The Role of Sleep Stages in Memory Consolidation: Comparing SWS and REM

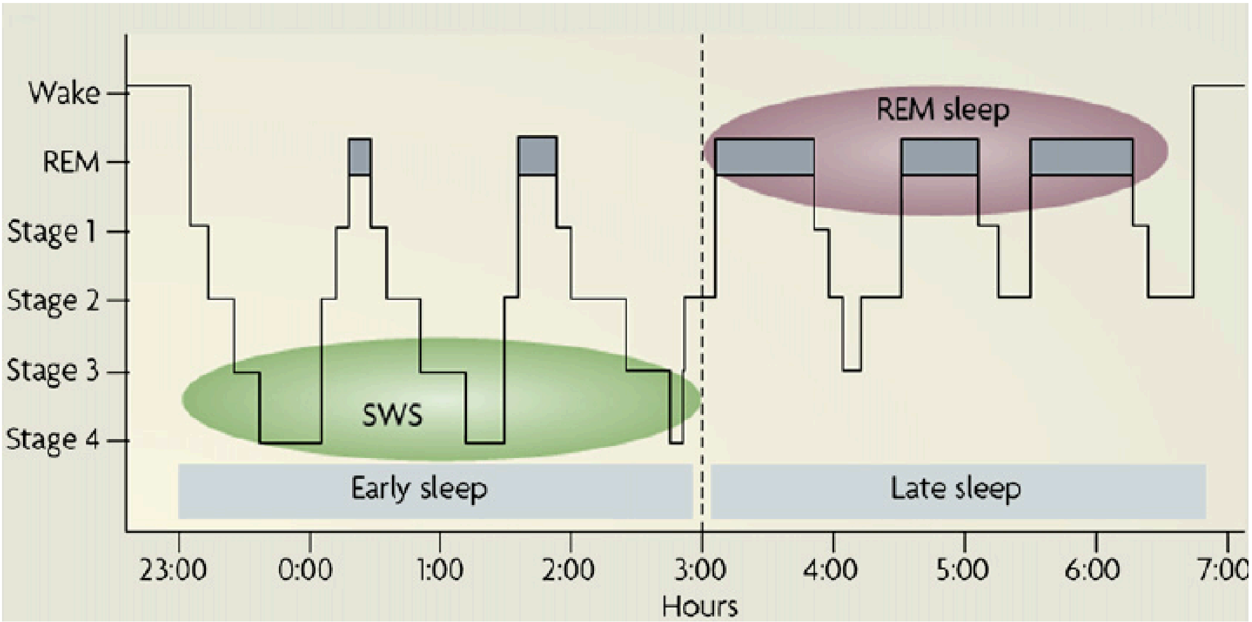

Figure 1. A sleep histogram showing the typical distribution of SWS and REM sleep

Note. From Learning, Memory, and Sleep in Humans, by Jessica Payne, 2011, Sleep Medicine Clinics. 6. 15-30. 10.1016/j.jsmc.2010.12.005.

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INTRODUCTION

After a tiring day, you go to bed subconsciously and wake up with a clearer memory in the morning. As many of you may have noticed, we recall information more effectively after a full night of sleep. This is an active process of our brain during sleep rather than just a mere coincidence. Beyond fundamental roles such as rest and maintaining our day-to-day lives efficiently, sleep plays a significant role in memory consolidation, stabilising and integrating newly acquired knowledge into long-term memories (Gais, 2004). Here, I aim to investigate the relationship between two sleep stages: Slow-Wave Sleep (SWS) and Rapid Eye Movement (REM), and memory consolidation.

SLOW-WAVE SLEEP (SWS)

Slow-Wave Sleep (SWS) is the deepest of the NREM sleep stages, during which it is the most difficult to be awakened, and mainly occurs in the first half of the typical 8-hour night (Payne, 2011). The Dual Process Hypothesis proposes that different stages of sleep selectively contribute to the consolidation of other types of memory (Walker, 2006). With respect to this theory, SWS has been identified as a crucial period for hippocampus-dependent memory, particularly in tasks such as word-pair and spatial learning (Plihal & Born, 1997; Rasch & Born, 2013). Here, the term declarative memory is primarily divided into episodic memory, which encompasses events specific to time and spatial contexts, and semantic memory, which involves general facts and knowledge.

Memory recall for declarative memories is strengthened during SWS through a process of covert reactivation (Maquet, 2001). This is evidenced by the hippocampal activity observed when encoding new information during prior learning appears to be replayed in the stage of SWS (Wilson & McNaughton, 1994). This replay activity during SWS is not only limited to the hippocampus, but further extends into the neocortex (Qin, 1997), and thereby integration of old and new memories is transformed into long-term memory storage (Dikelamann & Born, 2010), and this is called a system consolidation.

RAPID EYE MOVEMENT (REM) SLEEP

Rapid Eye Movement (REM) Sleep represents a lighter stage of sleep that occurs in approximately 90-minute cycles throughout the night, influencing procedural and emotional memories (Plihal & Born, 1997; Smith, 2001). In reference, Procedural memories are the gradual acquisition of skills through repeated practice and are non-hippocampal dependent, while emotional memories involve feelings associated with experiences.

A study using finger sequence tapping tasks has demonstrated that REM-rich sleep enhances motor skill performance (Fischer et *al.*, 2002), highlighting that REM facilitates procedural memories. Additionally, the motor memory consolidation is more than just strengthening previously acquired skills; instead, it reorganises smaller chunks into unified representations (Macquet & Pierre et *al.*, 1996). In contrast to SWS, which dominates the stabilisation of memories through reactivation, even without a full cycle of SWS-REM (Dikelmann, 2011), procedural memory is not only dependent on REM but also on N2 for sleep spindles and SWS to a lesser extent for local neuronal strengths (Gais, 2004).

REM sleep is implicated in the memory process for emotional memories (Hennevin, 2007); these emotional memories are enhanced through interactions between the amygdala and hippocampal memory-encoding processes (McGaugh, 2004). Emotional memories are generally remembered better than neutral ones and consolidated strongly from sleep than neutral memories (Wagner, 2001; Hu, Peter, et al., 2006); even after several years (Wagner, 2006). Furthermore, according to “Sleep to Forget and Sleep to Remember” (Walker, 2009), emotional memories are consolidated in 2 steps: the reactivation of fear-associated memories during non-REM sleep, specifically SWS, retains memory contents while reducing emotional intensity (Hauner 2013), suggesting that fear extinction occurs optimally under conditions where the brain is stable, low in stress hormone norepinephrine, and amygdala activity. This is enabled by the odor, which is a cue that doesn't trigger a fear response. However, recent studies challenge the idea of fear extinction during SWS, claiming fear response can be strengthened. If the brain detects a cue as a threat, it initiates the reconsolidation process, requiring new protein synthesis to restabilise the fear response. It indicates the memory outcome is dependent on the environment and affected by reconsolidation (Rolls et *al*., 2013).

CONCLUSION

Despite early studies that simply show Slow-Wave Sleep (SWS) benefits declarative memory and Rapid Eye Movement (REM) Sleep benefits non-declarative memories, recent studies propose that consolidation is multifactorial. In fact, procedural memories rely heavily on non-REM sleep, especially on N2 and sleep spindles rather than on REM sleep. Ultimately, further studies are required to resolve whether non-REM sleep (i.e, SWS and N2) and REM are strictly differential or interconnected in the system consolidation during reactivation, as well as how the environments of different sleep stages influence the extinction or reconsolidation of emotional memories.

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