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Role of Napping for Learning Across the Lifespan

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Abstract

Purpose of Review Napping is a common behavior across age groups. While studies have shown a benefit of overnight sleep on memory consolidation, given differences in nap frequency, composition, and intent, it is important to consider whether naps serve a memory function across development and aging.

Recent Findings We review studies of the role of naps in declarative, emotional, and motor procedural memory consolidation across age groups. Recent findings in both developmental and aging populations find that naps benefit learning of many tasks but may require additional learning or sleep bouts compared to young adult populations. These studies have also identified variations in nap physiology based on the purpose of the nap, timing of the nap, or age.

Summary These studies lend to our understanding of the function of sleep, and the potential for naps as an intervention for those with reduced nighttime sleep or learning impairments.

Keywords Naps · Memory · Aging · Development · Sleep · Cognition

Introduction

Naps are colloquially viewed as either a reflection of laziness or a vacation indulgence. Yet, we easily recognize naps as being essential to the healthy behavior of toddlers who are inattentive or emotionally dysregulated in the absence of a nap. Research over the past two decades suggests that this cognitive benefit of naps may be present in young adults and even older adults as well. As such, not only does this evidence suggest the need to shift cultural views of napping but also that naps might even be considered therapeutic for some purposes. A particular area of interest is the influence of naps on learning and memory. Here we review evidence for memory benefits of naps and how these change across the lifespan for different types of memories.

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Nap Frequency and Physiology Across the Lifespan

Young infants are polyphasic, often napping four or more times per day to balance high sleep need and frequent feeding. Sleep becomes triphasic between 6 and 9 months and biphasic by between 12 and 18 months [1]. The adult-like monophasic sleep pattern becomes normative by 5 years [2, 3]. Nap frequency increases again in later ages, with 15% of 65–74 year olds and 25% of 75–85 year olds napping regularly (4–7 naps per week) [4]. Though nap frequency is generally low in young adulthood and middle age, many adults will nap if/when their schedule permits, particularly if they are not meeting their sleep need at night. For example, approximately 50–75% of college students report napping at least once per week [5, 6].

Developmental- and age-related changes in nocturnal sleep physiology are generally found in naps as well [7]. In early childhood, when naps are habitual, SWS and NREM2 sleep each comprise about 45% of the nap interval (90% combined; Fig. 1). SWS in naps decreases into young adulthood and continues to decline with aging. NREM2 in naps is generally stable across age groups while NREM1 increases from childhood to young adulthood and increases even more so from young adulthood to older age groups, as is the pattern seen in overnight

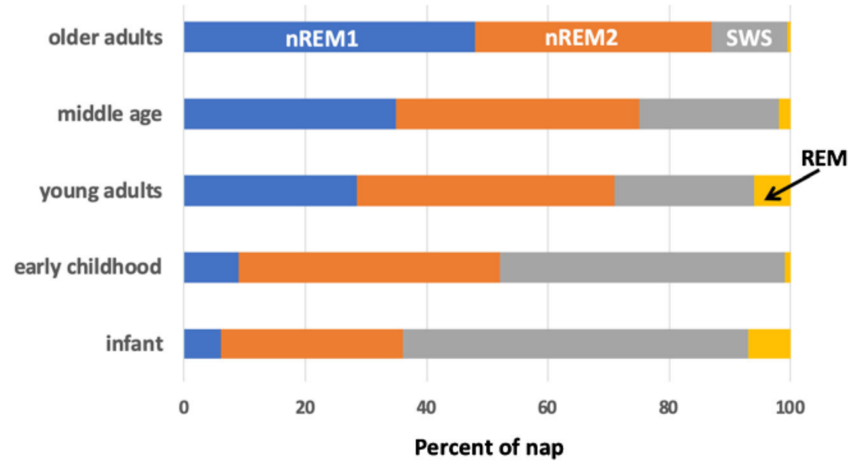

Fig. 1 Sleep stage composition of naps at different ages [based on 7,11,15,20,38]

sleep as well [8, 9]. The presence of REM in naturally occurring naps is rare or minimal in all age groups although dependent on sleep history and the length of the nap, with naps longer than 70–90 min more likely to contain REM [10].

Cognitive Functions of Naps Across the Lifespan

Naps have an array of cognitive benefits in young adults. At the most basic, naps counter the negative consequences of sleep restricted behavior, enhancing attention and alertness which has subsequent benefits on cognitive tasks [11–13]. Naps also impart a direct benefit to cognitive functions; most understood of these is memory.

Memory encoding engages unique brain regions depending on the type of memory encoded [14]. Declarative memories rely on the hippocampus at encoding. Emotional memories, while typically also declarative memories, uniquely engage the amygdala. Motor procedural memories, however, are independent of the hippocampus at least early in the learning process, instead relying on subcortical structures such as the cerebellum and striatum. Likely for this reason, the mechanism underlying sleep's benefit on memory is also thought to vary across memory tasks. As such, here we separately consider the benefit of naps on memory for declarative, motor procedural, and emotional memories.

Declarative Memories

Declarative memories, explicit memories often of facts or events, are protected by naps compared to equivalent intervals of wake. Already in infancy, a benefit of naps on declarative memory can be observed [15–17]. In one such study, infants who napped following observation of novel actions remembered the target actions at later test while those who stayed awake after the action observation did not [18]. Similar nap benefits have been observed across early childhood using a storybook sequence task [19], a visuospatial learning task [20], word learning tasks [21–23], and, in older children, a word-pair association task [24]. Naps have been shown to benefit many of these tasks in young adults as well [25–34]. For example, young adults who napped following learning of a word-pair association task recalled 17% more items than those participants that stayed awake following learning [25]. Few studies have investigated the influence of naps on declarative memory in older adults. Unlike the benefit frequently observed with overnight sleep [35–37], the benefit from naps often appears to be absent in older study populations [38, 39]. However, compared to both quiet rest and interference learning, a nap benefitted vocabulary learning in older individuals and this effect persisted the next day [40].

Consistent with studies of nocturnal sleep [41–47], the nap benefit for declarative memory has been associated with NREM sleep, particularly SWS and the presence of sleep spindles. Although few studies in infancy and childhood have considered such physiological mechanisms, nap sleep spindles predicted episodic memory in infants [10] (but see [15, 48]), visuospatial learning in early childhood [20], and word-pair learning in adolescents [49]. Likewise, sleep spindle characteristics in naps of young adults have been associated with greater memory protection in tasks of contextual learning [33], word-pair learning [34, 50, 51], film clip recall [52], and face-city association learning [53]. However, other studies find that declarative memories benefit from nap SWS. For instance, a recent study in preschoolers that tested learning of a sequence of events in a storybook task found that the over-nap protection of memory was specifically associated with the amount of SWS in the nap [19]. Likewise, in adults, nap SWS has been associated with nap-dependent benefits in picture recognition memory [54], word-pair learning [27, 38], and word-sound association learning [55]. Findings regarding sleep spindles and SWS are consistent with the active system consolidation model whereby coordinated interactions between slow waves and sleep spindles (and hippocampal sharp wave-ripples) underlie hippocampal memory consolidation [56].

Consistent with a role of SWS in declarative memory consolidation, studies showing an absent sleep benefit in older adults observed reduced SWS and SWA in the naps of these older participants. Greater nap SWA predicted reduced activation of the hippocampus during post-nap recall in young adults but not older adults, perhaps suggesting reduced systems consolidation in the latter [38]. Thus, older adults may not achieve sufficient SWA during naps to consolidate memories. Indeed, transcranial slow-oscillatory stimulation that enhances nap SWA led to improved nap-dependent memory consolidation in older adults [57, 58].

Emotional Memories

Although emotional memories are a form of declarative memory, the emotional tone provides additional salience and engages additional limbic regions during encoding. For this reason, emotional memories are often found to be prioritized for processing during naps in adults [59, 60] (but see [61, 62]). Little research has considered how naps may support emotional memory in children. A study from our lab found a benefit of naps for emotional memory performance in young children (3–5 years); however, this benefit was only found after subsequent overnight sleep [63]. Specifically, although there was no difference in memory for emotionally encoded faces following a nap and an equivalent interval spent awake, memory the following day was greater when a nap followed learning the previous day even though no feedback was given. Those that forgot the most over the nap had the greatest performance improvement following overnight sleep. This result is interpreted to suggest that naps yield an initially destabilized emotional memory that is most labile to plastic processes in overnight sleep. Thus, children may need multiple sleep cycles and/or the presence of REM sleep (which is typically not obtained in their naps) to fully consolidate emotional memories.

Preferential consolidation of emotional memories following naps is maintained with aging. Adults 18–39 and adults 40–64 years of age had similar nap-dependent memory benefits for emotional foreground objects at the expense of memory for neutral backgrounds [64]. Aging may be associated with a "positivity effect" whereby positive information is prioritized over negative information [65]. While an age-related positive memory bias has been observed in overnight sleep-dependent consolidation [66, 67], it remains to be seen whether such a memory bias would emerge over a nap.

Slow wave sleep in naps may be particularly critical for emotional memories. In early childhood, worse emotional memory following the nap was associated with greater slow wave activity in the nap, consistent with the interpretation that naps destabilized emotional memories which promoted subsequent overnight improvement [63]. In young and middle-aged adults, recognition of emotionally negative scenes and foreground objects viewed prior to sleep positively correlated with the percent of the nap spent in SWS [60, 64, 68]. However, emotional and reward-related memory consolidation has also been associated with nap sleep spindles and sigma activity [64, 69–71] and nap REM sleep in young adults [59, 72]. These mixed findings may lend support to a sequential processing model of memories over sleep, with alternating processing of both NREM and REM sleep. For instance, slow waves and embedded sleep spindles may support the consolidation of the declarative memory while REM may support processing of the emotional tone and prioritizing the memory for additional NREM processing [73].

Motor Memories

While motor learning tasks have a clear nap benefit in young adults [74–80], this benefit is reduced both with developmental- and aging-related changes. A finger motor sequence learning task is a common task used across age groups. Young adults' reaction time and speed when performing a learned movement sequence improves by 6–17% [75, 76, 81–83] more following a nap compared to performance changes following an equivalent interval awake. This distinction between nap- and wake-dependent improvements is noticeably absent in children under the same conditions [81]. However, similar to emotional memory findings, following subsequent overnight sleep, a benefit of a nap following learning emerges [84]. Intriguingly, overnight performance improvements are greater for children whose performance was reduced by a nap, even in the absence of feedback. One interpretation of these results is that, for a motor procedural learning task, mechanisms of plasticity (e.g., protein synthesis, dendritic spine formation) may impede behavioral benefits initially but may ultimately facilitate successful consolidation. Alternatively, children who slept more deeply may have consolidated their learning but also had longer sleep inertia which led to worse performance after the nap but greater overnight improvement. An immediate benefit of the nap on motor sequence learning has also been observed in children by providing additional training. When children receive additional training prior to the nap/wake interval, performance improves by about 8% more following a subsequent nap compared to performance improvements following a similar interval of wake, an equal benefit to that of adults [81].

With aging, the nap benefit on motor learning tasks is sometimes absent [85, 86]. However, similar to results in children, one study found a delayed benefit of a nap on motor sequence learning when performance was assessed again following subsequent overnight sleep [87]. The overnight benefit was similar to that obtained in young adults who did not nap following the learning session. In one case, a nap led to both an immediate and delayed benefit on motor sequence learning in older adults [88]. When tested shortly after a nap or wake interval, performance was maintained relative to the end of training in the nap group but had declined in the wake group. Both groups improved overnight, such that the nap group showed enhanced performance relative to training whereas the wake group showed equivalent performance to training. Functional imaging indicated that nap-related improvements were linked to activation in a motor-related network during encoding. Notably, older adults practiced the motor sequence prior to encoding which led to a higher level of performance at training compared to a similar study where no benefit was observed [85]. Thus, as in children, additional training may promote nap-dependent consolidation in older adults.

Motor learning improvements have primarily been associated with sleep spindles in the nap. Motor sequence performance gains over a nap positively correlated with sleep spindle count [81] and spindle density [74, 76]. Spindle count in naps was found to be lower in children and not associated with nap-dependent motor learning improvements [81]. Compared to young adults, older adults showed shorter sleep spindle duration, and spindle density was associated with over-nap activation change in brain areas involved in earlier stages of motor learning [85]. In a combined sample of young and older adults, increased density of sleep spindles in a nap following motor learning compared to a baseline nap mediated the relationship between thalamo-cortical white matter integrity and over-nap performance improvement in motor sequence learning [89]. Thus, white matter integrity may be essential for sleep spindle activity that consolidates motor learning.

Types of Naps and Nap Function

Naps can be classified based on the motivation for the nap [7, 90], and nap function and physiology may vary based on this motivation. For instance, recovery naps are naps that are initiated because of prior sleep loss. These naps are thus likely to be longer and contain more REM sleep than naps taken to prepare for upcoming sleep loss (prophylactic naps) and naps taken for pure enjoyment (appetitive naps). Essential naps, those due to sickness or inflammation, may be physiologically distinct. Though not tested in humans, mice given influenza virus show increases in NREM sleep and delta power and decreases in REM sleep [91]. Increases in NREM sleep during illness may be important for immune system response [92]. Finally, fulfillment naps, which are taken to meet a high sleep need, are also likely to be physiologically distinct from a nap of a rested person with less sleep need (e.g., an appetitive nap or laboratory-based nap). For instance, reflecting sleep need, a fulfillment nap would be expected to contain more slow wave activity, a marker of homeostatic sleep pressure [93].

Studies comparing the nap benefit for habitually napping children, for whom naps are fulfillment naps, and non-habitually napping children, for whom naps are experimental and thus like appetitive naps, find that the benefits of naps for memory are similar across these two nap types. That is, declarative memories were similarly protected by the nap for habitually and non-habitually napping children [20]. Likewise, the delayed benefit of the nap on emotional memory consolidation was similar for habitually and non-habitually napping children [63]. Importantly, what differed for both studies was the damage from staying awake for a comparable interval. Memories decayed to a greater extent over wake for habitually napping children compared to performance of non-habitually napping children. Thus, fulfillment naps in young children may be necessary to prevent memory loss throughout the day. One possible explanation for these naps is that the hippocampus is still developing in the first years of life and needs to "offload" its encoded memories more frequently. Indeed, we found larger hippocampal volume in the CA1 subfield in children who were habitual nappers compared to non-habitual nappers, suggesting the hippocampus is more mature (from synaptic pruning) in non-habitually napping children [94]. In more mature children, the hippocampus is capable of storing memories over the day without interference from ongoing learning.

In young adults, half of whom report napping at least once per week, the most commonly endorsed reason for napping is for restorative/recovery purposes (e.g., feeling tired and/or not getting enough sleep the previous night), whereas higher frequency of napping is associated with appetitive reasons (e.g., enjoying napping, feeling better with a nap; [5]). Thus, whereas habitual naps in children are fulfillment naps, habitual naps in young adults appear most often to be appetitive. Increased frequency of napping has been associated with larger amounts of light sleep (NREM1 and 2) and smaller amounts of SWS in the nap [95]. Compared to a wake group, participants who regularly napped (at least once per week) received a nap benefit on perceptual learning whereas those who rarely or never napped did not receive a nap benefit [5]. Regular nappers had more sleep spindles in NREM2 sleep, and improvement over the nap was positively linked to spindle density in this group but negatively associated with spindle density in non-nappers. On the other hand, slow oscillation power was positively associated with improvement in non-nappers but not in regular nappers. In a brief (~ 15 min) nap, NREM2 spindle density was linked to post-nap performance in motor learning in habitual nappers but not non-habitual nappers [96]. Thus, due to differences in nap physiology, habitual (appetitive) young adult nappers may benefit more from naps on tasks that rely on NREM2 sleep physiology than individuals who rarely or never nap. Though the effect of nap frequency on declarative memory consolidation has not been tested in young adults, habitual nappers may be expected to benefit less than non-habitual nappers given evidence of less SWS in the former group.

In older adults, increased daytime sleepiness and napping can often be considered essential napping, as this pattern is frequently associated with pathological conditions including cognitive impairment [7, 97, 98]. However, habitual naps of moderate length have been linked to preserved cognition in some instances, particularly in healthy older adults [99, 100]. The effect of nap frequency on nap-related memory consolidation has not been tested in older adults. However, given that experimental naps, akin to appetitive naps, provide at least a limited memory benefit on some tasks, appetitive napping may provide an opportunity to improve cognition in aging. For example, in healthy older adults, a daytime nap had no adverse effect on subsequent overnight sleep and led to improvement on multiple indices of cognitive and psychomotor performance on both the nap day and subsequent day [101].

Conclusions

Naps can be beneficial for learning at all ages. The benefit for declarative learning is most reliable in children and young adults and declines with aging. This pattern may be due to reductions in SWA in naps with aging, which in turn may be related to reduced sleep pressure [102] and/or gray matter [103] with aging. The effect of napping on emotional memory has rarely been studied in children and older adults. However, given that both SWS and REM sleep may contribute to aspects of emotional memory consolidation, a longer nap may be needed, and an immediate nap benefit may be most prevalent in young adults who are most likely to obtain sufficient amounts of both SWS and REM sleep in their naps. A nap without sufficient SWS and/or REM sleep may still impart a delayed benefit that emerges after subsequent overnight sleep, as was observed in children [63]. A nap benefit for motor procedural learning is reliable in young adults but appears reduced in children and older adults. This pattern may be due to age differences in sleep spindle properties. However, when children and older adults get extra training [81, 85] or the addition of subsequent overnight sleep [84, 87], a nap benefit can emerge. Finally, sleep architecture and memory benefits may vary to some extent with the type (and timing) of naps. Fulfillment naps are needed in young children to prevent memory loss throughout the day. In young and older adults, appetitive napping may provide limited memory benefits in addition to other cognitive benefits.

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Code Availability NA

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Data Availability NA

Compliance with Ethical Standards

Conflict of Interest The authors have no relevant conflicts to declare.

Ethics Approval NA

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Consent for Publication NA

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