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Memory Process and the Function of Sleep

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Abstract: This work outlines a theory for a new human memory model. The model is based on two hypotheses: the temporary memory hypothesis and the function of sleep hypothesis. The author proposes that there is a temporary memory stage to bridge the gap between short-term memory and the long-term memory. During our waking time, the memory formed from the working memory is not saved directly into the long-term memory; instead it is saved into a temporary memory. The function of sleep is to process, encode and transfer the data from the temporary memory to the long-term memory. To test this new memory model, some well-known research and observational results, which could not be understood before, have been explained based on this new memory model.
Keywords: memory, working memory, temporary memory, long-term memory, REM, non-REM, sleep, dream

1. Introduction

Memory has been divided into three categories based on the amount of time the memory lasts: sensory memory, short-term memory and long-term memory. The sensory memory acts as a buffer for stimuli received from the senses. A sensory memory exists for each sensory channel. Sensory memory is the shortest-lived memory lasting only milliseconds to a few seconds. The memory lasting from several seconds to at most a few minutes is called short-term memory (or immediate memory). Information is passed from sensory memory into short-term memory by attention. A more dynamic view of short-term memory, called working memory, proposes a more active system in which information is not only stored but also processed [1~4]. The memory lasting anywhere from an hour to lifetime is called long-term memory. Long-term memory can be divided as so-called 'procedural' (implicit) and 'declarative' (explicit) memory [5]. Procedural memory is defined as information we possess, but cannot describe verbally. It refers to skilled performance, such as typing, riding a bicycle and playing a musical instrument. Historically, this type of memory was referred to as motor skills and involved study of how motor performance is learned. Declarative memory represents all knowledge that can be consciously accessed and expressed symbolically through speech or writing.

It is believed that the incoming information is first held in sensory memory. By attention, the information will then be passed to working memory for processing. Finally, the mnemonic and the rehearsal cause the memory to move from working memory into long-term memory through consolidation [6].

How and when is the information transferred from the working memory to the long-term memory? What is the function of sleep? Why do we dream? The answer is not clear, although many models and hypotheses have been proposed. In this paper, a new memory model is hypothesized, and based on this new memory model many mysteries about memory, sleep and dreaming can now be explained.

2. Theory

2.1. The Temporary Memory Hypothesis

The temporary memory, as it is so named, is a temporary memory system with a limited capacity. Information in temporary memory is stored in a quickly accessible and stable form. Different from long-term memory, its existence is to be assumed to meet the demand for fast data storage, rather than compressed file size and permanent storage. Data that comes from the working memory will stay in the temporary memory until either being deleted, or transferred to the long-term memory. Overloading the temporary memory will cause interference with the data saved there and impair the learning process. Different kinds of temporary memories are stored in separate areas. There are two kinds of temporary memory stores in the human brain: one for declarative memory and one for procedural memory. The temporary memory location for the declarative memory is assumed to be the hippocampus and the adjacent brain areas.

2.2. The Function of Sleep Hypothesis

Because the temporary memory capacity is limited, it is important to avoid overload. It must be cleared periodically. Our waking brain cannot perform this task when the working memory is busy processing large amounts of incoming information. To perform this housekeeping, the temporary memory has to be shut off from the environment to ensure the memory transfer process is uninterrupted.

The function of sleep is to process the data saved in the temporary memory, encode and transfer that data to long-term memory. This will include comparing the newly saved information from the temporary memory with old files saved in the long-term memory, in order to identify and delete unwanted, duplicate and overlapping data. The remaining information is then encoded and transferred to long-term memory.

2.3. Zhang's Memory Model

Based on the hypotheses of the temporary memory and the function of sleep, a new memory model is given in figure 1 and figure 2. This new model has two stages: the waking brain and the sleeping brain.

During waking time, the sensory memory is continuously receiving information from all five senses. The information is first held in the sensory memory store. By attention, some of the information will then be passed to the working memory for processing. To process the incoming information, the working memory will retrieve related information from the temporary memory and or the long-term memory. The processed information will then be sent to the temporary memory for rapid memory saving. In general, all processed human information from the working memory in our waking brain will be saved in the temporary memory. While awake, the long-term memory is in retrieval-only mode.

During sleeping time, the sensing rate of all the sensors are slowed and the arousal thresholds are increased. This will ensure that the data transfer process is uninterrupted, unless a danger or threat signal occurs. Without incoming information flowing from the sensors/environment, the working memory can now perform the data transfer – housekeeping process. The working memory will retrieve data from the temporary memory, compare it with related files previously saved in the long-term memory, and delete any unwanted, duplicate or overlapping data. The information deemed relevant as new or updated, is encoded and transferred to long-term memory. During this period of time, the temporary memory is in retrieval-only mode. Any brain activities, such as dream, could not be recorded to the temporary memory. The only memory store that can record brain activities consciously in this time period is the short-term/working memory store.

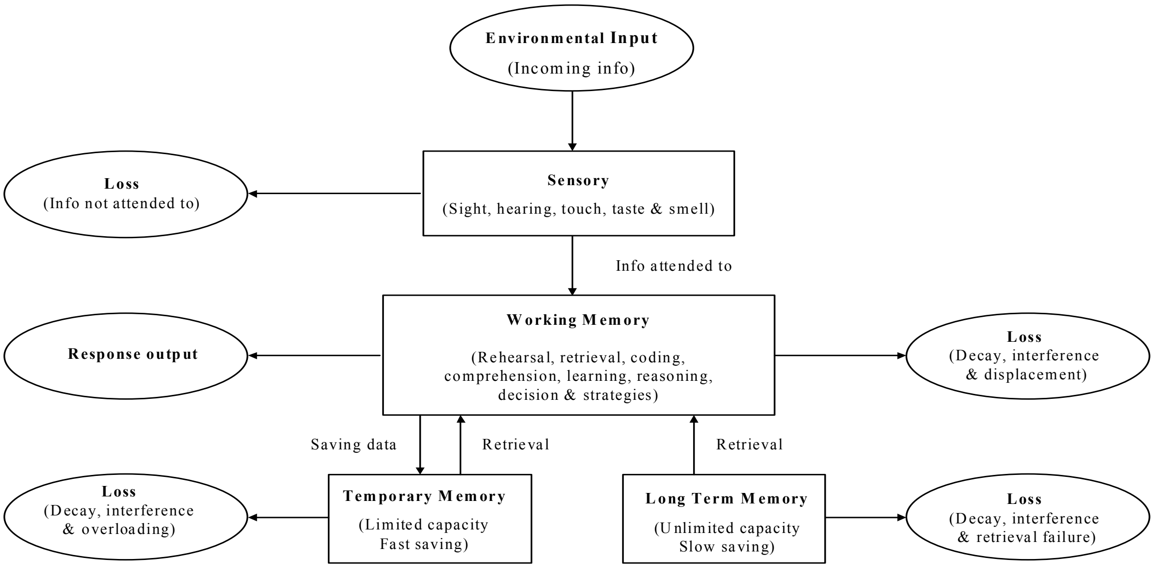

Fig. 1. **Memory model for the waking brain**.

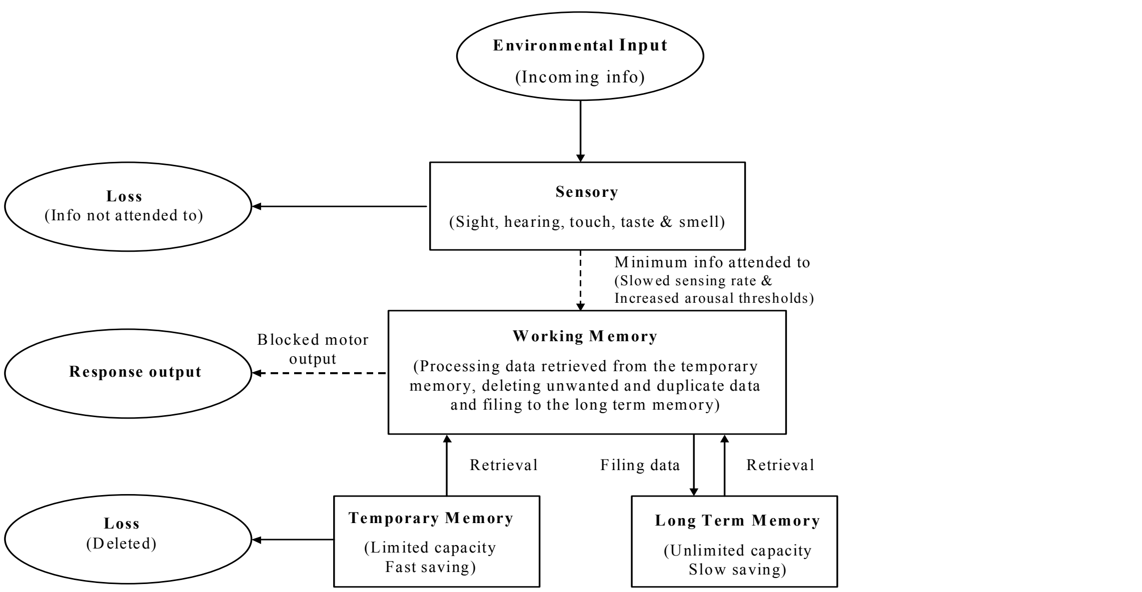

Fig. 2. **Memory model for the sleeping brain**.

2.4. Working Memory and Consciousness

The working memory model, first proposed by Baddeley and Hitch in 1974, assumed three separable components: the central executive, and two subsidiary systems. The subsidiary systems are the phonological loop, which is responsible for holding and manipulating auditory-verbal information, and the visuo-spatial sketch-pad, which performs a similar function for visual, spatial and kinaesthetic information [4]. In the Zhang memory model, the concept of working memory has been extensively widened. This new model assumes that the working memory has the ability to execute all types of human information, both declarative memory and procedural memory. From this point of view, the working memory should have two groups of subsidiary systems, one for processing declarative (conscious) memory and one for processing procedural (non-conscious) memory. The importance of the working memory in this model is clearly exhibited in the figures. It is in fact, the consciousness center of human brain. If we define dreaming as a state of consciousness, then consciousness can be defined as the act of processing declarative memory data in working memory. The declarative memory data stream may come from the sensory stores, temporary memory, long-term memory or any combination of them. Dysfunction of the working memory (damage to the central executive and conscious subsidiary system) will lead to unconsciousness (coma). From this perspective, the home for the working memory is very likely located at the brainstem, not the frontal lobe area as some researchers have suggested. This has been evidenced by the fact that unconsciousness can be caused by brainstem lesions, but not frontal lobe lesions or a Lobotomy [7].

2.5. Sleep Stage and Dream

As the Zhang memory model assumes that there are two types of temporary memory stores, one for declarative memory and one for procedural memory, sleep should also have two different stages which would correspond to the type of memory being transferred. These two stages were discovered about 50 years ago in fact by Nathaniel Kleitman, Eugene Aserinsky and William Dement [8], and were named rapid eye movement (REM), and non-REM (NREM) stages. Based on their findings, the author assumes that the NREM stage is responsible for the processing of the declarative memory, and the REM stage is responsible for the processing procedural memory. This could be evidenced by the observation that we are almost completely paralyzed in REM sleep with only the heart, diaphragm, eye muscles and the smooth muscles operating. The purpose of body paralysis during REM stage is to prevent the sleeper from reacting to the procedural data being processed, not as some researchers assumed to prevent the sleeper from reacting to the dreaming event, since dreaming also occurs in the NREM stage. One curious finding, in both human and some animals, is that penile erection in males and clitoral engorgement in females occurs during REM sleep [9]. This as a matter of fact, is a substitute method for the paralyzed body muscles to prevent urination during REM sleep period, and has nothing to do with the dream content.

In a similar thinking, the author further proposes that there are two types of dreams as a result of different mental activity of the sleeping brain. The type I dream, a thought-like mentation, is the consequence of the memory replay when the declarative memory data is retrieved from the temporary memory store to the conscious subsidiary systems of the working memory for processing during NREM sleep. On the other hand, type II dream, a more dream-like mentation, often occurs during REM sleep, when the procedural memory is being transferred from the temporary memory to the long-term memory. It is easy to see that the type II dream has no direct causality with the REM state. That is, the type II dream and REM are, in fact, two different states. The rapid eye movement observed in REM stage is the consequence of the procedural memory processing. However, the paradoxical state of scalp electroencephalograph (EEG) in REM sleep is mainly the consequence of the dreaming brain. It seems that the type II dream occurs when no attended conscious data stream flows into the conscious subsidiary system of working memory. From this point of view, although it occurs most often in REM sleep, the type II dream can also occur in any other state, including NREM sleep and even waking state.

In the rest of the paper, using Zhang's memory model and the assumptions above, the author will try to explain some of the well-know observations and study results.

3. Discussion

3.1. Sleep Time

It is well known that people of different ages require different amounts of sleep. A newborn baby may sleep 16 hours, whereas a person aged 50 might sleep only six hours. Why? Referring to the Zhang memory model, sleep time depends on two factors, the amount of the data that needs to be transferred to the long-term memory, and the speed of the data transfer from the temporary memory to the long-term memory. It is obvious that the database in the long-term memory of a newborn baby is just starting to establish. He/she has to file almost every memory, both declarative and procedural, from the temporary memory to long-term memory. Since the procedural memory (skill to control body movement) is very crucial to the newborn, they spend about 50% of their sleep time in the REM stage. In contrast to this, adults have significant less information that needs to be transferred to the long-term memory since a huge database has already been created. It is also reasonable to assume that adults with a mature brain should have a higher processing and data transfer rate from the temporary memory to long-term memory. In fact this data processing/filing rate could well be different in each person. This would explain variations in required sleep times, why some people always need to sleep longer than others.

3.2. Why We Forget Our Dreams

Although we all dream every day when we sleep, we can seldom recollect more than a few minutes worth of our dreams after waking. Unless being recalled immediately after waking, dreams cannot be remembered. This observation leads some researchers to suggest that dreams are probably meant to be forgotten. Nevertheless, the reason that we forget our dreams is because our temporary memory store has been switched to retrieve-only mode in the sleeping brain for memory processing. Any brain mentation during this period could not be saved in the temporary memory store. Only the short-term memory (working memory) store is still available for memory storage during sleep. Since the short-term memory has a very limited capacity, decays rapidly and will be replaced by new incoming information if distracted, a sleeper can only recall the memory from the short-term memory store immediately after waking. This explains why one can recollect so little of their dreams.

3.3. Sleep Deprivation

In January of 1965, Randy Gardner, a San Diego high school student, created a new Guinness World Records by staying awake for 264 hours or 11 whole days. Dr. William C. Dement, a pioneer sleep researcher from Stanford University Medical School, closely monitored this long-term sleep deprivation. One of the most astonishing results of this experiment was that after having been awake for 11 days, Randy had slept only 14 hours and 40 minutes for the first recovery day, 10 hours and 30 minutes the next day, and 9 hours on the third day. Dr. Dement noticed that Randy's usual sleep requirement was a little less than 7 hours a day. Based on this figure, he calculated that Randy lost about 75 hours of sleep [8]. But why had he only slept 14 hours 40 minutes on his first recovery day? After almost four decade, this question is still left unanswered. Now, using the temporary memory theory, this can be easily explained. The key is that the temporary memory has a limited capacity. Let's assume that the temporary memory can hold about three days worth of data, based on Randy's sleep deprivation experiment, in which Dr. Dement noticed that it became very difficult to keep Randy awake by the third day. Therefore, what happened in this case is that Randy's temporary memory started to reach its capacity and became overloaded on or around the third day of wakefulness. Although micro-sleeps and sleepwalking might help free a little temporary memory storage, his temporary memory was basically in an overloaded state throughout the rest of the sleep deprivation marathon. Almost all of the incoming information would not be saved into his temporary memory in this overloaded state. Learning should be extremely difficult, if not impossible. This, by the way, would explain why sleep deprivation would weaken learning and memory. However, although 14 hours 40 minutes recovery sleep, which was equivalent to a little bit more than 2 nights sleep, might not clean up all of Randy's temporary memory, it would relieve most of his temporary memory at least and keep him well awake again. This interpretation could lead to another prediction that Randy would probably need about the same amount of time for his first recovery sleep, even if it were only a three day sleep deprivation. In the same way, it is easy to understand that sleep deprivation will cause sleep rebound, since any unprocessed data left in the temporary memory will become sleep debt for future sleep.

3.4. The H. M. Case

After removal of large sections of the medial temporal lobes of the brain to relieve epilepsy in 1953, twenty-seven year old H.M. could only remember recent events for a few minutes. The removal of the medial temporal lobe, which includes the hippocampus and adjacent brain areas, left H.M. unable to form any new personal memories. He also suffered a partial loss of memory of events before the operation. But he had good recall of facts learned long before his operation, meaning that his long-term memory was unharmed. His working memory seemed also unaffected by the loss of his hippocampus. Researchers found that H.M.'s procedural memory was also intact [10]. Although H.M. is the most studied individual in the history of brain research, the only conclusion of this study so far is that the medial temporal lobe seems to play a role in converting memory from a short-term to a long-term form, but not for memory maintenance or retrieval. Comparing the H.M. case with this new memory model, if we assume that what H.M. actually lost was his whole declarative temporary memory store, then all these discoveries from H.M. would have been predicted by the new memory model. His declarative temporary memory store along with any unprocessed data in it was removed from his head forever during that surgery.

4. Conclusions

As indicated in this paper, the theories presented above covers a very broad area, from brain science, sleep research to dreaming study. They are readily testable, and are proved in agreement with many observations and research results.

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References

1. Baddeley, A, Prose recall and amnesia: implications for the structure of working memory. Neuropsychologia 2002, 40; 1737-1743
2. Baddeley, A, The episodic buffer: a new component of working memory? Trends in Cognitive Sciences 2000. Vol. 4, No. 11; 417-423
3. Baddeley, A, Recent developments in working memory. Current opinion in neurobiology 1998, 8; 234-238
4. Baddeley, A.D. and Hitch G, Working memory. In the psychology of learning and motivation. Academic press. 1974, 48-79
5. Squire, L.R., Memory and brain. New York, Oxford University Press, 1987
6. Restak, R, The secret life of the brain, The DANA Press and Joseph Henry Press, 2001
7. Robin, A, and Macdonald, D, Lessons of leucotomy, Henry Kimpton Publishers, 1975
8. Dement, W.C., The promise of sleep, Delacorte Press, 1999
9. Fisher, C, Gross, J, Zuch, J, Cycle of penile erection synchronous with dreaming (REM) sleep. Arch Gen Psychiatry. 1965, 12:29-45
10. Hilts, P.J., Memory's ghost, New York, Simon & Schuster, 1999