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How Naps Shape Memory: Mechanisms, Memory Types, and Modulating Factors

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Abstract. Napping is a behavior observed across diverse cultures worldwide and has been associated with numerous benefits for cognitive function, particularly for memory consolidation and the restoration of alertness. Foundational studies have demonstrated that brief daytime naps reliably enhance cognitive performance, especially declarative memory consolidation and executive alertness, by dissipating homeostatic sleep pressure and facilitating neural oscillations. However, the specific mechanisms underlying the relationship between napping and cognitive function remain incompletely characterized. This review synthesizes current evidence on the mechanisms by which naps enhance cognitive function, focusing on their differential effects on declarative, procedural, as well as on emotional memory and the neural oscillations, such as sleep spindles and slow oscillations, that underlie these effects. It further examines the individual and contextual factors, including age, habitual napping, nap timing and duration, that modulate these outcomes, and concludes by identifying key limitations in the current literature while outlining directions for future research.

Keywords: Naps, Memory consolidation, Sleep oscillations, Declarative memory, Cognitive function

1. Introduction

Napping is a behavior found across virtually every human culture, from the Mediterranean siesta to the structured afternoon rest periods common in East Asia and Latin America [1]. In modern industrial societies, where chronic sleep restriction has become increasingly prevalent, brief daytime sleep has gained renewed scientific and public attention as a low-cost strategy for restoring cognitive performance and offsetting the consequences of insufficient nocturnal sleep. A growing body of work over the past two decades has shown that even short naps can produce measurable improvements in alertness, executive function, and memory, in some cases approaching the magnitude of benefits derived from a full night of sleep [2-4].

These cognitive benefits are increasingly understood to reflect specific neurophysiological processes that take place during sleep. According to the active systems consolidation framework, newly encoded memories, initially stored in a labile form within hippocampal networks, are gradually redistributed to neocortical regions during non-rapid eye movement (NREM) sleep, where they become stabilized as long-term traces [5, 6]. This process is supported by the coordinated

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activity of slow oscillations, sleep spindles, and hippocampal sharp-wave ripples (SWR), all of which can be engaged during a daytime nap. Brief naps confined to lighter NREM stages predominantly restore alertness with minimal sleep inertia, whereas longer naps that include slow-wave or rapid-eye-movement sleep (REM) additionally support the consolidation of declarative, procedural, and emotional memory [7, 8].

Despite this progress, several questions remain only partially resolved. The differential sensitivity of distinct memory systems to napping, the precise oscillatory mechanisms underlying each type of consolidation, and the individual and contextual factors that determine who benefits most have only recently begun to receive systematic attention. The present review brings these strands together. This study first outline the major memory systems and the neural processes that support their encoding and consolidation. This study then describes the architecture of sleep and its established role in memory processing, before introducing the nap as a tractable model for studying these mechanisms within a compressed time frame. The subsequent sections discuss the effects of napping on different types of memory, the influence of nap duration, quality, and timing, the individual and contextual factors (age, habitual napping behavior, and physiological state) , and physiological state, and the translation of this body of evidence into clinical, educational, and occupational applications, along with current limitations and directions for future research.

2. Memory

2.1. Types of memory

Memory is not a unitary faculty but comprises several functionally and neuroanatomically distinct systems [9]. Within long-term memory, a fundamental division is drawn between declarative (explicit) and non-declarative (implicit) memory [10]. Declarative memory refers to consciously accessible information that can be verbally expressed, and is further subdivided into episodic memory, which stores personally experienced events, and semantic memory, which encompasses general facts and knowledge. Non-declarative memory, by contrast, operates largely outside conscious awareness, its most extensively studied form, procedural memory, supports the acquisition and execution of motor and cognitive skills, such as riding a bicycle or playing an instrument, and is typically expressed through performance rather than verbal recall [9]. These distinct systems interact to support the encoding, retention, and retrieval of information.

2.2. Memory encoding

Encoding constitutes the initial stage of memory processing, during which incoming sensory information is transformed into internal neural representations that can subsequently be stored and retrieved. This transformation proceeds through a hierarchical pathway: sensory inputs are first processed within modality-specific cortical regions and converge upon multimodal association areas, before being relayed via the entorhinal cortex to the hippocampus, which rapidly binds the disparate features of an experience into a unified episodic trace through activity-dependent synaptic plasticity [11]. Crucially, encoding is not a passive registration of input but an active process shaped by higher-order cognition: the prefrontal cortex supports attentional control and the integration of new information with pre-existing semantic schemas [12], such that the strength of the resulting memory trace depends critically on the depth of processing applied at this stage. Consistent with this, encoding-related activity in the hippocampal-prefrontal network reliably predicts whether information will later be remembered or forgotten [13].

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2.3. Memory consolidation

Once a memory has been encoded, it remains initially labile and susceptible to interference, its transformation into a stable, long-lasting representation is achieved through a set of post-encoding processes collectively referred to as memory consolidation [14](PMID: 14744210). Two complementary levels of consolidation are conventionally distinguished. Synaptic consolidation operates within minutes to hours after learning and involves activity-dependent molecular cascades that stabilize long-term potentiation at the synapses recruited during encoding [15]. Systems consolidation, in contrast, unfolds over days to years and entails a gradual reorganization of memory traces, whereby hippocampus-dependent representations are progressively integrated into neocortical circuits [16, 17]. Critically, both forms of consolidation are strongly modulated by behavioral state, and substantial evidence indicates that sleep provides a privileged window during which these stabilization processes are most effectively engaged [5], as elaborated in the following section.

3. Sleep

3.1. Connection between memory and sleep

According to the Active Systems Consolidation hypothesis [6], newly acquired declarative memories are initially encoded as labile traces within hippocampal networks and are subsequently redistributed to neocortical regions during sleep to form stable long-term representations. This hippocampal-cortical transfer occurs predominantly during NREM sleep and is mediated by the precise temporal coordination of three nested neural oscillations: neocortical slow oscillations (SOs, <1 Hz), thalamocortical sleep spindles (11-16 Hz), and hippocampal sharp-wave ripples (SWRs) [18]. During hippocampal replay, neuronal ensembles that were active during prior encoding are sequentially reactivated within SWRs, recapitulating the spatiotemporal firing patterns associated with the original experience. Cortical slow oscillations are thought to orchestrate this process by generating alternating up- and down- states that provide global windows of excitability and inhibition, thereby gating the timing of memory reactivation. Sleep spindles, generated by thalamocortical circuits, are preferentially nested within the depolarized up-state of slow oscillations. The hierarchical phase-amplitude coupling among SOs, spindles, and hippocampal ripples (SO-spindle-ripple coupling) is widely regarded as the key neurophysiological substrate enabling the redistribution and integration of memory traces from the hippocampus into long-term neocortical stores [19, 20].

3.2. Sleep stages

Sleep is organized into alternating NREM and REM stages, with a typical night comprising four to six cycles of approximately 90 to 110 minutes each. According to the American Academy of Sleep Medicine (AASM) scoring criteria, NREM sleep is subdivided into stages N1, N2, and N3, reflecting progressively deeper sleep. N1 represents a brief transition from wakefulness to sleep and accounts for only a small proportion of total sleep time. N2 occupies approximately 45-55% of total sleep and is characterized by sleep spindles and K-complexes, oscillatory features that have been implicated in memory consolidation and the maintenance of sleep continuity [21]. N3, also known as SWS, is the deepest NREM stage and is considered critical for both physical restoration and the consolidation of declarative memory [5]. REM sleep accounts for approximately 20-25% of total

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sleep, is associated with vivid dreaming, and is characterized by rapid eye movements, muscle atonia, and wake-like cortical activity [22].

3.3. Naps

Although the cognitive and restorative functions of sleep have been most extensively characterized in the context of nocturnal sleep, a growing body of evidence indicates that brief naps recapitulate many of these neurophysiological and behavioral benefits within a substantially compressed time frame [3, 4]. Naps are typically classified by their function and by their duration, with each category exhibiting a distinct profile of cognitive outcomes. Short naps of approximately 10 to 20 minutes, which remain largely confined to NREM stages N1 and N2, have been shown to enhance alertness, vigilance, and processing speed without producing pronounced sleep inertia [7, 23]. In contrast, longer naps extending beyond 30 minutes are more likely to incorporate SWS and a greater proportion of N2 spindle activity, thereby conferring additional benefits to declarative and procedural memory consolidation, albeit at the cost of transient post-awakening grogginess [4]. Given these differentiated effects, naps represent a uniquely tractable model for examining the relationship between sleep architecture and cognitive function, and thus constitute the central focus of the present review.

4. The effect of naps on different types of memory

4.1. Effects on declarative memory

Declarative memory, encompassing the conscious recollection of facts and events, has been the most extensively investigated domain in nap-based memory research. A substantial body of work employing paired-associate word-learning paradigms has demonstrated that a daytime nap protects newly acquired declarative information against forgetting relative to an equivalent period of wakefulness [8, 24]. In a seminal study, Tucker et al. reported that a nap containing SWS but no REM sleep was sufficient to enhance declarative memory retention, implicating NREM rather than REM processes in this benefit. Consistent with this finding, the magnitude of nap-related declarative memory improvement has been repeatedly linked to specific NREM oscillatory features, particularly the density of sleep spindles and the amount of slow-wave activity recorded during the nap [25, 26]. Converging causal evidence comes from stimulation studies, in which the disruption of slow-wave activity during an afternoon nap selectively impaired subsequent word-pair recall [27]. Notably, the consolidation benefit appears to be selective rather than uniform, with hippocampus-dependent associative memories and weakly encoded or emotionally salient items preferentially strengthened during sleep [28], suggesting that napping actively prioritizes certain memory traces for stabilization.

4.2. Effects on procedural and other types of memory

Beyond declarative memory, naps also support the consolidation of procedural and emotional memory, although through partly distinct mechanisms. For procedural motor-skill learning, a daytime nap has been shown to produce offline performance gains comparable to those observed across a full night of sleep. In a seminal finger-tapping study, Nishida and Walker reported that only participants who napped exhibited significant post-nap improvement, and that the magnitude of this gain correlated specifically with sleep-spindle activity in the cortical region engaged during learning

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[29]. Consistent with this, meta-analytic evidence indicates that spindle-memory associations are even stronger for procedural than for declarative tasks [30]. Emotional memory, in contrast, has traditionally been linked to REM sleep, although more recent work implicates sleep spindles in this domain as well [31]. Together, these findings suggest that different memory systems are preferentially consolidated by distinct sleep features within a single nap.

4.3. The effect of nap duration, quality and timing on memory

The cognitive consequences of napping are critically modulated by nap duration, quality, and timing. Controlled comparisons of 5 to 30 minutes naps indicate that a brief nap of approximately 10 minutes optimally restores alertness while minimizing sleep inertia, as such naps remain confined to stages N1 and N2 [7]. Longer naps reaching SWS confer additional declarative memory benefits but increase the likelihood of pronounced sleep inertia [4]. Beyond duration, sleep spindles appear to be the principal oscillatory substrate of nap-related declarative memory gains: Mednick et al. demonstrated that pharmacologically increasing spindle density with zolpidem selectively enhanced verbal memory consolidation [31]. Finally, early-afternoon naps (approximately 13:00-15:00) are dominated by NREM sleep and thus particularly conducive to spindle-mediated consolidation, whereas later naps incorporate more REM sleep and risk disrupting subsequent nocturnal sleep [4].

5. Individual differences and other factors

5.1. Age-related differences

The cognitive benefits of napping are substantially shaped by age, owing to well-documented changes in sleep architecture across the lifespan. Healthy ageing is accompanied by a marked decline in SWS and a reduction in the density, amplitude, and topographical organization of sleep spindles [32]. Because these NREM oscillations constitute the principal substrate of sleep-dependent memory consolidation, their deterioration is thought to contribute to age-related declines in declarative and procedural memory. Consistent with this, older adults often exhibit a reduced consolidation benefit from a daytime nap relative to younger adults, despite comparable initial learning [33]. Moreover, the precise temporal coupling-weakens and even reverses its hierarchical organization with age [34]. These findings suggest that the restorative and mnemonic value of napping is not uniform but is progressively attenuated across the adult lifespan.

5.2. Habitual and non-habitual nappers

Whether an individual naps further moderates the cognitive outcomes of daytime sleep. Habitual nappers tend to remain in lighter NREM stages with more frequent stage transitions, whereas non-habitual nappers accumulate proportionally more SWS which predisposes them to greater post-nap grogginess, or sleep inertia, upon awakening [35]. Reflecting these physiological differences, habitual nappers have been shown to derive larger performance gains from a nap, particularly on tasks dependent on N2 spindle activity such as motor and perceptual learning. Nevertheless, the picture is task-dependent: Leong et al. found that an afternoon nap enhanced long-term declarative memory regardless of napping habit, whereas benefits for a hippocampus-dependent short-term task were specific to habitual nappers, who also showed memory decline when nap opportunity was withheld [36]. These findings indicate that habitual napping shapes both nap microstructure and its mnemonic consequences.

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5.3. Other factors

Beyond age and napping habits, additional physiological and pre-sleep state variables further modulate the cognitive benefits of napping. The level of homeostatic sleep pressure accumulated prior to a nap is particularly influential: as predicted by the two-process model of sleep regulation [37], individuals who are sleep-deprived enter slow-wave sleep more rapidly during a nap, which, while accelerating recovery from fatigue, also increases the likelihood of waking directly from slow-wave sleep and thereby exacerbates sleep inertia [23]. Metabolic and body-composition factors also shape sleep microstructure relevant to nap-related consolidation. Higher body mass index (BMI) has been associated with increased sleep fragmentation and elevated arousal indices [38], and is frequently accompanied by obstructive sleep apnea, which in turn reduces slow-wave activity and sleep-spindle density [39]. Together, these findings indicate that the mnemonic benefits of napping are not uniform but emerge from the dynamic interplay of multiple physiological and state variables, underscoring the need for personalized nap intervention strategies in future research.

6. Future directions

6.1. Clinical and health implications

In the clinical and public health field, the cognitive consequences of napping carry particularly important implications for older adults and for neurodegenerative disease. In healthy individuals, a brief nap can serve as a protective behavior against transient cognitive fatigue. In ageing populations, excessive or irregular daytime napping exhibits a complex bidirectional relationship with Alzheimer's disease and cognitive decline. On one hand, the accumulation of amyloid-β and tau pathology disrupts nocturnal sleep continuity and degrades wake-promoting nuclei in the brainstem and hypothalamus, thereby promoting compensatory daytime sleep. On the other hand, prolonged or fragmented daytime napping may itself disturb circadian organization and accelerate subsequent cognitive deterioration . Importantly, sleep-wake and circadian disturbances have been shown to emerge in the preclinical stages of Alzheimer's disease, often preceding the onset of cognitive symptoms. These findings suggest that long-term monitoring of nap duration and regularity should be regarded not merely as a behavioral observation, but as a potential early clinical biomarker for neurodegenerative disease and a candidate target for future intervention.

6.2. Educational and workplace applications

Beyond clinical applications, translating the science of napping into educational and workplace practice offers a low-cost lever for cognition, performance, and safety. Chronic sleep restriction is widespread among adolescents and impairs both memory encoding and academic functioning [40]. In ecologically valid studies conducted in school settings, scheduled afternoon naps have been shown to enhance the consolidation of declarative material learned earlier in the day, including vocabulary, biology facts, and prose recall [41] . A split-sleep schedule combining a shorter nocturnal sleep with a 1.5h afternoon nap can even outperform a longer continuous night of restricted sleep on declarative learning tasks. Comparable benefits extend to high-fatigue occupational contexts. Among night-shift workers, drivers, and pilots, prophylactic naps of approximately 20 to 30 minutes have been shown to restore alertness during the circadian low, reduce performance lapses, and lower accident risk . Embedding evidence-based nap protocols into

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school schedules and shift-work policies thus represents a practical and inexpensive strategy for protecting learning, productivity, and operational safety.

6.3. Limitations and future research directions

Despite accumulating evidence, several limitations constrain current nap research. First, most mechanistic studies of sleep spindles and nap microstructure are conducted in tightly controlled laboratory settings with participants instrumented for polysomnography, it remains uncertain whether sleep obtained under such conditions faithfully reflects naturalistic napping at an office desk or on a sofa at home. Second, existing work relies heavily on standardized tasks such as paired-associate word learning and finger-tapping sequences, whereas real-world learning involves the integration of multidimensional, high-level concepts that these paradigms do not capture, the role of napping in such complex knowledge integration remains poorly understood. Third, classic studies have disproportionately sampled young, healthy university students and predominantly employed short-term designs, leaving the lifelong impact of habitual napping largely unexamined.

Future research could address these gaps along complementary lines. The growing availability of validated wearable EEG and consumer sleep-tracking devices now permits ecologically valid studies in large, free-living populations, and recent work shows that closed-loop interventions delivering stimulation contingent on real-time oscillation detection can enhance memory consolidation outside the laboratory. Finally, longitudinal designs incorporating neuroimaging are needed to disentangle the documented bidirectional relationship between long daytime naps and cognitive decline, whether excessive napping is a compensatory response to impaired nocturnal protein clearance or an active contributor to neurodegeneration remains an open question.

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