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CLINICAL REVIEW

Naps, cognition and performance

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S U M M A R Y

Daytime napping is a frequent habit of many individuals, whether healthy or not, and may occur in a wide variety of contexts. There are several reasons for napping in the human adult, including prophylactic strategies or recuperative need, respectively before or after sleep loss, or even pure appetitive drive. Thus, it is of great theoretical and clinical interest to assess the impact of naps on individuals' performance, especially on cognitive functioning. As the outgrowth of a symposium held by the authors at the 5th Congress of the World Federation of Sleep Research and Sleep Medicine Societies in Cairns, Australia, September 2007, this review will specifically explore: a) the newly developed experimental daytime split-sleep schedules and their effects on recovery, compared with those deriving from a single consolidated sleep episode of equal duration; b) whether naps may be beneficial to wakefulness performance in the working context, through accurate review of "on field" studies; c) the impact of naps on cognition, in light of the very recent advances in the study of naps and memory processes; d) the main features of napping behavior in older individuals and its impact on their health and general functioning, since it is widely recognized that napping may change as a result of the aging process.

Introduction

Daytime napping is a frequent habit in many individuals, whether healthy or not, and may occur in a wide variety of contexts. Seminal research on naps, extensively reviewed in a volume by Stampi,[1] has tried to address the regulatory mechanisms sustaining polyphasic sleep structure, as well as to identify the determinants of napping, on both the psychobiological and the psychosocial level. These studies have focused on several different reasons for napping including: recuperative need, due to prolonged wakefulness or increased sleep pressure; prophylactic strategies, aimed to counteract an expected sleep deprivation and to maintain performance in particular contexts such as shift work or sustained operations; and pure appetitive drive, linked to sociocultural and individual characteristics. Thus the causes of napping are likely to be multifaceted, a picture made even more complex by the continuous interactions of each of these factors with the others. However, the question of what impact napping might have on the general functioning of individuals, with special regard to wakefulness performance and memory processes, has so far received little attention.

This review seeks to raise interest in these theoretically and clinically fundamental aspects of napping. It is the outgrowth of a symposium, "The Effect of Naps on Health and Cognition", held by the authors at the 5th Congress of the World Federation of Sleep Research and Sleep Medicine Societies in Cairns, Australia, September 2007, specifically conceived to pay thorough attention to the relationships between daytime napping and cognitive processes, in light of the very recent advances in the study of naps, memory and performance. Here we will examine the interrelationships of napping, cognition and performance in four specific contexts.

First, the hypothesis that a split-sleep schedule provides more recovery than a single consolidated sleep period of the same total duration is examined. We will start with this particular approach since it represents the most recent experimental contribution, after the classical 80s studies on daytime sleep regulatory mechanisms,[1] to set the basis for the understanding of nap effects in "real life" situations. Second, the advantages and disadvantages of napping in the work environment are examined. Third, the purported benefits of napping for the learning of new material, either declarative (e.g., lists of words) or procedural (e.g., perceptual or motor tasks) are explored, including a discussion of why daytime naps, due to their peculiar sleep infrastructure, might represent a useful model of memory consolidation mechanisms during sleep. Finally, the prevalence of regular napping in the elderly and its association with

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sleep complaints, excessive daytime sleepiness, and mental and physical health problems are examined, with a focus on whether regular napping among older adults, particularly those in good health, may be beneficial to daytime wakefulness or detrimental to night-time sleep propensity.

Effects of split-sleep schedules on sleep stage architecture and neurobehavioral performance

Can split-sleep enhance recuperative benefits to performance?

The idea of splitting a sleep period up into two parts of the same total duration to provide enhanced recuperative benefits was first posed in 1897 and came from observations about the exponential time-course of sleep depth from measured auditory arousal threshold.[2] The idea was that exponential functions are steepest in the first half of the function (i.e., provide more recovery per unit time invested in sleep), thus breaking sleep into two parts would exploit this property advantageously yielding more recovery than a single sleep period of the same total duration. In recent decades, others have reported that alertness and performance are restored as a saturating exponential function of total sleep,[3,4] however only a small number of studies have directly compared split-sleep and monophasic sleep to determine if in fact there are neurobehavioral benefits of splitting sleep into parts. We begin with a review of the factors related to split-sleep schedules that impact sleep architecture and neurobehavioral performance including circadian timing of sleep, duration of prior wakefulness, and cumulative sleep loss.

Factors related to split-sleep that affect sleep architecture

Circadian timing of sleep has been extensively examined in experiments involving long-term temporal isolation, multi-cyclic sleep wake schedules, and forced desynchrony. These experiments showed that circadian phase as well as the duration of prior wakefulness affects sleep propensity (i.e., sleep onset latencies and sleep duration) and sleep architecture by primarily impacting rapid eye movement (REM) sleep. In fact it has been shown that there are certain circadian "forbidden zones" where nap sleep initiation would be improbable at normal homeostatic levels.[5,6] For an extensive review of these experiments see the review by Dijk and Czeisler.[7] Sleep loss resulting from total sleep deprivation and chronic partial sleep deprivation has also been shown to affect sleep propensity and sleep architecture.[8,9] Experiments about sleep loss effects on sleep architecture are reviewed by Dinges et al.[10]

Factors related to split-sleep that affect neurobehavioral performance

In order to fully characterize the impact of napping on neurobehavioral performance associated with split-sleep performance, factors such as mood, cognitive performance, and motor function must be examined across a range of homeostatic levels resulting from both acute total sleep deprivation and chronic partial sleep deprivation. It is known from controlled laboratory experiments that sleep loss resulting from acute total sleep deprivation negatively affects mood, cognitive performance, and motor function due to an increasing sleep propensity and destabilization of the wake state.[11] Sleep loss resulting from chronic partial sleep deprivation progressively impacts these same factors in a dose-response relationship with TIB across days of sleep restriction.[9,12] The duration of prior wakefulness at the time of testing has been shown to impact performance and to interact with circadian phase.[13] The important theoretical question is whether split-sleep schedules mitigate neurobehavioral deficits resulting from homeostatic pressure associated with sleep restriction when compared to consolidated sleep. Sleep inertia must also be accounted for in the interpretation of experiments designed to measure the impact on neurobehavioral performance of split-sleep schedules. Sleep inertia impacts neurobehavioral performance for 2 or more hours after waking [14] and is most pronounced at adverse circadian phases in the middle of the habitual night.[15] It has been shown to increase in magnitude and duration with total sleep deprivation and can be mitigated by caffeine.[16] Finally, experimental evidence has demonstrated that there are large, stable, trait-like differences among individuals in the amount of daily sleep required to maintain stable levels of performance.[17] In fact, individual differences in the response to sleep loss should be considered when studying any of the above mentioned factors related to split-sleep schedules.[18]

Experiments that directly compare consolidated and split-sleep schedules

We now review experiments that specifically compared consolidated sleep with split sleep. In all of the experiments described in this section cognitive performance was assessed using objective measures such as a digit symbol substitution task, mental arithmetic tasks, or simple and choice reaction times tasks. Mood and sleepiness were assessed with subjective scales. The first experiment considered was a within-subjects design by Nicholson et al. that compared 8 h of continuous nocturnal sleep to a split-sleep schedule that was comprised of two 4 h sleep periods bisected by 10 h of nocturnal wakefulness.[19] No differences in performance were detected in subsequent daytime performance between the consolidated and split-sleep schedules. Other experiments examining split-sleep compared to consolidated sleep of the same total duration found increases in subsequent daytime performance; however these effects were attributed to experimental confounds related to differences in duration of prior wakefulness at the time of testing.[20,21] A recent controlled laboratory experiment by Dinges' group examined performance impairments associated with a range of split-sleep schedules that were comprised of restricted nocturnal sleep augmented with a daytime nap or no nap. In order to minimize confounds related to circadian phase and duration of prior wakefulness, data were analyzed based on daily-average-performance to identify the functional relationship between performance and nocturnal anchor sleep and diurnal nap sleep. Tests that occurred immediately after awakening from a nocturnal sleep or diurnal nap were not included in the daily performance averages to avoid measuring sleep inertia effects. The overall finding was that performance was a function of total daily time in bed independent of whether sleep was consolidated or split into two parts.[22] In terms of total sleep time and neurobehavioral performance, it did not substantively matter whether sleep was consolidated or scheduled in two parts.[22,23] Less is known, however, about any health impacts of any types of split-sleep regimen, even if this strategy of sleep would be favorable for maintaining performance.

Effects of naps on vigilance/performance/subjective well-being as assessed from "on field studies"

With respect to napping in working life, most naps occur in association with night work. Although the majority of naps seem to be compensatory in nature (i.e., a result of sleepiness/sleep pressure), the large number of naps occurring before the first night shift demonstrate that many workers also take prophylactic naps to reduce night-shift sleepiness.[24,25] Some studies report that up to

65% of the workers take a nap before the first night shift, and this number may increase up to 91% if preceded by a morning shift the same day.[26,27] After the first night shift, the numbers of nap takers are reduced, to about 10–40%,[25,27] mainly because the main sleep bout now occurs during the day. Napping on the night shifts is strongly affected by occupation, culture and whether the naps are sanctioned or not.[24] While the literature is largely limited to voluntary naps, night shifts are also affected by involuntary naps. It has been estimated that the risk for unintentional sleep increases by about 60% during night shifts.[28] In fact, in a larger diary study, with self-reports of 230 train drivers and air traffic controllers, up to 50% reported dozing off during the night shift.[27] Some of the scarce objective data on involuntary naps (i.e., using ambulatory electroencephalogram) revealed that 20% of the workers fell asleep during the night shift, whereas none fell asleep during morning or afternoon shifts.[29] Similar findings have also been shown amongst pilots.[30] An important finding from the former study was that many sleep episodes were unreported by the workers themselves, suggesting that falling asleep during a night shift is more common than in self-reports.

The main reasons for reduced alertness and performance during the night are the circadian system, promoting sleepiness and long waking hours. Waking hours are particularly long the first night shift, often more than 20 h. Several strategies, such as napping, caffeine, modafinil and bright-light exposure, have been proposed as effective countermeasures against sleepiness and performance decrements. However, rather few studies have actually been carried out on how effectively these countermeasures work in real life situations. As of today, the most evidence exists for napping, and it has been concluded that naps can alleviate shift work problems in a reliable and inexpensive manner.[31] Naps and caffeine are the most common countermeasures and a recent intervention study has assessed their combined effect.[32] Below we review the studies carried out in operational settings, particularly regarding interventions. A final section will provide some guidelines on how to make naps more effective.

Implementation of naps to improve late night alertness

Multiple laboratory studies have demonstrated that naps from 30 min to 4 h improve alertness and performance in laboratory conditions of simulated night-work, e.g.,[32,33] However, in most cases, the research samples included young volunteers rather than experienced shift/night workers and the performance tests were most often short performance tests such as reaction time tasks rather than work related output or safety. In an experimental study including oil refinery shift-workers, Sallinen and co-workers showed that naps of either 30- or 50-min taken at 01:00 h or 04:00 h improved performance at the end of the night shift.[34] The fact that daytime sleep was somewhat impaired by the 50-min naps suggests that longer naps may also have positive effects on the drive home after the night shift. Naps taken before the night shift may also improve nighttime performance and alertness. Clearest evidence arise from studies using rather long naps,[32,35] 2–3 h, which seem obvious if the aim is to have effects many hours later.

Effects of naturally occurring naps

In contrast to the positive findings found in laboratory studies, naturally occurring naps have been found to relate to greater sleepiness and poorer performance in shift workers.[25] This finding supports the idea that most naps are compensatory in nature rather than prophylactic On the other hand, in a study of 250 pilots, less fatigue was reported amongst pilots stating that they took cockpit naps or routinely took naps prior to overnight flights.[36] A recent study of 1195 police drivers found that napping was related to fewer car accidents.[26] Notably, almost 90% of the subjects took a nap before the night shift in this extremely rapidly rotating shift system. The unusually high degree of nap takers should be seen in light of the fact that the night shift was preceded by several short recovery periods and a morning shift the same day. Rather than suggesting that prophylactic naps are effective against accidents, these results highlight the serious consequences (substantial increase of accident risk) for those 10% not managing a nap between the morning and the night shifts if these occur the same day. With the exception of this rather extreme working schedule, there is limited knowledge as to whether naturally occurring naps are really effective.

Implementation of naps in operational shift-work settings

Only a few studies have investigated the effects of nap interventions in operational shift-work settings. In 24 aircraft maintenance workers, Purnell and co-workers found that a short 20-min nap taken around 03:00 h had a positive effect on vigilance performance at 07:00 h and on alertness when driving home.[37] A study confirming possible long-term effects was carried out by Bonnefond and co-workers. This study followed 12 industrial workers having a one-hour nap possibility between 23:30 h and 03:30 h for a whole year.[38] The majority of the workers reported reduced fatigue and improved general satisfaction. Interestingly, the effect of the nap improved progressively over the year. These long-term effects are rather unexpected and need to be confirmed, particularly as no control group was included.

Napping interventions have perhaps been most successful in extended working shifts. In a study with 20 nurses working 16 h shifts, Takahashi and colleagues [39] found that a 2 h nap opportunity improved alertness and reduced heart rate. In another study of 12-hour shifts, it was shown that a 40-min nap opportunity at 03:00 h had positive effects on sleepiness and driving simulator performance at 07:30 h, indicating positive effects on alertness on the drive home from work. As many as 90% out of the 49 physicians and nurses actually fell asleep during the time interval allotted for the nap.[39,40] Two studies have also introduced nap strategies in medical interns working 30-hour shifts. Arora and colleagues showed that the introduction of a nap-schedule with on-call coverage resulted in more sleep and less fatigue.[41] In the other study on medical interns,[42] advice to take naps before the night shift was part of a larger (successful) intervention including the reduction of maximum working hours to 16 rather than 30. Also short 30-min cockpit naps may improve performance.[43]

A limitation with many of the presented studies is the lack of work output and safety measures. However, more recent studies have included "real accidents",[26] driving simulator performance after work [40] and "work logs".[42] Short tests are not similar to most work tasks, but can still indicate where severe sleepiness and improvements can be expected.

In real life situations, workers are free to combine several countermeasures to improve their on-shift alertness. However, few studies have investigated the combined effects of more than one countermeasure in a systematic manner. In a recent study by Schweitzer and colleagues [32] it was shown that an individualised nap and caffeine intervention can be successfully introduced. Workers at different work sites were instructed to take a 2-hour nap at home before the first two night shifts and combine this with a 300 mg of caffeine at the beginning of the shift. The effects included less sleepiness and better performance at the end of the shift. Still, further studies are required if we intend to understand the combinatory effects of several countermeasures to maximize alertness at crucial time points. For example, is caffeine an effective way to reduce sleep inertia after naps on the shift?

These intervention studies have reported a series of problems with the implementation of naps. Some workers are obviously non-nappers.[37] Earlier studies have proposed that almost 50% are non-nappers,[38] but the fact that up to 90% nap during an extended night shift or between a morning and a night shift suggest that napping is possible for the majority. On the other hand, intervention studies may suffer from selection problems in that non-nappers tend to abstain from participation; it is unclear how inclusion/exclusion of participants in most of the studies have been carried out. Similar selection biases may also be at play in night workers and it seems reasonable that the capability to nap makes it possible to manage strenuous working hours. Also sleep conditions are important and noise has been reported as a major reason for disturbed nap sleep.[37] Sleep inertia is another concern as it severely interferes with working capacity and safety in the period after awakening.[15,44] In a study on nurses with 16-hour shifts it was shown that sleep inertia may last as long as 2 h.[39] In addition, the beneficial effects of brief naps may be less effective in severely sleep deprived subjects.[45] Another problem that affects napping in real life situations is the demand on the worker. Medical interns stated that the main reason for not taking full advantage of their nap opportunities were concerns for their own patients.[41] One of the major concerns deriving from laboratory findings has been disturbed day sleep after the night shift. Although this topic was not addressed in all studies, day sleep impairment was not found in those subjects taking relatively short, 20–30 min, naps.[34,37] Nevertheless, a slight negative effect on subsequent day sleep should be seen as a good sign as this also implies improved alertness on the drive home from the night shift.

Implementation of naps to improve alertness in the afternoon

A number of laboratory studies have shown that short day-time naps (3–30 min) may improve alertness and performance for up to 2–3 h.[46–48] Surprisingly, Brooks and Lack found that 10-min naps were more effective than slightly longer ones.[48] The improvements were immediate, hence avoiding sleep inertia, and lasted for the remainder of the 2.5 h during which the subjects were tested. Although most studies on brief naps are limited to subjects with restricted sleep, typically 4–6 h of night sleep, there is some support for brief naps to be beneficial also after normal sleep. Takahashi and colleagues found that subjects allowed 7 h of sleep benefited from a 15- or 45-min nap at 12:30 h – alertness was improved more than 3 h later.[49] On the other hand, a small-scale intervention study in eight Japanese industry workers showed that a brief, 15-min, nap at 12:30 h failed to improve performance measured at 15:00 h in workers with no prior sleep deprivation.[50] Perhaps the results would have been different if more than eight participants had been included. Nevertheless, the authors reported that the short naps improved post-nap alertness at the end of the working week, and half of the workers continued napping the following work week when napping was no longer obligatory.

General guidelines

In conclusion, it appears that napping should be always implemented when severe sleepiness is most likely to occur. For night workers, the worst periods coincide with the circadian trough, around 3–6 in the morning, and on the way home from the night shift. For the day worker, naps should be taken to avoid the afternoon dip. In most cases, the afternoon dip is rather limited and can often be relieved by caffeine. However, daytime napping should be seen as a legitimate alternative for those suffering from hypersomnia, disturbed sleep or non-coffee drinkers.[31]

Intervention studies clearly demonstrate that napping can improve night shift alertness and performance. Shorter naps seem more successful than longer naps, although there is clearly a limited literature about the latter in operational settings. Naps before the night shift should preferably be as long as possible, when avoidance of sleep inertia is less important, but avoided during work time or other periods when high performance is required. To avoid sleep inertia, naps should not be too long (max 20–30 min), not occur at the bottom of the circadian phase, i.e., early morning hours, nor taken after long waking times.[15,44] An alternative to long naps may be several short naps, but this possibility requires further exploration.

Napping seems a very important countermeasure during extended work shifts and in operational settings,[51] particularly in those contexts where safety is an important issue. Furthermore, although most studies have been conducted in young and sleep deprived subjects, the practical advice is that short daytime naps are effective for those with moderately disturbed sleep and possibly for normal sleepers. If the aim is to alleviate afternoon sleepiness, the timing of the nap should not be too early. The alerting effect can be further enhanced if the nap is combined with caffeine.[52]

Laboratory studies suggest that caffeine at the beginning of the shift may also help in reducing sleep inertia from nighttime napping.[14] However, further studies are needed to verify how the use of naps and caffeine can be best combined in operational shift-work settings. Lastly, napping recommendations should be an integral part of all real life fatigue management.

The effect of naps on memory processes

Daytime naps as a model for the study of sleep-memory relationships

Although the positive role of sleep for memory consolidation of material learned before sleep (either procedural or declarative) has been largely explored in the frame of the so-called "sleep effect" hypothesis (e.g., [53,54] for extensive reviews) and is widely accepted today, there is still an intense scientific debate on which sleep- or memory-related factors are crucial for the effect.

Amongst these factors the role of a minimum sleep duration has never been fully clarified.[54] Obviously, nap studies would be the natural model to study the time component of sleep for memory, but surprisingly few studies have addressed the existence of such a "nap effect". Another concern is whether sleep at different circadian phases has the same impact on memory. Likewise, rather few (and controversial) studies have addressed this issue.[55,56] Thus, it is somewhat premature to predict whether daytime naps could be as effective in favouring memory consolidation as normal night sleep. This still open question of the "nap effect" is reviewed in detail below, and in the "Research Agenda" section.

It is important to recognize that daytime naps can work as a powerful experimental model to elucidate mechanisms through which sleep supports memory processes. In fact, experiments using daytime naps on memory can avoid some of the drawbacks which affect studies of nighttime sleep. First, if naps facilitate memory, experimental designs can use multiple naps during the day to better understand the role of the circadian factor. Second, day-time nap protocols may avoid severe sleepiness, which is a factor partly hampering the validity of studies on sleep and memory when the control group has received no night sleep. Differences of memory recall may indeed depend on a reduction of the control group's recall due to sleepiness, rather than to an increase of the sleepers' thanks to sleep. Instead, it is much easier to maintain comparable levels of alertness when comparing, at daytime, subjects who take naps with subjects who are "normally" awake and who most probably will not experience any significant vigilance reduction.

Third, as clearly explained by Backhaus and Junghanns,[57] sleep effect on memory consolidation can be more confounded during night sleep than during naps by hormone secretions, especially cortisol and GH, influencing memory encoding and recall. Finally, the peculiar sleep architecture of daytime naps is particularly adequate to give hints as to the role of sleep organization (i.e., the presence of uninterrupted NREM-REM cycles), which has been proposed to be a crucial factor for memory consolidation.[54,58] In fact, about half of the daytime naps contain a full sleep cycle, with a short REM episode whose presence is linked to a certain minimum amount of preceding slow wave sleep (SWS).[59] Any effect on memory of this kind of naps is likely to depend on other factors than the absolute amount of sleep states, and their percentage out of total sleep time (TST), which are overall quite small.

Effects of daytime naps on procedural memory

Most data on naps and memory processes have been produced by administering procedural tasks.

The study which brought new interest to the "nap effect" was the one by Mednick et al. [60] at the beginning of the decade, who showed how the habitual perceptual deterioration across time on a visual discrimination task (VDT) may be prevented by taking a nap. Deterioration over consecutive sessions was effectively counteracted by a nap (at 14:00 h) between sessions. The authors found that the performance at this procedural memory task was dependent on the duration of the nap: a shorter (30-min) nap seems to prevent the habitual deterioration across the last two sessions, allowing the maintenance of performance, whereas a longer (60-min) nap reverses this impairment and improves subsequent performance. A significant difference was found in SWS and REM sleep amount in the short versus the long naps and, interestingly, the impact of memory consolidation processes on sleep structure was also suggested by the increase of the amount of SWS and REM sleep during experimental compared with baseline naps.

Further support to the role of naps on procedural memory was given by a later work of the same group,[61] reporting that naps including both SWS and REM led to performance enhancement, whereas naps containing only SWS only prevented deterioration across sessions. Discussing the results of this study, the authors proposed that the amplitude of the nap-dependent improvement on the VDT is similar to the one they had previously seen after an eight hour sleep night.[62] They suggested that SWS may be necessary to stabilize performance whereas REM sleep may facilitate an actual performance improvement.

Backhaus and Junghanns [57] recently reported day-time naps to favor procedural motor learning, as indexed by performance at a mirror-tracing task. Cajochen et al. showed positive effects of naps on procedural memory consolidation in a serial reaction time task (SRT), in the context of a circadian protocol.[63] Korman et al.,[64] after training subjects on a finger-to-opposition sequence-learning task, showed that an interfering reversed sequence affects the overnight gain normally observed at this procedural task. However, a post-training 90-minute nap is capable of reversing this interference effect, resulting in a larger performance gain. Finally, a very recent study [65] has shown the benefit of a midday nap (60–90 min) on motor memory consolidation. This clear memory enhancement in the nap condition correlated with sleep spindle density and power at specific regional sites (centroparietal, as expected given the areas involved in the motor task).

The only evidence in disagreement with the aforementioned results came from a study by Tucker et al.,[66] assessing both procedural and declarative performance after a short nap (about 50-min duration) administered at 13:00 h, which did not find any significant difference between sleep and wakefulness at a procedural task. Methodological factors may explain this discrepancy. Tucker et al.,[66] utilized duration of naps shorter than those used in other studies, with accompanying relevant differences in sleep architecture, e.g., absence of REM sleep. Furthermore, Tucker et al. adopted a very long retention interval (five hours between the baseline recall test and the delayed cued recall test), different from previous studies where recall was requested after a brief interval from awakening, just enough to permit sleep inertia dissipation.

Interestingly, Milner et al. [67] found that although motor learning was consolidated in a brief nap and was associated with stage 2 spindles, this occurred only for those subjects who habitually take naps, thus introducing the theoretical issue of distinguishing nap effects in habitual and non-habitual nappers.

Effects of daytime naps on declarative memory

Some notable evidence of a "nap effect" has been produced for declarative memory. The first such study was conducted by Schoen and Badia.[68] In their study, a 2-hour nap was administered to the subjects after learning non-meaningful (nonsense syllables) and meaningful (short stories) material. The protocol included two subgroups, taking a nap respectively at 7:00 h and at 15:00 h, and a control group spending the 2-hour retention period awake. Placing the experimental naps either early in the morning or late in the afternoon was intended to detect a time-of-day effect, and should have also allowed to make assumptions on the role of sleep stages, because, due to circadian and homeostatic reasons, REM sleep is more prevalent in early morning naps, while SWS is more prevalent in afternoon naps. Results showed a better recall for all kinds of verbal material in both nap conditions compared with wakefulness, with no difference in the recall between morning and afternoon naps.

The relationship between declarative memory processes and daytime naps has been readdressed only recently, some twenty years after Schoen and Badia's work. Schabus et al. [69] studied word-pair association performance using a cued recall procedure, before and after a 60-min nap at 14:00 h. Subjects were later divided in two groups according to the composition of sleep stages: nappers with or without SWS. No REM-nap group was included because the short nap duration (50-min average) did not permit the REM sleep occurrence. Results indicated that only those nappers with SWS in their sleep showed an improvement at the declarative memory task after the nap. Quantitative electroencephalogram (EEG) analysis showed increased theta activity during those naps which were associated with memory improvement.

Muto et al. [70] also evaluated the recall of non-associated paired words after a daytime nap: after an immediate free recall of verbal material, subjects took a 2-hour nap (at 14:00 h). Successive recall tests were carried at awakening and at a further point in the early evening (around 19:00 h). Results showed a preventive effect of naps against the loss of the material clearly going on in the wake condition. Interestingly, the authors, by comparing those naps containing a minimum amount of REM sleep ($\geq$10 min) to those without REM sleep, found that only the naps containing REM were linked to an actual improvement of memory performance. Since the amount of REM sleep as a fuction of total sleep time was very small, the authors concluded that the role of REM sleep for the post nap improvement was more likely linked to the completion of the sleep cycle than to its presence *per se*. This intriguing result needs to be replicated with a larger sample, and a study employing a larger sample is currently in preparation by the same research group.

In the aforementioned study by Tucker et al.,[66] unlike the findings for procedural memory, subjects taking a nap improved more at the declarative memory task than those subjects who stayed awake. Moreover, a positive though non-significant correlation was observed between improvement on the verbal task and minutes of SWS, whereas no other sleep parameter appeared to correlate with declarative memory. Thus, the authors were basically replicating data about the purported role of non-REM (NREM) sleep for declarative memory processing.

Recently Lahl et al. [71] showed that free word recall was better after a 60-min retention interval spent asleep rather than awake. Differently from previous research,[69,70] no sleep parameters correlated with recall scores. In a second experiment, the authors tried to examine the effects of an ultra short nap (mean TST = 6.3 min) or a longer nap (mean TST = 35.8 min) on verbal material consolidation. The results indicate that even the ultra short nap is sufficient for a better recall when compared with wakefulness. These data are interpreted in light of a possible facilitating effect of the mere sleep onset on memory consolidation processes, independent of sleep stages or sleep duration. This hypothesis had already been put forward by Tietzel and Lack [72] regarding the effect of sleep onset on cognitive performance assessed through symbol-digit substitution and letter-cancellation tasks.

Schmidt et al. [73] investigated the effects of declarative learning on sleep EEG activity changes during daytime sleep, under controlled homeostatic and circadian conditions. Unrelated verbal material was constructed with the aim of obtaining two word lists differing in the level of concreteness, resulting in an easier and a more difficult associative encoding condition. Immediate and delayed cued recall were assessed respectively pre and post a 4-hour daytime sleep. Relative to a control condition, the authors reported an increase of the power density in the spindle frequency range and of the density of low-frequency sleep spindles. This increase was observed after the difficult encoding condition but not after the easy one. Moreover EEG spectral activity changes positively correlated with memory performance changes between pre- and post-nap test sessions. The authors concluded that the nature of the declarative material is a determiningt factor for sleep parameter changes.

Napping, sleep and health in older adults

The prevalence of daytime napping increases with advancing age.[74,75] Many factors are likely to contribute to this, including age-dependent changes in nighttime sleep and circadian rhythms, co-morbid illnesses and lifestyle factors. However, the impact of the napping of older adults on their nighttime sleep and on their daytime functioning and health remains to be fully determined. Here we briefly review the epidemiology of napping, the impact of napping on nighttime sleep, and the associations between napping and health in older adults.

Epidemiology of napping in older adults

Although prevalence rates for napping in older adults vary widely depending on how napping behavior is defined or measured and the population studied, older adults consistently report more frequent napping than younger adults.[74–76] The prevalence of napping seems to increase with advancing age within the older population itself, with the "older old" typically reporting more frequent naps than the "younger old".[75,76] For example, in their analysis of the National Sleep Foundation's "2003 Sleep in America Poll," that focused on the topic of "sleep and aging" in 1506 older adults (aged 55–84 years), Foley and colleagues found that 15% reported regular napping (4–7 times/week), ranging in prevalence from 10% among those 55–64 years of age to 25% among those 75–84 years of age.[75] MaCrae et al. [77] reported that in their sample of 413 older men and women (aged 60–96 years) nearly half (47.5%) reported regular napping (>3 times/week), while 18% reported napping more than six times per week. Finally, a recent large multi-center study of 8101 older community-dwelling women (mean age 77.0 years), found that approximately 11% reported napping daily, with those reporting daily napping significantly older than those who did not.[78]

There does not appear to be a clear gender difference in napping among older adults. While a few studies have suggested that older men may nap more frequently than older women,[79,80] most other studies report no such differences.[74,75,77]

A limitation of the survey technique employed by studies reviewed above is that older adults often take unplanned or unintentional naps, which they may not even be aware of doing (for example, falling asleep in the evening while reading or watching television) and therefore underestimate their napping behavior. This problem is illustrated by the study of Yoon and colleagues [81] who studied napping behavior in younger and older adults using wrist actigraphy. They reported that many older adults may have bouts of sleep during the evening but not report them as naps, although they also recognize that actigraphy may have difficulty distinguishing true napping from sitting quiescently while watching television or reading.

Little work has been done examining planned versus unplanned napping. Recent preliminary work in this area has been conducted by Vitiello and Foley [82] using the National Sleep Foundation's "2003 Sleep in America Poll," of 1506 older (aged 55–84 years) adults. They found that 36% of the sample (n = 515) reported napping 1–7 times/week, with half of those (50.7%) reporting planned versus unplanned napping. Being older and unmarried, excessive daytime sleepiness, anhedonia and drinking <4 coffees/day were all predictors of unplanned napping. However, neither measures of nighttime sleep complaint nor of health burden predicted unplanned napping, suggesting, albeit counter-intuitively, that these factors have little influence on one's plans for napping.

Causes of daytime napping in older adults

Daytime napping may be the result of a variety of causes, including: disturbed nighttime sleep,[83,84] age-related phase advance of circadian rhythm,[85] co-morbid medical and psychiatric illnesses,[75] and lifestyle factors, or some combination of these. However, the evidence supporting the direct contribution of any of these factors to napping is far from conclusive. This may be because the relationships between napping and many, and possibly most, of these possible causal factors are likely to be bi-directional, with disturbed sleep, advanced phase of circadian rhythms, or poor sleep habits leading to daytime napping and daytime napping, in turn, disrupting nighttime sleep, shifting circadian rhythm or prompting poor sleep-related behaviors.

Impact of napping on nighttime sleep in older adults

The impact of daytime napping on nighttime sleep is unclear, as studies in this area have yielded inconsistent findings. It is commonly assumed that daytime napping should decrease homeostatic sleep drive during the following night, resulting in increased nighttime wakefulness and decreased sleep efficiency, which would result in being tired the next day, increasing the likelihood of napping that day with the resulting nighttime impact, maintaining this pattern through a positive feedback process. Several studies provide support for this conceptualization that daytime napping can negatively impact nighttime sleep in older adults. Monk and colleagues [86] found that a daytime nap shortened nighttime sleep, decreased sleep efficiency and led to earlier morning awakening among nine healthy older adults. Yoon et al. [81] observed that healthy older adults who were evening nappers had shorter sleep durations and awakened earlier in the morning compared to older adults who did not nap in the evening. Campbell et al. [87] examined the impact of an afternoon nap on subsequent nighttime sleep quality in healthy older adults concluding that napping had little effect, although they reported a significant 40% increase in sleep latency and non-significant increases in nighttime wakefulness following napping compared to sleep following an afternoon sedentary period. Liu and Liu [88] in their study of 1820 older Chinese adults reported that older age, poor perceived health, being female, being unmarried and frequent napping were all risk factors for insomnia.

However, other studies have not supported this relationship between napping and sleep quality. Metz and Bunnell [76] surveyed 132 older adults (ages 58–95) and reported that no significant relationship was observed between any reported napping dimension and indicators of nocturnal sleep difficulty. Rather age had the greatest effect on napping, with older subjects taking more frequent and longer naps; although a non-significant trend suggested that the duration of naps might be associated with increased difficulty initiating nocturnal sleep. Bliwise [89] examined sleep quality and related factors in 36 healthy older women, self identifying as good or poor sleepers. While poor sleepers reported longer sleep latencies, less total sleep time, more non-restorative sleep, and more daytime fatigue than did good sleepers, no differences were found between good and poor sleepers in their number of daily naps. Mallon and Hetta,[80] reporting on the sleep habits and difficulties of 876 older Swedes observed that daytime napping was common, but not related to poor sleep. This lack of a relationship was confirmed by Hsu [90] who also found no correlation between naps and quality of sleep among 80 community-dwelling Chinese elders. Finally, Foley et al,[75] reporting on napping in 1506 older adults, observed that frequent napping was associated with excessive daytime sleepiness, depression, nocturia and pain, but not with complaints of poor nighttime sleep.

Napping and health in older adults

Napping has been reported to be associated with increased risk of mortality, cardiovascular disease, falls and cognitive impairment in older adults. A number of studies have reported that napping is related to increased risk for mortality (e.g., [91–95]), whereas the association between napping and cardiovascular disease is unclear, with some studies reporting an association (e.g.,[87,94]), but not all, (e.g., [96,97]) including a very recent large-sample study, which controlled for pre-existing co-morbidites.[98] Brassington et al. [99] and Stone et al. [78] have both reported that napping is associated with increased risk for falls, with Stone et al. also reporting napping was associated with an increased risk of hip fracture. Napping may also be associated with increased risk of cognitive impairment, particularly compromised executive function in older women.[100] This last observation would seem at odds with a previous section of this review which noted the positive impact of napping on cognition, particularly memory. However, it is important to distinguish the potential beneficial effect of experimentally imposed naps on memory from the cognitive impairment associated with the frequent napping of older adults that has been shown to be associated with increased morbidity [77,78,82,88,99] and mortality.[91–95] This contrast clearly illustrates the complexity of the interrelationships among napping, health and cognition, which have yet to be fully delineated.

Concluding remarks

Evidence from both laboratory experiments and "field" studies appears to indicate an overall beneficial role of napping for neurocognitive functions. First, all studies to date demonstrate that correctly timed split-sleep either had a positive effect or no effect on subsequent neurobehavioral performance supporting the hypothesis that the restorative effects of sleep on performance may be mantained when splitting the overall sleep episode into multiple naps. However, whether or not performance differences between consolidated and split-sleep schedules were observed, all of the experiments that measured sleep with PSG reported significant differences in the architecture of sleep stages in terms of the proportion of slow wave sleep and REM.[19,21–23] This raises the theoretical question of why split-sleep schedule induced differences in sleep architecture do not translate into differences in subsequent neurobehavioral performance.

This result has important implications about the operational feasibility of split-sleep schedules because, even if performance is not enhanced by split-sleep, it provides more flexibility to schedule sleep in work environments that involve restricted nocturnal sleep due to critical task scheduling.

The majority of nap studies in the work environment clearly lead to the same conclusion. In fact, the literature on shift workers shows that the alertness- and performance-enhancing effects of naps during both night and afternoon shifts can be quite dramatic. For instance, it appears that a daytime nap as short as 10-min can improve alertness and performance for about 2.5 h in the face of prior sleep loss, and for almost 4 h if preceded by normal sleep. However, it remains to be determined what the best nap duration is to achieve the most effective alerting effects, and to what extent this might be modulated by individual variables. Moreover, whether and how different cognitive functions (attention, working memory, higher cognitive functions such as decision making and planning) are differentially influenced by napping remains an open question.

The overview pattern of results also seems to point to a global beneficial effect of daytime naps for memory recall. Quite surprisingly, and differently from what has been reported in the "night sleep effect" literature, almost all authors report a beneficial "nap effect" for both procedural and declarative tasks. However, the effect strength ranges from quite dramatic changes, even including the actual improvement of memory performance at awakening,[61,70] to less relevant modifications, usually limited to a reduction of the forgetting/deterioration rate,[60,67,70] which seemingly depend on numerous factors, either related to sleep or memory. In fact, further studies are needed to better understand: a) what sleep features are crucial for the "nap effect" on memory consolidation, clarifying the role of nap duration, sleep states amount, sleep continuity and organization, and whether a memory-enhancing process is triggered by sleep onset *per se*; and b) whether and to what extent each memory task is differentially responsive to such a nap effect.

It is also worthwhile underscoring that the effects of naps on health and on the whole spectrum of cognitive functions might be different for habitual compared to non-habitual nappers.

As for the relationships between napping and age, we have not examined the effects of naps on babies' and children's cognitive processes and learning abilities, since no data have been produced on this topic apart from a pioneering study by Gomez et al.[101] Instead, we focused on napping behavior in the elderly. The state-of-the-art concerning napping in older adults was summarized in a recent Journal of the American Geriatrics Society editorial.[102] The prevalence of spontaneous napping increases with age in adults. This increase is likely the result of increases in nighttime sleep disturbances, phase advance of circadian rhythms, co-morbid medical and psychiatric illnesses and poor sleep habits. Napping does not seem to be associated with nighttime sleep quality but rather with excessive daytime sleepiness and medical and psychiatric co-morbidities. Frequent, unplanned, longer daytime naps in older adults have the potential to negatively impact nighttime sleep quality and may be associated with significant negative health consequences such as increased risk of morbidity, cardiovascular illness, falls and cognitive impairment. However, it is possible that brief planned naps may be of benefit to the function of healthy older adults (e.g., [84]), and perhaps even older adults in poorer health.[31]

We can conclude by saying that research on naps is at a very early stage and that there is much more to learn about napping. As suggested by Vitiello,[102] the field needs to move away from relatively simplistic assessments of napping to more nuanced assessments employing more elaborate self-reports paralleled by objective assessment techniques, e.g., actigraphy, which will allow for a better appreciation of the complexity of napping behavior. Such techniques would be best employed in large, representative samples which include both nappers and non-nappers. Only once such quantitative assessment techniques are employed longitudinally in large representative samples will a better understanding of the prevalence, antecedents and consequences of napping across the full spectrum of sleep and health patterns be possible.

Practice points

- Correctly timed split-sleep, shown to have positive effects, or at least no negative consequences on neurobehavioral performance, might be used for sleep-wake schedules in work environments that involve restricted nocturnal sleep due to critical task scheduling.
- Napping is an effective important countermeasure to maintain adequate performance levels during extended work shifts, and in operational settings. Napping strategies should be a natural part of programmes having the aim to improve safety and health in the work place.
- Short day-time naps are effective on vigilance and cognitive functions for subjects with moderately disturbed sleep and possibly for normal sleepers. Actually, a nap as short as 10 min can improve alertness and performance for about 2.5 h if prior sleep loss exists and for almost 4 h if preceded by normal sleep.
- Naps appear beneficial for memory consolidation of material newly acquired before the nap, either procedural or declarative. More robust effects seem to be given by slightly longer naps, about 60–90 min, possibly due to the build-up of both SWS and REM sleep.
- The prevalence of spontaneous napping increases with age in adults. This increase is likely the result of increases in nighttime sleep disturbances, phase advance of circadian rhythms, co-morbid medical and psychiatric illnesses and poor sleep habits.
- Frequent, unplanned, longer daytime naps in older adults have the potential to negatively impact nighttime sleep quality and may be associated with significant negative health consequences such as increased risk of morbidity, cardiovascular illness, falls and cognitive impairment.
- However, brief planned naps may be of benefit to the function of healthy older adults, and perhaps even older adults in poorer health.

Research agenda

- How and to what extent the neurocognitive effects of naps may change as a function of their circadian placement should be explored in more details.
- Further studies are needed if we aim to understand the combinatory effects of several countermeasures to maximize alertness at crucial time points: for instance, it would be important to verify how the use of naps and caffeine are best combined in operational shift-work settings.
- It is still to be understood what sleep features are crucial for the ''nap effect'' on memory consolidation.
- Lab studies could seek the effects of naps on specific higher cognitive functions using ad-hoc paradigms and tasks.
- Research on naps and cognition should include the study of oneiric activity (i.e., dream features) during napping.
- The cognitive effects of napping at early ages should be explored, because this might be of interest with respect to learning processes and school performance.
- More elaborate self-report paralleled by objective assessment techniques, such as actigraphy, which allow for a better appreciation of the complexity of napping behavior, should be employed in large, representative samples of older adults which include both nappers and non-nappers.

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References

1. Stampi C, editor. *Why we nap. Evolution, chronobiology and functions of polyphasic and ultra short sleep*. Boston: Birkhäuser; 1992.
2. Michelson E. Untersuchungen über die Tiefe des Schlafes. *Psychologische Arbeiten* 1897;**2**:84–117.
3. Carskadon MA, Dement WC. Nocturnal determinants of daytime sleepiness. *Sleep* 1982;**5**:S73–81.
4. Jewett ME, Dijk DJ, Kronauer RE, Dinges DF. Dose-response relationship between sleep duration and human psychomotor vigilance and subjective alertness. *Sleep* 1999;**22**:171–9.
*5. Lavie P. Ultra short sleep-waking schedule: gates and forbidden zones for sleep. *Electroencephalography Clin Neurophysiol* 1986;**63**:414–25.
6. Strogatz SH, Kronauer RE, Czeisler CA. Circadian pacemaker interferes with sleep onset at specific times each day–role in insomnia. *Am J Physiol* 1987;**253**:R172–8.
7. Dijk DJ, Czeisler CA. Contribution of the circadian pacemaker and the sleep homeostat to sleep propensity, sleep structure, electroencephalographic slow waves, and sleep spindle activity in humans. *Journal of Neuroscience* 1995;**15**:3526–38.
8. Dinges D. Probing the limits of functional capability: the effects of sleep loss on short-duration tasks. In: Broughton RJ, Ogilvie RD, editors. *Sleep, arousal, and performance*. Boston: Birkhauser; 1992. p. 177–88.
9. Van Dongen HPA, Maislin G, Mullington JM, Dinges DF. The cumulative cost of additional wakefulness: dose-response effects on neurobehavioral functions and sleep physiology from chronic sleep restriction and total sleep deprivation. *Sleep* 2003;**26**:117–26.
10. Dinges DF, Baynard M, Rogers NL. Chronic sleep restriction. In: Kryger MH, Roth T, Dement WC, editors. *Principles and practice of sleep medicine*. Philadelphia:: W.B. Saunders; 2005. p. 67–76.
11. Durmer JS, Dinges DF. Neurocognitive consequences of sleep deprivation. *Seminars in Neurology* 2005;**1**:117–29.
12. Belenky G, Wesensten NJ, Thorne DR, Thomas ML, Sing HC, Redmond DP, et al. Patterns of performance degradation and restoration during sleep

* The most important references are denoted by an asterisk.

restriction and subsequent recovery: a sleep dose-response study. *J Sleep Res* 2003;**12**:1–12.
13. Czeisler CA, Dijk DJ, Duffy DJ. Entrained phase of the circadian pacemaker serves to stabilize alertness and performance throughout the habitual waking day. In: Ogilvie RD, Harsh JR, editors. *Sleep onset: normal and abnormal processes*. Washington, DC: American Psychological Association; 1994. p. 89–110.
14. Achermann P, Werth E, Dijk DJ, Borbély AA. Time course of sleep inertia after nighttime and daytime sleep episodes. *Archiv Ital Biol* 1995;**134**:109–19.
15. Scheer F, Shea TJ, Hilton MF, Shea SA. An endogenous circadian rhythm in sleep inertia results in greatest cognitive impairment upon awakening during the biological night. *J Biol Rhythms* 2008;**23**:353–61.
16. Van Dongen HPA, Price NJ, Mullington JM, Szuba MP, Kapoor SC, Dinges DF. Caffeine eliminates psychomotor vigilance deficits from sleep inertia. *Sleep* 2001;**24**:813–9.
17. Van Dongen HPA, Baynard MD, Maislin G, Dinges DF. Systematic interindividual differences in neurobehavioral impairment from sleep loss: evidence of trait-like differential vulnerability. *Sleep* 2004;**27**:423–33.
18. Van Dongen HPA, Vitellaro KM, Dinges DF. Individual differences in adult human sleep and wakefulness: leitmotif for a research agenda. *Sleep* 2005;**28**:479–96.
19. Nicholson AN, Pascoe PA, Roehrs T, Roth T, Spencer MB, Stone BM, et al. Sustained performance with short evening and morning sleeps. *Aviat Space Env Med* 1985;**56**:105–14.
20. Hartley LR. Comparison of continuous and distributed reduced sleep schedules. *Quart J Exp Psychol* 1974;**26**:8–14.
*21. Bonnet MH, Arand DL. Consolidated and distributed nap schedules and performance. *J Sleep Res* 1995;**4**:71–7.
22. Mollicone DJ, Van Dongen HPA, Rogers NL, Dinges DF. Response surface mapping of neurobehavioral performance: testing the feasibility of split-sleep schedules for space operations. *Acta Astronautica* 2008;**63**:833–40.
23. Mollicone DJ, Van Dongen HPA, Dinges DF. Optimizing sleep/wake schedules in space: sleep during chronic nocturnal sleep restriction with and without diurnal naps. *Acta Astronautica* 2007;**60**:354–61.
24. Åkerstedt T, Torsvall L, Gillberg M. Shift work and napping. In: Dinges DF, Broughton R, editors. *Sleep and alertness: chronobiological, behavioral, and medical aspects of napping*. New York: Raven Press; 1989. p. 205–20.
25. Rosa R. Napping at home and alertness on the job in rotating shift workers. *Sleep* 1993;**16**:727–35.
*26. Garbarino S, Mascialino B, Penco MS, Squarcia S, De Carli F, Nobili L, et al. Professional shift-work drivers who adopt prophylactic naps can reduce the risk of car accidents during night work. *Sleep* 2004;**27**:1295–302.
27. Sallinen M, Härmä M, Mutanen P, Ranta R, Virkkala J, Müller K. Sleep-wake rhythm in an irregular shift system. *J Sleep Res* 2003;**12**:103–12.
28. Åkerstedt T, Knutsson A, Westerholm P, Theorell T, Alfredsson L, Kecklund G. Work organization and unintentional sleep: results from the WOLF study. *Occup Env Med* 2002;**59**:595–600.
29. Torsvall L, Åkerstedt T, Gillander K, Knutsson A. Sleep on the night shift: 24-hour EEG monitoring of spontaneous sleep/wake behavior. *Psychophysiol* 1989;**26**:352–8.
30. Cabon P, Bourgeois-Bougrine S, Mollard R, Coblentz A, Speyer JJ. Electronic pilot-activity monitor: a countermeasure against fatigue on long-haul flights. *Aviat Space Environ Med* 2003;**74**:679–82.
*31. Takahashi M. The role of prescribed napping in sleep medicine. *Sleep Med Rev* 2003;**7**:227–35.
*32. Schweitzer PK, Randazzo AC, Stone K, Erman M, Walsh JK. Laboratory and field studies of naps and caffeine as practical countermeasures for sleep-wake problems associated with night work. *Sleep* 2006;**29**:39–50.
33. Bonnet MH, Arand DL. The use of prophylactic naps and caffeine to maintain performance during a continuous operation. Ergonomics 37:1009–1020.
*34. Sallinen M, Härmä M, Åkerstedt T, Rosa R, Lillqvist O. Promoting alertness with a short nap during a night shift. *J Sleep Res* 1998;**7**:240–7.
35. Macchi MM, Boulos Z, Ranney T, Simmons L, Campbell SS. Effects of an afternoon nap on nighttime alertness and performance in long-haul drivers. *Accid Anal Prev* 2002;**34**:825–34.
36. Petrie KJ, Powell D, Broadbent E. Fatigue self-management strategies and reported fatigue in international pilots. *Ergonomics* 2004;**47**:461–8.
37. Purnell MT, Feyer A-M, Herbison GP. The impact of a nap opportunity during the night shift on the performance and alertness of 12-h shift workers. *J Sleep Res* 2002;**11**:219–27.
38. Bonnefond A, Muzet A, Winter-Dill A-S, Bailloeuil C, Bitouze F, Bonneau A. Innovative working schedule: introducing one short nap during the night shift. *Ergonomics* 2001;**44**:937–45.
39. Takahashi M, Arito H, Fukuda H. Nurse's workload associated with 16-h night shifts. II: effects of a nap taken during the shifts. *Psychiatry Clin Neurosci* 1999;**53**:223–5.
40. Smith-Coggins R, Howard SK, Mac DT, Wang C, Kwan S, Rosekind MR, et al. Improving alertness and performance in emergency department physicians and nurses: the use f planned naps. *Acad Emerg Med* 2006;**48**:596–604.
41. Arora V, Dunphy C, Chang VY, Ahmad F, Humphrey HJ, Meltzer D. The effects of on-duty napping on intern sleep time and fatigue. *Ann Intern Med* 2006;**144**:792–8.
42. Lockley SW, Cronin JW, Evans EE, Cade BE, Lee CJ, Landrigan CP, et al. Effect of reducing interns' weekly work hours on sleep and attentional failures. *N Engl J Med* 2004;**351**:1829–37.
43. Rosekind MR, Graeber RC, Dinges DF, Connell LJ, Rountree MS, Spinweber CL. Crew factors in flight operations: IX. Effects of planned cockpit rest on crew performance and alertness in Long-Haul operations. In: *Technical memorandum 103884*. Moffett Field, CA: NASA; 1994.
44. Dinges DF, Whitehouse WG, Orne EC, Orne MT. The benefits of a nap during prolonged work and wakefulness. *Work & Stress* 1988;**2**:139–53.
45. Lumley M, Roehrs T, Zorick F, Lamphere J, Roth T. The alerting effects of naps in sleep-deprived subjects. *Psychophysiol* 1986;**23**:403–8.
46. Gillberg M, Kecklund G, Axelsson J, Åkerstedt T. The effects of a short daytime nap after restricted night sleep. *Sleep* 1996;**19**:570–5.
47. Hayashi M, Motoyoshi N, Hori T. Recuperative power of a short daytime nap with or without stage 2 sleep. *Sleep* 2005;**28**:829–36.
48. Brooks A, Lack L. A brief afternoon nap following nocturnal sleep restriction: which nap duration is most recuperative? *Sleep* 2006;**29**:831–40.
49. Takahashi M, Fukuda H, Arito H. Brief naps during post-lunch rest: effects on alertness, performance, and autonomic balance. *Eur J Appl Physiol Occup Physiol* 1998;**78**:93–8.
50. Takahashi M, Nakata A, Haratani T, Ogawa Y, Arito H. Post-lunch nap as a worksite intervention to promote alertness on the job. *Ergonomics* 2004;**47**:1003–13.
51. Rosekind MR, Smith RM, Miller DL, Webbon LL, Co EL, Gregory KB, et al. Alertness management: strategic naps in operational settings. *J Sleep Res* 1995;**4**(Suppl. 2):62–6.
52. Reyner LA, Horne JA. Suppression of sleepiness in drivers: combination of caffeine with a short nap. *Psychophysiol* 1997;**34**:721–5.
53. Peigneux P, Laureys S, Delbeuck X, Maquet P. Sleeping brain, learning brain. The role of sleep for memory system. *Neuroreport* 2001;**12**:A111–24.
54. Ficca G, Salzarulo P. What in sleep is for memory. *Sleep Med* 2004;**5**:225–30.
55. Barrett TR, Ekstrand BR. Effect of sleep on memory: III. Controlling for time-of-day effects. *J Exp Psychol* 1972;**96**:321–7.
56. Nesca M, Koulack D. Recognition memory, sleep and circadian rhythms. *Can J Exp Psychol* 1994;**48**:359–79.
57. Backhaus J, Junghanns K. Daytime naps improve procedural motor memory. *Sleep Med* 2006;**7**:508–12.
58. Ficca G, Lombardo P, Rossi L, Salzarulo P. Morning recall of verbal material depends on prior sleep organization. *Behav Brain Res* 2000;**112**:159–63.
59. Salzarulo P. Etude éléctroencéphalographique et polygraphique du sommeil l'aprèz midi chez le sujet normal. *Electroencephal Clin Neurophysiol* 1971;**30**:399–407.
*60. Mednick S, Nakayama K, Cantero JL, Atienza M, Levin AA, Pathak N, et al. The restorative effect of naps on perceptual deterioration. *Nature Neurosci* 2002;**5**:677–81.
61. Mednick S, Nakayama K, Stickgold R. Sleep-dependent learning: a nap is good as a night. *Nature Neurosci* 2003;**6**:697–8.
62. Stickgold R, James L, Hobson JA. Visual discrimination learning requires post-training sleep. *Nature Neurosci* 2000;**2**:1237–8.
63. Cajochen C, Knoblauch V, Wirz-Justice A, Kraüchi K, Graw P, Wallach D. Circadian modulation of sequence learning under high and low sleep pressure conditions. *Behav Brain Res* 2004;**151**:167–76.
64. Korman M, Doyon J, Doljansky J, Carrier J, Dagan Y, Karni A. Daytime sleep condenses the time course of motor memory consolidation. *Nature Neurosci* 2007;**10**:1206–13.
65. Nishida M, Walker MP. Daytime naps, motor memory consolidation and regionally specific sleep spindles. *PLoS* 2007;**4**:e341.
66. Tucker M, Yasutaka H, Wamsley E, Lau H, Chaklader A, Fishbein WA. Daytime nap containing solely non-REM sleep enhances declarative but not procedural memory. *Neurobiology of Learning and Memory* 2006;**86**:241–7.
67. Milner CE, Fogel SM, Cote KA. Habitual napping moderates motor performance improvements following a short daytime nap. *Biol Psychol* 2006;**73**:141–6.
68. Schoen LS, Badia P. Facilitated recall following REM and NREM naps. *Psychophysiol* 1984;**21**:299–306.
69. Schabus M, Hodlmoser K, Pecherstorfer T, Klosch G. Influence of midday naps on declarative memory performance and motivation. *Somnologie* 2005;**9**:148–53.
70. Muto V, Arpaia, L, De Padova V, Russo E., Ficca G. The effect of daytime naps on the recall of verbal material. In: Proceedings of the1st Congress of the World Association of Sleep Medicine, Medimond:Bologna; 2005; p.29–34.
71. Lahl O, Wispel C, Willigens B, Petrowsky R. An ultra short episode of sleep is sufficient to promote declarative memory performance. *J Sleep Res* 2008;**17**:3–10.
72. Tietzel AJ, Lack LC. The recuperative value of brief and ultra-brief naps on alertness and cognitive performance. *J Sleep Res* 2002;**11**:213–8.
73. Schmidt C, Peigneux P, Muto V, Schenkel M, Knoblauch V, Munch M, et al. Encoding difficulty promotes post-learning changes in sleep spindle activity during napping. *J Neurosci* 2006;**26**:8976–82.
74. Buysse DJ, Browman KE, Monk TH, Reynolds 3rd CF, Fasiczka AL, Kupfer DJ. Napping and 24-hour sleep/wake patterns in healthy elderly and young adults. *J Am Geriatr Soc* 1992;**40**:779–86.
*75. Foley DJ, Vitiello MV, Bliwise DL, Ancoli-Israel S, Monjan AA, Walsh JK. Frequent napping is associated with excessive daytime sleepiness, depression, pain and nocturia in older adults. *American J Geriatr Psychiatry* 2007;**15**(3):344–50.

76. Metz ME, Bunnell DE. Napping and sleep disturbances in the elderly. *Fam Pract Res J* 1990;**10**:47–56.
77. McCrae CS, Rowe MA, Dautovich ND, Lichstein KL, Durrence HH, Riedel BW, et al. Sleep hygiene practices in two community dwelling samples of older adults. *Sleep* 2006;**29**:1551–60.
78. *Stone KL, Ewing SK, Lui LY, Ensrud KE, Ancoli-Israel S, Bauer DC, et al. Self-reported sleep and nap habits and risk of falls and fractures in older women: the study of osteoporotic fractures. *J Am Geriatr Soc* 2006;**54**:1177–83.
79. Gislason T, Reynisdottir H, Kristbjarnarson H, Benediktsdottir B. Sleep habits and sleep disturbances among the elderly–an epidemiological survey. *J Intern Med* 1993;**234**:31–9.
80. Mallon L, Hetta J. A survey of sleep habits and sleeping difficulties in an elderly Swedish population. *Ups J Med Sci* 1997;**102**:185–97.
81. Yoon IY, Kripke DF, Youngstedt SD, Elliott JA. Actigraphy suggests age-related differences in napping and nocturnal sleep. *J Sleep Res* 2003;**12**:87–93.
82. Vitiello MV, Foley DJ. Predictors of planned and unplanned napping in older adults. *Sleep* 2007;**30**:A105–6.
83. Ohayon MM. Epidemiology of insomnia: what we know and what we still need to learn. *Sleep Medicine Reviews* 2002;**6**:97–111.
*84. Ohayon MM, Carskadon MA, Guilleminault C, Vitiello MV. Meta-analysis of quantitative sleep parameters from childhood to old age in healthy individuals: developing normative sleep values across the human lifespan. *Sleep* 2004;**27**:1255–73.
85. Monk TH. Aging human circadian rhythms: conventional wisdom may not always be right. *J Biol Rhythm* 2005;**20**:366–74.
86. Monk TH, Buysse DJ, Carrier J, Billy BD, Rose LR. Effects of afternoon "siesta" naps on sleep, alertness, performance, and circadian rhythms in the elderly. *Sleep* 2001;**24**:680–7.
87. Campbell SS, Murphy PJ, Stauble TN. Effects of a nap on nighttime sleep and waking function in older subjects. *J Am Geriatr Soc.* 2005;**53**:48–53.
88. Liu X, Liu L. Sleep habits and insomnia in a sample of elderly persons in China. *Sleep* 2005;**28**:1579–87.
89. Bliwise NG. Factors related to sleep quality in healthy elderly women. *Psychol Aging* 1992;**7**:83–8.
90. Hsu HC. Relationships between quality of sleep and its related factors among elderly Chinese immigrants in the Seattle area. *J Nurs Res* 2001;**9**:179–90.
91. Bursztyn M, Ginsberg G, Hammerman-Rozenberg R, Stessman J. The siesta in the elderly: risk factor for mortality? *Arch Intern Med* 1999;**159**:1582–6.
*92. Newman AB, Spiekerman CF, Enright P, Lefkowitz D, Manolio T, Reynolds CF, et al. Daytime sleepiness predicts mortality and cardiovascular disease in older adults. The cardiovascular health study research group. *J Am Geriatr Soc* 2000;**48**:115–23.
93. Bursztyn M, Ginsberg G, Stessman J. The siesta and mortality in the elderly: effect of rest without sleep and daytime sleep duration. *Sleep* 2002;**25**:187–91.
94. Bursztyn M, Stessman J. The siesta and mortality: twelve years of prospective observations in 70-year-olds. *Sleep* 2005;**28**:345–7.
*95. Stone KL, Ewing SK, Ancoli-Israel S, Ensrud KE, Redline S, Bauer DC, et al. Self-Reported sleep and nap habits and risk of mortality in a large cohort of older women. *J Am Geriatr Soc*; 2009 Feb 10 [Epub ahead of print].
96. Trichopoulos D, Tzonou A, Christopoulos C, Havatzoglou S, Trichopoulou A. Does a siesta protect from coronary heart disease? *Lancet* 1987;**2**:269–70.
97. Kalandidi A, Tzonou A, Toupadaki N, Lan SJ, Koutis C, Drogari P, et al. A case-control study of coronary heart disease in Athens. *Greece. Int J Epidemiol* 1992;**21**:1074–8.
98. Naska A, Oikonomou E, Trichopoulou A, Psaltopoulou T, Trichopoulos D. Siesta in healthy adults and coronary mortality in the general population. *Arch Intern Med* 2007;**167**:296–301.
99. Brassington GS, King AC, Bliwise DL. Sleep problems as a risk factor for falls in a sample of community-dwelling adults aged 64–99 years. *J Am Geriatr Soc* 2000;**48**:1234–40.
100. Blackwell T, Yaffe K, Ancoli-Israel S, Schneider JL, Cauley JA, Hillier TA, et al. Poor sleep is associated with impaired cognitive function in older women: the study of osteoporotic fractures. *J Gerontol A Biol Sci Med Sci* 2006;**61**:405–10.
101. Gòmez RL, Bootzin RR, Nadel L. Naps promote abstraction in language-learning infants. *Psychol Sci* 2006;**17**:670–4.
102. Vitiello MV. We have much more to learn about napping in older adults (Editorial). *J Am Geri Soc.* 2008;**56**:1753–5.