Do sleep deprivation, time of day and sleep pressure influence nap efficiency?

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Abstract:

Reduced alertness and cognitive performance due to sleep deficiency is experienced by a substantial part of the general population, which can lead to serious accidents during commute or at work. When insufficient sleep is inevitable, napping might be useful to counteract reduced daytime alertness and cognitive performance. Naps of over 20 minutes are often used to counteract reduced alertness and cognitive performance, but these naps can result in sleep inertia. Sleep inertia is a transitional state of reduced arousal which can occur in the first 30 minutes after waking up. Sleep inertia is problematic when immediate alertness and cognitive performance is required after waking up. What influences efficiency of naps of 20 minutes or less, is not well documented. Therefore, lab-based studies that tested naps of 20 minutes or less in healthy adults were investigated for this thesis. Specifically, studies investigating napping protocols in the context of the three factors (i) prior sleep deprivation, (ii) time of day and (iii) prior wakefulness were reviewed. Prior sleep deprivation did not influence nap efficiency. Naps taken in the mid-afternoon showed significant benefits on alertness and cognitive performance. Napping seemed to be effective at noon, but only after a minimum of four to six hours of wakefulness. Napping seemed ineffective at 02:00 a.m. and 09:00 a.m. Naps of 20 minutes or less proved effective in reducing incidents in driving simulation tests and could also be assisting pilots in-flight. Future field research is needed, to assess the efficiency of naps of 20 minutes or less for those at high risk of reduced alertness and cognitive performance, e.g. pilots, surgeons and night-shift workers.

Introduction:

According to the National Institute of Health (Czeisler, 2011) insufficient sleep is “the deficit in the quantity or quality of sleep obtained versus the amount needed for optimal health, performance, and well-being”. Sufficient sleep for adults on average is 8 hours, with large interindividual variation ranging from 6 to 10 hours (Drobnich et al, 2005; Czeisler et al, 2011). In the US, 70% of adults report that they obtain insufficient sleep or rest at least once each month, and 11% report insufficient sleep or rest every day of the month (Centers for Disease Control and Prevention, 2008). Insufficient sleep can range from less than 6 hours sleep to approximately 10 hours sleep per night, since this depends on the individual’s sleep requirements. Studies showed that insufficient sleep, either due to partial or total sleep deprivation, leads to sleep deficiency, which significantly reduces alertness and cognitive performance (Van Dongen et al, 2003; Belenky et al, 2003). Reduced alertness and cognitive performance, in turn, can cause human error, which causes accidents in e.g. traffic and health care (Rosekind et al, 1994; Baker et al, 1994; Veasey et al, 2002).

Efficiency of nocturnal sleep in sustaining alertness and cognitive performance is superior over daytime sleep (Jackson et al, 2014; Lo et al, 2014). Meeting the nocturnal sleep requirements is an effective way to avoid sleep deficiency. When this requirement cannot be met at night, napping during the day might be one way to counteract the detrimental effects of sleep deficiency on daytime alertness and cognitive performance (Stampi et al, 1992).

Napping often is defined in quantitative terms as “any sleep period with a duration of less than 50% of the average major sleep period of an individual” (Dinges et al, 1986). This thesis focuses on laboratory-based studies testing the effects of naps of 20 minutes or less, because longer naps (especially of 30 minutes or longer) can cause sleep inertia (Tietzel et al, 2001). Sleep inertia is a transitional state of reduced arousal, which occurs immediately after awakening from sleep (Tassi and Muzet, 2000). Awakening from slow wave sleep (SWS) increases the chances of sleep inertia (Stones, 1977), which is why long naps should be avoided to reduce the probability to reach the level of SWS.

Tests to assess alertness and cognitive performance that are used in these laboratory experiments described in this thesis are briefly explained in Table 1.

Table 1. The tests which were used in laboratory experiments described in this thesis are shown.

Test name	**Method**	**Goal**	**Reference**
Multiple sleep latency test (MSLT)	Measuring sleep onset latency (SOL): the time it takes an individual to fall asleep	Greater SOL indicates greater sleepiness	Carskadon et al, 1986
Psychomotor vigilance task (PVT)	Sustained attention to react to a certain (optical or acoustic) stimulus	Shorter reaction times (RT) indicate higher alertness levels	Dinges et al, 1985
P300 event related potential (ERP)	Electroencephalography (EEG) activity after certain optical or acoustic stimuli is measured	Cognitive functioning	Braverman and Blum, 2003
Letter Cancellation Task (LCT)	Detect a given number of specific letters out of a sequence of a few hundred	Working memory (Cognitive performance)	Casagrande et al, 1997
Serial addition/substitution tasks	Calculation test	Working memory (Cognitive performance)	Casagrande et al, 1997
Symbol Digit Substitution Task (SDST)	Symbols and digits are paired and have to be remembered to produce the right sequence of digits after being shown the corresponding symbols	Working memory (Cognitive performance)	McLeod et al, 1982
Logical reasoning test	Verify descriptions of relationships between certain letters/numbers	Cognitive performance	Baddeley, 1968

My thesis aimed to help determine those factors that influence nap efficiency of 20 minute or shorter naps on alertness and cognitive performance, verified with the tests shown in Table 1.

My main questions were:

Is there a difference in nap efficiency of 20 minute or shorter naps on alertness and cognitive performance between sleep deprived opposed to non-sleep deprived subjects?

Sleep deprivation causes reduced arousal, which can be counteracted with napping (Stampi et al, 1992; Van Dongen et al, 2003; Belenky et al, 2003). In this thesis, I examined whether 20 minute or shorter naps could increase alertness and cognitive performance irrespective of arousal and sleep deprivation status.

Does time of day affect the efficiency of napping for 20 minutes or less on alertness and cognitive performance?

Time of day plays an important role in the proneness to sleep and the effects of sleep on alertness and cognitive performance (Jackson et al, 2014; Lo et al, 2014). This is mainly because of the internal biological clock, which increases and decreases arousal with a 24-h period (increased arousal during the day and decreased arousal at night). This circadian rhythm ('circa'=about, 'dia'=day) is also referred to as process C, one of two processes that is thought to influence sleep timing (Daan et al, 1984; Borbély and Achermann, 1999; Higuchi et al, 2000). Process C, however, depends on the internal biological clock resulting in interindividual variation in sleep timing. The timing of sleep and wake can also be referred to as the individual's chronotype, which is defined by the mid-point of sleep on work-free days, corrected for sleep deficit on workdays (Roenneberg et al, 2003). In this thesis, I aim to find out if process C influences nap efficiency of 20 minute or shorter naps on alertness and cognitive performance.

Does the duration between waking up and napping (homeostatic component) play a role in the efficiency of napping for 20 minutes or less on alertness and cognitive performance?

Process S, is the homeostatic component of sleep timing, physically expressed as increased sleep pressure with time being awake (Daan et al, 1984). Increasing sleep pressure is correlated with decreasing arousal (Daan et al, 1984; Dijk and Czeisler, 1995). Process S rises during wakefulness and declines during sleep.

In Figure 1, time is indicated as local time. In this thesis I investigate if the temporal difference between waking up and napping plays a role in nap efficiency. If so, I am interested in the minimum duration of wakefulness, at which subjects can benefit from napping.

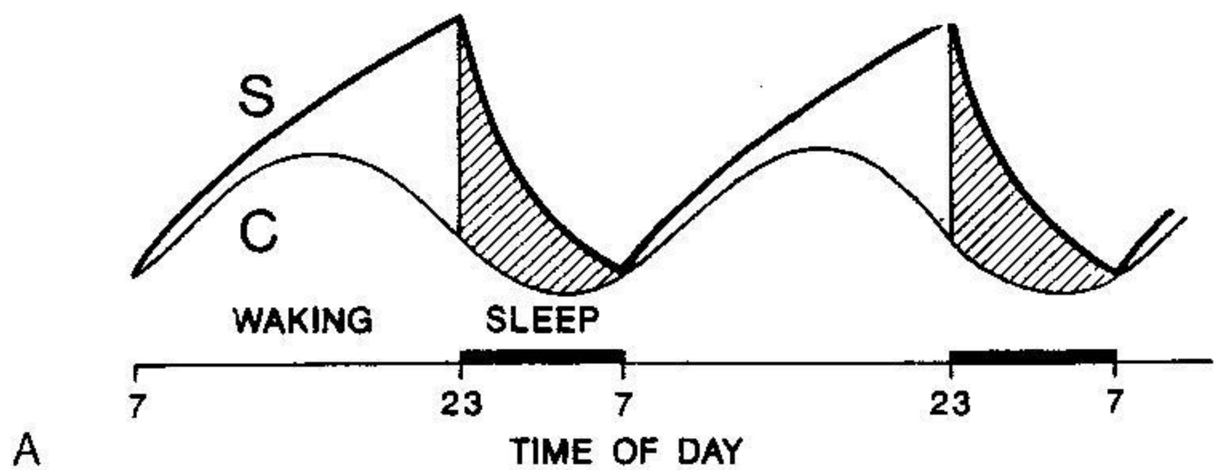


Figure 1. "Two process model of sleep regulation. Time course of homeostatic process S and circadian process C. S rises during waking and declines during sleep. The intersection of S and C defines time of wake-up." (Borbély and Achermann, 1999)

Can studies performed in the laboratory inform real-life scenarios?

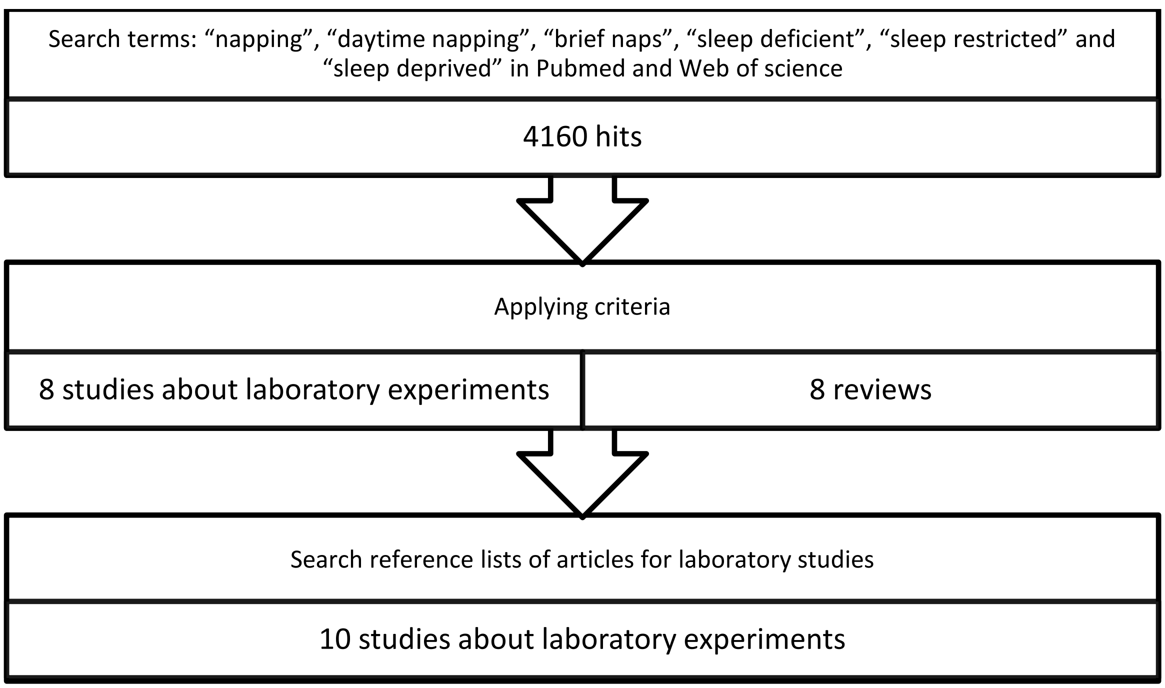
The outcome of the studies reviewed in this thesis might provide advice for certain occupations, such as truck drivers, surgeons, pilots or night-shift workers. For instance, in night-shift workers, naps of between 15 to 120 minutes are already used to increase alertness, as was outlined in a review by Ruggiero (Ruggiero, 2014). Laboratory tests could possibly provide insights on alertness and cognitive performance with the tests described in Table 1.

Methods:

For this thesis, the databases PubMed and Web of science were used. The search terms "napping", "daytime napping", "brief naps", "sleep deficient", "sleep restricted" and "sleep deprived" were used separately and combined. These terms got 4160 hits of articles published since 1986. Because the differences in results *between* studies are compared, as many confounds as possible were excluded. Therefore, I only focused on studies fulfilling all of the following criteria (some of which are explained in the introduction):

- Nap duration of 20 minutes or less
- Sleep prior the experiment was at night
- To best compare nap efficiency in sleep deprived subjects to non-sleep deprived subjects, only studies regarding one night of sleep restriction were used
- Outcomes were alertness and/or cognitive performance
- Subjects had to be healthy and without sleeping disorders

Applying these criteria resulted in 16 hits, including eight review studies and eight laboratory-based experiments. In addition, the reference lists of these 16 articles were searched to identify publications, which were not listed in the initial search in the online databases. Ten articles remained for final analysis.



Flowchart 1. Flowchart showing literature selection.

Results:

Ten articles about laboratory experiments, published between 1986 and 2012, were analyzed. In Table 2 the studies are shown with the main characteristics and results. In the laboratory studies described in this thesis, within subject designs were used. Thus, all subjects were exposed to both nap as no-nap conditions.

Table 2: Studies from 1986 to 2012 about the effects of short naps on alertness and memory are shown chronologically. Column "Time of day" indicates time of napping at local time.

Authors, year	Number of subjects	Nap length (min)	Sleep restricted (hours)	Time of day	Time awake prior napping	Tests applied	Main results
Lumley et al, 1986	10	15	Yes (0 hours)	09:00 h	25 hours	MSLT	No significant differences between napping and no-napping.
Takahashi et al, 1998	30	15	Yes (7 hours)	12:30 h	No data (N/D)	P300 latency	Significant decrease in latency till 3 hours after napping compared to no-napping.
Hayashi et al, 1999[a]	7	20	Yes (8 hours)	14:00 h	6 hours	Logical reasoning, addition, visual detection, auditory vigilance.	Significant increase in logical reasoning, addition and auditory vigilance in nap group compared to no-nap group.
Hayashi et al, 1999[b]	10	20	Yes (8 hours)	12:20 h	4 hours	Logical reasoning, addition, visual detection, auditory vigilance.	No significant differences between napping and no- napping.
Takahashi et al, 2000	12	15	Yes (4 hours), No (ad lib)	12:30 h	N/D	P300 latency	Significant decrease in latency till 3 hours after napping, compared to no-napping, in both sleep restricted as not sleep restricted.

Tietzel et al, 2001	12	10	Yes (5 hours)	15:00 h	10 hours	MSLT, SDST, LCT	Significant increase on all tests after napping compared to no-napping.
Brooks et al, 2006	24	5, 10, 20	Yes (5 hours)	14:30 h	8 hours	MSLT, SDST, LCT, visual reaction time test	Most and immediate significant improvements after 10 minutes naps compared to no-nap.
Lahl et al, 2008	26	6	No (ad lib)	13:00 h	6 hours	Word memory	Significant better recollection after napping compared to no-napping.
Horne et al, 2008	20	20	No (ad lib)	14:30 h	N/D	MSLT	Significant higher latency after napping compared to no-napping.
Mulrine et al, 2012	24	20	Yes (0 hours)	02:00 h, 12:00 h	20 hours, 30 hours	Vigilance test	Significant improvement after a nap after 30 hours compared to no-nap.

Difference in nap efficiency of 20 minute or shorter naps on alertness and cognitive performance between sleep deprived opposed to non-sleep deprived subjects:

Takahashi and co-workers (Takahashi et al, 2000) investigated the effects of napping (at 12:30 h) after sufficient nocturnal sleep and after nocturnal sleep restricted to four hours only. They found comparable improvements on the P300 latency test between sleep deprived and non-sleep deprived subjects, compared to their corresponding control groups, in which no nap was taken. Two studies regarded the effects of napping after total sleep deprivation (Lumley et al, 1986; Mulrine et al, 2012). In these studies, only naps at noon improved the subject's alertness, tested with a PVT, while naps at 2:00 h and 9:00 h after total sleep deprivation did not (Lumley et al, 1986; Mulrine et al, 2012). After five hours of nocturnal sleep, ten minutes naps (at 14:30 h and 15:00 h) increased SOL by four to six minutes (Tietzel et al, 2001; Brooks et al, 2006). Also, 35 minutes after napping, SDST scores and LCT scores improved by 13% to 20% and 16% to 26%, respectively. In one study, where subjects were allowed to sleep for seven hours, napping (at 12:30 h) improved alertness (Takahashi et al, 1998). In a different study, where subjects were allowed to sleep eight hours, naps (at 14:00 h) improved alertness and cognitive performance (Hayashi et al, 1999[a]). Another study, where subjects were allowed to sleep 8 hours, did not show any significant differences between napping and not napping (at 12:20 h) (Hayashi et al, 1999[b]). In two other studies, where subjects were allowed to sleep as much as they habitually do, naps (at 13:00 h and 14:30 h) improved alertness and cognitive performance (Lahl et al, 2008; Horne et al, 2008). Overall, naps (scheduled between 12:00 h and 15:00 h) improved alertness and cognitive performance after total, partial and no prior sleep deprivation.

The effects of time of day on the efficiency of napping for 20 minutes or less on alertness and cognitive performance:

In the two studies by Hayashi in 1999, discussed in this thesis, two different study groups were used (Hayashi et al, 1999[a]; Hayashi et al, 1999[b]). Protocols were comparable regarding sleep restriction and tests applied. However, the timing of the naps was different. In the first study, naps were scheduled at 14:00 h and resulted in improvements on logical reasoning, addition and auditory vigilance compared to the no-nap group (Hayashi et al, 1999[a]). In the second study naps were scheduled at 12:20 h, which resulted in no significant difference with the no-nap group (Hayashi et al, 1999[b]). In other studies, naps at approximately 12:20 h did show significant benefits on alertness and cognitive performance in either totally, partially and non-sleep deprived subjects (Takahashi et al, 1998; Takahashi et al, 2000; Mulrine et al, 2012). Naps scheduled between 13:00 h and 15:00 h showed benefits on alertness and cognitive performance (Hayashi et al, 1999[a]; Tietzel et al, 2001; Brooks et al, 2006; Lahl et al, 2008; Horne et al, 2008). Naps at 02:00 h and 09:00 h, respectively during and after a night of total sleep deprivation, improved neither alertness nor cognitive performance (Lumley et al, 1986; Mulrine et al, 2012).

The effects of the duration between waking up and napping (homeostatic component) on the efficiency of napping for 20 minutes or less on alertness and cognitive performance:

In Hayashi's study, where naps were scheduled after four hours of wakefulness, no significant differences were found between the nap group and the no-nap group (Hayashi et al, 1999[b]). Naps after six, eight and ten hours awake did show significant improvements on alertness and memory, either after non-deprived or deprived nocturnal sleep (Hayashi et al, 1999[a]; Tietzel et al, 2001; Brooks et al, 2006; Lahl et al, 2008). After 20 hours and 25 hours of wakefulness, no benefits from napping (at 2:00 h and 9:00 h, respectively) were found (Lumley et al, 1986; Mulrine et al, 2012). After 30 hours of wakefulness, a 20 minutes nap (at 12:00 h) improved alertness (Mulrine et al, 2012).

Discussion:

The aim of this thesis was to investigate whether the factors sleep deprivation, time of day and prior wakefulness influence the efficiency of naps of 20 minutes or less duration.

Is there a difference in nap efficiency of 20 minute or shorter naps on alertness and cognitive performance between sleep deprived opposed to non-sleep deprived subjects?

Only a single study (Takahashi et al, 2000) from the ten analyzed studies could be identified comparing nap efficiency in sleep-deprived subjects to non-sleep deprived subjects. However, comparing the outcomes of the ten analyzed studies in this thesis could indicate if there are differences in nap efficiency between sleep deprived and non-sleep deprived subjects. As in the study by Takahashi and colleagues (Takahashi et al, 2000), a between-studies comparison reveals similar improvements of alertness and cognitive performance after napping, irrespective of prior sleep deprivation. Noteworthy here is that, since the studies presented in the current report are heterogeneous in methods and study populations, their results cannot be generalized to the general population. I suggest more homogeneous studies like Takahashi's (Takahashi et al, 2000) to tests for differences between napping after sleep deprivation and napping after sufficient sleep for further research.

In addition, arguable is that subjects might have been, at least mildly, sleep deprived, when they were stated as non-sleep deprived. For example, in Takahashi's study in 1998, subjects with a mean age of 25 years were allowed to sleep seven hours at night prior to testing (Takahashi et al, 1998). According to the National Sleep Foundation (Drobnich, 2005), the recommended sleep per night for people of this age is between seven and nine hours. Therefore, we cannot know if the subjects in this study were mildly sleep deprived or not, while they were stated as non-sleep deprived. For the same reason, subjects in Hayashi's studies (mean age 20.6 and 20.7), could have been mildly sleep deprived after eight hours sleep and subjects in Takahashi's study in 2000 (mean age 22.1) after their regular 6.9 hours sleep (Hayashi et al, 1999[a]; Hayashi et al, 1999[b]; Takahashi et al, 2000).

One way to reduce the chance of testing sleep-deprived subjects is to extend the nocturnal sleep period. Horne and colleagues tested a third group with extended sleep periods with a maximum of 90 minutes (Horne et al, 2008). The subjects extended their sleep by an average of 74 minutes, but this did not nearly improve SOL (measured with a MSLT in the evening) as much as an afternoon nap did. This suggests that even after extended sleep, an afternoon nap can have benefits on sleepiness. This is in line with above named deduction of the results that sleep deprivation does not seem to have an effect on nap efficiency of naps of 20 minutes or less. A nap and no-nap- subgroup in the sleep extended group would have provided insight in the efficiency of napping in non-sleep deprived subjects.

In conclusion, naps of 20 minutes or less seem to increase alertness and cognitive performance after both sufficient and insufficient nocturnal sleep. Further research is needed to rule out the influence of sleep deprivation on nap efficiency. I suggest more homogeneous studies in tests and extended prior sleep for subjects in the non-sleep deprived group to diminish the chance that these subjects are sleep deprived.

Does time of day affect the efficiency of napping for 20 minutes or less on alertness and cognitive performance?

The investigated studies in this thesis show different findings after napping at different times of the day. Napping did not improve alertness and cognitive performance at 02:00 h and 09:00 h, compared to the no-nap group (Lumley et al, 1986; Murine et al, 2012). The lack of improvements after a nap at 02:00 h is remarkable, because other studies, investigating napping at night in night-shift workers, showed improvements on alertness and cognitive performance (Ruggiero, 2014). Studies investigating naps scheduled between 13:00 h and 15:00 h show significant improvements on alertness and cognitive performance.

Reviewed studies regarding the effects of naps at approximately 12:30 h, show varying findings (Takahashi et al, 1998; Hayashi et al, 1999[b]; Takahashi et al, 2000). This discrepancy between studies could be due to interindividual variation in circadian rhythm/process C between subjects. The investigated studies in this thesis only included subjects who were neither excessive evening types nor excessive morning types, measured with morningness/eveningness questionaires or diurnal type scales (Horne and Östberg, 1976; Horne and Östberg, 1977). This tells us something about the subjects' sleep timing preferences, but does not mean the subjects' chronotypes were measured. The local time of day, equal to each subject, might correspond differently to the internal clock due to different chronotypes, which can be individually assessed using the Munich Chronotype Questionnaire (MCTQ) (Roenneberg et al, 2003). Different chronotypes distributions in the studies of, for example, Hayashi and Takahashi, which both tested naps around 12:30h, may explain the different findings between these studies (Takahashi et al, 1998; Hayashi et al, 1999[b]; Takahashi et al, 2000).

The reason for possible significant differences in chronotypes distributions in the studies from Takahashi and Hayashi could be the mean age difference of almost 5 years (20.6 and 20.7 in Hayashi's study opposed to 25 in Takahashi's study). Also the fact that the subjects were from different universities (university of Hiroshima vs. Kawasaki) with possible different study schedules and differences in opening hours of facilities in the cities could ultimately lead to different chronotypes distributions between the two studies. If different chronotypes distributions were the case in Takahashi's and Hayashi's studies, a 20 minutes nap at 12:30 would correspond to an earlier time on the internal clock of late chronotypes than of early chronotypes. For instance, a difference of two hours between mid-points of sleep on non-working days could mean that a nap at the same time of day (e.g. 12:30 h) would actually mean a two hour difference in nap timing between the earlier and later chronotypes. Hypothetically, this would ultimately lead to greater efficiency of a nap at noon in earlier chronotypes than in later chronotypes. I hypothesize this, because, overall, afternoon naps were more efficient than morning naps in the analyzed studies in this thesis.

Significant improvements in alertness and cognitive performance measures after 20 minute naps between 13:00 h and 15:00 h and the lack of these improvements at 2:00 h and 9:00 h might give us insight in a possible timeframe in which naps can be efficient. This also suggests nap efficiency stems from a different pathway than sleep efficiency, since nocturnal sleep is superior over daytime sleep in effectiveness on sustaining alertness and cognitive performance.

A possible explanation could be that when subjects napped at 2:00 h and 9:00 h they transcended into SWS even though the aim was to completely avoid this by limiting the nap length to 20 minutes or less. Decreased arousal due to sleep inertia could have counteracted the beneficial effects of a 20 minutes nap at 2:00 h and 9:00 h. This could ultimately have led to no improvements on alertness or cognitive performance at all. For further research, naps of 20 minutes or less at night or in the morning should be monitored to check if there is SWS indicating brain activity, using electroencephalograms.

In conclusion, the variation between nap efficiency around noon could possibly be explained by varying average chronotypes between subjects. I suggest a study design where chronotypes are measured, with the MCTQ (Roenneberg et al, 2003). Moreover, to link 20 minutes nap efficiency to process C, further research is needed on napping at night and also in the evening, since no laboratory experiments on 20 minutes naps between 15:00 h and 2:00 h were found.

Does the duration between waking up and napping (homeostatic component) play a role in the efficiency of napping for 20 minutes or less on alertness and cognitive performance?

The investigated studies in this thesis show different effects of napping after different time durations between waking up and napping. The two reviewed studies by Hayashi (Hayashi et al, 1999[a]; Hayashi et al, 1999[b]) showed that naps taken four hours after waking up did not result in a significant difference with the no-nap group, while naps scheduled six hours after waking up did improve alertness and cognitive performance. Other studies in this thesis, describing the effects of napping between six and ten hours after waking up, also showed improvements of napping compared to not napping. This suggests a minimum duration between waking up and napping to be able to benefit from napping, of approximately four to six hours. Takahashi's studies also found improvements after napping at 12:30 h, but, as those studies do not report the subjects' exact waking time, the influence of the homeostatic component cannot be determined (Takahashi et al, 1998; Takahashi et al, 2000).

The differences between efficiency after short and long durations between waking up and napping can be explained by the increasing sleep pressure, also known as process S. This, however, does not account for the lack of improvements after napping after 20 or 25 hours awake (Lumley et al, 1986; Mulrine et al, 2012).

An additional possible conclusion to the last two questions could be that both process C as process S could possibly influence nap efficiency. A minimum amount of sleep pressure (homeostatic component/process S) should be present, as naps after four hours awake did not improve alertness and cognitive performance, while napping after six hours did, both at the same time of day. Also the timing of napping should be within a certain timeframe, as naps at 2:00 h and 9:00 h did not improve alertness or cognitive performance, even when time awake was 20 to 25 hours, while naps between noon and 15:00 h did, after only 6 to 10 hours awake. Late and early chronotypes should probably shift this timeframe, respectively, to accommodate their best napping time. Only when both requirements (sufficient sleep pressure and temporal placement in the timeframe adjusted to one's chronotype) are satisfied, a 20 minutes or shorter nap might significantly improve alertness and/or cognitive performance. The suggestion of the influence of the combination of both processes on 20 minutes nap efficiency needs further research.

Can studies performed in the laboratory inform real-life scenarios?

The laboratory studies investigated in this thesis show significant improvements after napping to alertness and cognitive performance. Increased alertness and cognitive performance are two essential assets in occupations, such as driving a car/riding a bike, surgical interventions, and professions like airline pilots, (air) traffic-controller, monitoring power plants.

To test whether naps of less than 20 minutes could reduce the number of traffic incidents, Horne and Reyner tested this in the lab with a car simulator (Horne and Reyner, 1996). They tested the effects of caffeine and napping against a placebo/no-nap group and found significant fewer incidents after caffeine intake and napping, Caffeine intake and napping did not significantly differentiate in decreasing incidents.

The incidents reducing effect of napping could also be functional for airline pilots, which was outlined more detailed in a review by Hartzler (Hartzler, 2014). In fact, many airlines permit their pilots to nap during flights in order to be as alert as possible for the upcoming approach and landing phases of the flight (Hartzler, 2014). Short sleep of 40 minutes has already been proven to aid pilots' in-flight alertness (Rosekind et al, 1994). However, napping of less than 20 minutes has not been tested with pilots in either laboratory settings or real life scenario.

One advantage of 20 minutes naps versus 40 minutes sleep is the reduced sleep inertia upon waking-up, resulting in more immediate alertness. The 40 minutes sleeping periods are regularly held more than an hour before landing, which is the most crucial phase to be alert for a pilot. This rules out the chance that any detrimental effects of sleep inertia will be experienced during this crucial phase. Still, sleep inertia can occur shortly after waking up from these sleeping periods. Sudden instances that require a pilots' full attention, that occur when the pilot experiences the effect of sleep inertia, could end catastrophically. Therefore, further research is needed on the effects of naps of less than 20 minutes in aviation.

This thesis suggests that insufficient nocturnal sleep does not influence the effects of napping compared to sufficient nocturnal sleep. This finding could be convenient for previously named occupations and professions. A lack of influence of sleep deprivation means alertness can be increased even after sufficient nocturnal sleep. This can be helpful in professions with long work shifts that require sustained attention, such as with surgical interventions and intercontinental flights (McDonald et al, 2013). Prior to such work shifts, short naps could help to increase alertness and cognitive performance.

Lastly, napping was tested and is used in many night-shift professions, e.g. in nursing service (Takeyama, 2005; Ruggiero, 2014). Naps of about 16 minutes were shown to improve PVT performance in health care workers in their working environments (Smith et al, 2007). Napping of less than 20 minutes also increased the speed of reaction in vigilance tests in aircraft maintenance engineers, during their 12-hour night shifts (Purnell et al, 2002).

While some applications of napping in real-life have been tested, efficiency of naps of 20 minutes or less needs further research. In this further research, the effects of sleep deprivation and the subjects' different chronotypes on nap efficiency should be tested in working settings

Conclusion:

This thesis reviewed laboratory experiments of the last 30 years on the efficiency of naps of 20 minutes and less on alertness and cognitive performance. The aim of this study was to find out if the three factors (i) prior sleep deprivation, (ii) time of day and (iii) sleep pressure influence these outcomes. From the ten reviewed laboratory studies, I conclude that 20 minutes or shorter naps improve alertness and cognitive performance in sleep deprived and non-sleep deprived subjects. Especially napping between 13:00 h and 15:00 h significantly improved alertness and cognitive performance. Napping around 12:30h also improved alertness and cognitive performance, after a minimum duration of wakefulness of four to six hours. Further research is needed to look into the effects of napping at noon and other times of the day. In this further research I suggest the use of questionnaires, such as the MCTQ, to find out if chronotype affects nap efficiency depending on time of day. The lack of effects of napping at 02:00 a.m. and 9:00 a.m. could not be explained with the two process model and has to be investigated further. Naps of 20 minutes are also applicable to help increase alertness in traffic, since it reduces the number of incidents in car simulator tests. The effects of 40 minutes have already proven to assist pilots in maintaining alertness in-flight, but can come with the temporary downsides of sleep inertia. Therefore, the effects of naps of 20 minutes or less can be applicable for airline pilots. To inform those with the highest risk of reduced alertness and cognitive performance, e.g. experienced by people who work in full attention requiring shifts or night shifts, future research is needed about the factors that influence naps of 20 minutes or less in working settings.

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