

The effects of sleep debt and monotonous work on sleepiness and performance during a 12-h dayshift

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SUMMARY The study examined the effects of the amount of preceding sleep and work pace on sleepiness and cognitive performance during a 12-h dayshift. Twelve process operators (aged 28–56 years) completed a study with four single 12-h dayshifts and preceding night sleep in the laboratory. A simulated distillation process served as a work task. The 12-h shifts differed from each other in terms of the amount of preceding night sleep (23:00–06:30 hours or 2:30–6:30 hours) and work pace (slow or fast). All shifts contained four work simulation sessions of 1.5 h, and each of them included a 15-min alarm session. Cognitive performance was also measured with a 10-choice reaction time test and a mental subtraction test. Objective sleepiness was measured with a continuous electroencephalography/electro-oculography (EEG/EOG) recording during the work periods and with a sleep latency test. Subjective sleepiness at work was measured with the Karolinska Sleepiness Scale. Sleep debt increased the proportion of EEG/EOG-defined and subjective sleepiness at work, but did not impair work or test performance. The fatiguing effect of monotonous work as indicated by EEG/EOG-defined sleepiness was comparable with the effect of sleep debt. The alarm epochs in the middle of monotonous work temporarily decreased EEG/EOG-defined sleepiness. Sleep debt or monotonous work did not have a significant effect on the results of the sleep latency test. None of the sleepiness or performance measures indicated the impairment of a subject's functional capacity at the end of the 12-h shift. Our results suggest that monotonous work is at least as harmful as moderate sleep debt for alertness at work. The results support the view that the last hours of a single 12-h dayshift with frequent pauses are not associated with an increase in sleepiness or performance errors.

KEYWORDS control room operators, extended working hours, monotony, performance, sleep, sleepiness

INTRODUCTION

The main concern with widely used extended working hours is increased fatigue-related errors possibly leading to unwanted consequences, although there is no convincing evidence that long work shifts compromise safety (Smith *et al.*, 1998).

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Thus far, the results on fatigue and performance in 12-h shifts have been conflicting. Studies by Rosa and his co-workers have shown that fatigue increases, and cognitive and psychomotor performance deteriorate in a 12-h shift system compared with an 8-h system (Rosa, 1991; Rosa *et al.*, 1985, 1989). These observations were made in a simulated data entry task in day work (Rosa *et al.*, 1985) as well as among control room operators working on both day and night shifts (Rosa, 1991; Rosa *et al.*, 1989). The investigators speculated that mild

to moderate sleep debt observed in the 12-h shift system could explain the impairment of performance and alertness.

Later field studies comparing 8-h and 12-h shift systems have not confirmed the results of Rosa and his co-workers. Williamson *et al.* (1994) found that self-rated tiredness of computer operators improved with the change from 8-h to 12-h shifts. The signs of impaired work performance were also absent during the last half of the 12-h night shift. Also Axelsson *et al.* (1998) found that the change from an 8-h to a 12-h system did not impair alertness or performance in two psychomotor tests. The authors concluded that sleepiness in a 12-h morning shift is related to the amount of prior sleep and not to the length of the shift. In the night shifts, the most important determinant of sleepiness seemed to be the level of physical effort within the past 2 h.

The above-mentioned studies suggest that the amount of prior sleep and work content are even more important determinants of sleepiness in 12-h shifts than the length of a shift *per se*. Experimental studies have shown that sleep debt impairs both cognitive performance and alertness (Jones and Harrison, 2001; Van Dongen *et al.*, 2003). The significance of work pace in sleepiness is emphasized by the study of Åkerstedt *et al.* (2002), which showed that having to work fast protects against unintentional sleep at work. This finding is in line with a questionnaire study showing that low-information processing assignments are closely associated with fatigue at work (Finkelman, 1994). In addition, a risk for sleep-related vehicle accidents is known to be higher on monotonous motorways than on urban roads full of activity-demanding events (Horne and Reyner, 1995; Maycock, 1996).

The joint effect of sleep debt and monotonous work that leaves a worker with only the passive role of an observer is also a relevant issue in many occupations. This effect is demonstrated by sleep-related vehicle accidents, which occur most likely at night, especially on monotonous roads (Horne and Reyner, 1995). However, to our knowledge there is no experimental study that would have systematically varied both

the amount of preceding sleep and environmental stimulation when measuring sleepiness and cognitive performance.

The aim of the present study was to examine the main and joint effects of monotonous work and moderate sleep debt on sleepiness and cognitive performance in simulated monitoring work during a 12-h dayshift. To increase the ecological validity of this laboratory study we recruited process operators who were used to controlling a similar distillation process in their work as the one used in the present study.

METHODS

Subjects

Twelve male process operators from an oil refinery, aged 28–56 years, participated in the study. Before the experiment, a physician examined the health status of the subjects and they slept an adaptation night in the sleep laboratory, during which a polysomnogram recording was performed. The sleep recording of the adaptation night showed that the apnea–hypopnea index (AHI) was normal in two subjects (<5/h), mildly increased in four (5 to <15/h), moderately increased in four (15 to <30/h), and severely increased in two (39.0 and 43.3/h). In the medical examination, none of the subjects reported problems with sleep or daytime alertness.

Design

The study contained four 12-h dayshifts (07:10–19:10 hours) separated by at least 1 week and preceding night sleep in the laboratory. Each subject participated in all four experimental conditions in a counterbalanced order. The experimental conditions differed from each other in terms of the length of the sleep period preceding the dayshift, and the work pace of a simulated distillation process (slow pace called a monotonous workday, and fast pace called a busy workday). During the normal sleep and sleep debt conditions, the sleep period was

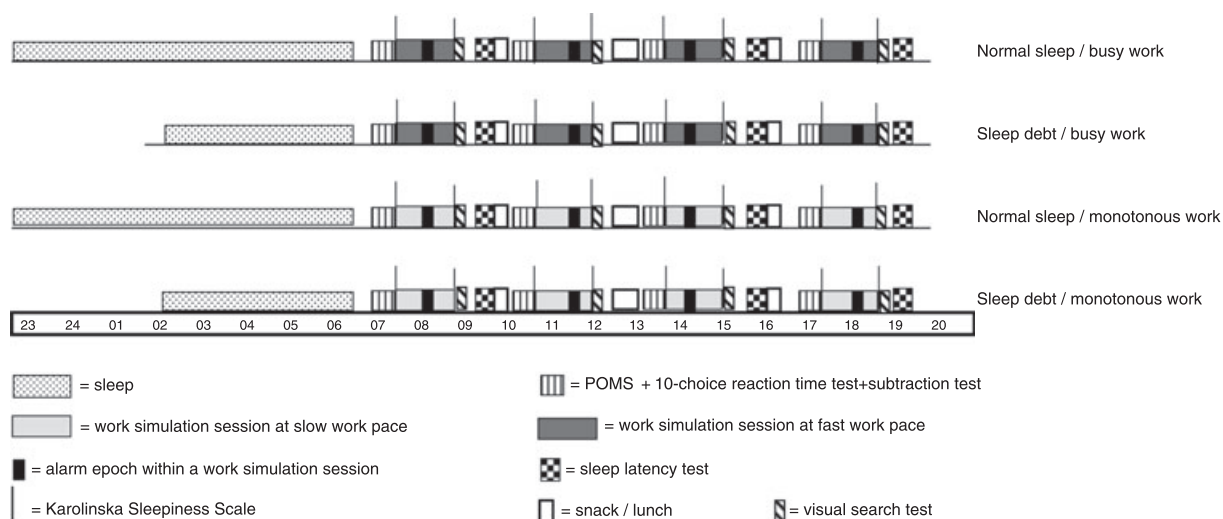


Figure 1. Study design. All subjects underwent single 12-h dayshifts in a counterbalanced order.

timed between 23:00 and 6:30 hours (7.5 h) and between 2:30 and 6:30 hours (4 h), respectively. The study design is presented in Fig. 1. The ethics committee of the Finnish Institute of Occupational Health approved the study.

Procedure

Before starting the series of experiments, the subjects trained the simulated distillation process for an hour (for details see below). The simulated process was a simplified version of the real distillation process, and the subjects reported that they easily learnt to control the simulated process.

The subjects kept a sleep diary for 2 days before each experiment to ensure that they had slept normally and were not on night shifts just prior to the experiment. The use of alcohol was not permitted for 24 h before the experiment. All the subjects managed without caffeine. Tobacco was allowed to the extent necessary to exclude withdrawal symptoms. If tobacco was needed, its dose was kept constant throughout the experiment.

Before each experiment, the subjects arrived at the laboratory at 19:00 hours and operated the simulated process for half an hour. Next, electrodes were attached and impedances were measured. Depending on the experimental condition in question, a subject went to bed at 22:45 hours or at 02:15 hours. The lights were switched off 15 min later after checking the quality of the sleep registration.

In each experimental condition, the subjects were awakened at 06:30 hours and served breakfast. If a subject fell asleep during a test block as indicated by a K-complex or a sleep spindle in electroencephalography, he was awakened to minimize the effect of possible microsleeps on sleepiness. The course of the workday is shown in Fig. 1.

Measurements and variables

Sleep before the 12-h dayshift was recorded by polysomnography including electroencephalography (EEG), electro-oculography (EOG), submental electromyography (EMG), electrocardiography (ECG), and static charge sensitive bed (Alihanka *et al.*, 1981). EEG was recorded from the 10–20 system derivations F3-A2, F4-A1, C3-A2, C4-A1, O1-A2, and O2-A1. The EOG electrodes were placed according to the standards by Rechtschaffen and Kales (1968). The sampling rate was 200 Hz for each signal. The recorded sleep periods were classified into sleep stages according to the classification system of Rechtschaffen and Kales (1968). The recordings were conducted with a digital recorder (Embla, Flaga HF, Iceland). During the adaptation night before the start of the experiment series, the sleep recordings included sensors for body movements, body position, snoring, thermistor and blood oxygen saturation, in addition to the channels used in the sleep recording before each 12-h shift.

Cognitive performance was measured with a simulated distillation process and with cognitive tests. The interface of the work simulation consisted of three pages: one page

showing original tanks of water, glycol and two types of plastic particles, one page for carrying out the separation of plastic particles from the fluid, and one page for feeding the fluid to a distillation tank. The main task in the simulation process was to feed the mixture of water and glycol to the distillation colon at a speed of 15 kg/h. To ensure that the subjects followed this instruction with reasonable precision, we recorded the feeding pace every other second. The feeding of the fluid to the distillation colon required sustained attention and adjustment of the settings of various valves and heaters during the epochs of fast work pace. In the case of slow work pace, the feeding process went smoothly without human control for most of the time. The difference in work pace between the monotonous and busy workdays appeared in a latency to the collapse of the process when the process was functioning without human control. During the monotonous workdays, the process was very stable, i.e. the parameters and fluid levels of the tanks varied only little, and the latency to a collapse was quite long, about 60 min. During the busy workdays, the process was very unstable and the latency to a collapse was only 1 min. The increase in the functional instability of the process was obtained by reducing the original volume of the tanks to their 10th part without changing the layout of the process chart. As the subjects had no simultaneous activities available (e.g. other tasks or a possibility to talk with another person) their main task was just to follow the course of the process presented on the three pages of the interface when the work pace was slow.

The subjects operated the distillation process in 1.5-h sessions, during which the basic work pace was either fast or slow, and included also an alarm epoch of 15 min. During the alarm epoch, which was identical during the monotonous and busy workdays, the process was as dynamic as during the fast basic work pace, and contained five preplanned alarms. The subjects' task was to take care of the visually presented preplanned alarms and keep the process functioning at the same time. During the busy workdays, the occurrence of an alarm epoch was hard to observe, but during the monotonous workdays the alarm epochs clearly deviated from the periods of basic work pace. The onset latency of an alarm epoch varied randomly between 30 and 60 min from the beginning of the work session. The main measure of performance was the proportion of the time that the feeding of water and glycol to the distillation tank was nil. This meant that a subject had failed to operate the process so totally that it had collapsed, and productivity was nil.

The cognitive tests were selected from a computer-based test battery CogniSpeed® (Revonsuo and Portin, 1995). One of the tests was a 10-choice visual reaction time (RT) test containing digits from 0 to 9. The task was to press a button on the keyboard that corresponded to the digit that was shown. Each digit was presented for a maximum of 10 s. The response immediately switched off the stimulus. The interval between two successive stimuli (from offset to onset) was 1 s. The other cognitive test was a subtraction test. The subject was presented the same digits at the same frequency as in the 10-choice test,

but the task now was to subtract the digit shown on the screen from nine, and press the corresponding button on the digit keyboard. The duration of both tests was 5 min. The mean RT of all responses and the mean RT of the slowest 10% of the responses were used as measures of test performance. The subjects also performed a 10-min visual search test after each work simulation session, but its results are not reported here.

We had two measures of sleepiness at work. Objective sleepiness during the work simulation sessions was measured with continuous EEG and EOG recordings using the same recorder as in the polysomnogram. Hereafter this category of sleepiness is called EEG/EOG-defined sleepiness. EEG and EOG were recorded from the same locations and at the same sampling rate as in the polysomnogram measurement. The EEG and EOG recordings were first divided into the following four categories in 20-s epochs: (i) wakefulness, (ii) drowsiness indicated by slow eye movements accompanied by theta activity of < 5 s period in EEG, (iii) microsleep indicated by theta activity for 5 to < 10-s in EEG, and (iv) stage 1 sleep denoted by theta activity for at least a 10-s period in EEG. Alpha activity was not considered as an indication of sleepiness in the present study, as there is great interindividual variation in alpha production. Secondly, an increase in alpha activity is not an unambiguous indication of sleepiness, as it can also be seen in an alert person when he or she just closes his or her eyes. Moreover, the cognitive demands of a task modulate alpha activity as such (e.g. Schier, 2000). EEG/EOG epochs that contained artifacts (< 1% of all the epochs) were excluded from the data. EEG/EOG-defined sleepiness during the work session was qualified as the proportion of the time spent in drowsiness, microsleep or stage 1 sleep, as all these categories indicate severe sleepiness.

Subjective sleepiness during the work simulation was measured with the Karolinska Sleepiness Scale (KSS), which is a nine-point scale ranging from very alert (1) to very sleepy/fighting sleep/effort to keep awake (9) (Åkerstedt and Gillberg, 1990). The KSS was given immediately before and after each work session. The mean value of these two ratings was used as the measure of subjective sleepiness during the work session.

Objective sleepiness outside the work sessions was evaluated with a modified version of the Multiple Sleep Latency Test (Carskadon *et al.*, 1986). The test lasted for 20 min and was

carried out three times per dayshift. The subject was instructed to lie quietly in bed, to close his eyes and try to fall asleep. The latency to stage 1 sleep (three successive 30-s epochs of stage 1 sleep) served as the measure of sleepiness. Later this category of sleepiness is referred as Multiple Sleep Latency Test (MSLT)-defined sleepiness.

Statistical analyses

Prior to the statistical tests, a part of the dependent variables were transformed to approximate a normal distribution. Sleep latencies in the sleep latency test were transformed to logarithms, RTs in the 10-choice RT test and the subtraction test were transformed to their inverse, and the proportions of EEG/EOG-defined sleepiness and nil production during the work simulation sessions were transformed to the arcsine of their square roots. The original values are shown in the figures and tables.

A linear mixed model for repeated measurements including amount of sleep (normal sleep, sleep debt), work pace (slow, fast) and time of day (morning, noon, mid-afternoon, late afternoon) as within factors was used for all analyses. In this model, mean values are compared as in the classical ANOVA models but the model offers advantages over the conventional ANOVA models. One of these advantages is that the missing data values are not necessary to be filled in with the estimated values. Therefore we did not use any technique based on imputation to replace the missing values in our data. Our performance data contained missing values because of technical failures in the registration phase. Of 192 sessions, the performance data of six work simulation and cognitive test sessions were lost. When paired *t*-tests were used, the reported significance values were corrected with the Bonferroni correction.

RESULTS

Sleep prior to 12-h dayshifts

The amount of sleep prior to a 12-h dayshift varied as planned between the normal sleep and sleep debt conditions (Table 1). On average, the subjects slept 433 min (SD 45 min) in the

Table 1 Sleep architecture in the normal sleep and sleep debt conditions

Sleep variables	Normal sleep/busy work	Sleep debt/busy work	Normal sleep/monotonous work	Sleep debt/monotonous work
Total sleep time (min)	424 (55)	223 (6)	441 (35)	217 (13)
Sleep latency (min)	16 (15)	11 (10)	18 (12)	13 (12)
Sleep efficiency (%)	86 (11)	92 (3)	89 (5)	90 (5)
Wake (%)	14 (11)	7 (3)	10 (5)	9 (6)
Stage 1 sleep (%)	13 (6)	12 (8)	12 (5)	11 (4)
Stage 2 sleep (%)	53 (12)	54 (12)	54 (9)	54 (12)
Stage 3 sleep (%)	5 (5)	8 (7)	5 (4)	9 (5)
Stage 4 sleep (%)	2 (4)	4 (5)	3 (4)	5 (9)
Movement time (%)	1 (1)	1 (0)	1 (0)	0 (0)
REM sleep (%)	15 (4)	17 (11)	19 (5)	15 (6)

Standard deviation values are given in parentheses.

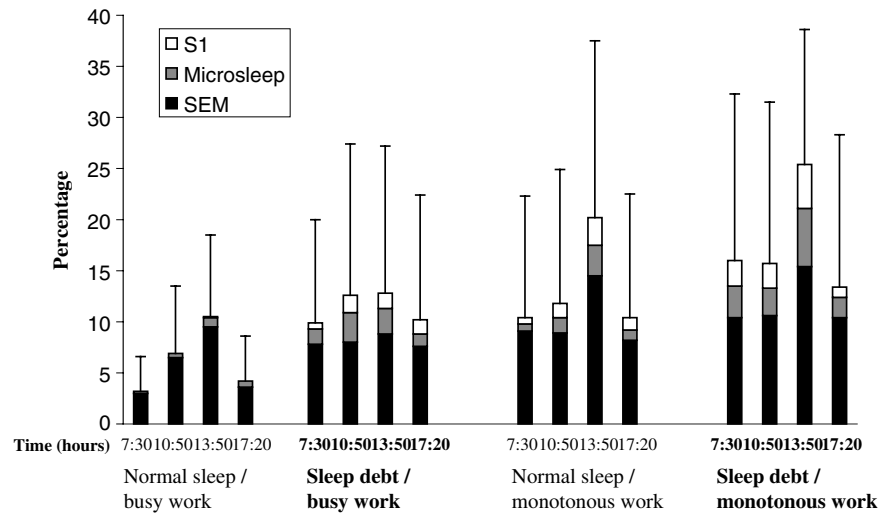


Figure 2. The percentage of EEG/EOG-defined sleepiness during the *basic work epochs* of the various 12-h dayshifts (alarm epochs removed). Black indicates drowsiness (SEM = slow eye movement); grey, microsleep; white, stage 1 sleep (S1). The vertical lines indicate standard deviations.

normal sleep conditions, and 220 min (SD 10 min) in the sleep debt conditions prior to the 12-h dayshift. The proportion of stages 3 and 4 sleep was clearly higher, and that of wakefulness was somewhat lower for the restricted sleep periods than for the normal sleep periods.

EEG/EOG-defined sleepiness during work epochs of slow or fast pace

The percentage of EEG/EOG-defined sleepiness during the basic work epochs (excluding the alarm epochs) was affected by all three factors – the amount of preceding sleep, work pace and time of day – but not by any of their interactions (Fig. 2, Table 2). The proportion of the time spent in drowsiness, microsleep or stage 1 sleep was lowest, 6.2% (SD 6.3), during the busy workday preceded by normal sleep and highest, 17.5% (SD 15.3), during the monotonous workday preceded by sleep debt. During the busy workday preceded by sleep debt and the monotonous workday preceded by normal sleep, the proportion of EEG/EOG defined sleepiness was 11.4% (SD 12.6) and 13.1% (SD 13.9), respectively. Paired *t*-tests revealed that the proportion of EEG/EOG-defined sleepiness was lower for the busy day after normal sleep than for the monotonous day after both normal and restricted sleep [$t(33) = 3.57-5.67$,

$P < 0.01-0.001$]. In addition, the proportion of EEG/EOG-defined sleepiness was lower for the busy workday than for the monotonous workday when the preceding sleep period was limited to 4 h [$t(33) = -3.08$, $P < 0.05$]. The rest of the comparisons remained non-significant.

The mean response of the two subjects with severely elevated AHI to sleep debt did not clearly differ from the corresponding response of the other subjects, except that during the monotonous workday, the fatiguing effect of sleep debt was the least for the subject with the highest AHI. Spearman’s correlation coefficient did not show a significant relationship between AHI and the fatiguing effect of sleep debt ($\rho = 0.22$).

The proportion of EEG/EOG-defined sleepiness was lowest in the beginning and at the end of the 12-h shift regardless of the previous sleep time and work pace. The highest proportion of EEG/EOG-defined sleepiness was reached in the mid-afternoon session (13:50–15:20 hours) on all workdays.

EEG/EOG-defined sleepiness during alarm epochs

In contrast to the basic work epochs, the proportion of EEG/EOG-defined sleepiness during the alarm epochs was not affected by sleep debt, monotonous work or time of day (Table 2, Fig. 3). Only the interaction between sleep debt and

Table 2 Results of linear mixed model including the amount of preceding sleep, work pace and time of day as within factors

Sleepiness variables	Sleep (DF 1,11)		Work pace (DF 1,11)		Time of day (DF 3,33)		Sleep by work pace (DF 1,11)		Sleep by time of day (DF 3,33)		Work pace by time of day (DF 3,33)		Sleep by work pace by time of day (DF 10,109)	
	F	P-value	F	P-value	F	P-value	F	P-value	F	P-value	F	P-value	F	P-value
EEG/EOG-defined sleepiness during basic work epochs	11.40	0.006	21.65	<0.001	9.48	<0.001	0.11	NS	0.25	NS	1.05	NS	0.49	NS
EEG/EOG-defined sleepiness during alarm epochs	2.57	NS	0.07	NS	1.50	NS	6.48	0.03	0.80	NS	0.59	NS	1.25	NS
Subjective sleepiness at work (KSS)	36.69	<0.000	4.34	0.061	2.11	NS	0.27	NS	3.13	0.039	0.65	NS	1.69	NS
Sleep latency test	2.66	NS	0.00	NS	3.65	0.04	1.20	NS	0.17	NS	11.22	<0.000	3.39	0.003

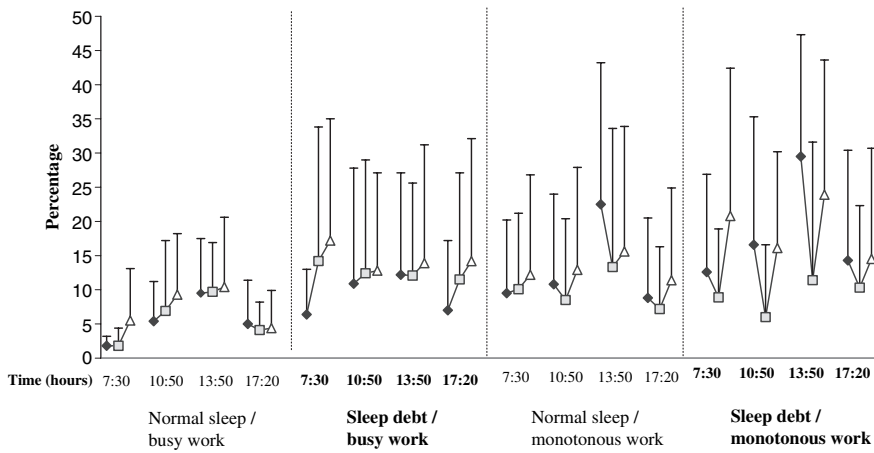


Figure 3. The percentual proportion of EEG/EOG-defined sleepiness (drowsiness + microsleep + stage 1 sleep) during the epochs of *basic and alarm pace* of the various 12-h dayshifts. Dark, diagonal squares and white triangles indicate the epochs of basic pace (slow or fast) and grey squares those of alarm pace.

monotonous work became significant. Sleep debt about doubled the proportion of EEG/EOG-defined sleepiness during the alarm epochs of the busy workdays (5.6% versus 12.6%), but had no effect during the alarm epochs of the monotonous workdays (9.8% versus 9.1%).

The proportion of EEG/EOG-defined sleepiness was clearly lower during the alarm epochs than during the preceding epochs of basic work pace in the sleep debt/monotonous work condition [$t(47) = 4.07$, $P < 0.001$; Fig. 3]. This pattern was not significant when the subjects had slept normally before the monotonous workday ($P = 0.087$). However, the alerting effect of the alarm epochs was short-lived. The proportion of EEG/EOG-defined sleepiness clearly increased during the monotonous work epoch that followed the alarm epoch in the sleep debt condition [$t(48) = -5.35$, $P < 0.001$]. A similar phenomenon could be seen in the normal sleep condition [$t(48) = -2.19$, $P = 0.034$]. During the busy workdays, the proportion of EEG/EOG-defined sleepiness was not clearly affected by the alarm epochs.

Subjective sleepiness at work

Subjective sleepiness during the work sessions was increased by sleep debt (Fig. 4; Table 2). During the sleep debt conditions,

the mean level of the KSS ratings was between 6 and 7 while during the normal sleep conditions, the mean ratings were between 5 and 6. Monotonous work also tended to increase subjective sleepiness, but the effect was non-significant. This was true also when only the KSS ratings given at the end of each work session were included in the statistical analysis. The effect of preceding sleep on subjective sleepiness interacted with the time of day factor. In the sleep debt conditions, the level of sleepiness remained stable from mid-afternoon (13:50–15:20 hours) to late afternoon (17:20–18:50 hours) whereas in the normal sleep conditions, the level of sleepiness decreased from mid-afternoon to late afternoon.

MSLT-defined sleepiness

The MSLT-defined sleepiness was affected by the two-way interaction between work pace and time of day, and the three-way interaction between preceding sleep, work pace and time of day (Table 2, Fig. 5). The two-way interaction meant that MSLT-defined sleepiness decreased progressively through the monotonous workdays, but not through the busy workdays, during which sleepiness was lowest in the morning and highest in the mid-afternoon. The three-way interaction meant that sleep debt affected differently MSLT-defined sleepiness in the

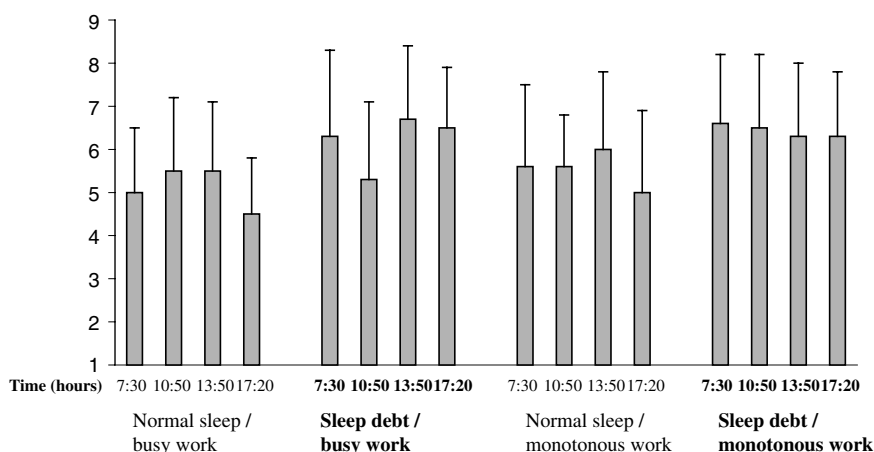


Figure 4. Ratings of subjective sleepiness (Karolinska Sleepiness Scale, KSS) during the work sessions of the various 12-h dayshifts. The vertical lines indicate standard deviations.

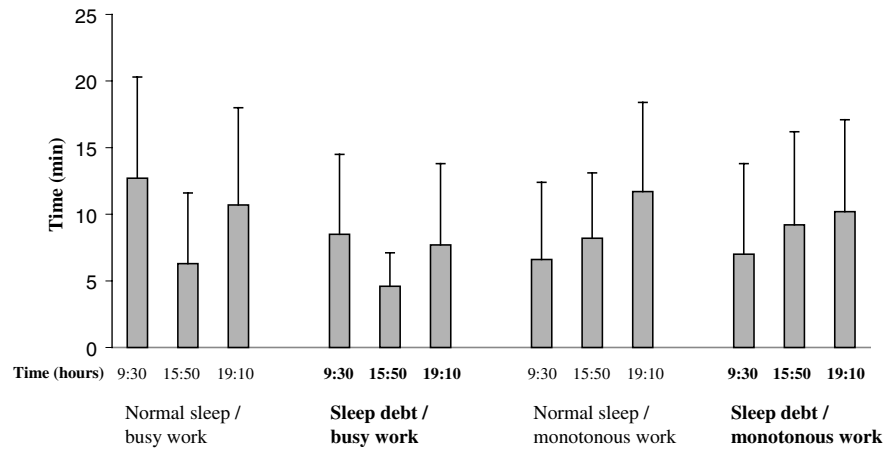


Figure 5. Sleep latencies in a modified Multiple Sleep Latency Test of 20 min during the various 12-h dayshifts. The vertical lines indicate standard deviations.

three tests of the monotonous and busy workdays. The fatiguing effect of sleep debt was clearly greater for the forenoon and mid-afternoon tests of the busy workday than for the corresponding tests of the monotonous workday (difference of 40 and 45 percentage units in the effect of sleep debt between the monotonous and busy workdays). During the late afternoon tests of the busy and monotonous workdays, the fatiguing effect of sleep debt was quite similar (difference of 15 percentage units between the monotonous and busy workdays). The mean change in sleep latency caused by sleep debt was not deviant for the two subjects with severely elevated AHI compared with the other subjects. Neither did the Spearman's correlation coefficient show a significant relationship between AHI and the fatiguing effect of sleep debt ($\rho = 0.25$).

Performance in work simulation

During the work simulation sessions, the subjects had no difficulties in following the instruction of keeping the feeding pace of water and glycol at 15 kg/h. After the periods of nil production were removed, the mean feeding pace varied from 16.2 kg/h (SD 2.5) during the monotonous workday after

normal sleep to 14.3 kg/h (SD 1.7) during the busy workday after normal sleep. The time of nil production from the total work time was longer for the high basic work pace than for the low one [$F(1,11) = 68.60, P < 0.001$; Fig. 6]. Also the time-of-day effect approached the level of significance [$F(1,11) = 2.74, P = 0.06$]. The time of nil production tended to be the shortest around noon (10:50–12:20 hours) and in late afternoon (17:20–18:50 hours). The amount of prior sleep did not affect the time of nil production. This was true for all interactions between the amount of prior sleep, work pace and time of day. During the alarm epochs, none of the independent variables or their interactions became significant.

Performance in cognitive tests

Performance on the 10-choice RT test was affected by work pace [$F(3,33) = 6.12-6.49, P = 0.030-0.027$] and time-of-day [$F(3,33) = 5.19-4.09, P = 0.005-0.014$]. The mean of all RTs were an average of 26 ms longer during the monotonous workdays (841 ms, SD 229) than during the busy workdays (815 ms, SD 142) when the sleep debt and normal sleep conditions were combined. For the mean of the slowest 10%

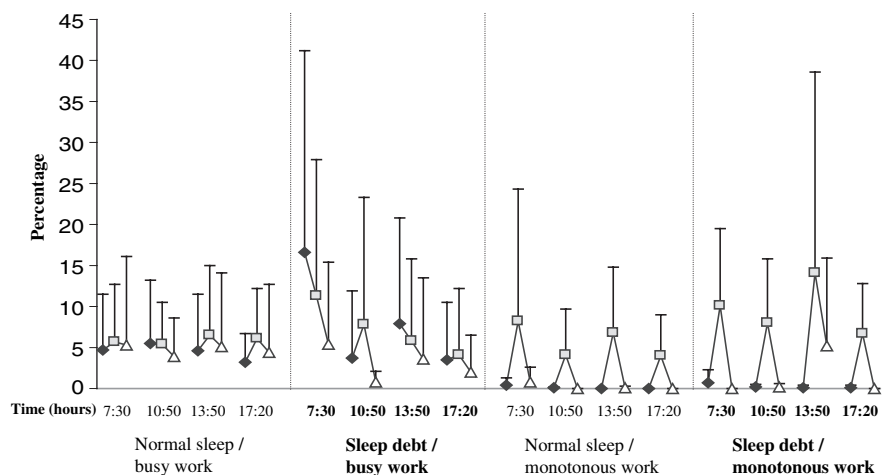


Figure 6. The percentual proportion of nil production in relation to total work time during the epochs of basic and alarm pace of the various 12-h dayshifts. Dark, diagonal squares and white triangle indicate the epochs of basic pace (slow or fast) and grey squares those of alarm pace.

of the RTs, the corresponding deceleration was 68 ms (monotonous workdays: 1233 ms, SD 704 versus busy workdays: 1301 ms, SD 286). On average, the mean of all RTs and the slowest 10% of the RTs shortened from the morning to the late afternoon session 52 and 99 ms [$t(33) = 3.66-2.85$, $P = 0.005-0.045$], respectively. The effect of preceding sleep on the RTs remained non-significant.

Performance on the subtraction test was affected by time-of-day [$F(3,33) = 9.47-4.28$, $P = 0.0001-0.012$]. On average, the means of all RTs and the slowest 10% of the RTs shortened from the morning (all RTs: 1063 ms, SD 204 ms; slowest 10% RTs: 1622 ms, SD 492) to the late afternoon (all RTs: 975 ms, SD 170; slowest 10% RTs: 1441 ms, SD 350) session 88 and 181 ms [$t(33) = 3.66-2.85$, $P = 0.005-0.045$] respectively. Performance was also affected by work pace [$F(3,33) = 5.91$, $P = 0.033$]. The mean of the slowest 10% of the RTs was an average of 60 ms longer during the monotonous workdays (1539 ms, SD 463) than during the busy workdays (1479 ms, SD 390). The effect of preceding sleep on performance remained non-significant.

DISCUSSION

The main finding of the present study was that normal sleep is not a sufficient condition for alertness at work, but that also the content of work must be stimulating. Another interesting result was that all measures of sleepiness and performance indicated that a subject's functional capacity is not impaired at the end of a single 12-h dayshift. This pattern persisted regardless of the amount of prior sleep and work pace.

The effects of work pace and the amount of preceding sleep

EEG/EOG-defined sleepiness

The proportion of EEG/EOG sleepiness at work was increased by about 50% by both sleep debt and slow work pace compared with the dayshift at fast work pace after normal sleep. Our finding that the proportion of EEG/EOG-defined sleepiness did not differ significantly between the sleep debt/busy work condition and the normal sleep/monotonous work condition also suggests that moderate sleep debt and monotonous work similarly impair alertness. The fatiguing effect of moderate sleep debt at work is consistent with the above-mentioned hypothesis of Rosa, i.e. that mild to moderate sleep debt is responsible for increased sleepiness in 12-h shift systems. The soporific effect of monotonous work emphasizes the significance of work content as a determinant of manifested sleepiness at work. This finding is in line with earlier field studies showing that monotonous, undemanding tasks facilitate sleepiness (Åkerstedt *et al.*, 2002; Finkelman, 1994; Horne and Reyner, 1995; Maycock, 1996). The significance of work content for alertness may, however, easily be forgotten in the present situation where many work tasks can be automated to a great extent, and only a passive monitoring task is left to the worker for most of the work time.

The alerting effect of the alarm epochs, which occurred during the work sessions with slow work pace especially when a subject was under sleep debt, also demonstrates the importance of work content for alertness. During these epochs, the proportion of EEG/EOG-defined sleepiness decreased about 8 percentage units as compared with the proportion observed during the preceding epoch of slow work pace. This finding suggests that temporary, machine-based acceleration in otherwise slow work pace, which raises the level of human activity, suppresses manifested physiological sleepiness. The alerting effect of the alarm epoch seemed, however, to be short-lived as the proportion of EEG/EOG-defined sleepiness rose during the epoch of slow work pace following the alarm epoch.

Our results suggest that the proportion of EEG/EOG-defined sleepiness at work is increased by the joint effect of sleep debt and monotonous work, as compared with the main effects of these factors. The proportion of EEG/EOG-defined sleepiness during the work sessions was the highest in the combination of both sleep debt and monotonous work and the lowest when nocturnal sleep was of normal length and the work task was stimulating. In addition, the proportion of EEG/EOG-defined sleepiness observed after the night of restricted sleep was greater during the monotonous workday than during the busy workday. In practice this probably means that workers who are simultaneously exposed to both sleep debt and monotonous work are at highest risk for making sleepiness-related errors. This conclusion is in agreement with the finding of Horne and Reyner (1995) showing that the combination of night-time and a monotonous road makes a driver particularly prone to a sleep related vehicle accident.

Subjective sleepiness at work

The amount of prior sleep seemed to be more important than work pace for subjective sleepiness, in contrast to EEG/EOG-defined sleepiness, which was sensitive to both these factors. However, similar to the findings of EEG/EOG-defined sleepiness at work, the highest level of self-rated sleepiness was reached during the monotonous workday after sleep debt, and the lowest level during the busy workday after normal sleep. On the whole, the mean level of subjective sleepiness approached its critical level (level 7; Åkerstedt and Gillberg, 1990) under sleep debt regardless of work pace. From the practical point of view, the relative insensitivity of experienced sleepiness to the soporific effect of monotonous work verified in the EEG/EOG-recordings is important. Monotonous work as a source of sleepiness may be underestimated in relation to sleep debt because in work life, sleepiness is normally evaluated through subjective experience. This increases the possibility that the effect of work content on alertness is not taken into account when planning work tasks.

MSLT-defined sleepiness

The MSLT-defined sleepiness was not affected by the amount of prior sleep or work pace in contrast to EEG/EOG-defined

sleepiness at work. The insensitivity of MSLT-defined sleepiness to 50% sleep debt of one night is in accordance with a previous doze-response study on the effect of total sleep time on sleep latency in the Maintenance of Wakefulness Test (Härmä *et al.*, 1998). In this study, daytime sleepiness increased only when the preceding nocturnal sleep period was 2 h or less. In our study, an interesting finding was that the subjects were most somnolent in the forenoon MSTL measurement during the monotonous workdays, but most alert during the busy workdays. This difference was particularly pronounced after normal night sleep. One explanation for this observation is that busy work, contrary to monotonous work, effectively removed sleep inertia. The finding that the proportion of EEG/EOG-defined sleepiness during the morning work session after normal sleep was much lower for the busy work (3.2%) than for the monotonous work (10.4%) supports this interpretation.

Performance in work simulation

Performance in the distillation process was impaired only by the acceleration of work pace, not by sleep debt. This finding was unexpected, as the curtailment of sleep increased EEG/EOG-defined sleepiness at work. Usually, if sleep debt increases sleepiness, it also impairs performance (e.g. Belenky *et al.*, 2003). One explanation for our observation is that the distillation process was a rather routine type of cognitive task for the process operators, even when performed at a high pace. The quantitatively small difference between the monotonous and busy workdays in the proportion of nil production supports this explanation. It has been shown that sleep debt causes deterioration in human performance especially in tasks demanding executive functions, while routine tasks are more resistant to the effects of sleep debt (Horne, 1988). Another explanation for the found insensitivity of work performance for sleep debt is that our measure of performance (nil production) was too rough to demonstrate a significant sleep debt-related effect. As shown in Fig. 6, the time of nil production was very short in almost every work session.

An interesting and new finding was that one night's partial sleep debt did not significantly impair human readiness to cope with hectic situations on otherwise monotonous workdays. A rapid change from slow to high work pace is common in the process industry, traffic control, as well as in road and railway transportation. One explanation for this somewhat unexpected result is that the subjects were quite sleepy before the alarm epochs during the monotonous workdays, even when they had slept normally on the preceding night. Our results showed that the proportion of EEG/EOG-defined sleepiness prior to the alarm epochs was quite high during the monotonous workday regardless of the amount of preceding sleep (Fig. 3). It is also possible that the alarm epoch of 15 min was too long to detect a transient sleep-debt-related impairment in readiness to cope with the alarm epochs. Unfortunately we could not check this possibility from our data by dividing the alarm epochs into shorter time segments because of our rough measure of performance.

Performance in cognitive tests

Similarly to work performance, performance in the 10-choice RT test and subtraction test was affected by work pace, but not by sleep debt. The improvement of test performance during the busy workdays is surprising as there were always 1.5–2 h between the beginning of the cognitive tests and the end of the previous session of the distillation process. The most likely explanation is that anticipation of the coming intensive work session increased arousal, which in turn affected positively the readiness to perform the simple cognitive tasks.

The effect of time on shift

Our findings that neither sleepiness nor performance errors peaked at the end of the 12-h dayshift are in line with previous studies (Gillberg, 1998; Reid and Dawson, 2001; Rosa, 1991; Rosa *et al.*, 1985). A new observation was that this was true irrespective of the amount of prior sleep and work pace.

The proportion of EEG/EOG-defined sleepiness peaked in the mid-afternoon session after 6–8 h of work and returned to its morning level at the end of the shift. Subjective sleepiness did not show this pattern, but was quite stable over the measurements, especially under the sleep debt conditions. In the normal sleep conditions, subjective sleepiness tended to increase during the first 8 h of the shift and then decrease even below its morning level. Thus it seems that sleep debt flattens the day profile of subjective sleepiness at work, but not that of EEG/EOG-defined sleepiness.

The mid-afternoon peak in physiological sleepiness can be explained by the well-known phenomenon called post-lunch dip (Lavie, 1986). This would mean that a 12-h shift scheduled between 7:00 and 19:00 hours does not lead to a progressive increase in sleepiness throughout the shift, but alertness fluctuates according to the 12-h rhythm of sleep pressure. It can be speculated that the return of alertness to its starting level at the end of the 12-h dayshift was because of psychological relief associated with awareness of the fact that the laboratory experiment was ending. The fact that two field studies have shown the same phenomenon, however, suggests that this pattern is not specific to laboratory settings, but it can be seen in work life as well (Peacock *et al.*, 1983; Rosa, 1991).

Performance in the work simulation or the cognitive tests did not follow the inverted U-curve as constantly as did EEG/EOG-defined sleepiness at work. The subjects' work performance was at its best at noon and during the late afternoon sessions, and at its worst in either the morning or the mid-afternoon sessions. The proportion of nil production time was especially high during the morning session after sleep debt. A practical implication of this result is that fast paced work should be avoided especially during the first hours of early morning shifts. These shifts are usually preceded by nocturnal sleep of only 4–6 h (Sallinen *et al.*, 2003).

Performance in the cognitive tests, which were timed just before each work session, was at its worst in the morning

session and at its best during the late part of the workday. Interestingly, the daily profile of the proportion of EEG/EOG-defined sleepiness while working gave a very different picture of the changes in a subject's functional capacity. This observation suggests that poor performance in a short cognitive test just before a work session does not predict severe sleepiness at work.

The amount of productive work and the organization of rest pauses in 12-h shifts is an important issue when the suitability of these shifts is evaluated. In this study, the total duration of work was 6 h and other tests took up 80 min on each workday. According to a foreman of the subjects, 7–7.5 h of work during a 12-h shift corresponds well to the proportion of the actual time that the operators control the production process in their oil refinery. However, there are jobs, for example in transportation, in which the proportion of effective working hours of the total work time is higher than in our example. It can be hypothesized that the cumulating fatigue during the shift shows up more clearly in these work tasks.

To conclude, the present results indicate that in addition to sufficient sleep, more attention should be paid to the activity-provoking nature of work tasks in order to maintain alertness at work. Another conclusion from our results is that a single 12-h dayshift can be considered as an alternative for an 8-h dayshift, at least when the number of productive working hours is limited to 7–7.5 h.

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