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Napping and cognitive performance during night shifts: a systematic review and meta-analysis

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Running Title: Napping and cognitive performance in night shifts

Abstract

STUDY OBJECTIVES: To examine the benefits of napping during night shifts on cognitive performance.

METHODS: Medline, Cochrane Library, Science direct and Embase databases were searched up to 01/07/2019. Cognitive performance during night shifts, both before and following napping or under control conditions (no nap), in working-aged adults, were analysed by time and by type of cognitive function (executive function, attention, instrumental function and memory). Estimates were pooled using random-effects meta-analysis.

RESULTS: 18 articles (6 in real-work and 12 in laboratory) with a total of 494 participants were included. The mean nap duration was 41.6 ± 28.3 min, occurring between 12.00 and 4.10 am, with a mean time set at 2.12 am. Cognitive performance did not differ at baseline between the groups (effect size 0.02, 95%CI -0.09 to 0.13). There was an overall improvement in performance following a nap compared to the control condition without a nap (0.25, 0.10 to 0.41). Positioning naps early in the night and activity (simulated work tasks) tended to improve cognitive performance (-0.57, -1.16 to 0.002, and 0.082, -0.04 to 0.33, respectively). The improvements were primarily seen 30 minutes after awakening. Only memory deteriorated immediately after awakening without an overall change in global cognitive performance.

CONCLUSION: Napping during night shifts seems to improve cognitive performance. Napping early in the night and activity may benefit cognitive performance over time. Considering lack of data in real work environments, further studies are warranted before preconizing napping during night shifts as a preventive strategy (safety, health, economic outcomes).

Keywords: night shift; nap; cognitive performance; prevention; sleep

Statement of significance

Shift patterns involving night work represents 20% of the workforce, causing sleep deprivation and disruption of circadian rhythms. Napping during night shifts is a non-pharmacological strategy that has been suggested to limit the deterioration of cognitive performance. In this systematic review and meta-analysis, we aimed to evaluate the effect of napping during night shifts on cognitive performances (executive function, attention, instrumental function and memory), in comparison with a control condition (no nap). The main findings were that napping during night shifts improved cognitive performance, specifically attention. Despite lack of high-power studies on real work environments and that most studies concern simulated night shifts, napping early in the night and activity (simulated work tasks) may be beneficial to cognitive performance during a night shift.

Introduction

Shift patterns involving night work is common with a prevalence surpassing 20% of the workforce,¹ and is a major cause of circadian rhythm disruption.² The circadian timing system coordinates physiological processes encompassing the vigilance state.^{3,4} Thus, night shifts have immediate effects on sleepiness in the workplace,^{5,6} with potential cognitive impairments,⁷⁻¹⁰ a risk of errors,^{11,12} and possible harm causing work injuries.^{13,14} Napping during night shifts is a non-pharmacological strategy that has been suggested to limit the deterioration of cognitive performance, despite conflicting results concerning the effects of different nap durations.¹⁵⁻¹⁸ However, a potential negative effect of napping could be sleep inertia, i.e. a transitional state of low arousal with temporarily deteriorated performance that occurs immediately after awakening.¹⁹ In the absence of major sleep deprivation, sleep inertia rarely exceeds 30 minutes¹⁹ and interferes with preferentially high levels of attention¹⁹ or working memory.²⁰ Furthermore, it has been reported that the benefits of napping depends on the duration and circadian placement of the nap.²¹ Moreover, cognitive performances are influenced by activity or other stimuli, such as physical activity,²²⁻²⁴ light²⁵ or noise²⁶ exposure. To the best of our knowledge, no meta-analysis has assessed the benefits of napping on objective cognitive performance during night shifts. Meta-analysis is an important tool for illustrating trends that may not be apparent in a single research. Therefore, we hypothesised that 1) napping would improve cognitive performance; 2) cognitive performance would mainly improve after a 30-minute sleep inertia period; 3) the effect of napping would vary depending on the type of cognitive performance; 4) the influence of napping on cognitive performance would be linked to the characteristics of the nap (duration, time in the night) and of the individuals (age,²⁷ gender²⁸); 5) activity may benefit cognitive performance. Thus, we aimed to conduct a systematic review and meta-analysis of the benefits of napping during night shifts on cognitive performance.

Methods

Literature Search

We reviewed all studies reporting cognitive performance following a nap during a night shift compared to a control group without a nap. Medline, Cochrane Library, Science Direct and Embase databases were searched up to July 1, 2019, using the following keywords: ("nap*" OR "sleep*") AND ("performance" OR "task" OR "cognitive") AND ("night" OR "shift*" OR "work*" OR "occupation*"). Animal studies were excluded. The search was not limited to specific years. No minimal sample size and no language restrictions were applied. The search strategy was inclusive of working-age adults (18 to 65 years-old), undertaking regular night shift work. We excluded studies mentioning the use of therapeutic adjuvants in addition to a nap. To be included, articles needed to be controlled studies describing our primary outcome variable, which was the measurement of any cognitive performance during the night shift. We imposed no limitation on the regional origin or the nature of the control group. Studies needed to be primary research. In addition, reference lists of all publications meeting the inclusion criteria were manually searched to identify any further studies that were not found with the electronic search. Ancestry searches were also completed on previous reviews to locate other potentially eligible primary studies. The search strategy is presented in Figure 1. Two authors (BB and VN) conducted all the literature searches and collated the abstracts. Three authors (BB, FD and VN) separately reviewed the abstracts and decided the suitability of the articles for inclusion based on the selection criteria. A third author (BP) was asked to review the articles where consensus on suitability was debated. All authors then reviewed the eligible articles.

Quality of Assessment

The “Consolidated Standards of Reporting Trials” (CONSORT)²⁹ and Revised Cochrane risk-of-bias tool (RoB 2)³⁰ were used to evaluate randomised controlled trials. The “STrengthening the Reporting of OBservational studies in Epidemiology” (STROBE)³¹ and Newcastle-Ottawa Scale (NOS)³² were used to check the quality of nonrandomized studies. CONSORT, Rob2, STROBE and NOS statements consisted of a checklist of several items and sub-items, which relate to the title, abstract, introduction, methods, results and discussion sections of articles. One point was attributed per item or sub-item when the study fulfilled the criteria. CONSORT, Rob2, STROBE and NOS statements could achieve a maximal score of 37, 22, 32 and 9 respectively. The obtained score was then converted into a percentage.

Statistical Considerations

Statistical analysis was conducted using the Stata software (version 13, StataCorp, College Station, USA).³³ Baseline characteristics were summarised for each study sample and reported as a mean (with standard-deviation). When raw data were not available, data were scaled from graphs with the measuring tool in the Gimp software (version 2, Gnome Foundation, Orinda, USA) and then converted from pixels to the appropriate unit. Article pages containing these graphs were initially converted from .pdf to .xcf format at a high resolution of 8250px*11000px. Heterogeneity in the study results was evaluated by examining forest plots, confidence intervals (CI) and using formal tests for homogeneity based on the I^2 statistic, which is the most common metric for measuring the magnitude of between-study heterogeneity and is easily interpretable. I^2 values range from 0% to 100% and are typically considered low for <25%, modest for 25–50%, and high for >50%. Random effects meta-analyses (DerSimonian and Laird approach) were conducted when data could be pooled.³⁴ Cognitive tests were stratified in four types of cognitive function:³⁵ executive function, attention, instrumental

function and memory. All meta-analyses were carried out on cognitive performances in the nap and control groups. We first conducted a meta-analysis on the cognitive performance at baseline (t0) stratified on the types of cognitive performance. We then conducted a meta-analysis on the overall cognitive performance after a nap, stratified on the time of the analysis: t1 (<30 min after the nap), t2 (31 min to 120 min) and t3 (>121 min). Finally, we conducted a meta-analysis on the performance after the nap (t1, t2 and t3) for each type of cognitive function. We calculated the effect size (ES, standardised mean differences - SMD) of the cognitive performance for each dependent variable.³⁶ A positive ES denoted improved performance. A scale has been suggested for ES with 0.8 reflecting a large effect, 0.5 a moderate effect, and 0.2 a small effect.³⁷ Funnel plots of these meta-analyses were used to search for potential publication bias. In order to verify the strength of the results, further meta-analyses were then conducted excluding non-randomised studies and studies that were not evenly distributed around the base of the funnel.³⁸ We also conducted further detailed meta-analyses by environment type (workplace vs laboratory) and by stratifying the first 30 minutes after awakening in greater depth in order to further explore the sleep inertia period. Meta-regression analyses were performed to study the influence on effect size of several study and subject characteristics: age, gender, total sleep time monitored by polysomnography, baseline performance, activity (performing tasks after nap to simulate a real work for participants involved in a laboratory protocol), delay between the nap and the cognitive test, time occurrence of the nap (time at the beginning of the nap and the time of awakening), and the type of environment: workplace vs laboratory. Results were expressed as regression coefficients and 95%CI.

Results

An initial search produced 26,055 possible articles. Removal of duplicates and the use of the selection criteria reduced this number to 18 articles reporting cognitive performance following a nap during night work (Figure 1). All articles were written in English.

Quality of the Articles

The assessment of the quality of the 18 studies included was performed using the CONSORT and RoB2 for the eleven randomised studies,^{15,16,18,39-46} and STROBE and NOS for the seven non-randomised studies.⁴⁷⁻⁵³ The mean CONSORT/STROBE score was 50.8 ± 15.2 , varying from 16.0⁵³ to 74.2%;¹⁸ the mean RoB2 score was 78.4 ± 6.2 , varying from 68.2⁴⁵ to 90.1%;¹⁸ and the mean NOS score was 84.1 ± 8.74 , varying from 77.8^{48,51,52,54} to 100%.⁵⁰ Overall, the studies performed best in the discussion section and worst in the result section. Most studies (14/18 i.e. 77.8%) mentioned ethical approval.^{15,18,40-49,51,52} (Appendix 1 and 2)

Inclusion Criteria of Participants

The main inclusion criteria were to be a regular shift worker with a specific occupation^{18,43,47,49-51} or to be an adult with self-reported good health^{39-42,44-46,48,52,53} or self-reported good sleep.¹⁵ The main exclusion criteria were any sleep disturbance^{15,16,39-42,44-46,48,50,51} or habitual daytime napping^{15,39-42,52}, not to be an intermediate morningness-eveningness type^{40-42,44-46,52}, not to have recently undertaken transmeridian travel^{40-42,52}, not to be a smoker^{15,39-42,44-46,48,52,53}, not to be a consumer of excessive alcohol^{15,39-42,44-46,52} or caffeine^{16,39-42,44-46,52} or use any medication except oral contraception^{41,42,44-46,53} and not use medication affecting sleep architecture.^{15,16,44-47,52} A minimal exposure to shiftwork was required in two studies, from 4 months⁴⁹ to two years.⁵⁰

Population

Sample size: 494 subjects were included: 407 in the nap group and 377 in the control group, among which 290 were enrolled in a crossover condition. The mean population size was 22.8 ± 12.3 ranging from 8⁴⁷ to 49.¹⁸ The mean proportion of participants in the nap group was $53.1 \pm 6.0\%$ ranging from 50.0^{15,16,39,43,47-53} to 64.5%.^{41,42} (Table 1)

Age: The mean age in the nap group was 27.3 ± 7.3 years old and 27.3 ± 7.4 years old in the control group. Two studies did not report the mean age of the nap and control group.^{42,50}

Gender: The proportion of males in the nap group was $62.4 \pm 38.4\%$ and $63.4 \pm 37.9\%$ in the control group. Six studies included only males,^{15,48-50,52,53} and four studies included only female.^{16,40,45,46}

Type of sleep: one crossover study evaluated the effect of napping based on the sleeping type of the individuals (morning or evening person).⁵³

Outcome and Aim of the Studies

The principal aim of most of the studies (12/15 i.e. 80.0%) was to evaluate the effect on cognitive performance of napping during a nightshift.^{16,18,39-47,49-51,53} The aim of two of the studies was to investigate the intensity of sleep inertia after napping^{48,52}, and one study investigated the relationship between perceived sleepiness and cognitive performance.¹⁵

Study Design

All included studies were prospective controlled trials, including twelve studies (66.7%) with a crossover design.^{15,43-53} Only one crossover study was not counterbalanced.⁴⁷ The order of condition was randomly assigned in two crossover studies.^{15,43} All non-crossover studies were randomised.^{16,18,39-42} (Table 1)

Characteristics of the Intervention

Nap: the mean duration of the nap was 41.6 min \pm 28.3 min, ranging from 10^{41,42} to 120 min.^{48,53}

Eight studies compared different length nap duration.^{40-42,45,50,52,54,55} (Table 1)

Number of naps per night: all studies evaluated the effect of one nap per night.^{15,16,18,39-44,46-53}

Two studies also evaluated the effect of two naps of 10 minutes⁴⁰ or two naps (90 min and 30 min) in a subgroup.⁴⁵

Start of nap: all studies gave information on the timing of the nap. The mean hour for the nap was 2.12 am (SD = 77.0 min), and ranged from 12.00 am^{48,49} to 4.10 am.⁵⁰

Study environment was the usual work environment in six studies,^{16,18,43,46,49,51} and in sleep laboratories in twelve studies.^{15,39-42,44,45,47,48,50,52,53} In eight of the studies occurring in a sleep laboratory, participants had no prescribed tasks between the cognitive tests and were permitted to rest or to engage in quiet activities of their own choice (no activity).^{15,39-42,45,47,52} Other studies (10/18 i.e. 52.6%) had defined tasks (activity) during a real or simulated night-shift.^{16,18,43,44,46,48-51,53} The subjects were aircraft maintenance engineers,⁴⁹ air-traffic controllers,⁵¹ nurses or physicians in a public hospital^{43,46} or in an academic emergency department¹⁸, or nurses in a psychiatric hospital.¹⁶ Simulated work tasks were typing^{44,55}, typing and arithmetic⁵³, computer monitoring.⁵⁰

Activity of the control group during the nap: The control group had to continue to work,^{16,18,43,46,50,53} or had the opportunity to rest^{38,39,41,44,45} or do a quiet activity without sleep.^{13,32-35,37,42,44,45}

Time of the tests: With the exception of two studies,^{16,44} all studies assessed baseline (t0) cognitive performance before the nap at the beginning of the shift.^{15,18,39-43,47-53} The mean time between the baseline testing and the beginning of the nap was 212.9 min \pm 187.1 min, ranging from 15 min⁴⁷ to 550 min.⁴⁰ Fourteen studies assessed cognitive performance within 30 minutes after the nap (t1).^{15,16,18,39,40,42,44,45,47,48,50-53} The mean time between the nap and the beginning of cognitive tests at t1 was 3.4 min \pm 5.5 min ranging from 0 min^{16,18,39,45,48,51-53} to 20 min.^{44,51}

Ten studies assessed cognitive performance between 31 min and 120 min after the nap (t2).^{15,39,41-45,50,52,53} The mean time between the nap and the t2 cognitive test was 68.9 min±26.9 min ranging from 45 min¹⁵ to 120 min.⁴³ Eleven studies explored cognitive performances between 121 min and the end of the shift (t3).^{15,18,40,41,43,45-47,49-51} The mean time between the nap and the t3 cognitive tests was 213.8 min±58.8 min, ranging from 135 min⁴⁷ to 290 min.⁵¹

Number of continuous nights: Most studies investigated the benefit of napping over one night.^{16,18,39-43,45,47,48,50-53} Two studies investigated the effect of napping over two consecutive night shifts,^{15,46} one investigated three consecutive night shifts⁴⁹ and another investigated five consecutive night shifts.⁴⁴

Measurement of Cognitive Performance

Cognitive performance were evaluated through the measurement of executive functions in seven studies,^{16,18,39,40,45,47,53} attention in thirteen studies,^{15,16,18,41-43,45-51} instrumental function in five studies,^{15,16,42,46,53} and memory in three studies^{18,44,52} (Figure 1; see details of the measurements in Appendix 3 and Table 1). Executive functions were evaluated using the Arrow Orientation Task,³⁹ a driving simulation,^{40,47} a simulation of an intravenous insertion,¹⁸ a typing task,⁵³ mental calculations⁴⁵ and the Wisconsin Card Sorting Test.^{16,56} Attention was evaluated with the 10min-Psychomotor Vigilance Test,^{15,18,41-43,45,47,51} the Two Choice Visual Reaction Time,⁵⁰ the Letter Cancellation task,⁴⁶ the Mackworth Clock Vigilance Time,⁴⁹ the Taiwan University Attention Test¹⁶ and the Visual Vigilance Task.⁴⁸ Instrumental function was analysed with a calculation test,^{42,53} the Information Process Index,¹⁶ and the Symbol Digit Substitution Task.^{15,46} Memory was evaluated with the 4min-Two Back Memory Task,⁵² the Probe Recall Memory Test¹⁸ and the Working Memory Digit Recall Test.⁴⁴

Meta-Analyses of Cognitive Performance at Baseline (t0)

Overall cognitive performance differed between napping vs control groups at baseline (effect size 0.13, 95% CI 0.03 to 0.24, $I^2=28.5\%$) but did not differ after exclusion of outcomes not evenly distributed around the funnel plot and after the exclusion of non-randomised controlled trials (0.02, -0.09 to 0.13, $I^2=0.0\%$) (Figures 2 and 3, Appendix 8-9), as well as for all types of cognitive performance on stratified meta-analysis, with the exception of attention (Appendix 4). There were no overall differences between napping vs control groups for all cognitive performances, including attention, after the exclusion of non-randomised studies⁴⁷⁻⁵³ and outcomes not evenly distributed around the funnel plot^{45,49} (Figure 3 and Appendix 9).

Meta-regression at baseline did not show any link between cognitive performance and the characteristics of the nap (total sleep time, time of awakening), the individuals (age, sex) or the various studies (study environment, activity, time of baseline) (Figure 4).

Meta-Analyses on Overall Cognitive Performance Over Time

Overall cognitive performance improved after a nap (effect size 0.25, 95% CI 0.10 to 0.41, $I^2=79.7\%$) compared to the control group. More specifically, cognitive performance improved at t2 (0.76, 0.51 to 1.01, $I^2=75.1\%$) and t3 (0.55, 0.35 to 0.75, $I^2=68.2\%$) but did not differ between napping vs control groups at t1 (-0.07, -0.28 to 0.14, $I^2=81.4\%$). Compared with baseline, overall cognitive performance improved at t2 (1.14, 0.65 to 1.63) and t3 (0.55, 0.35 to 0.75) and did not differ at t1 (-0.07, -0.29 to 0.14). Cognitive performance also improved at t2 (0.70, 0.31 to 1.09) and t3 (0.64, 0.37 to 0.90) compared with t1, without differences between t2 and t3. (Figures 2 and 3, Appendix 4-7)

Meta-analyses were repeated after the exclusion of outcomes not evenly distributed around the funnel plot (t1,^{16,51-53} t2^{39,52,53} and t3^{41,43,51}) and after the exclusion of non-randomised controlled trials (t1,^{47,48,50-53} t2^{50,52,53} and t3^{47,49-51}) and showed similar results. (Figure 3, Appendix 8-9)

Meta-Analyses on Categories of Cognitive Performance Over Time

Executive function improved globally after napping (effect size 0.43, 95% CI 0.24 to 0.62, $I^2=65.7\%$) compared with the control group, specifically at t2 (1.45, 0.88 to 2.02, $I^2=73.5\%$). Compared with baseline, executive function improved at t2 (1.45, 0.88 to 2.02, $I^2=73.5\%$) and t3 (0.53, 0.03 to 1.04, $I^2=58.7\%$) in the nap group. *Attention* improved generally after a nap (0.41, 0.29 to 0.53, $I^2=66.9\%$) compared with the control group, specifically at t2 (0.70, 0.31 to 1.09, $I^2=74.2\%$). *Instrumental function* improved after a nap (0.13, -0.05 to 0.31, $I^2=35.1\%$) compared with the control group, specifically at t2 (0.44, 0.01 to 0.89, $I^2=43.8\%$). *Memory* deteriorated globally after a nap compared with the control group (-0.52, -0.86 to -0.17, $I^2=85.2\%$), specifically at t1 (-1.92, -2.67 to -1.16, $I^2=89.7\%$). Compared with baseline, memory deteriorated at t1 (-1.92, -2.67 to -1.16, $I^2=89.7\%$); but improved again at t2 (4.10, 1.19 to 7.01) in the nap group (Figures 2 and 3, Appendix 4-7).

Between the cognitive function categories, memory deteriorated less after a nap than attention, executive function and instrumental function, overall (-2.41, -3.11 to -1.71; -2.43, -3.21 to -1.67; -2.39, -3.24 to 1.53, respectively) and at t1 (-2.41, -3.11 to -1.71; -2.43, -3.21 to -1.67; -2.39, -3.24 to -1.53, respectively) (Figure 4).

Meta-analyses were repeated after the exclusion of outcomes not evenly distributed around the funnel plot (t1^{16,51-53}, t2^{39,52,53} and t3^{41,43,51}) (Figures 3 and 4, Appendix 8 and 9) and after the exclusion of non-randomised controlled trial (t1^{47,48,50-53}, t2^{50,52,53} and t3^{47,49-51}) and demonstrated similar results. In general, *executive function*, *instrumental function* and *memory* did not differ after a nap (t1, t2 and t3) compared to the control group, specifically at t1, t2 or t3. Overall, *attention* improved after a nap (0.37, 0.26 to 0.48, $I^2=52.0\%$) compared with the control group, specifically at t2 (0.76, 0.42 to 1.09, $I^2=62.3\%$) and t3 (0.59, 0.33 to 0.85,

$I^2=67.4\%$). *Between the cognitive function categories*, no overall differences were seen after a nap and at each time point (t1, t2 and t3). (Figures 2, 3 and 4, Appendix 4-7).

Comparing Real Work and Laboratory Environment

There were no differences between the napping vs. control groups at baseline when considering only the real work environment (0.08, -0.04 to 0.20, $I^2=0.0\%$), whereas studies only in a laboratory differed between napping vs. control groups (0.15, 0.02 to 0.28, $I^2=34.3\%$). Overall cognitive performance improved after a nap for both the real work or laboratory environments (effect size 0.37, 95% CI 0.21 to 0.54, $I^2=59.3\%$; and 0.32, 0.17 to 0.50, $I^2=80.5\%$, respectively), and also at each time point (t2: 0.59, 0.04 to 1.14, $I^2=0.0\%$; and 0.76, 0.50 to 1.02, $I^2=76.5\%$; and t3: 0.43, 0.21 to 0.66, $I^2=62.5\%$; and 0.64, 0.28 to 1.00, $I^2=70.1\%$, respectively), with the exception of t1. At t1, overall cognitive performance improved in real work (0.28, 0.01 to 0.55, $I^2=65.2\%$), but not in laboratory studies – where a deterioration in memory (-2.12, -2.91 to -1.34, $I^2=81.6\%$) was observed. (Figure 5) However, meta-regressions showed no statistical differences between the real work and laboratory environments. (Figure 4)

Exploration of the Sleep Inertia Period

In order to explore the sleep inertia period in more depth, and since most studies within the t1 group (<30 min after the nap) measured a cognitive performance immediately upon awakening, we also stratified t1 into three periods: immediately after awakening, 1 to 15 minutes after awakening, and 15 to 30 minutes after awakening. There were no differences between the groups (nap vs no nap) from 1 to 15 minutes and from 15 to 30 minutes after awakening, irrespective of the cognitive performances categories. In general, cognitive performance did not change immediately after awakening (i.e. within the first minute). However, the stratifications

demonstrated a deterioration in memory (effect size -2.30, 95% CI -3.22 to -1.38, $I^2=88.0\%$), and an improvement in instrumental function (0.60, 0.11 to 1.10, $I^2=34.9$). (Figure 6)

Relationship with Napping or Individuals or Study Characteristics

Overall cognitive performance after napping improved with a delay between the nap and the test (0.18, 95% CI 0.04 to 0.33), and tended to improve with total sleep time (0.56, 95% CI -0.10 to 1.22) and activity (0.29, 95% CI -0.04 to 0.61). Cognitive performance at t1 improved with activity (1.10, 95% CI 0.38 to 1.83), and tended to improve with total sleep time (1.57, 95% CI -0.12 to 3.26) but to deteriorate in the male gender (-0.05, 95% CI -0.08 to 0.02) and with age (-0.25, 95% CI -0.53 to 0.38) (Figure 4).

Meta-regression was repeated after the exclusion of outcomes not evenly distributed around the funnel plot and after the exclusion of non-randomised controlled trials, and showed similar results. Overall cognitive performances after a nap improved with a delay between the nap and the test (0.08, 95% CI 0.00 to 0.16, $p=0.041$), and tended to improve with an early awakening time (0.57, 95% CI -1.16 to 0.02, $p=0.060$), and to deteriorate with the male gender (-0.01, 95% CI -0.02 to 0.00, $p=0.037$) (Figure 4).

Discussion

The main findings were that napping during night shifts improved cognitive performance in a delayed manner, specifically attention. Despite lack of data precluding robust conclusions during the sleep inertia period, only memory deteriorated immediately after awakening without an overall change in global cognitive performance. Napping early in the night and activity may be beneficial to cognitive performance.

Napping and Cognitive Performance

Sleepiness in night-shift workers is a main concern with increased risk of work injury and economic consequences.^{57,58} Many strategies against sleepiness have been proposed for night shift workers, such as caffeine and bright light.⁵⁹ Nonetheless, the benefits of napping could be superior and without detrimental effects.⁵⁹ In line with our study, a review of the literature concluded that napping in night shifts led to improved sleep related performance.⁶ Using a sound statistical approach, we demonstrated that napping during night shifts improved cognitive performance. A recent meta-analysis did not demonstrate an effect of napping on subjective sleepiness or on sleepiness-related performance in shift-workers.⁶⁰ However, this meta-analysis included only four studies.^{18,43,47,61} We included those studies^{18,43,47} in our study, with the exception of one which did not report cognitive test performance.⁶¹ Moreover, our meta-analysis did not focus on subjective feelings but on objective cognitive performances.¹⁵ We demonstrated that attention was significantly improved after napping in a delayed manner, without detrimental effects during the sleep inertia period. The included attention tests were mostly simple reaction times, which are sensitive markers of sleepiness.⁶² Napping in night shifts could also have larger implications on safety, decreasing the risk of professional error¹² and work injury.⁶³ Moreover, napping during night shifts could also be a countermeasure for the general health impairment of shift workers who have an increased risk of long-term cognitive impairment,⁶⁴ insomnia,^{5,65} depression,⁶⁶ metabolic syndrome,⁶⁷ diabetes,⁶⁸ vascular events^{69,70} and cancer.^{71,72}

Sleep Inertia

Surprisingly considering the literature on sleep inertia effects,^{19,39,42} only memory deteriorated immediately after awakening without an overall change in global cognitive performance. Sleep inertia is described as a transitional state of low arousal immediately after awakening, with a

temporary deteriorated performance.¹⁹ Sleep inertia is one of the perceived barriers of napping during night shift for workers.⁷³ Despite a lack of evidence-based data in real work environment during the sleep inertia period, we reported that cognitive performance tended to improve in the first 30 min with total sleep time, whereas the duration of sleep is generally suspected to increase sleep inertia.¹⁹ Thus, brief naps (less than 30 min) were proposed to limit this phenomenon but a recent review of the literature did not find any clear results.⁷⁴ Furthermore, it has been suggested that cognitive tasks involving high levels of attention¹⁹ or working memory²⁰ deteriorated more through sleep inertia than easier tests. Our study included only one non-randomised controlled trial reporting results on memory during the sleep inertia period,⁵² but the analyses were not highly powered, precluding any robust conclusions. Interestingly, an age effect on higher cognitive impairment was only demonstrated during sleep inertia in older individuals. Comparisons of the benefits of napping in different age groups are not clear in the literature.⁵⁹ Napping early in the night and activity at awakening may also prevent the sleep inertia effects.

Short Nap Early in the Night and Activity

We demonstrated that napping early in the night and activity may benefit cognitive performance. Circadian placement of the nap has been identified as influencing its benefits, with poor regenerative effects when napping is set at the circadian nadir around 4 a.m. (late in the night).²¹ In addition, the benefits of napping were greater when individuals were active after the nap, especially during the sleep inertia period. Maintaining activity increases sympathetic tone and may help individuals to emerge from sleep inertia, and to increase the overall benefits of the nap.⁷⁵ Moreover, we did not find any dose-response relationships between total sleep time and cognitive performance, in line with the literature.⁷⁶⁻⁷⁸ Long naps do not demonstrate greater benefits, emphasising the practical interest of shorts naps at the workplace. Some

authors have suggested that simply inducing sleep with ultra-short naps could be sufficient to gain significant benefits,²¹ whereas other authors suggest a minimum sleep time of around 10 min.⁷⁸ However, we did not find any study with less than 10 minutes of napping that met our inclusion criteria. Interestingly, we did not find a deterioration in cognitive performances in real work environment during the sleep inertia period, whereas memory deteriorated under laboratory conditions. This may be due to the stimuli provided by occupational stressors. Finally, for other measurements, we did not find any significant differences between studies at the workplace or under laboratory conditions, demonstrating that napping could have similar benefits if an appropriate quiet setting is available at the workplace.

Limitations

Our study has some limitations. We conducted the meta-analyses on only published articles, so they are theoretically exposed to publication bias. However, this risk is limited because the analyses of the funnel plots revealed a homogenous distribution. The inclusion criteria were similar, but not identical. We included studies reporting several performance tests. In the absence of a clear consensus on the cognitive tests, and to avoid selection bias, some studies appeared several times in our meta-analysis, with different data or populations. Therefore, the weighting of the studies required careful thought.⁷⁹ However, arbitrary choosing one subcategory for those studies did not affect the results. We limited the influence of extreme results and heterogeneity by repeating analyses after the exclusion of non-randomised studies and those with results not evenly distributed around the funnel plots. Although some studies were randomised, the assessors were not blind for the intervention (nap) as performing blinding in this type of intervention is difficult. Considering the type of cognitive performances, executive functions were highly improved 30 min to 120 minutes after awakening. However, executive functions were reported in only two studies, both of which were non-randomised

controlled trials precluding robust conclusions.³⁹ The number of studies including memory and instrumental functions was not sufficient to draw a conclusion from the stratified results. Moreover, we noted that the classification of the type of cognitive performance varies between authors and suffers lack of consensus.⁶² We also noted that there was a high probability that performances could be linked together. Complementary studies should be performed to study the impact of napping on high-level cognitive functions, like decision-making, in the context, for example, of a medical diagnostic process. Most studies were also lab studies, making it hard to draw conclusions on napping and performance during ‘night shifts’. However, randomised controlled trials are more difficult to achieve in real working conditions. Even if comparisons between real work environments and lab conditions were difficult because lab studies were often limited to young adults, we showed similar results, except for the memory deterioration during sleep inertia found in lab studies. In addition, possible naps occurring prior to the night shift, and their timing, were not reported in the studies included and were not the focus of our meta-analysis.

Conclusion

Napping during night shifts improves cognitive performances in a delayed manner, especially attention. Napping early in the night and activity may benefit cognitive performances over time. Despite the lack of data in real work environments precluding robust conclusions during the sleep inertia period, only memory deteriorated immediately after awakening without an overall change in global cognitive performance. Before recognizing guidelines for napping during night shifts as a preventive strategy, further studies should evaluate the consequences of napping during night shifts on immediate safety (work errors and work injuries), and on long-term specific health and economic outcomes.

Contributors

FD, BB, BP and VN were responsible for the design and conception of the study. BB and VN searched and collected studies and data. FD, BB, BP, LF and VN analysed and interpreted data. FD, BB, BP and VN were in charge of statistical analyses. FD, BB and VN wrote the manuscript. All authors made critical revisions to the article. All authors gave their final approval of the article.

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Figure Legends

Figure 1. Search Strategy

Figure 2. Meta-analysis on cognitive performance between groups (nap vs control) stratified on time of analysis

95%CI: 95% confidence intervals; 2RTT: two choice visual reaction time test; AOT: arrow orientation task; cathsim: CathSim intravenous insertion virtual reality simulation; IPI: information process index; MCVT: Mackworth clock vigilance time; PRMT: probe recall memory test; PVT: 10min-psychomotor vigilance test; SDST: symbol digit substitution task; TUAT: Taiwan university attention test; VVT: visual vigilance task; WCST: Wisconsin card sorting test; WMT: 4min-two back working memory task

Each individual study or subgroup used in the meta-analysis is represented in the forest-plot by a dot on a horizontal line. The black dots represent the effect estimate (effect size - ES), and the length of each line around the dots represent its 95% confidence interval (95CI). Shorter lines represent a narrower 95CI thus higher precision around study ES, usually found in larger studies. Conversely, longer lines represent a wider 95CI and less precision around ES usually found in smaller studies. An overall summary pooled-estimate (result of the meta-analysis) is represented by a blue lozenge at the end of the graph. The black solid vertical line represents the null estimate (with a value of 0 for ES) and the red dotted vertical line represents result of the meta-analysis (pooled-estimate). Horizontal lines that cross the null vertical line represent non-significant studies.

Figure 3. Summary of meta-analysis on cognitive performance between groups (nap vs control), stratified on time of analysis: before (left) and after (right) exclusion of studies not evenly distributed around the funnel plot and non-randomised controlled trials.

For details of the meta-analysis at each analysis time, please see Appendix 2 for meta-analyses at t0, Appendix 3 for t1, Appendix 4 for t2, and Appendix 5 for t3.

t0: baseline; t1: <30 min after nap; t2: from 31 min to 120 min after nap; t3: >120 min after nap

Each overall summary of a meta-analysis is represented in the graph by a dot on a vertical line. The black dots represent the overall pooled-effect estimate of individual meta-analyses (pooled effect size - ES), and the length of each vertical line around the dots represent their 95% confidence interval (95CI). Shorter lines represent a narrower 95CI thus higher precision around pooled-ES. Conversely, longer lines represent a wider 95CI and less precision around pooled-ES. The black solid horizontal line represents the null estimate (with a value of 0 for pooled-ES). Vertical lines that cross the null horizontal line represent a non-significant overall summary of the meta-analysis at each time analysed (t0, t1, t2, and t3).

Figure 4. Meta-regressions

95%CI: 95% confidence intervals; t0: baseline; t1: up to 30 min after nap; t2: from 31 min to 120 min after nap; t3: from 121 min after nap

The effect of each variable on the outcome is represented in the forest-plot by a dot on a horizontal line. The black dots represent the coefficient for each variable, and the length of each line around the dots represent their 95% confidence interval (95CI). The black solid vertical line represents the null estimate (with a value of 0). Horizontal lines that cross the null vertical line represent non-significant variables on the outcome.

“Environment” means that studies with real workplace protocol have been considered as a reference in comparison with laboratory conditions. “Activity” means that participants involved in a laboratory protocol realized a task after nap to simulate a real work.

Figure 5. Summary of meta-analyses on cognitive performance for each time analysed, in real work and laboratory environments.

Each summary of several meta-analysis is represented in the forest-plot by a dot on a horizontal line. The black dots represent the pooled-effect estimate (pooled effect size - ES), and the length of each line around the dots represent their 95% confidence interval (95CI). Shorter lines represent a narrower 95CI thus higher precision around pooled-ES. Conversely, longer lines represent a wider 95CI and less precision around pooled-ES. An overall summary of the results of the meta-analyses pooled-estimate (result of the overall meta-analysis) is represented by a blue lozenge at the end of the graph. The black solid vertical line represents the null estimate (with a value of 0 for pooled-ES). Horizontal lines that cross the null vertical line represent the non-significant overall summary of the meta-analysis.

Figure 6. Summary of meta-analyses on cognitive performance at t1, stratified in three periods: beginning of the tests immediately after awakening, from 1 to 15 minutes after awakening, and from 15 to 30 minutes after awakening.

Each summary of several meta-analyses is represented in the forest-plot by a dot on a horizontal line. The black dots represent the pooled-effect estimate (pooled effect size - ES), and the length of each line around the dots represent their 95% confidence interval (95CI). Shorter lines represent a narrower 95CI thus higher precision around pooled-ES. Conversely, longer lines represent a wider 95CI and less precision around pooled-ES. An overall summary of the results of meta-analyses pooled-estimate (result of the overall meta-analysis) is represented by a blue lozenge at the end of the graph. The black solid vertical line represents the null estimate (with a value of 0 for pooled-ES). Horizontal lines that cross the null vertical line represent non-significant studies overall summary of meta-analysis.

Supplement files

Appendix 1. Methodological quality of included articles using Newcastle – Ottawa Quality Assessment Scale and Revised Cochrane risk-of-bias tool for randomised trials (RoB 2)

Appendix 2. Summary bias risk of included randomised and non-randomised studies using Newcastle – Ottawa Quality Assessment Scale and Revised Cochrane risk-of-bias tool for randomised trials (RoB 2)

Appendix 3. Details of the tests used in the included articles to measure cognitive performance

Appendix 4. Meta-analysis at baseline (t0) between groups (nap vs control) stratified on cognitive performance

Appendix 5. Meta-analysis at t1 (0 to 30 min) between groups (nap vs control) stratified on cognitive performance

Appendix 6. Meta-analysis at t2 (31 min to 120 min) between groups (nap vs control) stratified on cognitive performance

Appendix 7. Meta-analysis at t3 (>121 min) between groups (nap vs control) stratified on cognitive performance

Appendix 8. Funnels plots - Meta-analysis on cognitive performance between groups (nap vs control) stratified on time of analysis

Appendix 9. Funnels plots - Meta-analysis on cognitive performance between groups (nap vs control) stratified on type of cognitive function

Table 1. Characteristics of included studies.

Study	Design			Participants						Night Shift	Nap		Time between nap and test			Test of	
	Cross-over	Rando-mised	Environ-ment	Nap			Controls			Time schedule	Duration min	Time hours	t1	t2	t3	cognitive performance	
				n	Age mean±SD	Sex % men	n	Age mean±SD	Sex % men				0 to 30 min	31 to 120 min	>120 min	Name	Function
Asaoka 2012	no	yes	Laboratory	10	21.5±1.0	70.0%	10	21.1±1.1	-	21:00-3:30	60	1:00-2:00	0	60	-	AOT	Executive function
Centofanti 2016	no	yes	Laboratory	10	24.7±2.7	40.0%	11	24.5±3.3	36.4%	22:00-7:00	30 or 20	3:30-4:00 3:50-4:00	-	190	-	Driving simulator	Executive function
Centofanti 2017	no	yes	Laboratory	10	24.7±2.7	-	11	24.5±3.3	-	22:00-7:00	10 or 30	3:50-4:00 3:30-4:00	-	90	150	PVT	Attention
Chang 2015	no	yes	Real work (nurses)	21	25.3±3.6	-	21	25.7±1.8	-	00:00-8:00	30	2:00-3:00	0	-	-	WCST TUAT IPI	Attention Executive function Instrumental function
Davy 2017	yes	yes	Laboratory	33	21.4±1.6	45.5%	33	21.4±1.6	45.5%	00:00-8:00	200	0:00-3:20 4:00-7:20	20	40	-	WMT	Memory
Hilditch 2016	no	yes	Laboratory	10	-	50.0%	11	-	-	22:00-7:00	10 or 30	3:50-4:00 3:30-4:00	2	47	-	PVT DSST	Attention Instrumental function
Howard 2010	yes	no	Laboratory	8	31.0±9.6	28.6%	8	31.0±9.6	-	21:00-7:00	30	4:00-4:30	0	-	135	Driving simulator PVT	Executive function Attention
Kubo 2010	yes	no	Laboratory	12	21.6±2.8	100%	12	21.6±2.8	100%	22:00-8:00	60 or 120	0:00-2:00 0:00-1:00 0:00-6:00 0:00-5:00	0	-	-	VVT	Attention
Oriyama 2017	yes	no	Laboratory	12	22.2±0.4	0%	12	22.2±0.4	0%	22:00-9:00	90 or 120	22:30-0:00 0:30-2:00 0:30-5:00	0	60	-	PVT Mental calculation	Attention Executive function
Purnell 2002	yes	no	Real work (aircraft engineers)	24	34.8±10.1	100%	24	34.8±10.1	100%	19:00-7:00	20	0:00-3:00	-	-	-	MCVT	Attention
Sallinen 1998	yes	no	Laboratory	13	-	100%	13	-	100%	23:00-7:10	30	1:20-1:50 0:00-1:50 4:10-4:40 3:50-4:40	10	-	110	2RTT	Attention
Signal 2009	yes	no	Real work (air-traffic controllers)	26	35.4	-	26	35.4	-	22:30-6:00	40	0:30-1:10 2:30-3:10	0 20	-	-	2RTT	Attention
Signal 2012	yes	no	Laboratory	12	25.1±4.3	100%	12	25.1±4.3	100%	18:00-8:00	20 or 40 or 60	1:40-2:00 1:20-2:00 1:00-2:00	0	60	-	WMT	Memory
Smith 2007	yes	yes	Real work (nurses)	9	45.7±13.2	33.3%	9	45.7±13.2	-	20:30-7:00	30	2:00-2:00	-	60 120	-	PVT	Attention
Smith-Coggins 2006	no	yes	Real work (nurses and physicians)	26	30.0±5.5	19.2%	23	30±4.3	47.8%	19:30-7:30	40	3:00-4:00	0	-	-	PVT CathSim PRMT	Attention Executive function Memory
Takeyama 2002	yes	no	Laboratory	2 groups: 5 and 8	20	100%	2 groups: 5 and 8	20	100%	22:00-6:00	120	2:00-4:00	0	60	-	Typing Mental calculation	Executive function Instrumental function
Tremaine 2010	yes	yes	Laboratory	2 groups: 21 or 24	22.2±2.5	100%	2 groups: 21 or 24	22.2±2.5	100%	1:55-7:15	30	2:30-3:00	15	45	105	PVT DSST	Attention Instrumental function
Zion 2019	yes	yes	Real work (nurses)	109	39.0±9.1	0%	109	39.0±9.1	0%	23:00-7:00	30	4:00-04:30	-	-	150	DSST LCT	Instrumental function Attention

AOT, Arrow orientation task; **CathSim**, Intravenous insertion simulation; **DSST**, Digit Symbol Substitution Test; **IPI**, Information Process Index; **LCT**, Letter Cancellation Task; **MCVT**, Mackworth Clock Vigilance Time; **PRMT**, Probe Recall Memory Test; **PVT**, 10min-Psychomotor Vigilance Test; **TUAT**, Taiwan University Attention Test; **VVT**, Visual vigilance task; **WCST**, Wisconsin card sorting test; **WMT**, 4min-Two Back Working Memory Task; **WMDRT**, Working Memory Digit Recall Test; **2RTT**, Two Choice Visual Reaction Time Test.

Napping and cognitive performance during night shifts: a systematic review and meta-analysis

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Appendix 3

Details of the tests used in the included articles to measure cognitive performance

Executive function test and conditions of the analyses

Arrow orientation task (AOT) was reported in one article.³⁹ AOT is a spatial stroop task. A fixation cross was first presented on a computer. A white arrow was then presented above or below. The stimuli consisted of 2 compatible and 2 incompatible stimuli in relation to the direction in which the arrow was pointing. The task was to respond to the pointing direction of the arrow (up or down by pressing a button with the corresponding hand. Four outcomes were reported: reaction time compatible, reaction time incompatible, number of correct responses compatible, number of correct responses incompatible.³⁹

Mental calculation was reported in three article.^{48,49,53} The task consisted of performing single-digit mental calculations. The reported outcome was the number of calculations in 10 minutes.

Driving simulation - *40-min computer-based driving simulator task (York Computer Technologies)* - was reported in one article.⁴⁰ A five-minute circuit consisting of straight roads and gentle corners was repeated for the 40 min duration of the task. Subjects were instructed to adhere to the speed limit of 80 to 100 kph as closely as possible and to stay in the center of the left lane. The outcomes reported were lateral deviation and percentage of time spent in a safe zone.⁴⁰ The outcome “risk of a first crash” was not reported due to missing data.

AusEdTM driving simulator was reported in one article.⁴⁷ Subjects undertook a 30-minute monotonous night-time drive on a two-lane road with a series of curved and straight sections. Subjects had to brake in response to coming up behind 10 other vehicles. Subjects were asked to stay in the center of the left lane and keep their speed between 60 and 80 kph. The outcomes reported were variations in lateral deviation and speed.⁴⁷

Intravenous insertion simulation was reported in one study.¹⁸ The CathSim intravenous insertion virtual reality simulation is a validate computer-based intravenous insertion simulation (HT Medical Systems, Inc., Gaithersburg, MD).⁸⁰ The reported outcome was the elapsed time from tourniquet placement to successful completion of the procedure.

Typing was reported in one article.⁵³ The task consisted of typing figures listed randomly on sheets into a computer for 20 min. The reported outcome was typing speed. The outcome “error rate” was not reported due to missing data.

Wisconsin card sorting test (WCST) was reported in one article.¹⁶ The computerised WCST is considered a measure of frontal lobe ability. It consists of four stimulus cards and 128 response cards that depict figures of varying forms, colors, and numbers. Subjects had to match each consecutive card from the deck with one of the four stimulus cards that they thought it matched. The reported outcomes were the number of preservation errors, the number of total errors, the number of categories, the percent of conceptual level responses, and failure to the test.¹⁶

Attention Test and Condition of Analyses

10 min-Psychomotor Vigilance Test (PVT) was reported in eight articles.^{15,18,41-43,47,51}

It is a common and simple reaction time task.⁶² Subjects have to respond to a simple visual

stimulus as quickly as possible by pressing a button.⁴¹ The reported outcomes were mean reaction time or the mean of the 10% fastest reaction times or the number of lapses, defined as a reaction time greater than 500 ms.

Two Choice Visual Reaction Time Test (2RTT) was reported in one article.⁵⁰ It is a subtest of the NIOSH (National Institute Organization for Safety and Health) fatigue test battery.⁸¹ Subjects were randomly presented with the words 'true' and 'false' on the screen and instructed to answer as quickly as possible. The reported outcome was the mean reaction times.

Mackworth Clock Vigilance Time (MCVT) was reported in one article.⁴⁹ Subjects were presented with a circle of 25 dots on a computer screen. Each dot flashed in a clockwise sequence. When a dot flash was omitted, subjects were required to press a response button as quickly as possible. The reported outcome was the mean response latency.⁴⁹

Taiwan University Attention Test (TUAT) was reported in one article.¹⁶ Subjects had to cross out two target characters from a random list of 780 letters, numbers and symbols as fast and as accurately as possible. The reported outcome were completion time, number of omission and a speed score (number of omissions subtracted from the correct number of characters divided by completion time).¹⁶

Visual vigilance task (VVT) was reported in one article.⁴⁸ The VVT required the subjects to press the corresponding key to a number presented in the center of a computer screen as quickly and accurately as possible. The reported outcome were reaction time and response lapses over 5 s.

Letter Cancellation Task (LCT) was reported in one article.⁵⁰ Participants analysed a matrix of 340 capital letters in English and correctly crossed out two predetermined target letters (E and R) within 90 seconds while making as few errors as possible. The capacity (the number of letters the participant scanned), omissions and commission errors were recorded.

Instrumental Function Test and Condition of Analyses

Mental Calculation was reported in one article.⁵³ The task consisted of performing mental arithmetic with two adjacent figures listed randomly on sheets. The reported outcome was the speed of calculation. The outcome “number of errors” was not reported due to missing data.

Information Process Index (IPI) was reported in one article.¹⁶ It is a generic score obtained by using age to convert a raw score of two subsets of the Wechsler Adult Intelligent Scale⁸² involving cognitive, perceptual and motor abilities: the Symbol Digit Substitution Test (SDST) and the Symbol Searching Test (SST). In the SST, subjects have to respond to one of two target symbols from four selective symbols.¹⁶ The reported outcome was the general score.

Digit Symbol Substitution Test (DSST) was reported in three article.^{15,42,50} It is a subtest of the Wechsler Adult Intelligence Scale.⁸² The subject is required to associate certain symbols with certain other symbols. The reported outcome was the number of correct responses.

Memory Test and Condition of Analyses

4 min-Two Back Working Memory Task (WMT) was reported in one study.⁵² It requires participants to compare the spatial location of a stimulus with the second item shown two images before in a sequentially presented list of items. Participants are instructed to respond as quickly and as accurately as possible. The reported outcomes were the number of correct matches, the mean reaction time for correct matches and omissions.⁵²

Probe Recall Memory Test (PRMT) was reported in one study.¹⁸ Subjects had 30 seconds to memorize 6 word pairs.¹⁸ The reported outcome was the number of correctly recalled words.

Working Memory Digit Recall Test (WMDRT) was reported in one study.⁴⁷ Adapted from the psychological test battery, this numerically based recall test (performed on a computer) required participants to memorize a string of seven numbers (presented visually and individually, one after the other) and input them after a 2-s (simple condition) or 4-s (complex) delay using a key board.