Utrecht University

Applied Cognitive Psychology

Master thesis

The effect of power napping on performance

Name: Luke Crooymans

Student number: 0494992

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Philips Research
High Tech Campus,
5656 AE, Eindhoven, the Netherlands

Utrecht University:
Stella Donker & Maarten van der Smagt

Philips Research:
Roy Raymann & Els Møst

Contents:

Abstract

Introduction

Daytime (power) napping has been demonstrated to counteract feelings of fatigue and decreases in cognitive performance during the day. However, the duration and the composition of daytime naps are decisive for their restorative power. Short naps may be too brief to relieve sleep pressure, boost alertness and cognitive performance. Longer naps have an increased risk of waking up from deep sleep. As such, exaggerated feelings of fatigue can negatively impact alertness and cognitive performance, due to sleep inertia.

Study objective

Investigating the effect of different durations and composition (in terms of sleep stages) of daytime napping on subjective wellbeing, performance and alertness.

Design

24 participants were enrolled in a counter balanced protocol containing four different nap conditions. Sleep was measured using Polysomnography. Subjective wellbeing was measured using Questionnaires and performance was measured using computerized tasks quantifying vigilance, prefrontal functioning and motor functioning

Results

When comparing subjective sleepiness before and after the naps, participants reported being more fatigued after the nap as compared to before the nap in condition S1, S2 and S2max. Additionally, participants reported lower activation(vigor) after the naps. We found no significant changes in task performance related to the nap condition.

Conclusions

No beneficial effect of a powernap was found. We were not able to discriminate between the effect of nap duration and the effect of nap composition. Effects of sleep inertia however, can be ruled out, since most naps conditions did not contain any deep sleep. Hence we may conclude that short naps do not significantly affect performance or alertness immediately after wake up. However, we cannot rule out that the advantageous effects on wellbeing and performance will emerge later on or in sleep deprived individuals, as shown in previous literature.

Introduction

Sleep is an essential part of healthy living; alternating with wake in a stable, predominantly binomial cycle. One of the mechanisms responsible for maintaining this cyclic balance is called the homeostatic sleep drive. The homeostatic sleep drive (process S) also called sleep pressure, or the need to sleep, accumulates during continuous hours of wakefulness and declines during sleep. Process C represents the circadian rhythm cycle, which reflects the circadian sleep drive, mastered by the suprachiasmatic nucleus (also referred to as the biological clock), represented by an oscillation of around 24h (figure 1) [1].

While the homeostatic sleep drive increases, a drop in vigilance and alertness levels can be observed. During sleep, especially during deep sleep or slow wave sleep, the sleep drive is reduced and subsequently vigilance is restored after the sleep period (figure 1). Additionally, sleep deprivation will increase the homeostatic sleep drive (figure 1b). [2]

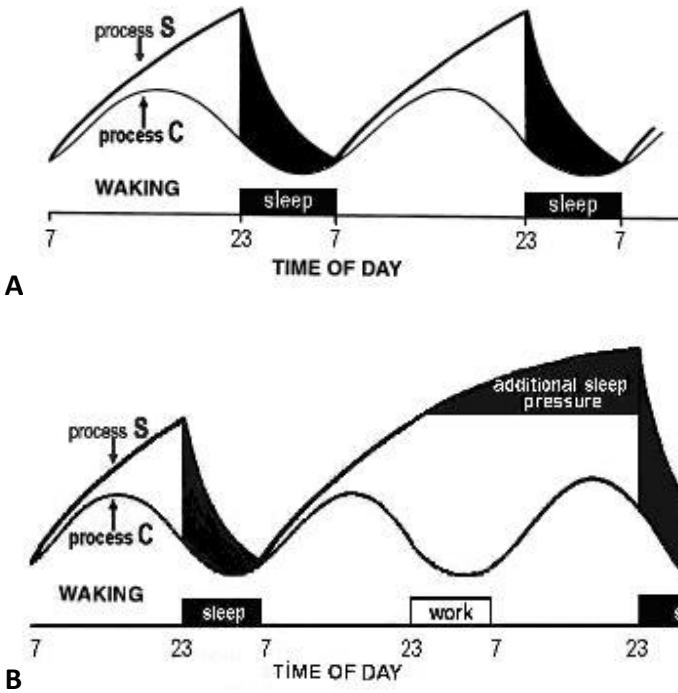

Figure 1: A: The homeostatic sleep drive (process S) together with the circadian oscillation (process C) in normal circumstances. B: The homeostatic sleep drive (process S) and circadian oscillation (process C) in sleep deprived circumstances.

During the wake period one may experience several small decreases in cognitive performance and alertness. These 'dips' are possibly more prominent nowadays due to the 24/7 economic, domestic and social demands on individuals causing a reduction in nocturnal sleep. Long term sleep restriction increases the sleep drive [3-5]. This has stimulated research

interest into countermeasures of daytime sleepiness. One way of counteracting these declines in alertness and performance is power napping. The purpose of a powernap is to feel refreshed and improve alertness [6, 7]. Power naps are briefer than regular naps and therefore contain relatively larger amounts of the lighter sleep stages, and less deep sleep [2].

Sleep comprises various sleep stages which characterize sleep depth, measurable through brain activity electroencephalogram (EEG), eye movement (electrooculography - EOG) and muscle tension (electromyography - EMG); together called Polysomnography (PSG). Sleep onset is determined through S1, a wake-sleep transition phase lasting 1-7 minutes and characterized by a decrease of alpha wave brain activity (frequency range 8-12 Hz) in favor of theta wave activity (4-7 Hz)[1]. After sleep onset, the S2 stage lasts 24-40 minutes, but in total composes the largest section of nocturnal sleep (45-55%) [8]. Physiologically, S2 sleep consists of a further increase in theta wave activity, and periodically occurring sleep spindles (short bouts of 12-15 Hz activity, lasting at least 0.5 seconds) and k-complexes (a brief negative high-voltage peak followed by a slower positive complex and final negative peak). The deeper sleep stages (S3, S4) are dominated by delta waves (0-4 Hz) and are initiated after 30-40 minutes of sleep [1]. Deep sleep (i.e. S3 and S4) is associated with brain restoration and memory consolidation and therefore thought to ameliorate sleep drive [9-11]. Rapid eye movement-sleep (REM) is characterized by random eye movements, low muscle tone and low voltage EEG. Sleep stages cycle multiple times during regular nocturnal sleep, as can be seen in figure 2 [1].

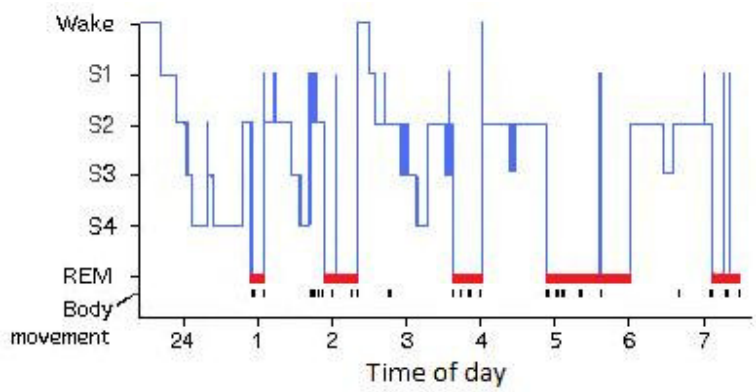

Figure 2: Hypnogram showing normal sleep of a healthy adult during normal nocturnal sleep. The figure illustrates the cycling through various sleep stages during the night (clock time is shown on the x-axis; the y axis depicts the different sleep stages)[1].

During daytime sleep the sleep stages cycle in a similar manner. However, not all stages will arise due to the reduced need for sleep as the homeostatic sleep pressure is still low and the sleep stage composition of a nap also depends on the daytime sleep duration [12]. Despite the lower probability of reaching deeper sleep stages, sleep can still be beneficial in various ways; brief daytime naps are at least as restorative as longer naps (45+ minutes). Literature shows that when comparing a 15 minute nap opportunity (average sleep duration 7 minutes) with a 45 minute nap opportunity (average nap duration 30 minutes) after a night of normal

sleep, the 15 minute nap significantly improved alertness both 30 minutes after and 3 hours after napping [13]. Under conditions of restricted nocturnal sleep, Tietzel et al found that an afternoon nap of exactly 10 minutes' sleep was at least as recuperative as a 30 minute nap in terms of improved alertness and performance for an hour following the nap [14, 15]. Gillberg et al found similar results for 19 minute naps [16]. Significant performance and alertness benefits have been observed in 9 minute naps [17]. Comparable benefits have also been observed from brief naps with an average duration of 20 and 7.3 minutes after normal nocturnal sleep [13, 17, 18]. Based upon these findings we can conclude that short bouts of daytime sleep have advantageous effects on performance and alertness.

Brooks et al compared naps of 5, 10, 20 and 30 minutes of sleep with a no nap control following a night with 5 hours of sleep [12].They reported a significant effect on subjective alertness in the 10 minute nap compared to the no nap control. In contrast, the 30 minute nap resulted in a period of reduced subjective alertness immediately after napping, followed by improved subjective alertness 95 and 155 minutes later. Fatigue and vigor measures also showed evidence of sleep inertia during the 30 minute nap condition, while the other conditions lacked significant differences.

With the longer naps, the amount of 'lost time' (i.e. non-productive time) increases, but the restorative power also grows, which can be attributed to a higher amount of S3 and S4 in longer naps. However, the probability of awakening during slow wave sleep (S3, S4) also increases, potentially resulting in sleep inertia: a physiological state characterized by a decline in motor performance and a groggy feeling, which interferes with the ability to perform mental or physical tasks (such as planning and motor tasks) [19-21]. Additionally, sleep inertia negatively influences affective state (i.e. mood) [20, 21].

As slow wave sleep habitually only occurs >30 minutes after sleep onset in non- sleep deprived people, it is imperative to consider naps shorter than half an hour. These short naps have also been found to be beneficial, even though they consist mostly of the light sleep stages (S1 & S2), which are not considered restorative. The main advantage of these brief power naps is that they improve performance on sustained alertness and motor performance tasks and that the risk of sleep inertia is low [14, 15]. In order to establish where the true benefits lie, it is pertinent to research this fringe area. An explanation for the effects can be that stage S2 sleep is sufficient to reduce sleep pressure, which allows for recovery of the aforementioned cognitive decline while avoiding possible adverse effects from sleep inertia, as S2's relative recuperative value is higher than that of S1, as S2 is baseline sleep instead of a merely transitional stage[15].

As homeostatic sleep drive increases during the day and alertness declines, we theorize that naps (containing stage S2 sleep) will mitigate this increase (and decline respectively), as is illustrated by the black line in figure 3. The effects of this mitigation are hypothesized to be increases in objective cognitive performance (vigilance, motor performance, and prefrontal

planning) directly after napping and an increase in subjective alertness directly after the nap as is illustrated by the red line.

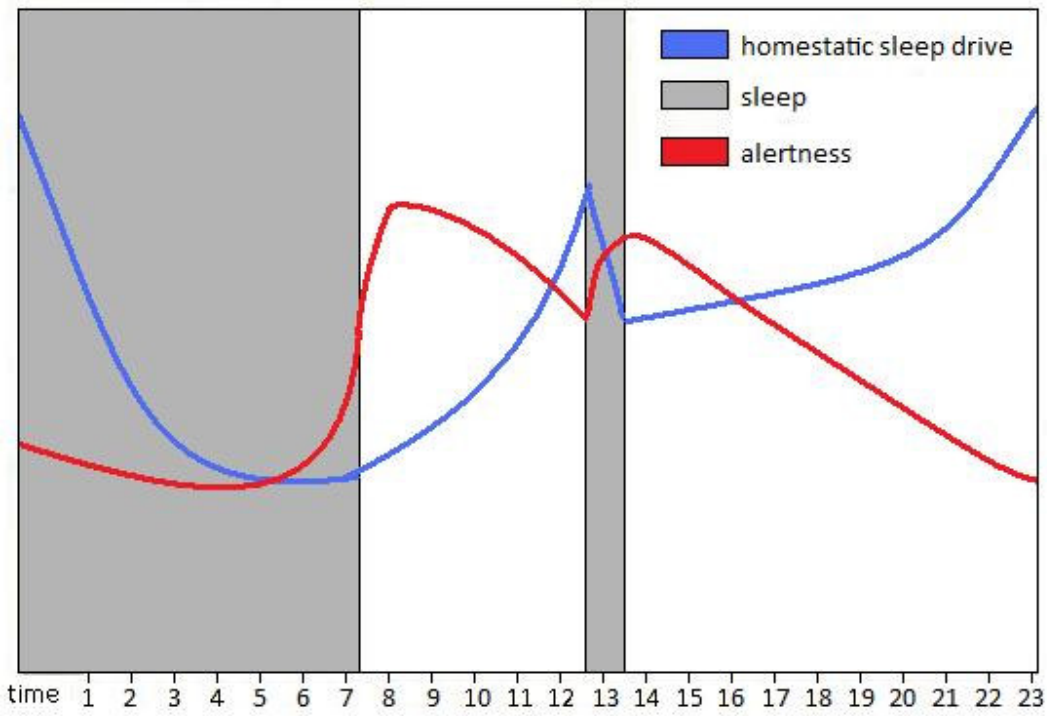

Figure 3: Timeline (clock time) showing the hypothesized levels of alertness and homeostatic sleep drive across the day. Grey blocks are sleep (nocturnal sleep, and nap sleep respectively). The mid day nap decreases the gradually increasing sleep drive, resulting in an increase in alertness levels.

This study aims to verify earlier findings regarding short daytime naps in a non sleep-deprived population, and furthermore define the effective nap duration in terms of sleep stages by assessing which sleep stage is responsible for the subjective and objective increases in performance and alertness. Since longer naps with longer subsequent periods of S2 are prone to contain epochs of deep sleep, these naps might lead to sleep inertia directly after wake.

We hypothesize that short daytime naps will decrease subjective sleepiness and increase global vigor immediately after the nap as compared to a no-nap control. Furthermore we expect naps to increase objective cognitive performance (vigilance, motor performance) compared to the no nap control.

Furthermore we postulate that due to the relative restorative effects of sleep stage S2 and the subsequent reduction in sleep drive, naps containing more sleep stage S2 will induce increasing effects on objective cognitive performance and subjective wellbeing when compared to naps containing less stage S2 sleep.

Our third hypothesis is that the longer naps with a large amount of S2, but no S3 will not show any sleep inertia effects (i.e. decreased subjective feelings of affect, impairments in prefrontal planning and motor performance).

Methods

Participants

Twenty-four participants (ranged 18 to 52 years old, 13 male 10 female) were included in the study after being recruited through internal advertisement, e-mail and personal request. All participants were healthy sleepers with a good sleep quality as reported with the Pittsburgh Sleep Quality Index (PSQI ≤ 7) [22]. All participants had normal or corrected-to-normal vision and used a computer mouse daily. The study was approved by the internal ethics committee at Philips Research and participants gave written consent prior to participation. Participation was compensated.

Design and procedure

Study design

The experiment employed a repeated measures design comprising 4 experimental conditions (figure 4):

- A no-nap condition (NN);
- Condition S1: only S1 (until S2 onset, approximately 7-10 minutes of sleep);
- Condition S2: 10 minutes of S2 (condition S1 + a max of 10 minutes of S2, comprising a total of 10-20 minutes of sleep);
- Condition S2max: the maximum amount of S2 (wake on S3) or 30 minutes of sleep (up to 30 minutes of sleep).

The 24 possible orders were randomized to mitigate any order effects, task specific learning effects and time of day effects. Sleep stages were estimated on-line according to the AASM criteria and scored offline after the experiment [23]. Subjective questionnaires were administered before and after each nap, and task performance measures were performed after each nap.

minute:	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Condition NN	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W
Condition S1	W	W	W	W	S1	S1	S1	S1	S1	S1	S1	S1	S2																	
Condition S2	W	W	W	W	W	W	S1	S1	S1	S1	S1	S1	S1	S2	S2	S2	S2	S2	S2	S2	S2	S2	S2							
Condition S2max	W	W	W	S1	S1	S1	S2	S2	S2	S2	S2	S2	S2	S2	S2	S2	S2	S2	S2	S2	S2	S2	S2	S2	S2	S2	S2	S3		

Figure 4: Example of various nap conditions and corresponding cumulative sleep stage(s) per minute. Red highlights inidicate the cutoff value for the specific condition at which the participant is awakened. W (purple) = wake; S1(light green) = sleep stage 1; S2 (dark green) = sleep stage 2; S3 = sleep stage 3.

Experimental protocol

The experiments were executed in the sleep area of the Philips experience lab (High Tech Campus, Eindhoven, the Netherlands). The temperature of the sleep area was kept constant at approximately 18 degrees Celsius, and the sleeping area was completely dark following lights off.

After arrival at 11:00, participants changed into their preferred sleeping attire and the EEG, EOG and EMG sensors were applied. All naps started at specific times during the day, in order to keep circadian influences constant (figure 5). Prior to the initial nap participants completed sleepiness, global affect and global vigor questionnaires, and completed a trial run of the performance test battery to increase proficiency with the tasks and counteract potential learning effects or poor performance due to unfamiliarity. Following lights off, sleep was monitored online with the Columbus software package (TEMEC, Kerkrade, the Netherlands) until the nap conditions were met. In the NN condition, participants were instructed to stay awake, in case of failure (i.e. sleep stage S1 detection; <50% alpha activity within a 30s epoch) a wake intervention ensued. In the S1 condition participants were awakened as soon as S2 was detected (defined by the occurrence of a sleep spindle or k-complex in an epoch). For the S2 condition wake ensued 10 minutes after initial S2 detection, and for the S2max condition participants slept for the full duration or were awakened as soon as there was >50% delta activity (i.e. slow wave sleep or S3) in the EEG signal.

Within 5 minutes after awakening, the participant completed the post nap test battery consisting of the aforementioned questionnaires, followed by performance tasks. The duration of the entire test battery was 20-30 minutes and the task order was constant as can be seen in figure 4. After this time the participant was free to engage in personal activities in the apartment area, however participants were not allowed to sleep in-between the naps, nor were they allowed any caffeine-containing beverages or food. The aforementioned process was repeated for a total of 4 times during the day-long experiment (figure 5).

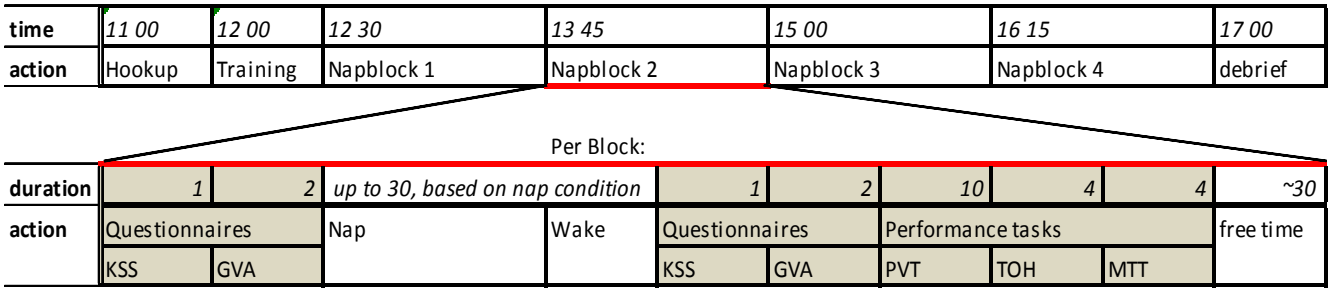

Figure 5: Chronological overview of the study. Top timeline is an overview of the entire protocol day, according to clock time. The lower timeline elaborates the and test battery order for a single napblock according to duration in minutes. Test elements of the test battery are shown in grey.
KSS =Karolinska Sleepiness Scale, GVA = Global Vigor and Affect scale, PVT = Psychomotor Vigilance Task, TOH = Tower of Hanoi task, MTT = Mirror tracing task.

Materials

Sleep and activity

Sleep was recorded using the Vitaport 3 polysomnograph system (TEMEC instruments, Kerkrade, the Netherlands), EEG was measured using gold plated EEG electrodes (Grass Technologies, F-E6GH-12, West Warrick, USA). Six EEG locations were measured: F3, F4, C3, C4, O1, O2, in addition to two references at the mastoids (A1, A2). The EEG electrodes were fixated to the skull using an electrode cap (BrainNet, Sleepnet, San Bernardino, USA) which is more open than conventional EEG-caps, in order to minimize the possible disturbance of wearing an electrode cap during sleep initiation. Disposable gel based KittyCat electrodes (Medi-Trace, KittyCat 4203, Kendall, Mansfield, USA) were used for the two submental EMG and two EOG (left and right eye) leads, as well as the for ground lead.

Subjective questionnaires

The Karolinska Sleepiness Scale (KSS) is a questionnaire measuring sleepiness [24]. The scale consists of nine items ratings from 'very alert' to 'very tired', resulting in a score between 1 and 9.

The Global Vigor and Affect scale (GVA) is based on eight unipolar visual analogue scales (VAS) ratings of 100mm long; four primarily concerned with subjective activation or vigor (alertness, sleepiness, motivation loss (effort)) and four concerned with feelings or "affective state"(happiness, sadness, calmness and tension) The GVA results in two scores ranging from 0-100, one reflecting the activation state (GV) and the other reflecting the affective state (GA) [25].

Performance tasks

The performance measures were performed on a TOSHIBA Portege M750-135 laptop with capacitive touch screen (Toshiba, Tokyo, Japan). All tasks were created in E-prime version 2.0 (Psychology Software Tools Inc, Sharpsburg, USA), unless mentioned otherwise.

The Psychomotor Vigilance Task

Vigilance was assessed using a 10-minute standalone windows-executable version of the Psychomotor Vigilance Task (PVT, programmed by Roy Raymann, NIN, Amsterdam, the Netherlands) [26,27]. In sleep research the task is considered to be the 'gold standard' in sustained alertness assessment. Its measures reflect fluctuations in endogenous cognitive condition. Research indicates that increased sleepiness correlates with deteriorated alertness, and increased rate of false responding [4].

During the task participants focused on a blank box in the middle of a computer screen. At random intervals, a millisecond counter started to scroll, and participants had to press a key to stop the counter as quickly as possible. After pressing the key, the counter displayed the

achieved reaction time (RT, in milliseconds) for 1 second, providing the participant with feedback on performance. Interstimulus intervals ranged randomly from 2 to 10 seconds.

The average response speed is indicative of how well participants are able to remain alert and maintain an attentive state during the entire task. The number of lapses(response speed >500 ms) represents the number of times a participant failed to respond to the stimulus, a high number is indicative for a low level of attention and was expected increase during the ten-minute task. The upper 10% and lower 10% of the response times yield information on the changes in the optimum response capability within the trial. Lapses of attention and general response capability during the 10 minute long task are assumed to correspond with homeostatic sleep drive levels, and therefore provide insight in our hypotheses[4].

Tower of Hanoi Task

In order to address the possible impact that any sleep inertia may have had on prefrontal planning abilities, a Tower of Hanoi task (TOH), developed by Paul de Groot (VU Amsterdam, the Netherlands) was conducted[28]. This is a computerized version of the classic Tower of Hanoi task in which the participant planned and executed a minimal number of moves in order to reach a specified end state from a given initial state, using mouse-clicks (figure 6). To avoid trial and error behavior participants were instructed to think of a possible solution before engaging in solving the puzzle. Four different versions of the task were used in order to avoid learning effects. The different versions were created from a single task, and were created by mirroring the task and/or inverting the goal and starting positions.

The rules of tower of Hanoi paradigm dictate that only one 'block' could be moved at a time. Each puzzle only had a single solution, as larger 'blocks' could not be placed on top of smaller 'blocks'. If a mistake was made the puzzle was reset to its initial state. The task consisted of 14 puzzles, which incrementally increased in difficulty. The trial started with 2 examples and then continued with 2 easy puzzles requiring only 2 steps, and ended with 2 complex puzzles requiring 7 moves. The critical element in the TOH-task is the ability to see and resolve a goal–subgoal conflict (i.e., to perform a counterintuitive backward move to reach to goal), which is an increasingly prominent issue in the more complex puzzles.

The increasing complexity and the pre-planning requirement of the more complex puzzles enabled the task to indicate a measure of prefrontal planning capacity, especially in comparison to the easier initial puzzles. The prefrontal planning capacity ability is assumed to be impaired when participants suffer from sleep inertia, consequently resulting in a decline in task performance on the tower of Hanoi task.

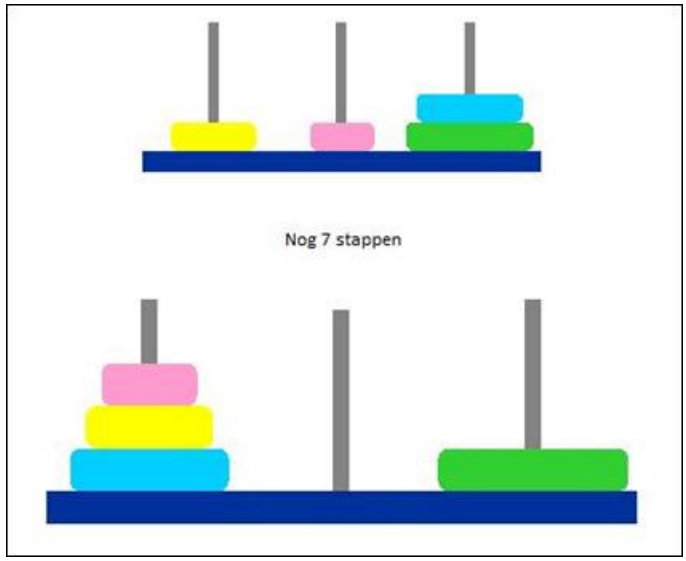

Figure 6: Example of a TOH task. The lower section shows the starting point of the task, the top section shows the goal of the task. The text in the middle indicates how many steps remain. The lower section can be manipulated to proceed to the wanted outcome.

Mirror Tracing Task

In the mirror tracing task (MTT, Neurobiology Research Unit, Denmark) participants controlled a cursor with a mouse. Recording of the cursor position occurred every 50 msec. Participants were instructed to use the cursor to trace a circle on the screen in a clockwise direction at the highest possible tracing-speed. Each round lasted 10 seconds and was ended by the circle disappearing. Before the next round participants moved the cursor back to the starting position and prepared for a new trial. The starting position was marked at the leftmost point of the circular path. After six rounds (one trial) participants had to perform a similar trial (the cursor-trajectory was the same), but the cursor movement on the horizontal axis was inverted, simulating the mirror tracing task as an objective measure for motor performance [29].

The effect of napping on motor performance during mirror tracing was investigated by comparing between successive rounds for all standard control and all mirrored trials.
We expected sleep inertia or high sleep pressure to cause an incremental decline in motor performance over the successive rounds, particularly in the mirrored condition as it presented a more complex novel proprioception situation.

Statistical procedure

Data exploration and reduction:

The data from the polysomnography recordings were scored according to AASM guidelines using the Somnologica software package (Embla, Broomfield, USA)[23]. The numbers of epochs in certain sleep stages were summed per nap. The sleep content was tested post hoc whether it met the a priori defined nap conditions. If a nap condition was not met, either due to technical problems or failure to complete nap criteria, the condition was removed from the data set. Additionally time of day effects were also tested, in order to assure that there were no circadian effects, these results are only reported in case of violation.

Subjective measures

All trials corresponding to a removed nap condition were also removed from the subjective measures dataset.

For the analysis of the subjective sleepiness values, differences between KSS scores pre-nap and KSS scores post-nap were calculated for the analysis.

KSSdif = KSSpost-KSSpre

In order to analyze the global vigor variable, the GV-variable was calculated conform to Monk[25]. To assess the effect of the nap, differences between pre and post nap questionnaires were calculated.

GVdif = GVpostnap – GVprenap

Performance measures

All trials corresponding to a removed nap condition were also removed from the performance measures dataset. Data output variables from the E-prime tasks and the PVT tasks were merged and summed to average and standard deviation variables per participant per condition. Data was explored by plotting histograms.

Psychomotor Vigilance Task

The four outcome parameters for the PVT task, as calculated in prior research[4]:

- RRT: Average reciprocal value of reaction times (RT), i.e. response speed. RRT = 1/RT. RT was measured in milliseconds. It is indicative of how well participants are able to remain alert and maintain an attentive state during the entire task
- SQRLapse: Square root of the number of lapses (lapse = RT larger than 500ms) It represents the number of times a participant failed to respond to the stimulus, a high number is indicative for a low level of attention and was expected increase during the ten-minute task
- MSlowRRT: Average response speed (1/RT) of the slowest 10% of responses.

- MFastRRT: Average response speed (1/RT) of the fastest 10% of responses. The 10% fastest and slowest responses indicate changes in the optimum response capability within the trial.

Lapses of attention and general response capability during the 10 minute long task are assumed to correspond with homeostatic sleep drive levels [4].

Tower of Hanoi Task

Outcome parameters representing prefrontal planning were calculated over the twelve puzzles (initial two practice puzzles were not used for analysis):

- *The average completion time*

Average completion time (MnComT) served as an index of the momentary frontal functioning capacity (i.e. planning capacity), as it required solving complex problems by contemplating several moves ahead and resolving subsequent goal-subgoal conflicts as fast as possible and without error.

- *The difference between the initial four and final four puzzles in average completion time.*

This difference (DifComT) was an indicator of frontal functioning capacity. Potential sleep inertia would increase the relative difficulty of the complex puzzles more than the simple puzzles. This effect on relative difficulty would not be revealed by the average completion time, therefore differences between the initial two and final two puzzles were calculated to assess this specific effect.

- *The average initiation time*

The average initiation time (MnIniT) compared the required pre-planning time (i.e. time between presentation of the puzzle and first mouse click to begin solving the puzzle). It served as an indication of the frontal pre-planning capacity, which was expected to be lower in case of sleep inertia.

- *The difference between the initial four and final four puzzles in average initiation time*

The increase in task complexity (DiffIniT) from the first four puzzles (little to no planning required) to the final four puzzles (a relative great deal of pre-planning required) was assumed to increase and cause a rise in the time required to pre-plan a solution for the task. It served as an index for prefrontal pre-planning capacity, which was expected to be reduced in a sleep inertia state.

- *The average number of errors*

Errors occurred when participants unsuccessfully resolved the goal-sub goal conflict, or otherwise considered an erroneous solution for the task. The average number of errors (MnErr) was indicative for a lapse in frontal functioning capacity, as the complex puzzles were insufficiently considered. In a sleep inertia-state the number of errors was expected to increase.

- *The difference between the initial and final four puzzles in average number of errors.*

We expected inertia to have a greater effect on frontal planning capacity in the complex puzzles rather than the simple puzzles. An increase in the number of errors from the initial four to the final four puzzles was indicative for a decrease in frontal functioning capacity, due to possible sleep inertia.

Mirror tracing task

Motor performance during each trial was quantified by the speed of movement (calculated as the ratio between total distance covered by the cursor and movement time) and by the radial trajectory error. Radial trajectory error was calculated as the difference between the distance from the center of the circular path to the cursor and radius of the circular path.

Successive motor performance was estimated by calculating the increase or decrease in distance or errors over the 6 rounds for each trial. This results in four variables; the distance increase over the 6 basic rounds (Linest_disBas) and mirrored rounds (Linest_disMir) and the increase in error over the 6 basic rounds (Linest_errBas) and the 6 mirror rounds (Linest_errMir).

Statistical analysis:

Data was analyzed with SPSS 19 (IBM SPSS Data Collection, Armonk, USA). Sphericity and equality of variance assumptions were tested with the Mauchly's sphericity test and Levenes test respectively, and reported in case of violation. In order to counteract alpha stacking due to multiple comparisons Bonferroni corrected alpha levels used for all t-tests.

To verify if the four nap conditions differed in average sleep duration, as well as by average sleep composition, paired t-tests were performed.

Repeated measures ANOVA's were used to analyze generic effects over the nap conditions. For a nap specific analysis individual nap conditions were compared to the no-nap control using paired t-tests, indicated as 'post hoc tests'.

Additionally time of day effects were also tested for all variables, in order to assure that there were no circadian effects. These results are only reported in case of violation.

All statistical calculations were tested two sided, $\alpha = 0.05$ (or for Bonferroni corrected alpha levels in the case of multiple t-tests).

Results

Sleep data

Due to a technical failure the complete dataset from one participant was discarded before analysis. Additionally five out of the remaining ninety-two naps could not be sleep scored off-line and were removed from analysis. Despite the online interpretation of the sleep signals, some conditions did not meet the a priori defined criteria, resulting in the removal of an additional six naps. Incidentally, some of these incomplete naps did meet other nap conditions. A newly assigned nap condition could only be used if it did not result in multiple identical conditions per participant. For example, if a S2 nap had a late sleep onset and reached the protocol trial limit (30 minutes) before the nap condition requirements were met (i.e. 10 minutes of S2), this nap could serve as a S1 condition if possible (i.e. not containing any epoch of S2)). Eleven naps were redesignated to other conditions. The newly assigned and removed conditions can be found in the appendix. Following these corrections there remained 80 valid nap conditions: 21 valid naps for condition NN, 21 for condition S1, 19 for condition S2 and 19 for condition S2max.

Sleep duration per condition

The average sleep duration differed significantly between the all conditions (Sphericity was violated; Mauchly $W=0.14$, $p=0.002$, Corrected rep measures ANOVA: $F(1.4,15,4)=75.60$, $p<0.001$) figure 7). The average sleep duration increased from the NN condition to the S2max condition indicating that, (with the newly assigned conditions and removals) the nap manipulation was successful regarding sleep duration. 7 of the 21 valid NN conditions contained up to 3 nonconsecutive 30 second epochs of S1, as wake interventions were required.

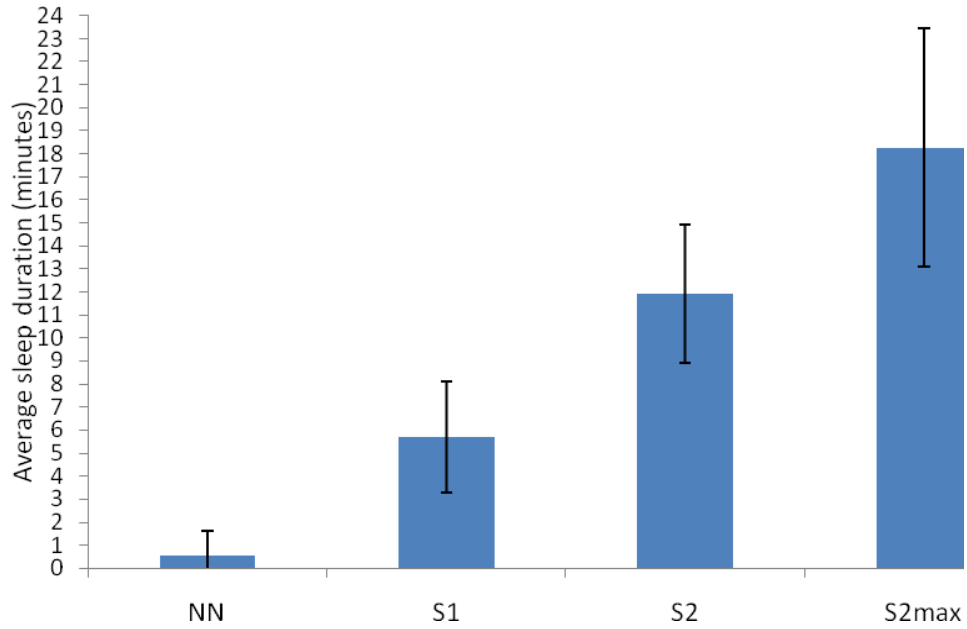

Figure 7: Average sleep duration per condition. Error bars represent standard deviation. Refer to the text for significant differences.

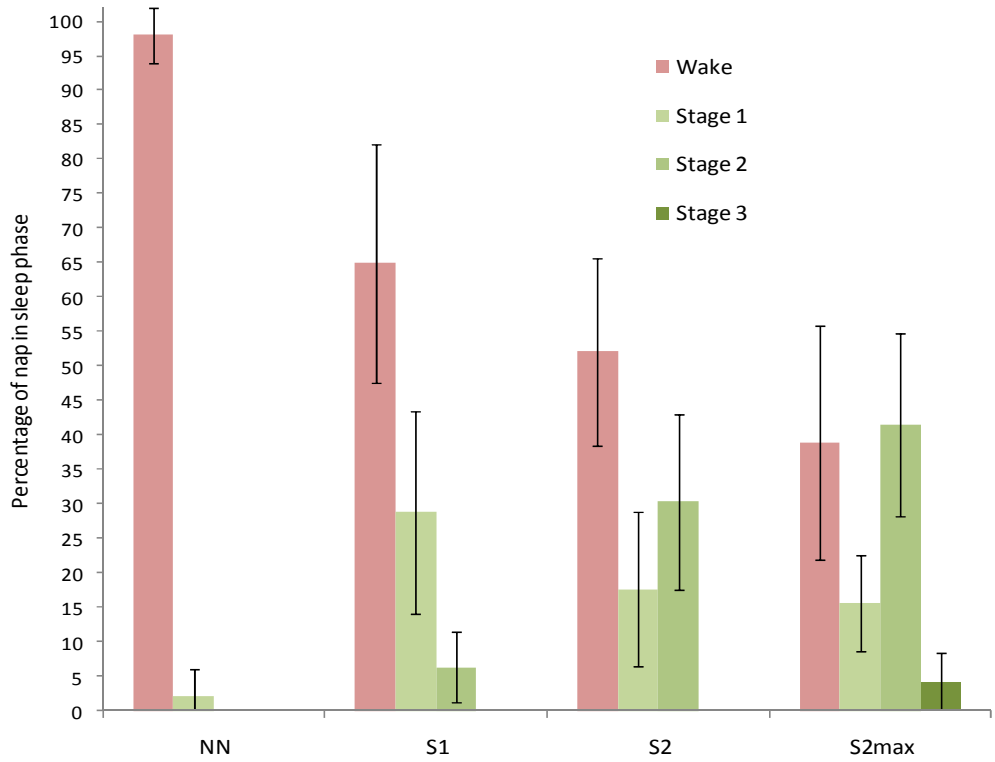

Figure 8: Percentage of nap spent in sleep stage, with standard deviations per stage. Refer to the text for the significant differences.

There was significantly more wake and significantly less stage 1 sleep in the NN condition compared to each of the other nap conditions (see table 1 for all p values). The amount of wake and stage 1 sleep did not differ significantly between the three other nap conditions. In the S1 condition there was a significantly lower amount of stage 2 sleep compared to the S2 and S2max conditions. The S2 condition also had a significantly lower amount of stage 2 sleep than S2max condition (table 1). This indicates that the intended manipulation regarding sleep stages was successful, considering that all naps differ from the NN condition and S2 varies consistently between the conditions. Sleep stage 3 was not tested as it only appeared in a single condition, nor was sleep stage 2 tested in the NN condition as it was nonexistent.

Table 1: Paired t-test comparisons of sleep stage content per nap condition. Comparison shows the two conditions that were compared. SD = standard deviation. t = paired t-test, df = degrees of freedom and p = significance level. Significant (Bonferroni corrected) differences are shown in bold.

	Compared Conditions	Condition 1 Average(±SD)	Condition 2 Average(±SD)	t	df	p
Wake	NN - S1	53.95 ±5.3	26.19 ±14.9	8.49	18	**0.001**
	NN - S2	53.95 ±5.3	27.58 ±10.7	8.95	16	**0.001**
	NN - S2max	53.95 ±5.3	23.32 ±11.1	9.47	16	**0.001**
	S1 - S2	26.19 ±14.9	27.58 ±10.7	0.34	16	0.742
	S1 - S2max	26.19 ±14.9	23.32 ±11.1	0.63	16	0.535
	S2 - S2max	27.58 ±10.7	23.32 ±11.1	0.88	15	0.390
Sleep stage S1	NN - S1	1.10 ±2.1	9.43 ±4.5	-9.63	18	**0.001**
	NN - S2	1.10 ±2.1	8.63 ±4.2	-5.81	16	**0.001**
	NN - S2max	1.10 ±2.1	9.00 ±4.1	-8.13	16	**0.001**
	S1 - S2	9.43 ±4.5	8.63 ±4.2	0.27	16	0.791
	S1 - S2max	9.43 ±4.5	9.00 ±4.1	-0.20	16	0.842
	S2 - S2max	8.63 ±4.2	9.00 ±4.1	-0.18	15	0.863
Sleep stage S2	S1 - S2	1.95 ±1.3	15.31 ±6.5	-9.11	16	**0.001**
	S1 - S2max	1.95 ±1.3	24.32 ±7.4	-11.40	16	**0.001**
	S2 - S2max	15.31 ±6.5	24.32 ±7.4	-3.80	15	**0.002**

In short, the sleep duration manipulation was successful in the 80 naps included in the analysis. Post-hoc redesignation of nap condition made comparisons to the no nap control condition possible, as the NN condition differed significantly from the all other conditions. Furthermore, the three sleep containing conditions (S1, S2, S2max) differed significantly in the amount of sleep stage S2, allowing the assessment of the effect of different amounts of sleep stage S2 on subjective measures and cognitive performance tasks.

Effects of nap conditions on Subjective wellbeing

KSS

Average differences between pre- and post-nap KSS scores can be found in figure 10. There was no significant overall on change in sleepiness as a result of any of the nap conditions (repeated measures ANOVA $F(3,33)=1.31$, $p= 0.29$). Post hoc paired t-test analyses showed that the change in subjective sleepiness without experimental manipulation (NN) did not significantly differ from the changes observed in any of the three true nap conditions (all $t<1.59$, all $p>0.13$), indicating that the amount of stage S2 sleep had no significant effect on changes in subjective sleepiness.

In addition, the effect of each nap condition on the momentary feeling of sleepiness directly after waking up was considered. No significant overall difference between nap conditions was observed in momentary sleepiness directly after waking up (repeated measures ANOVA $F(3,33)=2.77$, $p=0.059$).

Post hoc paired t-test analyses showed that the participants rated their momentary sleepiness in the NN condition significantly lower as compared to the S2max condition ($t(15)= -3.03$, $p=0.008$, $\alpha=0.017$). No other comparisons showed any significant differences (all $t<1.97$, all $p>0.07$). Possibly, larger amounts of S2 sleep or longer sleep duration significantly increased subjective sleepiness, compared to a no-nap condition.
Apparently there is a minimum of sleep stage S2 or sleep-duration needed to induce feelings of sleepiness directly after a power nap.

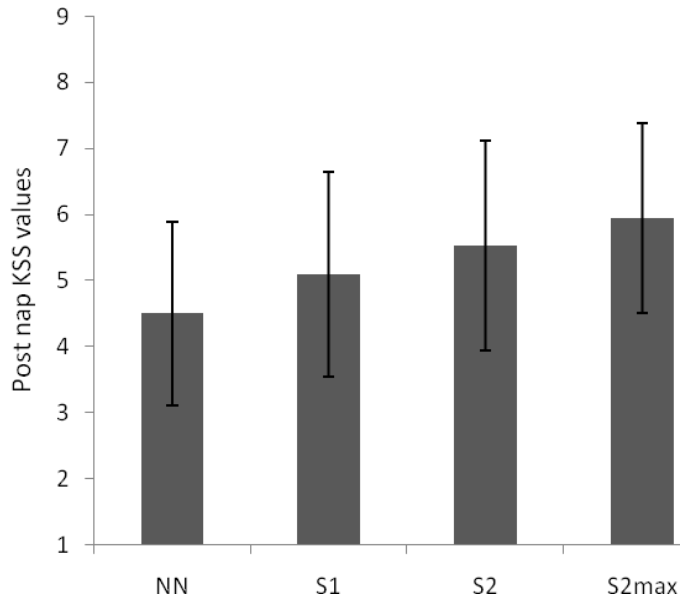

Figure 10: Post nap KSS values per condition with error bars. Low scores correspond with high alertness, high scores correspond with high sleepiness. Error bars indicate significant differences. Refer to the text for significant differences.

Global Vigor

Differences in reported global vigor due to the nap are depicted per nap condition in figure 11. Overall, the reported difference in global vigor significantly decreased over the nap conditions (repeated measures ANOVA $F(3,33)=4.02$, $p=0.015$).

Post hoc paired t-test analyses showed that participants showed significantly less decrease in activation level(vigor) in the NN condition than in the S2 (paired t-test $t(15)=2.81$, $p=0.013$ at $\alpha= 0.017$) and S2max ($t(15) = 2.19$, $p=0.017$ at $\alpha= 0.017$) conditions. No other conditions differed significantly (all $t<1.08$, all $p>0.30$)

A powernap including stage S2 sleep (and or with an average duration of at least 8 minutes) significantly reduced subjective alertness/vigor.

Overall, participants rated their momentary feeling of vigor directly after waking up significantly different in the different nap condition ($F(3,33) = 2.99$, $p=0.045$). Post hoc analysis did not show any significant differences between the NN and the nap conditions other conditions did not differ significantly (all $t<2.33$, $p>0.034$ at $\alpha= 0.017$).

In short, larger amounts of stage S2 sleep and/or longer sleep duration, significantly decreased feelings of vigor, compared to a the pre-nap condition. Additionally, momentary subjective feelings of vigor are also significantly reduced post-nap, yet post hoc comparisons between the conditions reveal no significant differences between the specific conditions. These results suggest that brief daytime napping –contrary to our hypothesis- reduces subjective feelings of alertness and increases feelings of sleepiness directly after waking up.

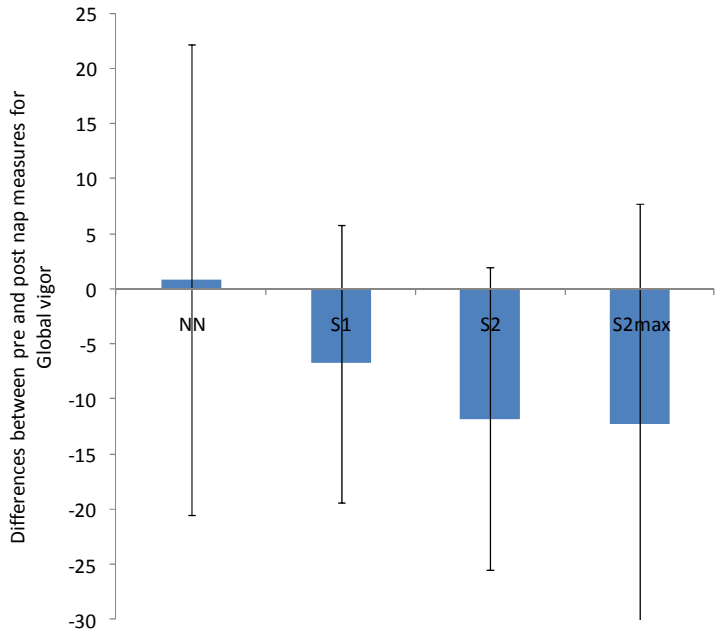

Figure 11: Differences between pre and post nap measures for global vigor per nap condition. Error bars show standard deviation. Refer to the text for the significant differences.

Global affect

Overall the difference in the reported affective state did not change significantly over the nap conditions (repeated measures ANOVA $F(3,30)=1.83$, $p=0.16$). Post hoc analysis revealed no significant changes in differences in reported affective state between the different conditions (all $t<0.92$, $p>0.37$).

Changes in momentary affective feelings directly after the naps also showed no significant changes overall (rep. measures ANOVA $F(3,33)=1.39$, $p=0.26$). The post hoc analysis revealed no significant differences for the reported affective feelings between the different nap conditions (paired t test, all $t<1.60$ $p>0.13$).

In short, nap duration did not affect participants' mood directly after waking up. This indicates that there were no (sleep inertia related) changes in affective wellbeing.

Performance test measures.

Psychomotor vigilance task

There was no significant effect of nap condition on response speed measures or number of lapses derived from the PVT task (table 2). Post hoc paired t-tests revealed that response speed measures or number of lapses did not differ significantly between the NN condition and the other nap conditions, nor were there any vigilance changes between the different S2 conditions. This indicates that the homeostatic sleep drive did not differ between the nap conditions.

Table 2. ANOVA-test reports per condition for PVT values. Results are shown for the average response speed, Lapses, Average slowest 10% of the responses (<10% response speed) and Average fastest 10% of the responses(>90% response speed). Significant results are in bold. Significant post hoc results are reported in the post hoc column.

Variable	NN Avg±SD	S1 Avg±SD	S2 Avg±SD	S2max Avg±SD	F	Df	p	Post hoc
Response speed	3.49 ±0.43	3.42 ±0.40	3.39 ±0.40	3.37 ±0.48	0.30	3, 76	0.82	all p>0.38
Lapses	3.09 ±1.19	2.91 ±1.63	3.21 ±1.89	3.65 ±1.95	0.69	3, 76	0.56	all p>0.34
<10% response speed	2.29 ±0.42	2.32 ±0.43	2.26 ±0.58	2.20 ±0.46	0.05	3, 76	0.99	all p>0.28
>90% response speed	4.44 ±0.54	4.34 ±0.49	4.32 ±0.46	4.30 ±0.52	0.77	3, 76	0.33	all p>0.31

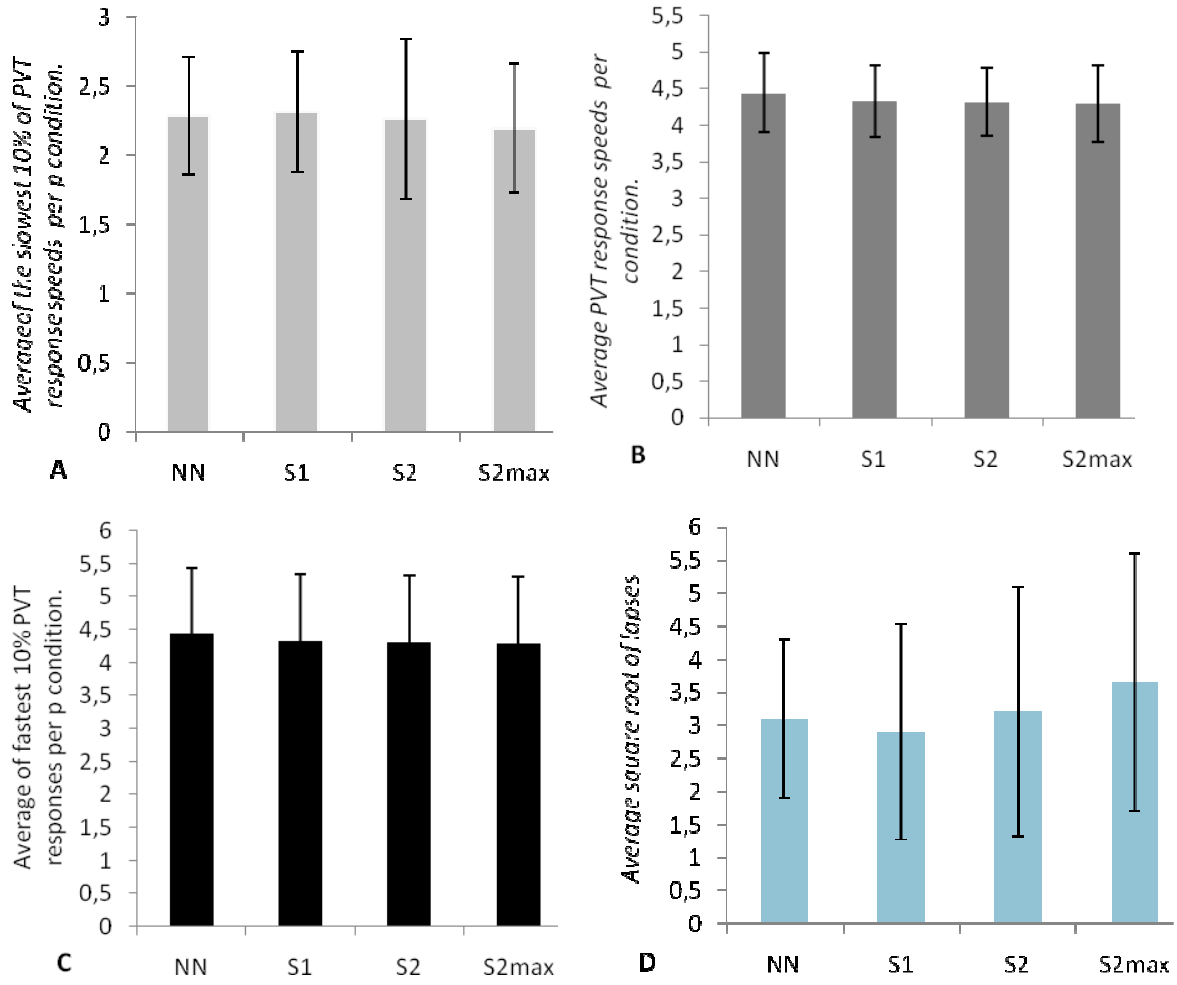

Figure 13. A: Averages of the slowest 10% of PVT response speeds per condition. B: Averages PVT response speeds per condition. C: Averages of the fastest 10% of PVT response speeds per condition. D: Average square root of lapses of the PVT task per condition. Error bars represent Standard deviation. Refer to the table 2 for the significant differences.

In short, brief daytime with different durations of sleep stage S2 and different sleep durations showed no significant effect on how well participants were able to remain alert and maintain an attentive state whilst executing a dull task, requiring minimal cognitive effort.

Tower of Hanoi task

The differences in average completion time from the simple initial four trials to the complex final four two puzzles (DifComT) violated the sphericity assumption (Mauchly's test = 3,110, p =0.031). Overall, no significant changes were observed over the nap conditions for average completion time, differences in average completion time, average initiation time, differences in initiation time, number of errors or differences in number of errors (table 3).

The post hoc analysis yielded no significant results for the increase in sleep stage 2 durations for TOH performance (table 3). The post hoc analysis comparing the TOH values per nap condition with the no-nap condition did not reveal any significant effects (table3).

Table 3: ANOVA-test reports per condition for TOH values. Results are shown for the average completion time (MnComT), average initiation time (MnIniT), Average number of errors. Additional results that are shown are increases from initial two trials to final two trials for completion time, initiation time and number of errors Lapses. Significant results are in bold. Significant post hoc results are reported in the post hoc column.

Variable	NN Avg±SD	S1 Avg±SD	S2 Avg±SD	S2max Avg±SD	F	df	p	Post hoc
MnComT(s)	13.36 ±3.23	13.17 ±4.07	13.47 ±4.03	13.52 ±3.77	0.19	3, 76	0.90	all p>0.48
DifComT(s)	15.66 ±4.96	15.81 ±6.70	16.96 ±5.79	16.61 ±7.11	0.47	3,76	0.70	all p>0.30
MnIniT(s)	5.59 ±1.92	5.79 ±1.64	6.19 ±1.55	6.01 ±2.08	0.21	3, 76	0.89	all p>0.53
DifIniT(s)	4.06 ±2.43	4.92 ±2.30	5.31 ±3.25	4.86 ±3.42	0.55	3, 76	0.65	all p>0.26
MnErr	0.36 ±0.24	0.28 ±0.22	0.32 ±0.23	0.34 ±0.30	0.81	3,76	0.48	all p>0.14
DifErr	0.84 ±0.66	0.63 ±0.56	0.74 ±0.60	0.79 ±0.65	0.83	3, 76	0.48	all p>0.13

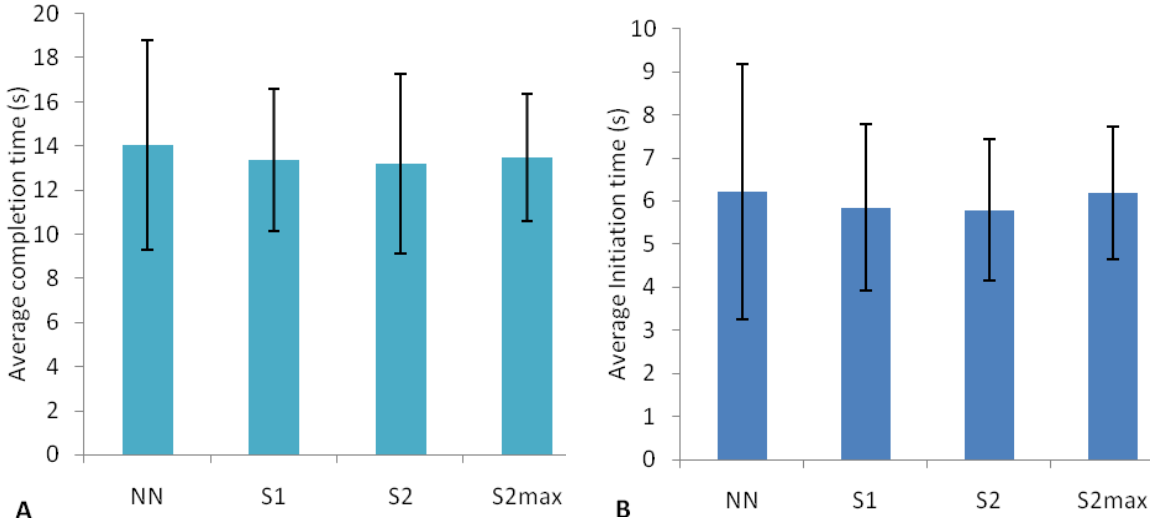

Figure 15. A: Average completion time per condition in seconds (MnCompletionT). B: Average initiation time per condition) in seconds (MnInitiationT). Error bars represent the standard deviations. Refer to the table 3 for the significant differences.

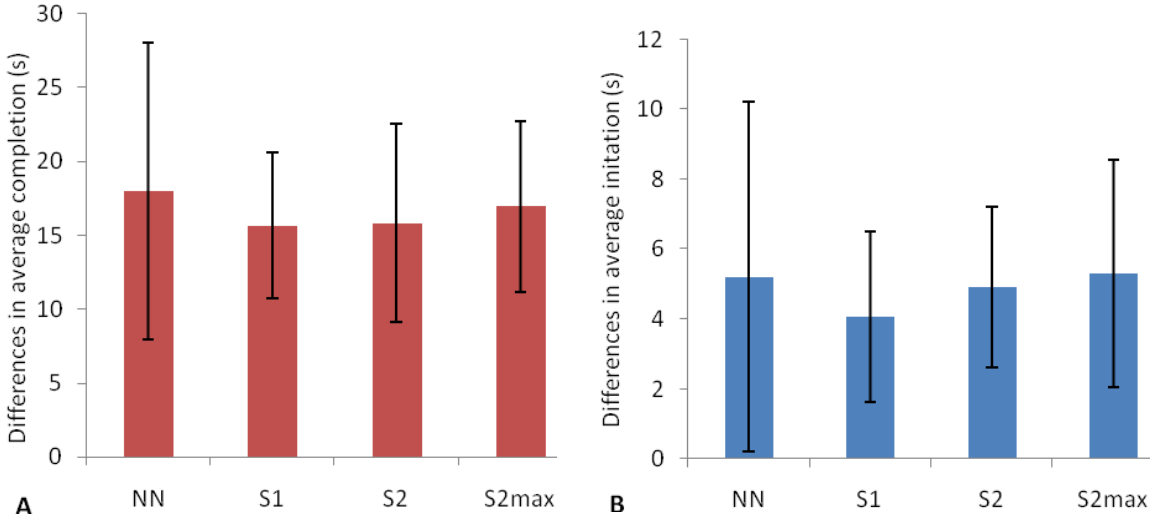

Figure 16 A: Increase in average completion time from initial four simple puzzles to the final four complex puzles (Diffcoml67_23) and B: increase in average initiation time from initial four simple puzzles to the final four complex puzzles (Diffinit67_23) for each nap condition. Error bars represent the standard deviations. Refer to the table 3 for the significant differences.

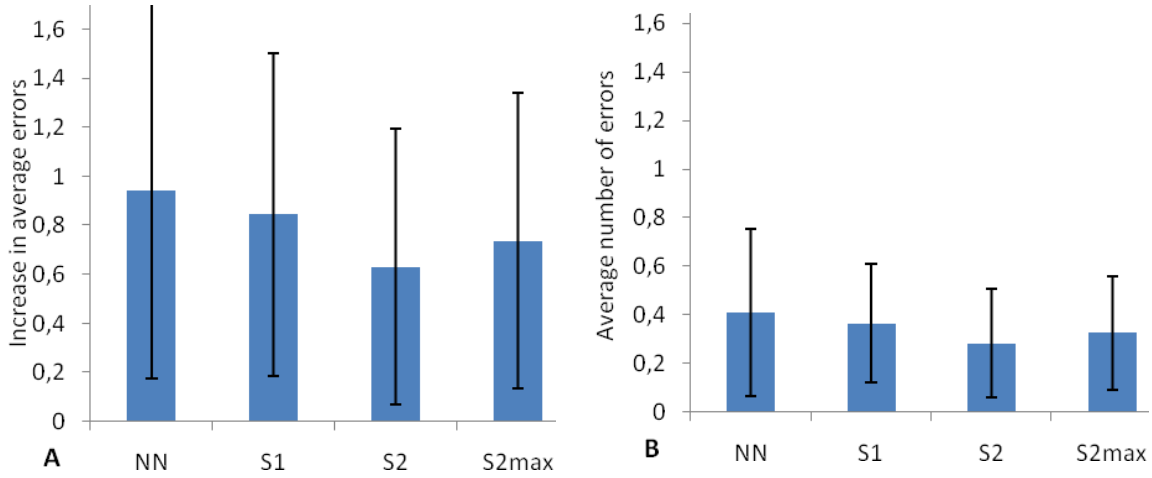

Figure 17.A Increase in average number of errors from initial four simple puzzles compared to the complex final four. B: Average number of errors per nap condition. Error bars represent the standard deviations. For significant differences refer to table 3.

In short, these results suggest that brief daytime napping (or the amount of stage S2 sleep in the naps or the duration) had no significant effect on the momentary frontal functioning capacity (i.e. planning capacity).

Mirror Tracing Task

Participants showed no significant changes between nap conditions on basic motor performance (repeated measures ANOVA F(1.7, 19.2)=0.839, p=0.471) or in complex mirrored motor performance (repeated measures ANOVA F(2.7, 29.2)=.839, p=0.471.)(figure 18), nor were there were there significant changes between nap conditions in basic motor performance error (repeated measures ANOVA F(1.7, 19.2)=0.75, p=0.47) or complex mirrored performance error(repeated measures ANOVA F(1.8, 33)=1.80, p=0.17) (figure 19).

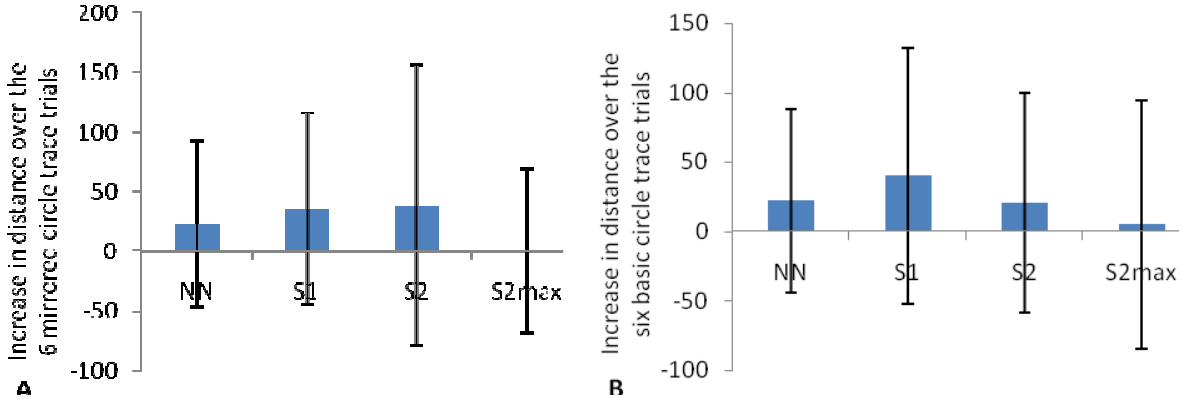

Figure 18: A: Average Increase in distance over the six mirrored circle trace trials per nap condition. B: Average increase in distance over the six basic circle trace trials per nap condition. Error bars represent standard deviation. Refer to the text for significance.

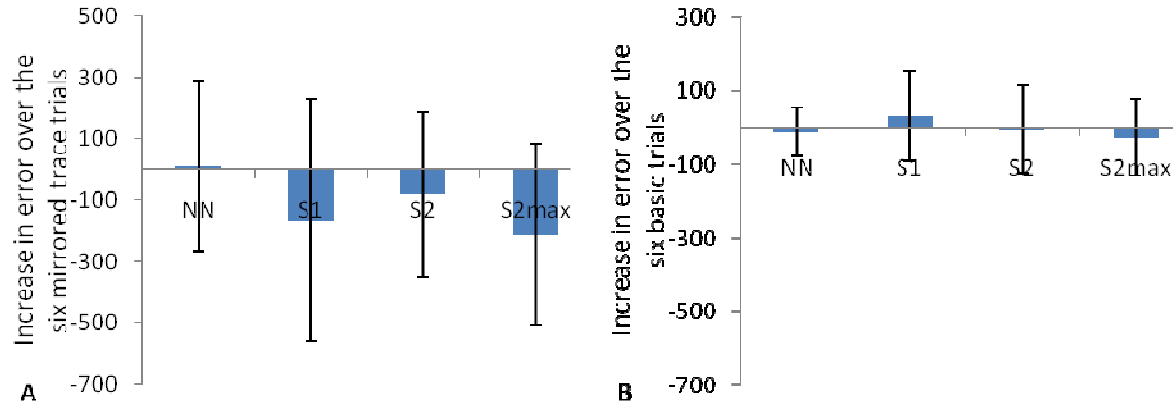

Figure 19: A: Average increase in error over the six mirrored trials per nap condition. B: Average increase in error over the six basic trials per nap condition. Error bars represent standard deviation. Refer to the text for significance.

In short, these results suggest that short daytime napping causes no significant changes in simple or complex motor performance.

Discussion

In summary, the intended sleep duration and composition manipulation regarding sleep stages was successful, as all naps significantly differed from the NN condition and S2 varies consistently between the sleep containing conditions (S1,S2, S2max).

Overall, subjective feelings of sleepiness prior to the nap did not change after the nap, nor were there overall changes in momentary sleepiness directly after the nap. However, participants did report an increase in subjective feelings of sleepiness in the longer nap conditions (S2 and S2max) compared to the no nap condition. Additionally participants reported higher momentary feelings of sleepiness directly after the S2max nap when compared to the no nap condition.

Our findings indicate that larger amounts of stage S2 sleep and/or longer sleep duration significantly decreased feelings of alertness, compared to a the pre-nap condition. Additionally, momentary subjective feelings of alertness are also significantly reduced after a nap. These results suggest that brief daytime napping *reduces* subjective feelings of alertness and increases feelings of sleepiness directly after waking up.

Regarding the cognitive performance measures, the results suggest that daytime napping (larger amounts of stage S2 sleep and/or the duration of the naps) causes no significant changes in how well participants were able to remain alert and maintain an attentive state, nor in frontal functioning capacity (i.e. planning capacity), nor in simple or complex motor performance.

Prior research.

Napping benefits have been observed in brief naps with an average duration of 20 and 7.3 minutes after normal nocturnal sleep [13, 17, 18]. Other research shows that nap durations of 10 and 30 minutes following a night with 5 hours of sleep show significant improvements in subjective alertness compared to a no nap control. Other findings in sleep research indicate that an afternoon nap of exactly 10 minutes was at least as recuperative as a 30 minute nap in terms of improved alertness and performance for an hour following the nap [14, 15]. Gillberg et al found similar results for 19 minute naps [16]. Significant performance and alertness benefits have also been observed in 9 minute naps [17]

Based upon these findings we would have expected to find daytime napping to provide *increases* in sustained alertness, subjective alertness and feelings of sleepiness.

Possible explanations

One might argue that our unexpected results might be caused by circadian influences, as multiple measurements were conducted at different times during the day. This is not the case, as nap condition ordering was sufficiently randomized over the participants (appendix) and no significant time of day effects were found.

The findings of Brooks et al, indicated that subjective alertness measures were lower directly after the a 30 minute nap condition, yet significantly higher 95 and 155 minutes later[1]. Additionally Takahashi et al found similar changes 30 minutes after the nap[13]. As subjective measures were only taken pre and post nap in the present study, possible effects emerging later were could not be ascertained. It could be argued that the hypothesized benefits of power napping might have arisen later on.

Other sleep research using a similar task found significant effects in time on task measures for the PVT-task, without finding any effects on generic PVT-parameters [26]. As this study has explored the generic effects and no effects were found, a more specific analysis in time on task effects for the PVT task should be considered. However, however this falls outside of the scope of this graduation thesis.

Considering prior research, one might argue that a majority of the beneficial effects ascribed to brief daytime napping were found in (mild) sleep deprivation studies. A possible explanation for the differences between those results and the findings in the present study would be that high relative sleep pressure is required prior to the power nap in order for it to be sufficiently restorative and subsequently improve performance.

Suggestions for future research

Multiple measurements during a single protocol may cause possible carry over effects between the naps. Sufficient counterbalancing is required to counteract this effect, or (in an ideal

situation) conducting a single nap protocol. The latter would also enable the researcher to further investigate later-emerging effects of power napping.

Literature regarding cognitive task performance in a power nap protocol is scarce, possibly because the cognitive performance measures performed in the present study are not sensitive to sleep pressure related effects. Exploring other measures of cognitive performance is merited as it might be able to provide more insight in the effects of power napping on task performance.

Another suggestion in regards to future power nap research would be to specifically consider the relative sleep composition versus the sleep duration. Investigating either one requires a different design, as sleep composition is highly related to sleep duration and separating the values is difficult due to individual differences in sleep depth composition.

Conclusion

Initially we hypothesized that short daytime naps would decrease subjective sleepiness and increase global vigor and objective cognitive performance immediately after the nap. Furthermore we postulated that due to the relatively restorative effects of sleep stage S2 and the subsequent reduction in sleep drive, naps containing more sleep stage S2 would induce increasing effects on objective cognitive performance and subjective wellbeing when compared to naps containing less stage S2 sleep. The results of this study indicate that neither hypothesis can be upheld. The third hypothesis regarding sleep inertia effects and decreased subjective feelings of affect or impairments in the prefrontal planning capacity also cannot be upheld.

In conclusion, further research is required to assess whether the postulated hypotheses have any merit. Also we would like to urge future research to consider more specific sleep pressure determinants, by inducing mild sleep deprivation prior to the experiment, by employing different tasks and by considering a single nap per day design.

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References

1. Kryger, M.H., *Principles and Practice of Sleep Medicine*. 5th ed2011, St. Louis: Elsevier.

2. Dijk, D.J., et al., *Electroencephalogram power density and slow wave sleep as a function of prior waking and circadian phase.* Sleep, 1990. **13**(5): p. 430-40.

3. Roehrs, T., et al., *A two-week sleep extension in sleepy normals.* Sleep, 1996. **19**(7): p. 576-82.

4. Dinges, D.F., et al., *Cumulative sleepiness, mood disturbance, and psychomotor vigilance performance decrements during a week of sleep restricted to 4-5 hours per night.* Sleep, 1997. **20**(4): p. 267-77.

5. Guilleminault, C., et al., *Preliminary observations on the effects of sleep time in a sleep restriction paradigm.* Sleep Med, 2003. **4**(3): p. 177-84.

6. Davidhizar, R., V. Poole, and J.N. Giger, *Power nap rejuvenates body, mind.* Pa Nurse, 1996. **51**(3): p. 6-7.

7. Moore, C.E., *The power nap.* J Fla Med Assoc, 1990. **77**(11): p. 955-6.

8. Ohayon, M.M., et al., *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**(7): p. 1255-73.

9. Power, A.E., *Slow-wave sleep, acetylcholine, and memory consolidation.* Proc Natl Acad Sci U S A, 2004. **101**(7): p. 1795-6.

10. Van Dongen, H.P., et al., *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**(2): p. 117-26.

11. Belenky, G., et al., *Patterns of performance degradation and restoration during sleep restriction and subsequent recovery: a sleep dose-response study.* J Sleep Res, 2003. **12**(1): p. 1-12.

12. Brooks, A. and L. Lack, *A brief afternoon nap following nocturnal sleep restriction: which nap duration is most recuperative?* Sleep, 2006. **29**(6): p. 831-40.

13. Takahashi, M., H. Fukuda, and H. Arito, *Brief naps during post-lunch rest: effects on alertness, performance, and autonomic balance.* Eur J Appl Physiol Occup Physiol, 1998. **78**(2): p. 93-8.

14. Tietzel, A.J. and L.C. Lack, *The short-term benefits of brief and long naps following nocturnal sleep restriction.* Sleep, 2001. **24**(3): p. 293-300.

15. Tietzel, A.J. and L.C. Lack, *The recuperative value of brief and ultra-brief naps on alertness and cognitive performance.* J Sleep Res, 2002. **11**(3): p. 213-8.

16. Gillberg, M., et al., *The effects of a short daytime nap after restricted night sleep.* Sleep, 1996. **19**(7): p. 570-5.

17. Hayashi, M., M. Watanabe, and T. Hori, *The effects of a 20 min nap in the mid-afternoon on mood, performance and EEG activity.* Clin Neurophysiol, 1999. **110**(2): p. 272-9.

18. Takahashi, M. and H. Arito, *Maintenance of alertness and performance by a brief nap after lunch under prior sleep deficit.* Sleep, 2000. **23**(6): p. 813-9.

19. van de Werken, M., et al., *Effects of artificial dawn on subjective ratings of sleep inertia and dim light melatonin onset.* Chronobiol Int, 2010. **27**(6): p. 1219-41.

20. Tassi, P. and A. Muzet, *Sleep inertia.* Sleep Med Rev, 2000. **4**(4): p. 341-353.

21. Wertz, A.T., et al., *Effects of sleep inertia on cognition.* JAMA, 2006. **295**(2): p. 163-4.

22. Buysse, D.J., et al., *The Pittsburgh Sleep Quality Index: a new instrument for psychiatric practice and research.* Psychiatry Res, 1989. **28**(2): p. 193-213.

23. Iber, C., et al., *The AASM Manual for the Scoring of Sleep and Associated Events: Rules, Terminology and Technical Specifications*. Vol. III. 2007, Westchester: American Academy of Sleep Medicine.

24. Akerstedt, T. and M. Gillberg, *Subjective and objective sleepiness in the active individual.* Int J Neurosci, 1990. **52**(1-2): p. 29-37.

25. Monk, T.H., *A Visual Analogue Scale technique to measure global vigor and affect.* Psychiatry Res, 1989. **27**(1): p. 89-99.

26. Raymann, R.J. and E.J. Van Someren, *Time-on-task impairment of psychomotor vigilance is affected by mild skin warming and changes with aging and insomnia.* Sleep, 2007. **30**(1): p. 96-103.

27. Dinges, D.F. and A. Powell, *Microcomputer Analyses of performance on a portable, simple visual RT task during sustained operations.* Behavior Research Methods, Instruments and Computers 1985(17): p. 652-655.

28. Goel, V. and J. Grafman, *Are the frontal lobes implicated in "planning" functions? Interpreting data from the Tower of Hanoi.* Neuropsychologia, 1995. **33**(5): p. 623-42.

29. Balslev, D., et al., *Enhanced accuracy in novel mirror drawing after repetitive transcranial magnetic stimulation-induced proprioceptive deafferentation.* J Neurosci, 2004. **24**(43): p. 9698-702.

Appendix

Appendix A: Condition listings

Table 2: A priori condition order per nap per participant(pp).

Cond	pp1	pp2	pp3	pp4	pp5	pp6	pp7	pp8	pp9	pp10	pp11	pp12
nap1	NN	NN	NN	NN	NN	NN	S1	S1	S1	S1	S1	S1
nap2	S1	S1	S2	S2	S2max	S2max	NN	NN	S2	S2	S2max	S2max
nap3	S2	S2max	S1	S2max	S1	S2	S2	S2max	NN	S2max	NN	S2
nap4	S2max	S2	S2max	S1	S2	S1	S2max	S2	S2max	NN	S2	NN

Cond	pp13	pp14	pp15	pp16	pp17	pp18	pp19	pp20	pp21	pp22	pp23	pp24
nap1	S2	S2	S2	S2	S2	S2	S2max	S2max	S2max	S2max	S2max	S2max
nap2	NN	NN	S1	S1	S2max	S2max	NN	NN	S1	S1	S2	S2
nap3	S1	S2max	NN	S2max	NN	S1	S1	S2	NN	S2	NN	S1
nap4	S2max	S1	S2max	NN	S1	NN	S2	S1	S2	NN	S1	NN

Table 3:Final condition order per nap per participant(pp), red cells indicate the changes. 22 nap conditions changed. 11 naps were removed and 11 were moved. Napchanges are indicated by red.

Cond	pp1	pp2	pp3	pp4	pp5	pp6	pp7	pp8	pp9	pp10	pp11	pp12
nap1	NN	NN		NN	NN	NN	S1	NN	S1	S1	S1	S1
nap2	S1	S1	S2	S2max	S2max	S2max	NN	S2	S2	S2	S2max	S2max
nap3	S2	S2max	S1			S1		S2max	NN	S2max	NN	S2
nap4	S2max	S2	S2max	S2	S1	S2	S2max	S1	S2max	NN		NN

Cond	pp13	pp14	pp15	pp16	pp17	pp18	pp19	pp20	pp21	pp22	pp23	pp24
nap1	S2	NN	S2	S2	S2	S2	S2max	S2max	S2max	S2max	S2max	
nap2	NN	S2	S1	S1	S2max	S2max	NN	NN	S1		S2	
nap3	S1		NN	S2max	NN	S1	S1	S2		S2	NN	S1
nap4	S2max	S1		NN	S1	NN	S2	S1	S2	NN	S1	S2max

Table 4: Crosstable of number of naps and nap condition.

condition	NN	S1	S2	S2max
nap 1	7	5	5	5
nap 2	4	7	5	5
nap 3	4	6	6	4
nap 4	6	3	3	5