STUDYING SLEEP...

the personal memory organizer

By Dayan Li

If sleep deprivation were a disease, then we most certainly have reached a pandemic. In our inexorable efforts to over-commit, over-work, and over-book, sleep has been dismissively shoved aside as a secondary need, or more appropriately, as a luxury in the breathless, sleepless drive towards productivity in the modern world. In our frantic rush to get things done, we must stop – sleep – and evaluate the genuine benefits of an overflowing schedule. Are we really more efficient and proficient than "time squanderers" who sleep eight hours a day? Current research uncovering connections between sleep and memory may provide an answer as it shows that sleep firmly roots and widely integrates memories into our brain.

Sleep, memory, and the brain

Thanks to rapid advances in neuroscience, the topic of sleep has transcended psychoanalytic stigma and has merited wide scientific interest, especially in regards to its role in memory processing. The past decade has seen a great increase in papers that describe behavioral and physiological experiments linking sleep to memory consolidation. Sleep has been shown to both prime neural connections before learning and strengthen memories after learning.

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Sleep is composed of 90-110 minute cycles of a non-rapid eye movement period followed by a rapid eye movement period (REM) (1). While dreams occur during REM sleep, most research concerning memory reorganization study slow wave sleep, which consists of the two deepest stages of non-REM sleep. During slow wave sleep, an individual is least sensitive to the outside environment and has the hardest time waking up to stimuli such as sounds or nudges. This decreased sensitivity to the surroundings is partly due to active memory organization within neural networks of the brain, as shown by high amplitude brain waves during slow wave sleep. With technological developments such as electroencephalography, which measures the brain's electrical activity, and functional magnetic resonance imaging, which traces changes in blood flow and blood oxygenation, neurobiologists have successfully identified the main sites of memory processing and storage during both wakefulness and slow wave sleep.

Two important brain regions involved in memory consolidation are the hip-

credit: Image adapted from <http://www.nlm.nih.gov/medlineplus/ency/imagepages/8692.htm>

pocampus and the neocortex. The hippocampus consists of two horseshoe-shaped bundles of neurons located at the bottom center of the brain, one in each hemisphere. Despite its small size relative to other brain structures, the hippocampus plays a critical role in encoding new memories (1). Individuals with a damaged hippocampus are often unable to form memories of new knowledge or experiences. The neocortex, in contrast, is the vast outer layer of neurons that envelops the entire brain. Due to its large surface area, it is the site of many cognitive processes such as sensory perception, spatial reasoning, and language (1). Recently, neuroscientists have uncovered a telling crosstalk between the hippocampus and the neocortex: During slow wave sleep, the hippocampus intensifies its communication with the neocortex by sending recently encoded information to specific neocortical regions for more permanent memory storage. This initial finding of an interaction between the hippocampus and the neocortex has led to a flood of seminal discoveries about the relationship between sleep, memory, and the brain.

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Sleep deprivation decreases memory encoding capacity

Although it seems obvious that sleep deprivation impairs memory, this idea was not scientifically substantiated until a recent study revealed that lack of sleep impaired hippocampus activity (2). In this study, researchers exposed two subject groups to picture slides and tested their ability to recall the slides two days later. One group slept normally before the slide-viewing session while the other group was deprived of sleep the night before. To eliminate the confounding factor that the fatigue of sleep deprived subjects would affect their test performance, members of both groups were allowed two nights of sleep prior to the test.

Despite exhibiting no significant differences in reaction times, the sleep deprived group experienced more difficulty recalling images than the sleep control group. Further analysis revealed that the varying performances were due to different patterns of brain activity. As expected, the sleep control group showed high levels of interaction between the hippocampus and the posterior temporal and parietal lobes, regions associated with episodic memory processing (memories of past experiences, like picture viewing). On the other hand, sleep deprived subjects

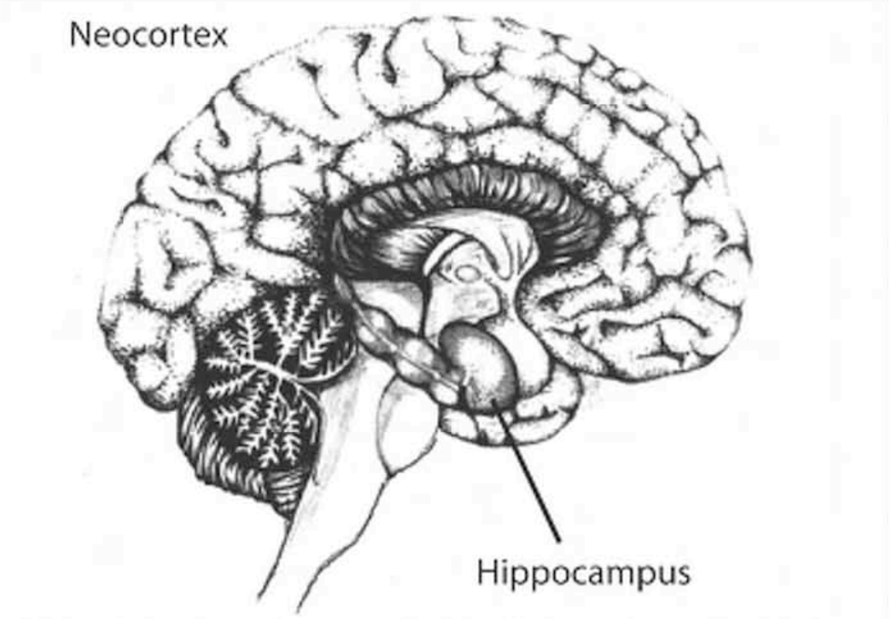

Figure 1. Diagram showing the regions of the brain affecting memory storage. Lack of sleep impairs functionality of the hippocampus—essential for forming new memories—including its connectivity to the neocortex, the site of many long-term storage centers.

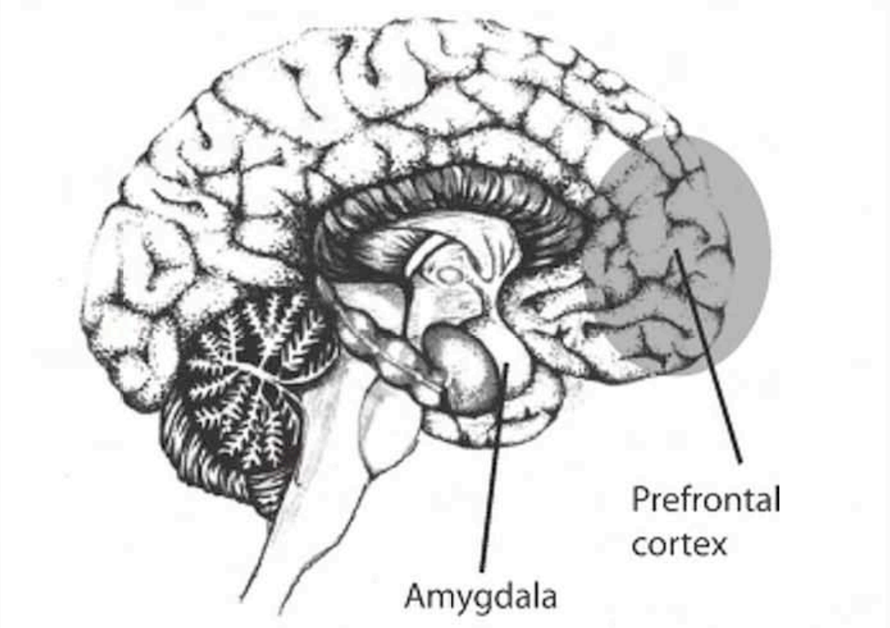

Figure 2. Diagram showing the regions of the brain involved in fear and stress. The prefrontal cortex is responsible for suppressing alarm response of the amygdala. In post-traumatic stress disorder, this control may become insufficient.

credit: Adapted from <http://www.ansto.gov.au/news_repository/how_old_is_your_brain.html>

exhibited an overall reduction in hippocampus activity and also a reduction in hippocampal crosstalk with the brain stem and thalamus, regions that control basic alertness (2).

In addition to impairing hippocampal function after sleep deprivation, the reduced interactions between the hippocampus and other regions of the brain provide a compelling neurobiological explanation of sleep deprivation-induced memory impairment. The rested brain favors strong connectivity between the hippocampus (the short-term memory storage center) and the regions responsible for image recall (2). This connectivity is vital in transferring the memories from short-term storage to more permanent storage centers in the neocortex. In sleep deprived individuals however, this usual connectivity is disrupted. Instead of activating hippocampal communication with the necessary image storage regions, the brain bypasses this process and stimulates the less sophisticated arousal regions to increase alertness during memory processing (2). In other words, the brain is more preoccupied with keeping sleep-deprived subjects awake than efficiently encoding new information.

For those used to staying awake until early morning before classes and work, the study provides a compelling argument against this practice. Though the effects of sleep deprivation may not be initially apparent, researchers propose that sleep deprivation eventually accumulates biological factors that inhibit normal neural function, impairing the hippocampus and its connectivity to the surrounding tissue (2). Additionally, a long period of wakefulness might overload the temporary storage hippocampus center with information to the extent that its ability to retain additional new memories is compromised (2). With an overloaded hippocampus, memory transfer to the neocortex is impaired and new memories can not be consolidated. Learning is thus fleeting. Sleep deprivation, it seems, jeopardizes not only next-day information retention, but also long-term memory storage abilities.

Sleep boosts memory retention and relational thinking

Though science has exposed the beneficial effects of sleep before learning, there has been even more insight about the favorability of sleep after learning. A slew of research articles has indicated that sleep plays an integral role in the retention of many types of memory, including declarative, spatial, and relational memory (3, 4, 5).

Memory can be divided into two

types, declarative and procedural. Simply put, declarative memory includes recall of factual information while procedural memory involves actions or skills, such as driving a car. Declarative memory can be further divided into semantic memory, which is factual and independent of time or place (e.g. name of a place), and episodic memory, which is the remembrance of past experiences and events (e.g. meeting with a loved one). Episodic memory itself branches into many subdivisions, one of which is spatial memory. Finally, as its own category, relational memory involves uncovering implicit relationships across existing stores of information.

Of the studies that measured brain activity, all of them showed that sleep control subjects exhibited higher activity in the right hippocampus than sleep-deprived patients, regardless of the type of memory in question (3, 5). These results pinpoint the hippocampus as the primary site of new memory processing. Like a packaging center, it receives information, sorts it, and sends it to the appropriate regions of the neocortex specifically designed to permanently store a type of input. Like hippocampal impairment before learning, hippocampal impairment after learning due to sleep deprivation results in weak hippocampus-neocortex communication. Unable to reach their secondary long-term storage sites, memories are quickly forgotten.

With such a strong link between sleep and memory consolidation, the fantasy of maximizing memory consolidation, increasing our ability to store large amounts of information, approaches reality. As our information-laden era demands higher and higher amounts of individual memory retention, academic and professional success has become even more tightly correlated with a broad and deep knowledge base. Potentially, pioneering studies of sleep and memory can yield ways of inducing memory consolidation during sleep with certain external stimuli. Already, research indicates that coupling learning with a sensory cue and reintroducing the cue during sleep optimizes learning and makes memories more permanent (7). It is not too farfetched to imagine a future of widely used and commercially available sleep-memory enhancer devices.

For now, the best we can do is minimize the negative effects of sleep deprivation, which may be long-lasting. One study shows that even after six months, individuals who were experimentally sleep deprived recalled information learned in the experiment more poorly than the sleep control subjects, despite the returning to normal sleeping habits after the study (3). Furthermore, the benefits of a good night's sleep might not be initially evident. While fully rested individuals may show low confidence in their recall abilities, their performances in memory tests are still better than those of sleep deprived individuals. Confidence levels therefore do not correlate with recall ability (5).

Encoding memories through a dual mechanism

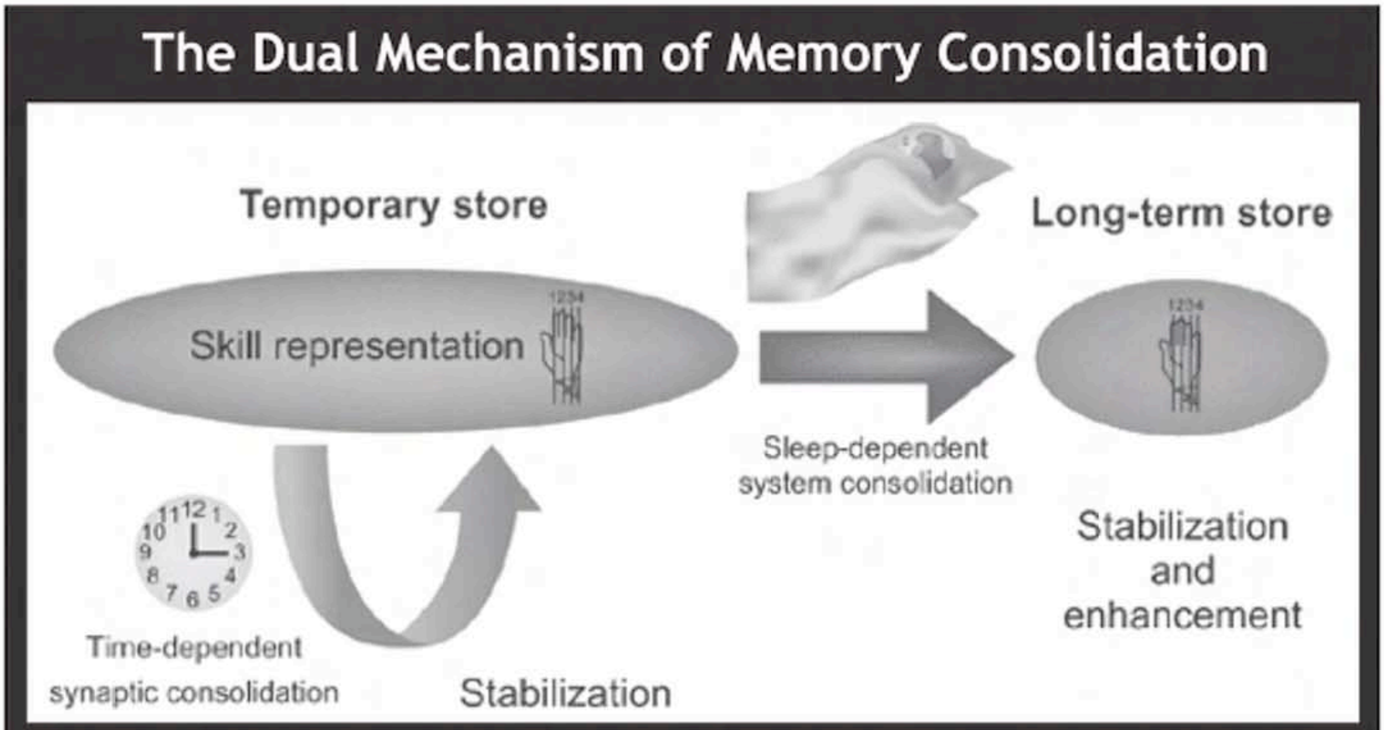

Figure 2. Model of skill memory consolidation. Representations of finger tapping skill are encoded in a temporary store. Resistance to interference of the representation can be achieved either through time-dependent synaptic consolidation in the temporary buffer or through sleep-dependent system consolidation that leads to a redistribution of the representation to different neuronal networks for long-term storage. Memory enhancement requires sleep-dependent system consolidation.

credit: Adapted from Ref. 3

So far, memory consolidation has been repeatedly mentioned without an adequate explanation of the meaning of the term "consolidation." Memory consolidation actually denotes two processes: One is synaptic consolidation and the other is sleep-dependent consolidation (6).

Synaptic consolidation refers to the strengthening of the neural signaling circuits activated during initial memory encoding (6). This kind of consolidation occurs independently of sleep and is mostly dependent on the amount time passed after the initial learning of an information or skill. Synaptic consolidation occurs as time passes after learning because time is needed for activation of protein synthesis, neural receptor interaction, and other molecular processes to cement the information pathway (6). In contrast with local circuit strengthening, sleep-dependent consolidation reactivates and redistributes memory signals to broad networks in the brain, spreading them to bigger and more permanent storage areas (6).

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Although both processes are involved in memory consolidation, sleep-dependent consolidation is faster and more stable. While a fresh memory is subject to interference from similar inputs during synaptic consolidation, during sleep, no interfering input is taken in and the new memories are transferred to long-term storage sites, thus preventing any future interference.

To illustrate such a paradigm, researchers performed a study on motor memories. Subjects were taught a finger-to-thumb tapping sequence, and after two hours, another slightly different sequence (6). Those who took a 90 minute nap after learning the first sequence were better able to fend off the second competing sequence and correctly produce the first sequence one day later than those who did not sleep in between.

This study reveals the important overarching principle of dual memory processing present not only in motor memory, but also in all other kinds of memory. As shown in studies on declarative, spatial, and relational memories, memory consolidation consists of two parts – the short-term hippocampus encoding and the long-term transfer to neocortical regions. Memory accumulation in the hippocampus can be regarded as synaptic consolidation whereas the transfer of information to more permanent storage areas as sleep-dependent consolidation. Recently discovered, dual memory encoding processes have contributed a lot to our current knowledge of sleep's essential role in changing, stabilizing, strengthening, and integrating memories (7).

Looking ahead

Already, scientists have sought to capitalize on this newfound knowledge of memory processing. A group of researchers has been successful in enhancing individuals' performances in a card memory game by exposing the subjects to the scent of a rose whenever they matched a pair of cards correctly and exposing them again to the scent during sleep (7). Having their memory trace reactivated through a contextual trigger, the subjects exposed to the rose during sleep remembered the card locations better than those who did not benefit from such trigger.

Expanding the applications even more widely, researchers view the externally induced memory consolidation as a possible treatment for individuals suffering from post-traumatic stress disorder. Post-traumatic stress disorder is a psychological disorder in which distressing memories are not adequately processed and connected with other memories. As a result, these memories often recur and loop around, and are unable to integrate into the larger memory network. An induced sleep-dependent memory consolidation could bypass this blockade and effectively reconcile the individual with his or her traumatic experience. One possibility is exposing an individual who is asleep to a stimulus present during the traumatic experience, so that the constant activation of the problematic memory will force its consolidation into the rest of the memory network. Although such practice may defy intuition, this psychoanalysis-like method of confronting troubling remnants of the past allows for effective processing of post-traumatic stress-related memories (7).

Seemingly, the applications of sleep and memory research are as far-ranging as the topic itself. As scientists at last recognize the potential of sleep-induced memory consolidation, the field inevitably expands. Who knows, with the development of efficient ways to consolidate our memories, sleep deprivation might not be so adverse to learning after all – that is, as long as we stay physically fit and mentally sane.

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