PERFORMANCE, SLEEP AND CIRCADIAN PHASE DURING A WEEK OF SIMULATED NIGHT WORK

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The current study investigated changes in night-time performance, daytime sleep, and circadian phase during a week of simulated shift work. Fifteen young subjects participated in an adaptation and baseline night sleep, directly followed by seven night shifts. Subjects slept from approximately 0800hr until they naturally awoke. Polysomnographic data was collected for each sleep period. Saliva samples were collected at half hourly intervals, from 2000 hr to bedtime. Each night, performance was tested at hourly intervals. Analysis indicated that there was a significant increase in mean performance across the week. In general, sleep was not negatively affected. Rather, sleep quality appeared to improve across the week. However, total sleep time (TST) for each day sleep was slightly reduced from baseline, resulting in a small cumulative sleep debt of 3.53 (SD = 5.62) hours. Finally, the melatonin profile shifted across the week, resulting in a mean phase delay of 5.5 hours. These findings indicate that when sleep loss is minimized and a circadian phase shift occurs, adaptation of performance can occur during several consecutive night shifts.

Introduction

An issue that usually needs to be taken into consideration when designing shift schedules is the speed of shift rotation. That is, the number of shifts worked consecutively. There is much support for permanent night work to maximize adjustment, rather than rapidly rotating systems which are designed to minimize circadian disruption. However, a primary argument against slow rotation or permanent night work is the evidence suggesting that the circadian rhythms of shiftworkers never completely adjust to shiftwork (DAHLGREEN, 1981; CZEISLER et al., 1990). This is because the timing of the internal circadian rhythms adjust only slowly to changes in the sleep/wake activity, such as those required by shift work (MINORS and WATERHOUSE, 1981; MOORE-EDDE et al., 1982). Specifically, it has been demonstrated that the speed of adjustment to a new circadian phase position is approximately one hour per day, or not at all (MILLS, 1976; WEVER, 1980).

Insufficient adaptation of the circadian system is problematic because it means that shift workers are forced to work during periods when the underlying circadian rhythm of performance is lowest (FOLKARD, 1975; CZEISLER et al., 1980; FOLKARD et al., 1985; DIJK, et al., 1992). Field studies indicate that in general, performance is slower and less accurate on the night shift (BROWNE, 1949; TILLEY et al., 1982). Further difficulties arise for shiftworkers because they are usually attempting to sleep during the day when the body is typically active (MILLS et al., 1974; CARSKADON and DEMENT, 1977; CZEISLER et al., 1980). As a consequence, daytime sleep following a night awake is typically shorter and of poorer quality than night sleep (KNAUTH and RUTENFRANZ, 1975; AKERSTEDT and GILLBERG, 1981; TILLEY et al., 1982). When such sleep disturbances persist across the week, a sleep debt (and consequently sleepiness) may accumulate.
Evidence strongly indicates that cumulative sleep loss is a salient problem among shiftworkers working a series of night shifts (AANONSEN, 1959; RUTENFRANZ et al., 1977). As it exacerbates the circadian performance deficits associated with night work, a large number of both laboratory and field investigations report cumulative sleep loss as a primary cause of the increased accident and lowered productivity over a week of night shifts (DAHLGRENS, 1981; TILLEY et al., 1982 MONK and WAGNER, 1989). In light of such findings, and the fact that maximum fatigue levels are most commonly reported with shift schedules that require long sequences of night shift (FOLKARD, 1981; TILLEY et al., 1982) it has been suggested that working several consecutive nights may be more detrimental than only working one or two nights.

The aim of this study was to investigate changes in performance, sleep quality and quantity, and circadian phase over seven consecutive nights of simulated shift work.

Method

Fifteen healthy individuals, aged 18 to 29 years, participated in the current study. Subjects were non-smokers with no current health problems, and were not taking any medication. They reported no history of sleep problems and did not regularly nap, nor had they undertaken shift work or transmeridian travel in the past month.

Each subject was required to attend the laboratory for nine consecutive nights. The first two nights were an adaptation and a baseline night sleep, directly followed by seven simulated night shifts and the subsequent daytime sleep periods. Throughout the study, participants were permitted to consult timepieces but were not permitted to set alarms. Napping was not permitted during free time or during the night shifts, and participants were required to abstain from caffeine, bananas, raspberry cordial and cheese each night.

From 2300 to 0700hr each night, performance was tested at hourly intervals using a 10-minute visual Psychomotor Vigilance Task (PVT) to evaluate sustained attention. The PVT is reported to have a learning curve of 1-3 trials (Dinges et al., 1997), participants were required to individually attend a short training session prior to the experimental period.

Polysomnographic (PSG) data was collected during all of the sleep periods. Sleep-wake state was assessed using a standard EEG montage. The PSG data was double-scored according to the criteria of RECHTSCHAFFEN and KALES (1969). The measures derived from the PSG data included total sleep time (TST), sleep onset latency (SOL), and wake time after sleep onset (WASO). Sleep efficiency was calculated as the TST/SPT (sleep period time) x 100.

Each night from 2000 hr to bedtime, saliva samples were collected at half-hourly intervals and subsequently assayed for the hormone melatonin using direct radioimmunoassay. The time of nocturnal salivary melatonin onset (dim light melatonin onset, DLMO) was used as a marker of circadian phase. For each participant, the mean (and SD) daytime melatonin concentration was determined using the 2000, 2030 and 2100 hr sample levels from the baseline night and each of the seven night shifts. Melatonin onset was defined as the time at which salivary melatonin concentration reached a level at least two standard deviations greater than the mean daytime level. The DLMO for each participant was determined for the baseline night and each of the seven simulated night shifts. The cumulative phase shift (from the baseline night) of each participant was calculated as the difference between the baseline DLMO and the DLMO for the respective night.

PVT response time scores for each subject were expressed relative to a baseline test score. For each night shift, a single score was obtained by calculating the mean of the eight test scores from that shift. Systematic changes in each of the variables (mean relative performance, PSG indices, and the cumulative phase shift) across the shift week were assessed separately using repeated-measures ANOVA. Due to last session effects, data from the sleep period on day 7 were not included in any of the analyses. Missing values were replaced by the group mean. To evaluate the changes in each sleep variable across the week relative to a 'typical' night sleep, a
second ANOVA was also applied which included the nocturnal baseline sleep. As a repeated measures design was used, the Greenhouse-Geisser procedure was applied to produce more conservative degrees of freedom for all ANOVA analyses.

**Results**

Figure 1 displays mean relative performance during the seven simulated night shifts. There was a significant ($F_{5,70} = 6.76, p = 0.0004$) increase across the week. Post Hoc comparison revealed that performance on shifts 4-7 was significantly better than performance on the first shift.

![Fig. 1. Mean relative performance during the seven simulated night shifts.](image)

TST did not significantly vary across the six daytime sleep periods, nor were there any significant differences between TST on the baseline night and any of the daytime sleeps (Fig. 2a). WASO significantly ($F_{5,70} = 3.38, p = 0.0271$) decreased across the week (Fig. 2b), however WASO during the six daytime sleeps did not significantly differ from the baseline night. SOL significantly ($F_{5,70} = 7.77, p = 0.0003$) increased across the week (Fig. 2c), and SOL for all six of the daytime sleeps was significantly ($p = 0.0001-0.0013$) shorter than on the baseline night. Sleep efficiency showed a trend towards greater efficiency across the week ($F_{5,70} = 2.23, p = 0.058$), however the pattern was not statistically reliable (Fig. 2d). On average, each daytime sleep period was reduced by 35 minutes relative to the baseline sleep, resulting in a small cumulative sleep debt which significantly increased ($F_{5,70} = 5.10, p = 0.0351$) across the week (Fig. 2e). Prior to the final night shift, the mean sleep debt was 3.53 (SD = 5.62) hours. As displayed in Fig. 2f, the melatonin profile significantly shifted ($F_{5,70} = 67.28, p = 0.0001$) across the week.

![Fig. 2. TST (A), WASO (B), SOL (C), Sleep Efficiency (D), Cumulative Sleep Debt (E) and Melatonin Profile (F) during the baseline night and the daytime sleep periods following the seven simulated night shifts.](image)
Discussion

In the current study, night-time performance improved across the seven consecutive simulated night shifts. This sharply contrasts with previous findings investigating the impact of permanent night work on performance. For example, in Tilley and colleagues (1982) study of experienced shiftworkers, a significant deterioration in performance over the course of five consecutive nights was found. Such deterioration in performance was, in large part, due to the loss of 1.5 to 2 hours sleep per day, which resulted in a cumulative sleep debt equivalent to one night of sleep by the end of the week. In the current laboratory study, the shortened daytime sleep characteristic of shiftworkers (KNAUTH and RUTENFRANZ, 1975; AKERSTEDT and GILLBERG, 1981; TILLEY et al., 1982) was not observed. Rather, sleep appeared to improve as the week progressed. Moreover, the daytime sleep periods observed in the current study were not only of equivalent duration to those obtained during the nocturnal baseline, but longer than reported in previous studies of shift workers. As a consequence, the cumulative sleep debt observed in the current study was substantially smaller than has been previously reported, which is one likely reason for the performance adaptation.

It is probable that the comparatively good daytime sleep observed in the current study is at least partly due to the fact that the subjects participating were considerably younger (and probably healthier) than most shiftworkers (REID and DAWSON, 2000). It is also likely that the environmental conditions associated with the study had a reasonable impact on the day sleep also. While not the only contributing factor, environmental disturbances such as noise and light are frequently considered a reason for difficulties encountered when attempting to sleep during the day (THIIS-EVENSEN, 1958; KNAUTH and RUTENFRANZ, 1975). In the current study the participants were provided with very dark and quiet sleeping areas that would have facilitated sound, unbroken sleep. It is worth noting that shortened daytime sleep has previously been reported under similarly optimal laboratory conditions (AKERSTEDT and GILLBERG, 1981). Nonetheless, caution should be taken when generalising the findings of the current study to real working populations who are likely to be older, less healthy and have sleeping environment's that are not as optimal.

The factor that we believe made the biggest impact on daytime sleep was the reduction or absence of competing social factors. Social and domestic factors often greatly influence how much sleep shiftworkers obtain (MONK and WAGNER, 1989). It is clear from studies comparing eight versus twelve hour shifts that night workers regard increased time for social and domestic activities as a major priority (LOWDEN et al., 1998). Thus, sleep may often be curtailed to spend time with friends, family or to complete domestic activities. For example, if a shiftworker has children that need to be cared for, their sleep will probably be shorter than that of colleagues without children. Participants in the current study were encouraged to sleep for as long as they could so that they could more easily maintain wakefulness and work at night. While participants were allowed to leave the laboratory once they had terminated their daytime sleep period, many chose to stay. Indeed, many turned the laboratory into their home for the week, having friends visit them and only leaving for brief periods to get some exercise. Unlike most shiftworkers, none of the participants in the current study had children, nor did many of them have any social or family commitments that needed to be attended to during the study. As such, with minimal competing social factors sleep was their major, and sometimes only, priority. This suggests that with reduced psycho-social input sleep during the day may be as long and as efficient as nocturnal sleep during consecutive night shifts.

A second contributing factor to the adaptation of performance over the shift week was the fact that partial circadian adaptation to the new sleep-wake schedule occurred. According to the data, a mean phase delay of 5.5 hours was observed after six consecutive nights. Phase delays of similar magnitude have been reported in several other laboratory studies of simulated shiftwork with non-natural sunlight exposure (CZEISLER et al., 1990; DAWSON and CAMPBELL, 1991;
HARMA et al., 1994). An improvement in performance in conjunction with circadian adaptation was intuitively expected. While few studies have systematically investigated the relationship between performance and circadian phase in shiftwork, previous research indicates that other detrimental symptoms of night work, such as poor sleep and fatigue, are reduced in individuals that exhibit phase shifts (MARTIN and EASTMAN, 1998). It is apparent from the current study that performance decrements are similarly reduced as individuals progressively adapt to working consecutive nights. However, it is worth noting that performance did not return to baseline levels. As shiftworkers would rarely adapt completely to night work, the fact that performance remained below baseline levels is likely to be representative of real night workers.

In summary, the findings suggest that competing social factors are a primary reason for the reduced daytime sleep quality and quantity of shiftworkers. In the absence of social factors and environmental disturbances, the sleep debt that accumulates during consecutive night shifts is relatively small and thus does not exacerbate decrements in night-time performance resulting from other factors. When partial adaptation of the circadian pacemaker occurs in conjunction with good daytime sleep, performance adaptation may be observed in night workers working several nights. However, as the current study examined young, non-shiftworkers in a laboratory setting, caution should be taken when applying the data collected here to real working conditions.

References


