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Altered sleep/wake patterns and mental performance

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Abstract

Altered sleep/wake patterns involve, by definition, displaced sleep. The present review concludes that mental performance is strongly influenced by many forms of displaced sleep. Being exposed to the circadian low (during work/activity), extended time awake or reduced duration of sleep will impair performance. The effect is most pronounced in the laboratory setting, however, even if a number of studies have shown effects of for example night work on neuropsychological tests, and simulated work. In real shift work situations performance changes have been less pronounced. No studies have evaluated the effects on production, but accidents and serious mistakes have been clearly established in road transport and there seems to be clear effects also in health care. The effects are similar in connection with flights across several time zones (jet lag) but less data are available. It is suggested that there is a need for establishing the significance of impaired performance due to work hours in white collar and service work. Also the notion of individual differences in performance impairment is an important issue.

Keywords: Sleep; Wakefulness; Sleepiness; Work hours; Jet lag; Shift work

1. Introduction

Altered sleep–wake cycles in real life bring to mind mainly different types of night work or shift work, or related types like sea watches, as well as flights across time zones and perhaps disorders that affect the sleep/wake cycle. This will be the main focus of the present review. However, in order to understand how the effects are brought about, it is also necessary to study sleep–wake schedules in different laboratory situations, such as continuous wakefulness, simulated night work, living on an extended or shortened "day" (24-h period) or other manipulations of sleep timing. The existing material does not, however, suffice for a systematic review. The present approach will instead have a more narrative character, with the weaknesses in quality control that accompany such an approach.

The issue of altered sleep–wake patterns is important for several reasons. Apart from the obvious aspect that, in night work, sleep is displaced to the daytime and wakefulness to the night time, the displacement also changes the duration of wakefulness (increased or decreased depending on pattern) which for the average day worker would be 16 hours. It also changes the conditions for optimal sleep. These changes should affect sleepiness and performance and one would expect real-life situations to reflect this, as discussed below.

2. Different types of performance

One might also consider the definition of "mental performance". Here the main focus will be on psychomotor performance, vigilance performance, and cognitive performance (memory, addition, logical reasoning). More complex decision-making (executive functioning) has not really been studied as a function of altered sleep–wake patterns other than as an effect of sleep loss. The latter type of cause will be discussed elsewhere in this issue.

It should also be pointed out that different types of performance tests are differentially susceptible to circadian influence and sleep loss. Thus, Balkin et al. [1] systematically investigated this issue in a partial sleep deprivation experiment and found that tests that demanded constant attention and contained monotony (like a driving simulator or a psychomotor vigilance test) were most sensitive. Least sensitive were tests with a higher cognitive load (like logical reasoning). One might assume that real-life situations that contain more or less of attention or cognitive load (like driving in a normal traffic

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environment or controlling actual industrial processes) might show different sensitivity to altered sleep/wake patterns.

3. The key components in altered sleep/wake patterns

As indicated above, the effects of altered sleep/wake patterns depend on the circadian pattern of mental performance, the amount of sleep, the time awake, and the effects of displaced sleep on sleep duration. These components are briefly introduced below.

3.1. The diurnal pattern of performance

The basic information on how mental performance is affected by altered sleep–wake patterns derives from laboratory studies under controlled conditions and manipulations of the sleep–wake cycle. As with physiology (as discussed elsewhere in this issue) performance and alertness are regulated by the biological clock in the suprachiasmatic nuclei in the hypothalamus [2]. Early studies mainly focused on school performance – learning – and involved only the normal waking span and gave information on the diurnal (pertaining to the day) pattern. In those studies the forenoon was thought to be the optimum time [3]. Kleitman [4] used simple repetitive tasks like card dealing and found higher daytime performance with lower levels in the morning and evening. Colquhoun and his group [5] developed this research into more performance tasks — visual search, logical reasoning, digit symbol substitution. Aschoff's research group demonstrated similar results for reaction time and computation speed [6,7]. One unusual trend was that in short memory tasks performance, which Blake [8] found to decline across the day. Folkard and others [9] later demonstrated that different levels of memory load resulted in different diurnal patterns.

The circadian pattern in mental performance was also observed in studies of sleep deprivation which freed the oscillatory pattern from influences of the sleep/wake alternation [10]. Even after 68 h of sleep loss, the circadian rhythm would still lift performance in the morning to somewhat less impaired levels.

3.2. Effects of sleep loss

The main result from the sleep deprivation studies was, however, the description of the gradual fall of performance with time awake [10,11]. The fall was essentially exponential, with a rapid fall during the hours immediately after awakening and a levelling out towards an asymptote after around 40–72 h of time awake [12].

Higher cognitive functioning was for a long time thought not to be susceptible to sleep loss because of the assumed challenging character of such tasks [13] but it appears that higher cognitive functioning or decision-making is susceptible to sleep loss [14–16]. One problem, however, is that tests of higher cognitive functioning cannot be repeated because of the strong learning effect. The impaired performance after sleep reduction has recently been related to increased slow wave activity in the left pre-frontal areas of the brain [17].

3.3. Adjustment

The adjustment to a new circadian phase position occurs at the speed of about 1 h/day [18,19]. The mechanism is mainly the light exposure at a particular circadian phase [20–22]. Light before the circadian trough will delay and light after the trough will advance the phase.

3.4. Internal desynchronization

Desynchronization between the sleep/wake cycle and physiological variables is a very special form of altered sleep/wake cycles. It normally does not occur in real life, except in blind individuals [23]. In the laboratory it occurs when individuals are isolated from synchronizers (Zeitgebers) for long periods (typically a month), thus depriving the circadian clock of the light input it needs to keep exact 24-h time. In 1/5 of the subjects the sleep–wake cycle then starts to extend its period to about 25 h, whereas that of performance and most physiological functions have difficulties extending their period length to the same extent and stop at a slightly shorter period length [24]. This difference in periods leads to a gradually widening temporal gap between sleep and, for example the low point of the rectal temperature rhythm (where sleep normally is taken). Ultimately, after around 20 days the sleep–wake pattern has completed full circle and once again occurs around the circadian low.

One has also exposed individuals to light–dark cycles of different lengths in order to force desynchronization to occur. This has yielded a "range" of entrainment of the biological clock to a sleep–wake rhythm of between 23 and 27 h (as indicated by rectal temperature) by the artificial sleep–wake cycle [25].

Using forced desynchronization over a period of a month, Dijk and Czeisler (1995) demonstrated the interaction of circadian phase and time awake in the regulation of performance. Subjective sleepiness and the EEG components of physiological sleepiness (4–7 Hz and 8–12 Hz) react to circadian and homeostatic influences in the same way [26].

3.5. Factors affecting sleep

Not only performance, but also sleep is affected by circadian influences. Foret and Lantin [27] showed that the later a train driver went to bed, the shorter time he slept. This clearly suggested a negative influence of shifting sleep to the daytime. This circadian modulation of sleep propensity was also confirmed in a study that experimentally placed sleep at different times of day [28]. Sleep duration decreased with later bedtimes, up to 11.00 h, reflecting the circadian interference with daytime sleep.

The circadian influence on sleep was also demonstrated in several studies of forced desynchronization. These demonstrated the very close relationship between sleep duration and circadian phase [29]. Sleep was promoted during the circadian low (of rectal temperature) and interfered with during the circadian high. Dijk and Czeisler [30] used their accumulated experience from studies of forced desynchronization to construct a model claiming that the time awake (homeostatic influence) and circadian phase together provided an optimal position for sleep, resulting in maximum alertness and performance during the time awake. Any deviation from this position would impair performance and alertness since it would displace sleep, when it would be shortened, as well as extend the time awake and bring work or activity closer to the circadian low.

The duration of sleep is also determined by the duration of time awake. This may not be all that obvious when sleep is starting at its normal position at 23.00 h. When sleep is started at 11.00 h, the homeostatic regulation becomes very obvious because of the strong truncating effect during the circadian high (daytime). With a full (7.5 h) prior night time sleep, subsequent daytime sleep may reach 2 h in duration, whereas 4, 2 and 0 h of sleep will gradually increase sleep duration to 4.5 h [31]. Thus sleep duration is clearly dependent on the amount of need for sleep.

3.6. Sleep loss and performance

The number of studies of the dose–response relationship between sleep duration and performance is lower than one would expect. However, Wilkinson et al. [32] carried out the first systematic study and found that 1–2 h of sleep loss did not affect performance but that greater sleep truncation did. Jewett et al. [33] used forced resynchronization studies to demonstrate the same dose–response relationship.

Relatively recently, sleep loss studies have began to focus on the ecologically more relevant partial sleep loss, but across 1 to 2 weeks. These experiments have led to an understanding of the sleep duration criteria for the accumulation of fatigue/sleep loss/performance impairment. The conclusion seems to be that gradual performance impairment starts when sleep duration falls below 7 h [34,35].

4. Simulated shift work

4.1. Effects on performance

Explaining the mechanism behind shift work problems was part of the rationale for many of the laboratory studies mentioned above (manned space flight was another). So simulations of shift work are a natural extension of the other laboratory studies, particularly since the real-life shift work situation is more difficult to control and to obtain usable data from.

A large number of such studies have been carried out either simulating night shift work or extending performance testing to the night hours for other reasons. These studies have indicated that most types of tasks that require sustained attention, including vigilance performance, reaction time performance or throughput in cognitive tasks, result in a marked reduction of capacity during the late night hours [36–39]. Czeisler et al. [40] brought shift workers to the laboratory and demonstrated a pronounced drop in reaction time performance (lapses) on the psychomotor vigilance test. This impairment was counteracted by treatment with the alertness enhancing drug modafinil.

Simulated night driving is associated with strongly increased accident risk [41,42]. Also the simulated drive home after a night shift involves a highly increased accident risk [43]. Flight simulation studies have shown that the ability to "fly" a simulator [44] at night results in a performance decrement corresponding to that seen after consuming alcohol up to blood alcohol levels of 0.05% (legal level for drunken driving in many countries). In an Australian study using more traditional neuropsychological tests, the performance decrement corresponded to that seen at blood alcohol levels of 0.08% [45]. However, in one study of simulated operation of a power station, no significant effects were observed despite high levels of physiological (increased 4–12 Hz EEG power) and subjective sleepiness [46]. This task did not make high demands on attention but had a rather high cognitive load.

4.2. Physiological indicators of sleepiness

It should be mentioned that physiological measures also support the observation of sleepiness-related performance impairment. Thus, when work or activity is extended into the night, the hours between 04.00 and 07.00 in the morning will show a strong increase in alpha and theta activity in ambulatory or sedentary subjects [47], as well as a major decrease (down to 2–4 min) in sleep latency [48–50]. The latter corresponds to the post-night shift sleep latency in the field studies cited above. The levels seen in these studies would be interpreted as pathological sleepiness, should they be observed during a day-shift. They also fall below the levels seen in connection with, for example, moderate intake of alcohol or hypnotics [51].

4.3. Adjustment to night work

Adjustment to night work is an important issue since it has a bearing on whether one should work many night shifts in sequence or only one or two shifts. This problem was addressed in an early series of studies by Colquhoun and others who systematically studied various performance measures in relation to different types of simulated shifts [37,38,52]. The results showed an adaptation that was gradual. The same group also studied different types of watchkeeping schedules for naval environments [53]. The main results demonstrated the strong impact of the circadian system with low performance in the early morning. Hughes and Folkard [54] tested the effect of 10 night shifts and found partial adaptation but also different speeds of adjustment. Thus verbal reasoning and arithmetic ability had adjusted most while visual search and manual dexterity had adjusted least.

The early studies of adjustment to simulated night work did not record sleep. It is, therefore, unclear whether the results were partly due to truncation of sleep (due to circadian influences on day sleep). However, recent laboratory studies suggest that performance (and alertness) improves across a week of night work [55,56]. The improvement was attributed to the optimal sleep conditions, meaning darkness during day sleep and to absence of competing social influences. Probably also the youth of the subjects may have contributed since sleep problems after night work increase with age [57–60]. Furthermore, phase adjustment occurred and must have contributed to the results. By night shift 4, performance in the study of

Lamond et al. (2004) had improved to what is found below legal blood alcohol levels (0.05%).

5. Interpolated tasks in real shift work settings

Most occupations lack measurable work performance measures. Thus, neuropsychological tests are used as proxies — interpolated performance measures. These are, of necessity, relatively short and simple in order to permit measures at work places. Thus, for example, reduced reaction time or poorer mental arithmetic have been demonstrated on the night shift [61–63]. Wojtczak-Jaroszova et al. [64] used manual dexterity and search performance and found worse performance on the night shift. Costa et al. [65] used reaction time, digit symbol substitution test and manual tracking but found no effect in night nurses. Neither did Lowden et al. [121] when comparing mean levels of reaction time performance, but night time reactions times at the end of the night shift were still longer than those for the day shift. Axelsson et al. (1998) obtained similar results.

Tests of problem-solving and decision-making have often been used to judge the effect of on-call work in physicians. On-call work is usually a euphemism for combined day work and night work and thus includes extended work hours. The results of such studies show negative effects on cognitive ability [66,67]. Several other studies have shown similar results [68–70]. In a variation of cognitive testing, Jacques et al. [71] found that interns who took an important examination in clinical medicine the results improved with the amount of sleep they had obtained during the on-call duty preceding the test.

While interesting, the use of neuropsychological tests does not provide any critical values that can be generalized to productivity or safety. However, in the medical area there have been several studies of simulated medical capacity which may have a higher face value. It has thus been demonstrated that the ability to discover significant changes in medical variables was reduced in anesthsiologists after a night on call [72,73]. Storer et al. [74] studied pediatricians in training and found that procedures requiring eye-hand coordination were impaired after 24 and 34 h on call. In a small study of 6 anesthetists, intubation became slower and the time to estimate the need for treatment in patients was increased [75]. Friedman et al. [76,77] showed a reduced ability to judge ECG print-outs and the ability to find pathological values in laboratory reports was impaired during on-call work [78].

5.1. Adjustment to night shifts

It has also been demonstrated that cognitive performance improves across night shifts and remains poor the day after a night shift [79]. Memory search performance was impaired after night work [80]. Rollinson et al. [81] found rather strong effects on visual memory in interns. Apparently, several days of recuperation was needed to regain normal performance levels.

5.2. Sleep after night work

It should be noted that most studies cited above have not used polysomnographical recording of sleep. Thus, we do not know whether sleep loss has been part of the cause of reduced performance. However, other studies using polysomnography indicate that sleep after a night shift (with bedtime at 07.00 h) will be shortened to 5.5–6 h [27,82–87]. Also night sleep before a morning shift is reduced, but the termination is through artificial means and the awakening usually difficult and unpleasant [62,88–90].

6. Work performance and accidents at work

6.1. Performance and errors

As discussed in the introduction, one would expect negative effects on performance and safety at night. There have been, however, only few studies on performance in normal work situations. One of the classic reports in this area is by Bjerner et al. [91] who showed that errors in meter readings over a period of 20 years in a gas works had a pronounced peak on the night shift. There was also a secondary peak during the afternoon. Similarly, Brown [92] demonstrated that telephone operators connected calls considerably slower at night. Hildebrandt et al. [93] found that train drivers failed to operate their alerting safety device more often at night than during the day. Woyczak-Jaroszova and Pawlowska-Skyga (1967) found that the speed of spinning threads in a textile mill went down during the night.

Recently, a study of interns on call showed high levels of medical mistakes when senior physicians were closely monitoring interns on call [94]. Improving rest conditions (by limiting work to 16 consecutive hours and 60 h/week) greatly reduced many types of medical mistakes, of which several were serious; several accidents were averted by the monitoring teams. It was suggested, however, that much of the effect was due to the new rule requiring 8 h of rest each 24 h. Otherwise, very few data are available in terms of patient safety. However, Wilkinson et al. [95] found that 37% of British physicians thought the long work hours impaired medical safety. Wu et al. [96] found that fatigue (related to on-call work) was the second largest reported cause of their own past medical mistakes. Nocera and Khursandi [97] analyzed (anonymously) self-reported mistakes by anesthesiologists and found that mistakes concerning dosage and control of equipment were due to fatigue. Cooper et al. [98] made similar findings.

6.2. Accidents

The transport area is where most of the available accident data on night shift sleepiness have been obtained [99]. Thus several studies [100–102] have demonstrated that single vehicle accidents have, by far, the greatest probability of occurring at night. So do fatigue-related accidents [103] but also most other types of accidents, for example head-on collisions, rear end collisions [104]. In interns the risk of having a crash was strongly increased after on-call duty [105]. The National Transportation Safety Board (NTSB) ranks fatigue as one of the major causes of heavy vehicle accidents [106]. Furthermore, The NTSB also found that 30–40% of all US truck accidents are fatigue-related (and grossly underestimated in conventional reports). The latter investigation was extended to search for the immediate causes of fatigue-induced accidents [106]. It was found that the most important factors were the amount of sleep obtained during the preceding 24 h and split-sleep patterns, whereas the length of time at the wheel seemed to play a minor role.

Less data are available from conventional industrial operations [107,108] but they indicate that, overall, accidents tend to occur, not surprisingly, when activity is at its peak (that is, during daytime). These values do not take account of exposure. The most carefully executed study, from car manufacturing, seems to indicate a moderate increase (30–50%) in accident risk on the night shift [109]. Most other studies show a night shift dominance [110–114], but not all. Folkard and Åkerstedt have attempted to put together data from several studies of accidents and shift work and demonstrated that accident risk is increased on the night shift and increases with subsequent night shifts [115].

An interesting analysis has been put forward by the Association of Professional Sleep Societies' Committee on Catastrophies, Sleep and Public Policy [116]. Their consensus report noted that the nuclear plant meltdown at Chernobyl occurred at 01:35 h and was due to human error (apparently related to work scheduling). Similarly, the Three Mile Island reactor accident occurred between 04:00 h and 06:00 h and was due not only to the stuck valve that caused a loss of coolant water but also, and more importantly, to the failure to recognize this event leading to the near meltdown of the reactor. Similar incidents, although with the ultimate stage being prevented, occurred 1985 at the David Beese reactor in Ohio and at the Rancho Seco reactor in California. Finally, the committee also states that the NASA Challenger space shuttle disaster stemmed from errors in judgment made in the early morning hours by people who had insufficient sleep (through partial night work) for days prior to the launch. Still, these analyses are single cases and it is not possible to prove that these disasters were caused by work-hour-related sleepiness. It does not, furthermore, give any information on the risks of night and shift work.

6.3. Sleepiness during night work

The increase in poor performance and sleepiness across the night shift is also reflected in the strong increases in subjective sleepiness during the night shift. When subjective rating scales have been administered repeatedly during the day and night, the results indicate moderate low sleepiness during the early night shift but very high sleepiness towards the end of the shift. [117–122]. This observation may be compared with no sleepiness at all during the day shifts and rather high levels at the start of the morning shift.

Also alpha and theta EEG activity is increased in the few studies in which polysomnography has been recorded at work. In an EEG-study of night workers at work (train drivers) we found that 1/4 showed pronounced increases in alpha (8–12 Hz) and theta (4–8 Hz) activity, as well as slow eye movements (SEM) towards 05.00–06.00 h, both of which were absent during daytime driving [120]. The correlations with ratings of sleepiness were quite high ($r=0.74$). In some instances obvious performance lapses, such as driving against a red light, occurred during bursts of SEM and of alpha/theta activity. The pattern is very similar in truck drivers during long-haul (8–10 h) drives [123]. Similar results have been demonstrated by Mitler et al. [86] in truck drivers, by Rosekind et al. [124] in air crew, and by Lockley et al. [87] in interns on call.

7. Additional shift work issues

Most of the impairment of performance in shift work is related to the night shifts. There are, however, several other issues that are of interest.

7.1. Morning shifts

One issue concerns morning work. This has received very little attention despite morning work being more unpopular than night work. Early times of rising (between 04.00 and 05.00 h) are also strongly associated with increased sleepiness during the rest of the day [125]. This sleepiness leads to an early afternoon nap in about 1/3 of the workers [126–128]. There are, however, no available data on performance.

7.2. Organisation of shift systems

There are a few studies which have compared three-shift workers with two-shift and day workers in the textile industry and which have found a higher accident rate for the former [129]. Angersbach et al. [130] found no differences, while Koller (1983) reported a higher rate in day workers. The question is whether two-shift work plus a night shift is a better solution than three-shift work.

With regard to shift scheduling there have also been attempts to show that clockwise shift changes should be less negative for performance than counter-clockwise ones, but the results are not consistent [131–133]. There has also been a continuing discussion of whether permanent shifts are better than rotating ones [134–136]. This issue has not been resolved.

One could also conceive of longer shifts since they would leave more days free for recuperation. This is probably not applicable to all occupation because of too high a work load, but in many studies, 12-h shifts have been shown not to affect performance negatively and they seem to be very attractive to the employees [137–141].

7.3. Countermeasures on the night shift

Another question concerns the countermeasures of night shift fatigue/sleepiness. A nap is one possibility [142–144]. Recent work on alertness enhancing drugs, like modafinil, is another possibility [40], even if it seems unlikely that it would be acceptable to treat healthy individuals with potent pharmaceutical products. The case is probably the same with the "chronobiotic" melatonin [135,136]. Light treatment is a third possibility, but little applied work has been carried out [145–147].

8. Jet lag

8.1. The nature and cause of the problem

One of the first reports of jet lag was that of Post and Gatty describing the out-of-phase problems during a flight across the globe [148]. Jet lag involves disturbed sleep, wakefulness and performance for some days after rapid transportation across several time zones [149]. Sleepiness seem to be the major component of jet lag, but also sleep, bowel movements, the need to urinate and other symptoms form part of the syndrome [137,150,151].

The reason for jet lag is that the biological clock adjusts slowly to a shift of the light–dark pattern [149]. Thus, for some days sleep will be placed at a circadian phase that interferes with sleep, and wakefulness (and work) will be placed at a circadian phase (the trough) when alertness is impaired. The effects differ depending on the direction of flight [152–154]. Westward flights across 4–10 time zones result in pronounced evening sleepiness and extremely early awakenings. Eastward flights result in difficulties falling asleep and morning/noon sleepiness. The effects of the eastward flight seem milder in terms of sleepiness than those of westward flights, but the adjustment takes longer time. The reason for the latter is probably that the traveler at the destination is exposed to light during his circadian low (around noon). That is, the local timing of light will affect both the phase delaying pre-trough time and the phase advancing post-trough time of the circadian response curve. Thus, adjustment becomes slow and often seems to involve adjustment in a westward direction [155].

8.2. Performance following time zone transitions

Flights across time zones will essentially produce the same performance impairment as shift work, and for essentially the same reasons. There are, however, rather few studies of performance of air crews and all use some types of neuropsychological test. The results clearly indicate reduced performance during long-haul flights and flights across many time zones [44,156–161]. Klein et al. [162] simulated flight during the night and found performance decrements similar to those obtained at 0.05% blood alcohol levels. The day after a 6-h flight across time zones the reaction time performance letter cancellation and digit summation were clearly affected in the new time zone. After a westward flight performance was impaired during the early evening but improved in the morning [161]. After an eastward flight impairment characterized most of the day, reflecting the circadian low point appearing in the middle of the day at the new destination.

8.3. Countermeasures

There have been several attempts to develop countermeasures against cockpit fatigue and the short nap in a crew bunk or in the seat seems to have good effects on performance [124,163]. Caffeine is the established drug alternative [164,10150]. There are a number of other approaches that focus on the speeding up of adjustment. One such is light treatment in the morning before a west–east flight which seems to have positive effects in some studies [165]. Another approach is to ingest melatonin in the evening after a similar flight [166]. Both approaches are based on the idea of phase-advancing the circadian rhythm. Westward flights normally contain their own adjustment promoters in the evening exposure to natural light, which will phase delay the circadian system.

9. Individual differences and the measurement of performance and sleepiness

Most of the discussion on mental performance above has been based on neuropsychological tests or subjective ratings. There are at least two methodological aspects that need to be discussed in this context, perhaps especially in relation to field studies. This involves individual differences, context and validity of subjective sleepiness.

9.1. Individual differences

Some individuals clearly have difficulties handling shift work. Many of these probably change to day work but it is not always possible. The major characteristics of these individuals seem to be excessive sleepiness or fatigue [167]. Performance has not been measured in these individuals yet but health and safety seem affected [168]. This category of individuals may fit into the diagnostic category of "Shift work sleep disorder" in the International Classification of Sleep Disorders [169]. Despite constituting a diagnostic category, individuals with this disorder have not been studied physiologically apart from one study finding decreased levels of testosterone in males [170]. It is important, however, to determine whether this group is not really a group of latent insomniacs or, maybe, simply has a sub-optimal sleep environment— or has a different reaction to light exposure than others. Apart from the clinical aspect there is also the tendency of individuals to react differentially to challenges like night work, sleep loss etc. [171,9194].

9.2. Effect of work itself and problems of estimates of sleepiness

Even if subjective and physiological sleepiness is increased during night shifts and performance reduced, one may still suspect that they may be masked by work activity. There does not seem to be any studies available on this issue, but it is likely that measures of sleepiness constitute underestimates of the true level of sleepiness. We recently carried out a small pilot study and found that physical activity, as expected, increased alertness considerably compared to sitting quietly [172]. Sleep latency in the morning was also decreased to 2–3 min, as demonstrated in most of the PSG studies of post-night shift sleep cited above. Also, the multiple sleep latency tests (MSLT) show similar values during the second half of a simulated night shift [40]. These levels fulfil the criteria for pathological sleepiness (<5 min). No MSLT studies of real-life shift work have been carried out, however. The reason is, very likely, that it is very difficult to get employees to lie down for 20 min every 2 h. Even if it were possible, one would still expect difficulties falling asleep because of the thoughts of work or being away from work.

It is questionable whether simple measures like subjective sleepiness or performance ratings may be used as proxies of performance in field studies. However, performance measures usually show high correlations with subjective sleepiness [173,174] and much of the introspection into one's own performance is based on the perception of one's sleepiness [175]. Recent studies have shown that high levels of subjective sleepiness are closely related to different types of performance impairment on vigilance-type tasks [176]. On the other hand there is very little data connecting laboratory performance with real-life performance, apart from tests of pathological states.

10. Conclusions

From the literature reviewed one may draw the conclusion that mental performance is affected by altered sleep/wake patterns and there are clear relations to serious mistakes and accidents. However, apart from road traffic and, perhaps, healthcare, we know very little about the consequences of altered sleep/wake patterns in terms of safety and production. Are decisions by factory workers, around-the-clock bankers, physicians, police officers, etc., worse during night shifts than they would be during day work? And do they affect production and safety? One would assume so, but the data are lacking. The same reasoning is probably valid for psychomotor tests and industrial performance. Lapses on a reaction time test or low performance on a digit symbol substitution test might predict output or safety, provided that the real-life task is dependent on continuous attention or on speed of translating symbols. The reason for the lack of evidence is probably the difficulty of measuring the consequences of decisions in most occupations. Obviously there is room for research, particularly when considering the increase in around-the-clock work and activity in society. Such research would, however, have to be focused on particular occupations in which individual performance is measurable (driving, some process-operating tasks, quality control, etc.).

References

[1] Balkin TJ, Bliese PD, Belenky G, Sing H, Thorne DR, Thomas M, et al. Comparative utility of instruments for monitoring sleepiness-related performance decrements in the operational environment. J Sleep Res 2004;13:219–27.
[2] Saper CB, Lu J, Chou TC, Gooley J. The hypothalamic integrator for circadian rhythms. Trends Neurosci 2005;28:152–7.
[3] Laird DA. Relative performance of college students as conditioned by time of day and day of week. J Exp Psychol 1925;8:50–63.
[4] Kleitman N. Studies on the physiology of sleep. VIII. Diurnal Variation in Performance. Am J Physiol 1933;104:449–56.
[5] Colquhoun WP. In: Colquhoun WP, editor. Circadian variations in mental efficiency, in Biological rhythms and human performance. London Academic Press; 1971. p. 39–107.
[6] Poppel E, Aschoff JC, Giedke H. Circadian variations in choice reaction time. Z Exp Angew Psychol 1970;4:537–52.
[7] Wever R. The circadian system of man: Results of experiments under temporal isolation. New York: Springer–Verlag; 1979.
[8] Blake MJF. Time of day effects on performance in a range of tasks. Psychon Sci 1967;9:349–50.
[9] Folkard S. In: Brown FM, Graeber RC, editors. Circadian rhythms and human memory, in Rhythmic Aspects of Behaviour. London: Lawrence Erlbaum Associates; 1982. p. 241–72.
[10] Fröberg J, Karlsson C-G, Levi L, Lidberg L. Circadian variations in performance, psychological ratings, catecholamine excretion, and diuresis during prolonged sleep deprivation. Int J Psychobiol 1972;2:23–36.
[11] Williams HL, Lubin A, Goodnow JJ. Impaired performance with acute sleep loss. Psychol Monogr 1959;73:1–26.
[12] Folkard S, Åkerstedt T. In: Ogilvie R, Broughton R. editors. A three process model of the regulation of alertness and sleepiness, in sleep, arousal and performance: problems and promises. Boston Birkhäuser; 1991. p. 11–26.
[13] Wilkinson R. Some factors influencing the effect of environmental stressors upon performance. Psychol Bull 1969;72:260–72.
[14] Harrison Y, Horne JA. One night of sleep loss impairs innovative thinking and flexible decision making. Organ Behav Hum Decis Process 1999;78:128–45.
[15] Killgore WD, Balkin TJ, Wesensten NJ. Impaired decision making following 49 h of sleep deprivation. J Sleep Res 2006;15:7–13.
[16] Nilsson JP, Soderstrom M, Karlsson AU, Lekander M, Akerstedt T, Lindroth NE, et al. Less effective executive functioning after one night's sleep deprivation. J Sleep Res 2005;14:1–6.
[17] Anderson C, Horne JA. Prefrontal cortex: links between low frequency delta EEG in sleep and neuropsychological performance in healthy, older people. Psychophysiology 2003;40:349–57.
[18] Wever R. Phase shifts of human circadian rhythms due to shifts of artificial Zeitgebers. Chronobiologia 1980;7:303–27.
[19] Mills JN. Partial adaptation to simulated time zone shifts. J Physiol (Lond) 1976;265:23p-23p.
[20] Czeisler CA, Richardson GS, Zimmerman MC, Moore-Ede MC, Weitzman ED. Entrainment of human circadian rhythms by light–dark cycles. Photochem Photobiol 1981;34:239–47.
[21] Minors DS, Waterhouse JM, Wirz-Justice A. A human phase–response curve to light. Neurosci Lett 1991;133:36–40.
[22] Czeisler CA, Allan JS, Strogatz SH, Ronda JM, Sanchez R, Rios CD, et al. Bright light resets the human circadian pacemaker independent of the timing of the sleep–wake cycle. Science 1986;233:667–71.
[23] Czeisler CA, Shanahan T, Klerman EB, Martens H, Brotman DJ, Emens JS, et al. Suppression of melatonin secretion in some blind patients by exposure to bright light. N Engl J Med 1995;332:6–11.
[24] Aschoff J, Wever R. Spontanperiodik des Menschen bei Ausschluss aller Zeitgeber. Die Naturwissenschaften 1962;49:337–42.
[25] Wever R. Virtual synchronization towards the limits of the range of entrainment. J Theor Biol 1972;36:119–32.
[26] Cajochen C, Brunner D, Kräuchi K, Graw P, Wirz-Justice A. Power density in theta/alpha frequencies of the waking EEG progressively increases during sustained wakefulness. Sleep 1995;18:890–4.
[27] Foret J, Lantin G. In: Colquhoun WP, editor. The sleep of train drivers: An example of the effects of irregular work schedules on sleep, in Aspects of Human Efficiency. Diurnal Rhythm and Loss of Sleep. London: The English Universities Press Ltd.; 1972. p. 273–81.
[28] Åkerstedt T, Gillberg M. The circadian variation of experimentally displaced sleep. Sleep 1981;4:159–69.
[29] Czeisler CA, Weitzman ED, Moore-Ede MC, Zimmerman JC, Knauer RS. Human sleep: its duration and organization depend on its circadian phase. Science 1980;210:1264–7.
[30] Dijk DJ, Czeisler CA. Paradoxical timing of the circadian rhythm of sleep propensity serves to consolidate sleep and wakefulness in humans. Neurosci Lett 1994;166:63–8.
[31] Åkerstedt T, Gillberg M. A dose–response study of sleep loss and spontaneous sleep termination. Psychophysiology 1986;23:293–7.
[32] Wilkinson RT, Edwards RS, Haines E. Performance following a night of reduced sleep. Psychon Sci 1966;5:471–2.
[33] Jewett ME, Dijk D-J, Kronauer RE, Dinges DF. Dose–response relationship between sleep duration and human psychomotor vigilance and subjective alertness. Sleep 1999;22:171–9.

[34] Belenky G, Wesensten NJ, Thorne DR, Thomas ML, Sing HC, Redmond DP, et al. Patterns of performance degradation and restoration during sleep restriction and subsequent recovery: a sleep dose–response study. J Sleep Res 2003;12:1–12.
[35] Van Dongen HP, Maislin G, Mullington JM, Dinges DF. The cumulative cost of additional wakefulness: dose-response effects on neurobehavioral functions and sleep physiology from chronic sleep restriction and total sleep deprivation. Sleep 2003;26:117–26.
[36] Fröberg J, Karlsson CG, Levi L, Lidberg L. Circadian variations of catecholamine excretion, shooting range performance and self-ratings of fatigue during sleep deprivation. Biol Psychol 1975;2:175–88.
[37] Colquhoun WP, Blake MJF, Edwards RS. Experimental studies of shift work. I: a comparison of "rotating" and "stabilized" 4-hour systems. Ergonomics 1968;11:437–53.
[38] Colquhoun WP, Blake MJF, Edwards RS. Experimental studies of shift work. II: stabilized 8-hour shift system. Ergonomics 1968;11:527–46.
[39] Johnson MP, Duffy JF, Dijk DJ, Ronda CM, Czeisler CA. Short-term memory, alertness and performance: a reappraisal of their relationship to body temperature. J Sleep Res 1992;1:24–9.
[40] Czeisler CA, Walsh JK, Roth T, Hughes RJ, Wright KP, Kingsbury L, et al. Modafinil for excessive sleepiness associated with shift-work sleep disorder. N Engl J Med 2005;353:476–86.
[41] Gillberg M, Kecklund G, Åkerstedt T. Sleepiness and performance of professional drivers in a truck simulator— comparisons between day and night driving. J Sleep Res 1996;5:12–5.
[42] Reyner LA, Horne JA. Early morning driver sleepiness: effectiveness of 200 mg caffeine. Psychophysiology 1999;37:1–6.
[43] Åkerstedt T, Peters T, Anund A, Kecklund G. Impaired alertness and performance wile driving home from the night shift — a driving simulator study. J Sleep Res 2005;14:17–20.
[44] Klein DE, Brüner H, Holtman H. Circadian rhythm of pilot's efficiency, and effects of multiple time zone travel. Aerosp Med 1970;41:125–32.
[45] Dawson D, Reid K. Fatigue, alcohol and performance impairment. Nature 1997;388:235-235.
[46] Gillberg M, Kecklund G, Göransson B, Åkerstedt T. Operator performance and signs of sleepiness during day and night work in a simulated thermal power plant. Int J Ind Ergon 2003;31:101–9.
[47] Åkerstedt T, Gillberg M. Subjective and objective sleepiness in the active individual. Int J Neurosci 1990;52:29–37.
[48] Carskadon MA, Dement WC. Sleepiness and sleep state on a 90-min schedule. Psychophysiology 1977;14:127–33.
[49] Webb WB. The forty-eight hour day. Sleep 1978;1:191–7.
[50] Walsh KK, Sugerman JL, Schweitzer PK. Physiological sleep tendency during sleep/wake schedule inversion. Sleep Res 1986;15:289.
[51] Roehrs T, Zwyghuizen-Doorenbos A, Roth T. Sedative effects and plasma concentrations following single doses of triazolam, diphenhydramine, ethanol and placebo. Sleep 1993;16:301–5.
[52] Colquhoun WP, Blake MJF, Edwards RS. Experimental studies of shift work. III: stabilized 12-hour shift system. Ergonomics 1969;12:865–82.
[53] Colquhoun WP, Blake MJF, Edwards RS. Experimental studies of watchkeeping. Cambridge: Medical Research Council; 1969. p. 16.
[54] Hughes DG, Folkard S. Adaptation to an 8-h shift in living routine by members of a socially isolated community. Nature 1976;264:232–4.
[55] Lamond N, Dorrian J, Roach GD, McCulloch K, Holmes AL, Burgess HJ, et al. The impact of a week of simulated night work on sleep, circadian phase, and performance. Occup Environ Med 2003;60:e13.
[56] Crowley SJ, Lee C, Tseng CT, Fogg LF, Eastman CI. Complete or partial circadian re-entrainment improves performance, alertness, and mood during night-shift work. Sleep 2004;27:1077–87.
[57] Foret J, Bensimon B, Benoit O, Vieux N. In: Reinberg A, Vieux N, Andlauer P, editors. Quality of sleep as a function of age and shift work, in Night and shift work: biological and social aspects. Oxford Pergamon Press; 1981. p. 149–54.
[58] Åkerstedt T, Torsvall L. In: Koella W, editor. Age, sleep, and adjustment to shift work, in Sleep 1980. Basel: Karger; 1981. p. 190–4.
[59] Härmä MI, Hakola T, Åkerstedt T, Laitinen JT. Age and adjustment to night work. Occup Environ Med 1994;51:568–73.
[60] Marquié JC, Foret J, Queinnec Y. Effects of age, working hours, and job content on sleep: a pilot study. Exp Aging Res 1999;25:421–7.
[61] Tepas DI, Walsh JK, Moss PD, Armstrong D. In: Reinberg A, Vieux N, Andlauer P, editors. Polysomnographic correlates of shift worker performance in the laboratory, in Night and shift work: biological and social aspects. Oxford Pergamon Press; 1981. p. 179–86.
[62] Tilley AJ, Wilkinson RT, Warren PSG, Watson WB, Drud M. The sleep and performance of shift workers. Hum Factors 1982;24:624–41.
[63] Hossain JL, Reinish LW, Heslegrave RJ, Hall GW, Kayumov L, Chung SA, et al. Subjective and objective evaluation of sleep and performance in daytime versus nighttime sleep in extended-hours shift-workers at an underground mine. J Occup Environ Med 2004;46:212–26.
[64] Wojtczak-Jaroszowa J, Makowska Z, Rzepecki H, Banaszkiewicz A, Romejko A. Changes in psychomotor and mental task performance following physical work in standard conditions, and in a shift-working situation. Ergonomics 1978;21:801–9.
[65] Costa G, Gaffuri E, Perfranceschi G, Tansella M. Re-entrainment of diurnal variation of psychological and physiological performance at the end of a slowly rotated shift system in hospital workers. Int Arch Occup Health 1979;44:165–75.
[66] Hart RP, Buchsbaum DG, Wade JB, Hamer RM, Kwentus JA. Effect of sleep deprivation on first-year residents' response times, memory, and mood. J Med Educ 1987;62:940–2.
[67] Leonard C, Fanning N, Attwood J, Buckley M. The effect of fatigue, sleep deprivation and onerous working hours on the physical and mental wellbeing of pre-registration house officers. Ir J Med Sci 1998;167:22–5.
[68] Robbins J, Gottlieb F. Sleep deprivation and cognitive testing in internal medicine house staff. West J Med 1990;152:182–6.
[69] Rubin R, Orris P, Lau SL, Hryhorczuk DO, Furner S, Letz R. Neurobehavioral effects of the on-call experience in housestaff physicians. J Occup Med 1991;33:13–8.
[70] Nelson CS, Dell'Angela K, Jellish WS, Brown IE, Skaredoff M. Resident's performance before and after night call as evaluated by an indicator of creative thought. J Am Osteopath Assoc 1995;95:600–3.
[71] Jacques CHM, Lynch JC, Samkoff JS. The effects of sleep loss on cognitive performance of resident physicians. J Fam Pract 1990;30:223–9.
[72] Beatty J, Ahern SK, Katz R. In: Mackie RR, editor. Sleep deprivation and the vigilance of anesthesiologists during simulated surgery, in Vigilance. New York: Plenum Press; 1977. p. 511–27.
[73] Denisco RA, Drummond JN, Gravenstein JS. The effect of fatigue on the performance of a simulated anesthetic monitoring task. J Clin Monit 1987;3:22–4.
[74] Storer JS, Floyd HH, Gill WL, Wimbish Giusti C, Ginsberg H. Effects of sleep deprivation on cognitive ability and skills of pediatrics residents. Acad Med 1989;64:29–32.
[75] Smith-Coggins R, Rosekind MR, Hurd S, Buccino KR. Relationship of day versus night sleep to physician performance and mood. Ann Emerg Med 1994;24:928–34.
[76] Friedman RC, Kornfeld D, Bigger TJ. Psychological problems associated with sleep deprivation in interns. J Med Educ 1973;48:436–41.
[77] Friedman RC, Bigger JT, Kornfeld DS. The intern and sleep loss. N Engl J Med 1971;285:201–3.
[78] Poulton EC, Hunt GM, Carpenter A, Edwards RS. The performance of junior hospital doctors following reduced sleep and long hours of work. Ergonomics 1978;21:279–95.
[79] Totterdell P, Spelten E, Smith L, Barton J, Folkard S. On-shift and daily variations in self-reported and performance measures in rotating shift and permanent night nurses. Work Stress 1995;9:187–97.
[80] Meijman T, van der Meer O, van Dormolen M. The after-effects of night work on short-term memory performance. Ergonomics 1993;36:37–42.
[81] Rollinson DC, Rathlev NK, Moss M, Killiany R, Sassower KC, Auerbach S, et al. The effects of consecutive night shifts on neuropsychological performance of interns in the emergency department: a pilot study. Ann Emerg Med 2003;41:400–6.
[82] Foret J, Benoit O. Structure du sommeil chez des travailleurs à horaires alternants. Electroencephalogr Clin Neurophysiol 1974;37:337–44.
[83] Matsumoto K. Sleep patterns in hospital nurses due to shift work: an EEG study. Waking Sleep 1978;2:169–73.
[84] Tilley AJ, Wilkinson RT, Drud M. In: Reinberg A, Vieux N, Andlauer P, editors. Night and day shifts compared in terms of the quality and

quantity of sleep recorded in the home and performance measured at work: a pilot study, in Night and shift work. Biological and social aspects. Oxford: Pergamon Press; 1981. p. 187–96.
[85] Torsvall L, Åkerstedt T, Gillander K, Knutsson A. Sleep on the night shift: 24-hour EEG monitoring of spontaneous sleep/wake behavior. Psychophysiology 1989;26:352–8.
[86] Mitler MM, Miller JC, Lipsitz JJ, Walsh JK, Wylie CD. The sleep of long-haul truck drivers. N Engl J Med 1997;337:755–61.
[87] Lockley SW, Cronin JW, Evans EE, Cade BE, Lee CJ, Landrigan CP, et al. Effect of reducing interns' weekly work hours on sleep and attentional failures. N Engl J Med 2004;351:1829–37.
[88] Dahlgren K. Adjustment of circadian rhythms and EEG sleep functions to day and night sleep among permanent night workers and rotating shift workers. Psychophysiology 1981;18:381–91.
[89] Åkerstedt T, Kecklund G, Knutsson A. Spectral analysis of sleep electroencephalography in rotating three-shift work. Scand J Work Environ Health 1991;17:330–6.
[90] Kecklund, G., Sleep and alertness: Effects of shift work, early rising, and the sleep environment (PhD-thesis). Stress Research Report 1996, 252: 1–94.
[91] Bjerner B, Holm Å, Swensson Å. Diurnal variation of mental performance. A study of three-shift workers. Br J Ind Med 1955;12:103–10.
[92] Brown RC. The day and night performance of teleprinter switchboard operators. J Occup Psychol 1949;23:121–6.
[93] Hildebrandt G, Rohmert W, Rutenfranz J. 12 and 24 hour rhythms in error frequency of locomotive drivers and the influence of tiredness. Int J Chronobiology 1974;2:175–80.
[94] Landrigan CP, Rothschild JM, Cronin JW, Kaushal R, Burdick E, Katz JT, et al. Effect of reducing interns' work hours on serious medical errors in intensive care units. N Engl J Med 2004;351:1838–48.
[95] Wilkinson RT, Tyler PD, Varey CA. Duty hours of young hospital doctors: effects on the quality of work. J Occup Psychol 1975;48:219–29.
[96] Wu AW, Folkman S, McPhee SJ, Lo B. Do house officers learn from their mistakes? J Am Med Assoc 1991;265:2089–94.
[97] Nocera A, Khursandi DS. Doctors' working hours: can the medical profession afford to let the courts decide what is reasonable? Med J Aust 1998;168:616–8.
[98] Cooper JB, Newbower RS, Kitz RJ. An analysis of major errors and equipment failures in anesthesia management: considerations for prevention and detection. Anesthesiology 1984;60:34–42.
[99] Lauber JK, Kayten PJ. Sleepiness, circadian dysrhythmia, and fatigue in transportation system accidents. Sleep 1988;11:503–12.
[100] Harris W. In: Mackie RR, editor. Fatigue, circadian rhythm and truck accidents, in Vigilance. New York: Plenum Press; 1977. p. 133–46.
[101] Langlois PH, Smolensky MH, Hsi BP, Weir FW. Temporal patterns of reported single-vehicle car and truck accidents in Texas, USA during 1980–1983. Chronobiol Int 1985;2:131–46.
[102] Hamelin P. Lorry driver's time habits in work and their involvement in traffic accidents. Ergonomics 1987;30:1323–33.
[103] Horne JA, Reyner LA. Sleep related vehicle accidents. Br Med J 1995;310:565–7.
[104] Åkerstedt T, Kecklund G, Hörte L-G. Night driving, season, and the risk of highway accidents. Sleep 2001;24:401–6.
[105] Barger LK, Cade BE, Ayas NT, Cronin JW, Rosner B, Speizer FE, et al. Extended work shifts and the risk of motor vehicle crashes among interns. N Engl J Med 2005;352:125–34.
[106] NTSB, Factors that affect fatigue in heavy truck accidents. National Transportation Safety Board. Safety Study 1995, NTSB/SS-95/01.
[107] Wojtczak-Jaroszowa J, Jarosz D. Time-related distribution of occupational accidents. J Saf Res 1987;18:33–41.
[108] Ong CN, Phoon WO, Iskandar N, Chia KS. Shiftwork and work injuries in an iron and steel mill. Appl Ergon 1987;18:51–6.
[109] Smith L, Folkard S, Poole CJM. Increased injuries on night shift. Lancet 1994;344:1137–9.
[110] Andlauer P. The effect of shift working on the workers' health. European Productivity Agency, TU Information Bulletin, vol. 29; 1960.
[111] Menzel W. Zur Physiologie und Pathologie des Nacht und Schichtarbeiters. Arbeitsphysiologie 1950;14:304–18.
[112] Pradhan SM. Reaction of workers on night shift. Proc. XVI Int. Congress of Occupational Health; 1969. Tokyo.
[113] Quaas M, Tunsch R. Problems of disablement and accident frequency in shift and night work. Stud Laboris Salutis 1972;4.
[114] Smith P. A study of weekly and rapidly rotating shift workers. Int Arch Occup Environ Health 1979;43:211–20.
[115] Folkard S, Åkerstedt T. Trends in the risk of accidents and injuries and their implications for models of fatigue and performance. Aviat Space Environ Med 2004;75:A161–7.
[116] Mitler MM, Carskadon MA, Czeisler CA, Dement WC, Dinges DF, Graeber RC. Catastrophes, sleep and public policy: consensus report. Sleep 1988;11:100–9.
[117] Fröberg JE, Karlsson CG, Levi L. Shift work. A study of catecholamine excretion, self-ratings and attitudes. Stud Laboris Salutis 1972;11:10–20.
[118] Folkard S, Monk TH, Lobban MC. Short and long term adjustment of circadian rhythms in "permanent" night nurses. Ergonomics 1978;21:785–99.
[119] Dahlgren K. Long-term adjustment of circadian rhythms to a rotating shiftwork schedule. Scand J Work Environ Health 1981;7:141–51.
[120] Torsvall L, Åkerstedt T. Sleepiness on the job: continuously measured EEG changes in train drivers. Electroencephalogr Clin Neurophysiol 1987;66:502–11.
[121] Lowden A, Kecklund G, Axelsson J, Åkerstedt T. Change from an 8-hour shift to a 12-hour shift, attitudes, sleep, sleepiness and performance. Scand J Work Environ Health 1998;24(suppl 3):69–75.
[122] Härmä M, Sallinen M, Ranta R, Mutanen P, Müller K. The effect of an irregular shift system on sleepiness at work in train drivers and railway traffic controllers. J Sleep Res 2002;11:141–51.
[123] Kecklund G, Åkerstedt T. Sleepiness in long distance truck driving: an ambulatory EEG study of night driving. Ergonomics 1993;36:1007–17.
[124] Rosekind MR, Graeber RC, Dinges DF, Connel LJ, Rountree MS, Gillen K. Crew factors in flight operations IX: Effects of planned cockpit rest on crew performance and alertness in longhaul operations. 1995. NASA Technical Memorandum.: Moffett Field, CA. p. 82.
[125] Kecklund G, Åkerstedt T. Effects of timing of shifts on sleepiness and sleep duration. J Sleep Res 1995;4(suppl 2):47–50.
[126] Knauth P, Rutenfranz J. In: Reinberg A, Vieux N, Andlauer P, editors. Duration of sleep related to the type of shift work, in Night and Shift Work: Biological and Social Aspects. Oxford: Pergamon Press; 1981.
[127] Tepas DI. Shiftworker sleep strategies. J Hum Ergol (Tokyo) 1982;11:325–36.
[128] Härmä M, Knauth P, Ilmarinen J. Daytime napping and its effects on alertness and short-term memory performance in shiftworkers. Int Arch Occup Environ Health 1989;61:341–5.
[129] Brandt A. Über den Einfluss der Schichtarbeit auf den Gesundheitszustand und das Krankheitsgeschehen der Werktät. Stud Laboris Salutis 1969;4:124–45.
[130] Angersbach D, Knauth P, Loskant H, Karvonen MJ, Undeutsch K, Rutenfranz J. A retrospective cohort study comparing complaints and disease in day and shift workers. Int Arch Occup Environ Health 1980;45:127–40.
[131] Cruz C, Boquet A, Detwiler C, Nesthus T. Clockwise and counterclockwise rotating shifts: effects on vigilance and performance. Aviat Space Environ Med 2003;74:606–14.
[132] von Amelsvoort LGPM, Jansen NWH, Swaen GMH, van den Brandt PAJ, K.I., Direction of shift rotation among three-shift workers in relation to psychological health and work-family conflict. Scand J Work Environ Health 2004;30:149–56.
[133] Knauth P. Speed and direction of shift rotation. J Sleep Res 1995;4 (suppl 2):41–6.
[134] Wilkinson RT. How fast should the night shift rotate? Ergonomics 1992;35:1425–46.
[135] Skene DJ. Optimization of light and melatonin to phase-shift human circadian rhythms. J Neuroendocrinol 2003;15:438–41.
[136] Smith MR, Lee C, Crowley SJ, Fogg LF, Eastman CI. Morning melatonin has limited benefit as a soporific for daytime sleep after night work. Chronobiol Int 2005;22:873–88.
[137] Lowden A, Åkerstedt T. Sleep and wake patterns in aircrew on a 2-day layover on westward long distance flights. Aviat Space Environ Med 1998;69:596–602.

[138] Smith L, Folkard S, Tucker P, Macdonalad I. Work shift duration: a review comparing eight hour and 12 hour shift systems. Occup Environ Med 1998;55:217–29.
[139] Tucker P, Smith L, Macdonald I, Folkard S. Distribution of rest days in 12 hour shift systems: impact on health, wellbeing, and on shift alertness. Occup Environ Med 1999;56:206–14.
[140] van der Hulst M. Long workhours and health. Scand J Work Environ Health 2003;29:171–88.
[141] Dembe AE, Erickson JB, Delbos RG, Banks SM. The impact of overtime and long work hours on occupational injuries and illnesses: new evidence from the United States. Occup Environ Med 2005;62:588–97.
[142] Schweitzer PK, Randazzo AC, Stone K, Erman M, Walsh JK. Laboratory and field studies of naps and caffeine as practical countermeasures for sleep-wake problems associated with night work. Sleep 2006;29:39–50.
[143] Garbarino S, Mascialino B, Penco MS, Squarcia S, De Carli F, Nobili L, et al. Professional shift-work drivers who adopt prophylactic naps can reduce the risk of car accidents during night work. Sleep 2004;27:1295–302.
[144] Purnell MT, Feyer A-M, Herbison GP. The impact of a nap opportunity during the night shift on the performance and alertness of 12-h shift workers. J Sleep Res 2002;11:219–27.
[145] Lowden A, Åkerstedt T, Wibom R. Suppression of sleepiness and melatonin by bright light exposure during breaks in night work. J Sleep Res 2004;13:37–43.
[146] Boivin DB, James FO. Light treatment and circadian adaptation to shift work. Ind Health 2005;43:34–48.
[147] Santhi N, Duffy JF, Horowitz TS, Czeisler CA. Scheduling of sleep/darkness affects the circadian phase of night shift workers. Neurosci Lett 2005;384:316–20.
[148] Post W, Gatty H. Around the world in eight days. London: John Hamilton; 1931. pPages.
[149] Haimov I, Arendt J. The prevention and treatment of jet lag. Sleep Med Rev 1999;3:229–40.
[150] Spitzer RL, Terman M, Williams JB, Terman JS, Malt UF, Singer F, et al. Jet lag: clinical features, validation of a new syndrome-specific scale, and lack of response to melatonin in a randomized, double-blind trial. Am J Psychiatry 1999;156:1392–6.
[151] Waterhouse J, Nevill A, Edwards B, Godfrey R, Reilly T. The relationship between assessments of jet lag and some of its symptoms. Chronobiol Int 2003;20:1061–73.
[152] Nicholson AN, Pascoe PA, Spencer MB, Stone BMRL. O., Nocturnal sleep and daytime alertness of aircrew after transmeridian flights. Aviat Space Environ Med 1986;57:B42–52.
[153] Sasaki M, Kurosaki Y, Mori A, Endo S. Patterns of sleep-wakefulness before and after transmeridian flight in commercial airline pilots. Aviat Space Environ Med 1986;57:B29–42.
[154] Wegmann HM, Gundel A, Naumann M, Samel A, Schwartz E, Vejvoda M. Sleep, sleepiness and circadian rhythmicity in aircrews operating on transatlantic routes. Aviat Space Environ Med 1986;57:53–64.
[155] Wegmann HM, Klein KE, Conrad B, Esser P. A model for prediction of resynchronization after time-zone flights. Aviat Space Environ Med 1983;54:524–7.
[156] Beh HC, McLaughlin P. Effect of long flights on the cognitive performance of air crew. Percept Mot Skills 1997;84:319–22.
[157] Beh HC, Mclaughlin PJ. Mental performance of air crew following layovers on transzonal flights. Ergonomics 1991;34:123–35.
[158] Foushee HC, Lauber JK, Baetge MM, Acomb DB. Crew factors in flight operations III: The operational significance of exposure to short-haul transport operations, in NASA Techn Memorandum. 1986.
[159] Graeber RC, Foushee HC, Lauber JK. Dimensions of flight crew performance decrements: methodological implications for field research, in Breakdown in Human Adaptation to Stress, J. Cullen H.M. Wegmann, Editors., The Hague M. Nijhoff. 1984; 1.
[160] Preston FS, Bateman SC, Short RV, Wilkinson RT. Effects of time-zone changes on performance and physiology of airline personnel. Aerosp Med 1976;47:763–9.
[161] Klein KE, Wegmann HM. Scheving LE, Halberg F. The effect of transmeridian and transequatorial air travel on psychological well-being and performance, in Chronobiology: Principles and Applications to Shifts in Schedules, LE Scheving F Halberg, Editors., Netherlands Sijthoff and Noordhoff, Alphen aan den Rijn. 1980: p339–352.
[162] Klein KE, Bruner H, Kuklinski P, Rugg S, Wegmann HM. The evaluation of studies of flight personnel of the German Lufthansa on the question of stress during flights on the short European routes. DFVLR Report; 1972. DLR355-74/2.
[163] Simons RM, Valk PJL. Effects of a controlled rest on the flight deck on crew performance and alertness. Netherlands: Aerospace Medical Centre; 1997. p. 31.
[164] Wesensten NJ, Killgore WD, Balkin TJ. Performance and alertness effects of caffeine, dextroamphetamine, and modafinil during sleep deprivation. J Sleep Res 2005;14:255–66.
[165] Samel A, Wegmann H-M. Bright light: a countermeasure for jet lag? Chronobiol Int 1997;14:173–83.
[166] Atkinson G, Drust B, Reilly T, Waterhouse J. The relevance of melatonin to sports medicine and science. Sports Med 2003;33:809–31.
[167] Axelsson J, Åkerstedt T, Kecklund G, Lowden A. Tolerance to shift work— how does it relate to sleep and wakefulness? Int Arch Occup Environ Health 2004;77:121–9.
[168] Drake CL, Roehrs T, Richardson G, Walsh JK, Roth T. Shift work sleep disorder: prevalence and consequences beyond that of symptomatic day workers. Sleep 2005;27:1453–62.
[169] American Academy of Sleep Medicine, The International Classification of Sleep Disorders. Diagnostic and coding manual. American Academy of Sleep Medicine. Westchester, Illinois; 2005.
[170] Axelsson J, Åkerstedt T, Kecklund G, Lindqvist A, Attefors R. Hormonal changes in satisfied and dissatisfied shift workers across a shift cycle. J Appl Physiol 2003;95:2099–105.
[171] Van Dongen HPA, Baynard MD, Maislin G, Dinges DF. Systematic interindividual differences in neurobehavioral impairment from sleep loss: evidence of trait-like differential vulnerability. Sleep 2004;27:423–33.
[172] Eriksen CA, Åkerstedt T, Kecklund G, Åkerstedt A. Comment on short-term variation in subjective sleepiness. Percept Mot Skills 2005;101:943–8.
[173] Gillberg M, Kecklund G, Åkerstedt T. Relations between performance and subjective ratings of sleepiness during a night awake. Sleep 1994;17:236–41.
[174] Dorrian J, Lamond N, Dawson D. The ability to self-monitor performance when fatigued. J Sleep Res 2000;9:137–44.
[175] Dorrian J, Lamond N, Holmes AL, Burgess HJ, Roach GD, Fletcher A, et al. The ability to self-monitor performance during a week of simulated night shifts. Sleep 2003;26:871–7.
[176] Ingre M, Åkerstedt T, Peters B, Anund A, Kecklund G. Subjective sleepiness, simulated driving performance and blink duration: examining individual differences. J Sleep Res 2006;15:47–53.