental designs in several subgroups of $n = 10$.

3. Study population

Healthy young subjects (undergraduates, $n = 62$ (Walker) and $n = 129$ (Mednick)).

4. Methods

Mednick et al. trained subjects four times during a single day on a texture discrimination task known to improve only after a night of sleep. Between the second and third training session, subjects had additional motivation, rest, a short or long nap, or none of these interventions. Analyzes were aimed at elucidating the effects of the polysomnographically assessed duration (0, 30 or 60 min) and sleep stage content of the nap on texture discrimination performance.

Walker et al. trained subjects in a simple five-keypress sequence task on a computer keyboard. The primary outcome measures were speed and accuracy changes, relative to the training session, during subsequent retesting at several intervals during the same day, with or without a period of complete rest of the hands, or after a night of sleep.

5. Results

Mednick et al. demonstrated that, after reaching a certain perceptual skill level on the first morning training session, additional training sessions during the same day in fact harm task performance. Neither rest nor additional motivation was of any help in overcoming the performance loss. Performance similar to that during the first training session could only be obtained by presenting a parallel task addressing different areas of the retina and other primary visual areas in the brain, or by allowing a nap between the training sessions. Across conditions, nap effectiveness increased with its duration and the amount of slow-wave sleep it contained. The involvement of slow-wave sleep was further supported by the fact that post-training naps showed significantly more slow-wave sleep than similar naps recorded on days without prior training.

Walker et al. showed that *accuracy* of the motor skill, defined as the absolute number of errors per 30 s of training or testing, did not change in any of the subsequent tests, except when the hand was kept at complete rest between the morning training session and evening test session. In that case, the percentage of incorrect sequences increased.

☆ Articles reviewed: Mednick SC, Nakayama K, Cantero JL, Atienza M, Levin AA, Pathak N, Stickgold R. The restorative effect of naps on perceptual deterioration. Nat Neurosci 2002;5:677–681. Walker MP, Brakefield T, Morgan A, Hobson JA, Stickgold R. Practice with sleep makes perfect: sleep-dependent motor skill learning. Neuron 2002;35(5):205–211.

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However, additional analyzes not published by this group, showed that when accuracy is defined as the percentage of errors per motor sequence typed, a 43% *decrease* in error rate was found [3]. The *speed* of the performance increased slightly with time in all tested conditions, but this increase was only significant when retesting was done after a night of sleep. Moreover, the increase in speed was significantly correlated to the amount of stage 2 sleep in the fourth quarter of the night.

6. Conclusions

Based on the outcome of the present as well as previous studies, Mednick et al. conclude that it is likely that slow-wave sleep plays a central role in the first processing stages of experience-dependent learning. Their study indicates that the *harmful* effect of overtraining can be *prevented* by the restorative effect of *daytime* slow-wave sleep. Previous, related studies of the Stickgold group demonstrated that an *improvement* of performance can only be obtained after *nocturnal* sleep, especially if the night is rich in slow-wave sleep during the first quarter and rich in REM sleep during the last quarter [4].

Contrary to the importance of slow-wave and REM sleep for the prevention of performance decrements during the day and for the overnight improvement on *perceptual* skill learning, Walker et al. conclude that stage 2 sleep appears essential for the consolidation of *motor* skill learning.

7. Comment

The process known as learning requires the acquisition and consolidation of memories. Two distinct types of learning have been recognized. Explicit learning refers to the acquisition of memories of experiences (episodic memory), facts or beliefs – in humans referred to as declarative memory, since they are capable of reporting such memories. The other type of learning involves the acquisition of perceptual and motor skills, or procedures. Explicit explanations of 'how to perform' are often very difficult and of limited use in learning and mastering a skill: only practice makes perfect. This type of learning has therefore been referred to as procedural, skill or implicit learning.

A wealth of papers has recently indicated that sleep may be particularly important for the consolidation of this second type of learning. The papers discussed here are no exception, and add considerably to the contention that sleep is involved in the neuronal plasticity processes necessary for the consolidation of perceptual (Mednick et al.) as well as motor (Walker et al.) skills.

Walker et al. suggest that the sleep spindles characteristic of stage 2 sleep may be involved in sleep-related information consolidation, as outlined previously by Sejnowski and Destexhe [5]. It is therefore somewhat surprising that their report lacks quantification of spindles to support this contention.

At present it is difficult to evaluate the extent to which these findings generalize to tasks of daily living. The involvement of sleep has been demonstrated only in a limited number of skill learning tasks. The deterioration of the specific perceptual skill may be extremely sensitive to experimental conditions, since it was not found previously by the same research group using the same task [4,6]. The suggestion of Mednick et al. – that the performance decrement during sustained training may be what we refer to as the feeling of 'burnout' associated with prolonged cognitive effort – seems somewhat preliminary. First, the subjective sleepiness ratings appeared unrelated to the performance decrement. Second, in real life, prolonged cognitive effort usually involves complex tasks, relying strongly on secondary and associative parts of the brain. However, the reported findings suggest that, in this case, the performance decrements are due to and limited to processes in the primary visual processing areas, and do not extend to secondary visual processing areas where retinotopic specificity is lost.

Mednick et al. further suggest that, according to their results, cognitive benefits of sleep can now be studied over a short period of (day) time without having to resort to time and resource consuming nocturnal sleep and sleep deprivation protocols. This conclusion seems somewhat optimistic, given the fact that their study only demonstrates that daytime sleep can prevent deterioration of performance. For practical implications, their results would argue for a single training session only; it seems rather pointless to spend more hours asleep or training, only to end up with a performance level not too much worse than that after a single training session and not improved whatsoever. Additional training sessions on a single day would be useful only if it could be demonstrated that such sessions, interleaved with naps, improve the performance increment normally found on the *next* day following a night of sleep. A follow-up study along this line would be a logical next step if optimization of skill learning is a major topic of interest.

If we suppose that the findings can be generalized to other skill learning, the following practical advice could be given to those who need to optimize their gain in training (for example in sports, musical performance or rehabilitation). In the case of perceptual skill training: do not overtrain during 1 day and make sure that a good night's sleep follows, rich in slow-wave sleep in the early part and REM sleep in the later part. In the case of motor skill training: stage 2 sleep at the end of the night is important, and it would thus be unwise for any type of skill learning consolidation to curtail sleep duration.

The findings may therefore be of special relevance to the acquisition of skills by elderly subjects for whom slow-wave sleep and spindles are compromised and early morning awakening frequent (e.g. ref. [7], reviewed in refs. [8,9]), and who thus, according to the findings of these authors, may lack the most important skill-favoring components of sleep.

It remains to be investigated to what extent the results of these studies can be generalized to tasks with more relevance to daily life. If, however, similar results can indeed be obtained in other and more complex skill learning tasks, sleep schedules may become an integral part of skill training programs, for example in sports or rehabilitation. Applying our present knowledge of the dependency of stage 2 sleep, slow-wave sleep and REM sleep on circadian phase and duration of prior wakefulness, such sleep schedules could be tailored to the optimal sleep pattern required for consolidation of the skills to be mastered.

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