



Work/rest cycles in railroad operations: effects of shorter than 24-h shift work schedules and on-call schedules on sleep†

JUNE J. PILCHER†* and MICHAEL K. COPLEN§¶

†Department of Psychology, Bradley University, Peoria, IL 61625, USA

§Volpe National Transportation Systems Center, Cambridge, MA 02142, USA

Keywords: Railroad engineers; Shift work; Irregular shifts; On-call schedules; Sleep quantity; Sleep quality.

The current study examined the frequency with which shorter than 24-h work/rest cycles occur in locomotive engineer work schedules, and what effects these work/rest cycles had on sleep quantity and sleep quality. The results indicated that shorter than 24-h work/rest cycles occurred in 33.6% of the work days reported by 198 locomotive engineers. In addition, the shorter than 24-h work/rest cycles occurred more frequently in work schedules that created an on-call work system, such as road pool turn and extra board assignments, than in work schedules that used more predictable or regular work times, such as regular road assignments and yard/local work. As would be expected, when engineers worked shorter than 24-h work/rest cycles, they reported less sleep and poorer sleep than under the longer than 24-h work/rest cycles. Similarly, on-call work assignments resulted in less sleep and poorer sleep than regular work assignments. These results indicate that specific aspects of the work schedules used in railroad operations, particularly on-call operations that result in shorter than 24-h work/rest cycles, can lead to increased sleep-related problems. Although the North American railroad industry is making significant changes in on-call operations to minimize sleep-related problems from on-call schedules, better fatigue-related models validated within the railroad industry are needed.

1. Introduction

Humans are a diurnal species, habitually sleeping at night while working and socializing during the day. Although the human circadian system largely functions on its own internal time structure, it is highly sensitive to temporal changes in the environment, particularly abrupt schedule changes that affect the timing and duration of sleep, such as transcontinental travel and rotating shift work. Numerous laboratory studies have identified three major scheduling factors that affect the structure and composition of sleep, including: (1) time of sleep onset; (2) length of prior wakefulness; and (3) prior sleep loss (Decoster and Foret 1979, Czeisler *et al.*

†The views of the authors do not purport to reflect the position of the Federal Railroad Administration or the Department of Transportation.

*Author for correspondence. e-mail: pilcher@bradley.edu

¶Current address: Office of Research and Development, Federal Railroad Administration, Washington, DC 20590, USA

1980, Strogatz *et al.* 1986, Babkoff *et al.* 1991). In an attempt to understand the impact of these factors on the sleep and subsequent performance of shift workers, applied research has focused mostly on the effects of regularly scheduled shift systems, such as fixed evening shifts, fixed night shifts, rotating shifts, direction of rotation, or rate of rotation (Rutenfranz *et al.* 1977, Winget *et al.* 1978, Colquhoun and Rutenfranz 1980, Knauth *et al.* 1980, Knauth and Rutenfranz 1982, Monk 1986). Relatively few studies have focused on irregular and unpredictable on-call shift systems, such as those found in traditional railroad operations.

The railroad industry is by necessity a continuous service industry, requiring round-the-clock delivery of goods and services to a variety of customers, 365 days a year. Predictable and regular scheduling of freight operations is difficult, if not impossible, to achieve. Enormous variations occur in weather, customer demand, traffic congestion, mechanical failures, and track outages due to planned maintenance, derailments, or other unplanned failures, resulting in frequent and unpredictable delays. Different types of on-call scheduling systems have evolved to accommodate the continuous operations required in railroad operations and the variability of train delays. Consequently, the vast majority of freight locomotive engineers must be available to work on-call with highly unpredictable and irregular hours. A much smaller percentage of locomotive engineers work under more predictable conditions such as in yard/local jobs, regular road assignments, or regularly scheduled passenger trains.

Two major types of on-call work schedules for locomotive engineers are road pool turn assignments and extra board assignments. In both of these assignments, when an engineer signs in for duty at the end of a work shift he or she is put at the bottom of a list, or pool, of names. The engineer at the top of the list will get called out for duty for the first arriving train, the second engineer for the second arriving train, and so on until each person on the list is called. Although patterns may develop, the time of day at which one is called, on either a pool turn assignment or extra board assignment, is fairly random (Foret and Lantin 1972, Reid *et al.* 1997). Regardless, those assigned to a road pool job will always work over the same track, or territory, unless they are called off their pool to fill in for a shortage elsewhere. Those assigned to the extra board seldom work the same track or territory two days in a row, because their function is to fill in for other locomotive engineer job vacancies. Regular road assignments and yard/local jobs have much more predictable work starting and ending times than either the road pool or extra board assignments. Although some minor differences exist between different railroad companies, regular road assignments typically require workers to begin a road job at approximately the same time each work day. Yard/local assignments generally consist of scheduled work days, work shifts and days off.

Although the Federal Hours of Service Act of 1907, 49 USC, 21101-08 (amended in 1989) regulates the maximum number of consecutive hours that can be worked (12 h), and the minimum number of hours that must be provided for rest after a full work shift (8 h), it does not control the regularity of the work/rest cycle, or the maximum number of continuous work days permitted without a day off. Locomotive engineers, for example, can work 12 h and then be required to be back at work 10 h later, resulting in a 22-h work/rest cycle. During periods of high work demand, it is not uncommon for engineers to have a 16- or 18-h work/rest cycle with 8 h off after an 8- or 10-h work shift. The frequency and periodicity of these shorter than 24-h work/rest cycles can

also vary considerably depending on job assignment, length of run, and how job pools are regulated by union agreement.

Clearly, the type of work/rest schedules used in railroad operations, with working hours fairly evenly distributed across the 24-h day (Foret and Lantin 1972, Reid *et al.* 1997), severely limit one's ability to obtain 8 h of sleep a night. For example, engineers working at night are forced to sleep during the day. However, the ability to sleep during the 24-h day, even under sleep deprivation conditions, varies with the internal circadian phase, in that little sleep occurs when the body temperature is rising, usually in the morning and in the late afternoon or early evening hours (Czeisler *et al.* 1980). Not surprisingly, it has been shown that locomotive engineers sleep significantly less during the daytime hours than at night (Torsvall *et al.* 1981).

Also, on-call work/rest schedules that alter either the timing or duration of sleep can lead to significant sleep and circadian rhythm disturbances. For example, without a regular 'anchor' sleep period during a specified time period each day, free-running circadian rhythms can develop (Minors and Waterhouse 1992). Displaced sleep, a common consequence of on-call schedules, can also lead to phase shifting of circadian rhythms (Knauth *et al.* 1981, Åkerstedt 1985) and other circadian rhythm disturbances (Elshaug *et al.* 1998). In addition, the shorter than 24-h work/rest schedules often generated by on-call systems are quite similar to some of the more deleterious types of scheduling systems, such as counter-clockwise rotating shift systems and airline flights that fly in an easterly direction (Aschoff *et al.* 1975, Aschoff 1978, Monk 1986).

These kinds of sleep and circadian rhythm disturbances can also lead to acute and chronic sleep deprivation, which are clearly associated with on-the-job performance decrements. A number of studies have demonstrated reduced alertness, increased sleepiness, and impaired task performance at night and following either total or partial sleep deprivation (Hildebrandt *et al.* 1974, Folkard *et al.* 1978, Hamelin 1987, Krueger 1989, Dinges and Kribbs 1991, Pilcher and Huffcutt 1996). Indeed, research conducted by the Federal Railroad Administration found that shorter than 24-h work/rest cycles impair performance of locomotive engineers on a locomotive simulator (Thomas *et al.* 1997). Moreover, fatigue resulting from irregular work/rest schedules has been implicated in a number of catastrophic railroad accidents (Lauber and Kayten 1988, Smiley 1990, National Transportation Safety Board [NTSB] 1991).

Although the sleep and circadian rhythm literature suggests that on-call work/rest cycles typical of locomotive engineers may be a serious threat to employee and public safety, as well as the productivity of railroad operations, few published studies have actually examined on-call work/rest cycles in the railroad industry. Most studies of locomotive engineers have focused on issues such as sleepiness (Torsvall and Åkerstedt 1987), circadian performance rhythms (Hildebrandt *et al.* 1974), sleep disturbances (Åkerstedt *et al.* 1983), and sleep length (Dekker *et al.* 1993). Only one study specifically examined the periodicity of work/rest cycles among locomotive engineers (Parrot and Petiot 1978). Although Parrot and Petiot found that work/rest cycles with a period length of less than 24-h occurred frequently in the French railroad industry, it is still not known how often shorter than 24-h work/rest cycles occur in different types of job assignments, or how often shorter than 24-h work/rest cycles occur among locomotive engineers in the USA.

The current study addresses four specific questions concerning shorter than 24-h work/rest schedules among locomotive engineers: (1) how often do shorter than 24-h

work/rest cycles occur among locomotive engineers in the USA?; (2) how often do these shorter than 24-h work/rest cycles occur within different on-call job assignments?; (3) to what extent do the shorter than 24-h work/rest cycles affect sleep quantity and sleep quality?; and (4) how do different on-call job assignments with differing frequencies of shorter than 24-h work/rest cycles affect sleep quantity and sleep quality?

2. Method

2.1. Participants

Volunteers were solicited from six major railroads. A total of 204 activity logs (described below) were gathered from locomotive engineers. Of these, five had numerous missing days and were excluded from the study. Therefore, the data set used in the current analysis included the data from 198 volunteers (195 males, 3 females). The mean age of the participants was 44.01 years ($SD = 6.67$ years). One page was missing from two of the diaries, therefore the data set used in the current analysis included 2770 days of work and rest data.

The 198 volunteers who successfully completed the activity log in the current study represent a sample of the almost 800 engineers initially contacted. It is conceivable that those engineers who actually completed the activity logs were interested in doing so because they experienced more sleep problems or worse work schedules than the engineers who did not choose to complete the activity logs. However, one indication of the robustness of the current sample is that the age and gender of the current sample are representative of the general population of engineers. Another indication is that the work assignments reported by the engineers in the current study were representative of the general population of engineers. In line with the general population of railroad engineers, most of the volunteers in the current sample reported working on schedules involving on-call duty (i.e. road pool turns and extra boards) while fewer of the volunteers reported working more predictable work assignments (i.e. regular road and yard/local). More specifically, a total of 162 of the 198 engineers reported working under on-call assignments; 115 engineers (age: 44.64 ± 6.62 years) on road pool turn assignments and 47 engineers (age: 41.64 ± 5.33 years) on extra board assignments. In contrast, 36 engineers reported working under regular assignments; 19 engineers (age: 48.37 ± 6.80 years) on road assignments and 17 engineers (age: 41.41 ± 7.29 years) on yard or local assignments.

2.2. Procedures

The participants were contacted through their unions or management. Union and management representatives helped to choose the terminals where the activity logs would be distributed. Potential participants were approached by an experimenter and were given an introductory letter from their union briefly describing the 14-day activity log. Volunteers were given the activity log with an accompanying instruction sheet and a business reply envelope in which to return the log. The participants were instructed to complete the activity logs for 14 days, starting and ending at midnight.

The locomotive engineers provided information on their activity for each 24-h day. They supplied times when they initiated any of the following activities: sleep at home, sleep away from home, working, commuting to work, and personal time. Thus, the logs provided a means of examining when each of these activities began in the 24-h period and the duration of each of these activities. In addition, three

additional measures related to sleep were completed for each 24-h period: (1) the participant's ability to go to sleep (1 = easily to 5 = not at all); (2) the participant's ability to stay asleep (1 = easily to 5 = not at all); and (3) how well rested the participant felt upon awakening (1 = well rested to 4 = not at all rested). Finally, the participants provided the times they went on and off duty within each 24-h period. A more complete description of the activity logs is available in a previous report (Pollard 1996). All data from the activity logs were encoded for data analysis by number only, thus ensuring confidentiality.

2.3. Data analyses

The activity log data were downloaded into SAS (SAS Institute Inc., NC, USA) for analysis. Of the 2770 days of reported activity, 698 days did not include any duty time. The current study was designed to examine the effects of specific types of work schedules on sleep during each 24-h period in which the engineers were required to modify their sleeping patterns around their work demands, therefore the days where no duty time occurred were eliminated from further analysis. An additional 151 days were eliminated from the data set, where the participants did not provide enough information to determine a complete work/rest cycle (e.g. the participants reported being on duty at midnight of the first day of the activity log, but did not report how long they had been on duty at that point). Therefore, the data set used for the current analyses consisted of 1921 work days. Not all participants filled in each part of the activity log for each day, resulting in fewer observations for some variables than others. There was no clear pattern to the missing data and the data from the participants who did not complete every aspect of the form were not different from the remaining data, therefore it was decided to analyse the data for all participants.

The first major step of analysis involved calculating specific work and rest data for each 24-h period in the data set. First, total time on duty, time asleep at home, time asleep away from home, and total time asleep were calculated. Second, the time from work onset to work onset was calculated, creating a variable indicating whether the time elapsed between work onsets was shorter than 24-h (a ST 24-h work/rest cycle) or greater than or equal to 24-h (a GE 24-h work/rest cycle).

The second major step of analysis was to determine whether sleep-related variables differed by work/rest cycle or by work assignment category. As one indication of how sleep was affected by work schedules and assignments, the percentage of days under ST 24-h work/rest cycles and under GE 24-h work/rest cycles where no sleep was reported were calculated. In addition, the percentage of days with no sleep across all work assignments and for on-call (road pool turn and extra board) and regular (regular road and yard/local) assignment categories were determined. Second, the number of days requiring a ST 24-h work/rest cycle across the two categories of work assignments was calculated. Third, the frequency of on-call and regular assignments and the frequency with which each of the assignments required a ST 24-h work/rest cycle was assessed. To examine whether ST 24-h work/rest cycles differed significantly between the work assignment categories, a one-way ANOVA using work assignment categories as the factor for the ST 24-h variable was completed. Finally, a MANOVA using the work assignment categories and the ST 24-h variable as factors for time asleep at the home terminal, time asleep at the away terminal, total time asleep, difficulty in going to sleep, difficulty in staying asleep, and feeling rested upon awakening was completed. Tukey's Studentized range statistic, which accounted for the different number of participants in each factor grouping,

was used for *post hoc* analyses to identify the source of significant main effects. An α level of 0.05 was used for all *post hoc* analyses.

3. Results

The locomotive engineers in this sample reported sleeping a mean of 7.18 h (SD = 2.3 h) each day. In addition, they reported working a mean of 7.51 h (SD = 3.3 h) in each 24-h period on those days when duty time was reported. It is interesting to note that the engineers reported no duty time during 698 days of the total 2770 days recorded. Thus, 25.2% of the total number of days from the activity logs did not contain work time. As a comparison, the average worker, working 5 days out of 7, has approximately 28.6% of off-duty time during each work week.

Although the engineers in this sample reported sleeping approximately 7 h during each 24-h day when averaged across a 14-day period, engineers often reported much less than 7 h of sleep in a 24-h period. For example, the engineers in the current sample reported sleeping less than 5 h in a 24-h period for 13.0% of reported work days. Furthermore, they reported no sleep during 1.2% of the work days. It is also interesting to note that many of the engineers sleep away from their homes on a regular basis. For instance, when looking only at sleep reported at home, engineers reported less than 5 h in a 24-h period for 46.8% of the work days and no sleep at all for 19.8% of the work days. Therefore, the locomotive engineers in the current sample obtain a substantial amount of their sleep away from their home.

3.1. Analysis by ST 24-h variable

A work/rest cycle of shorter than 24-h occurred remarkably often in the current data set. The percentage of work days with a ST 24-h work/rest cycle across all work assignments was 33.6% as indicated in table 1. The distribution of the ST 24-h work/rest cycles across the two categories of work assignments is shown in table 1. The one-factor ANOVA indicated that on-call assignments required ST 24-h work/rest cycles significantly more often than regular assignments [$F(1, 1919) = 16.69$, $p < 0.0001$].

Figure 1 shows the amount of sleep at the home terminal, the amount of sleep at the away terminal and the total amount of sleep for the ST 24-h work/rest cycles and the GE 24-h work/rest cycles. The engineers on a ST 24-h work/rest cycle reported less sleep at the home terminal than at the away terminal and less total sleep than those under the GE 24-h work/rest cycle. When analysed by a two-factor MANOVA, the participants reported significantly less sleep at the home terminal [$F(1, 1917) = 198.79$, $p < 0.0001$], more sleep at the away terminal [$F(1,$

Table 1. Frequency of shorter than 24-h work/rest cycles.

Work assignment	Number of engineers	Total number of work days	Days with shorter than 24 h work/rest cycle	Percentage of work days with shorter than 24 h cycle
All assignments	198	1921	645	33.6
On-call assignments	162	1571	560	35.6
Regular assignments	36	350	85	24.3

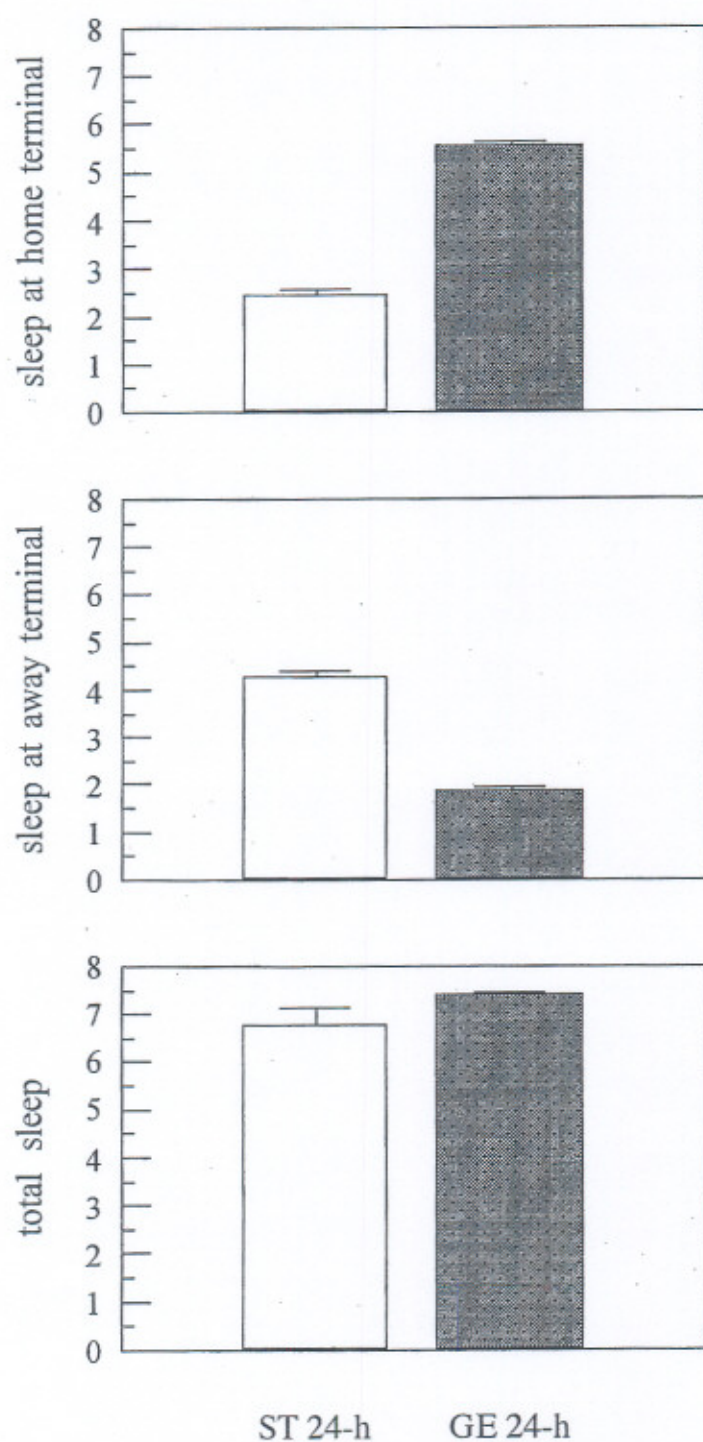


Figure 1. Amount of sleep at the home terminal, sleep at the away terminal, and total sleep by length of the work/rest cycle. ST 24-h = shorter than 24-h work/rest cycle; GE 24-h = greater than or equal to 24-h work/rest cycle.

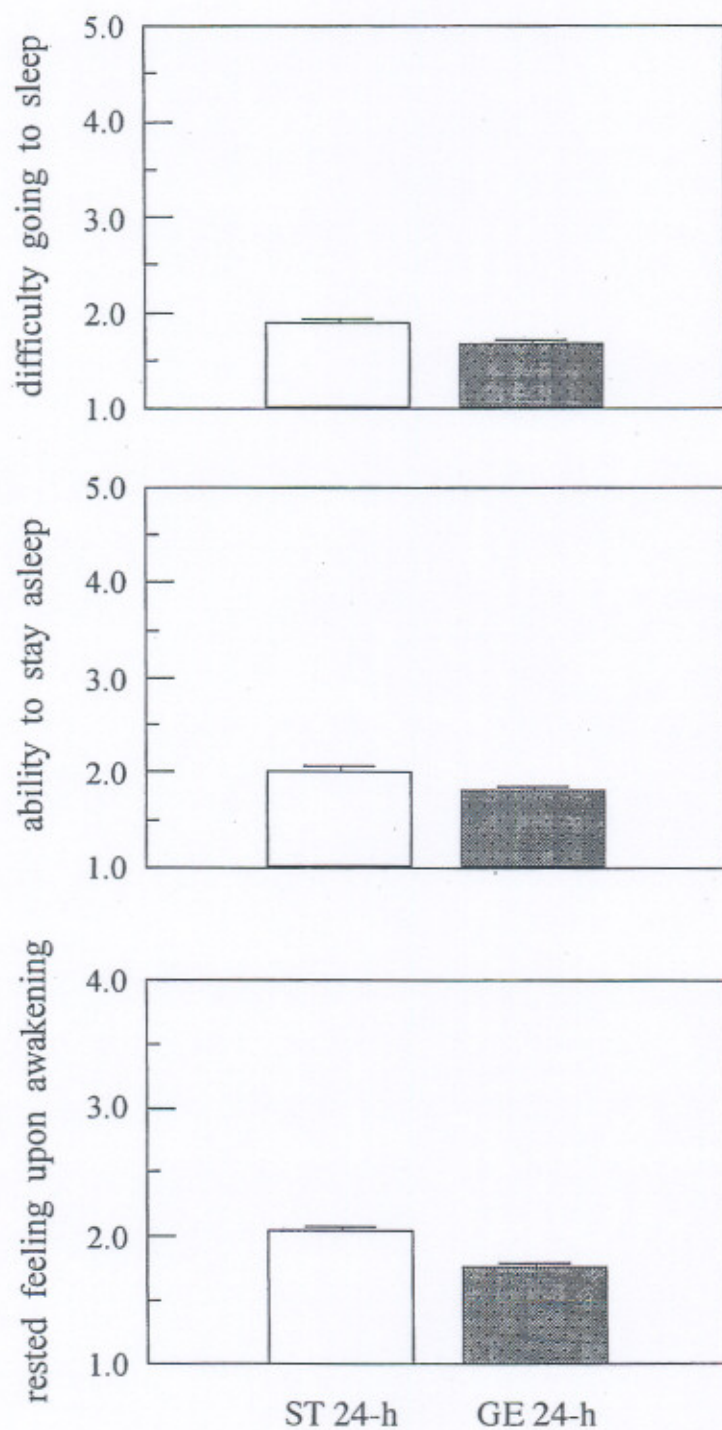


Figure 2. Sleep quality measures of difficulty in going to sleep, ability to stay asleep, and rested feeling upon awakening by length of the work/rest cycle. ST 24-h = shorter than 24-h work/rest cycle; GE 24-h = greater than or equal to 24-h work/rest cycle.

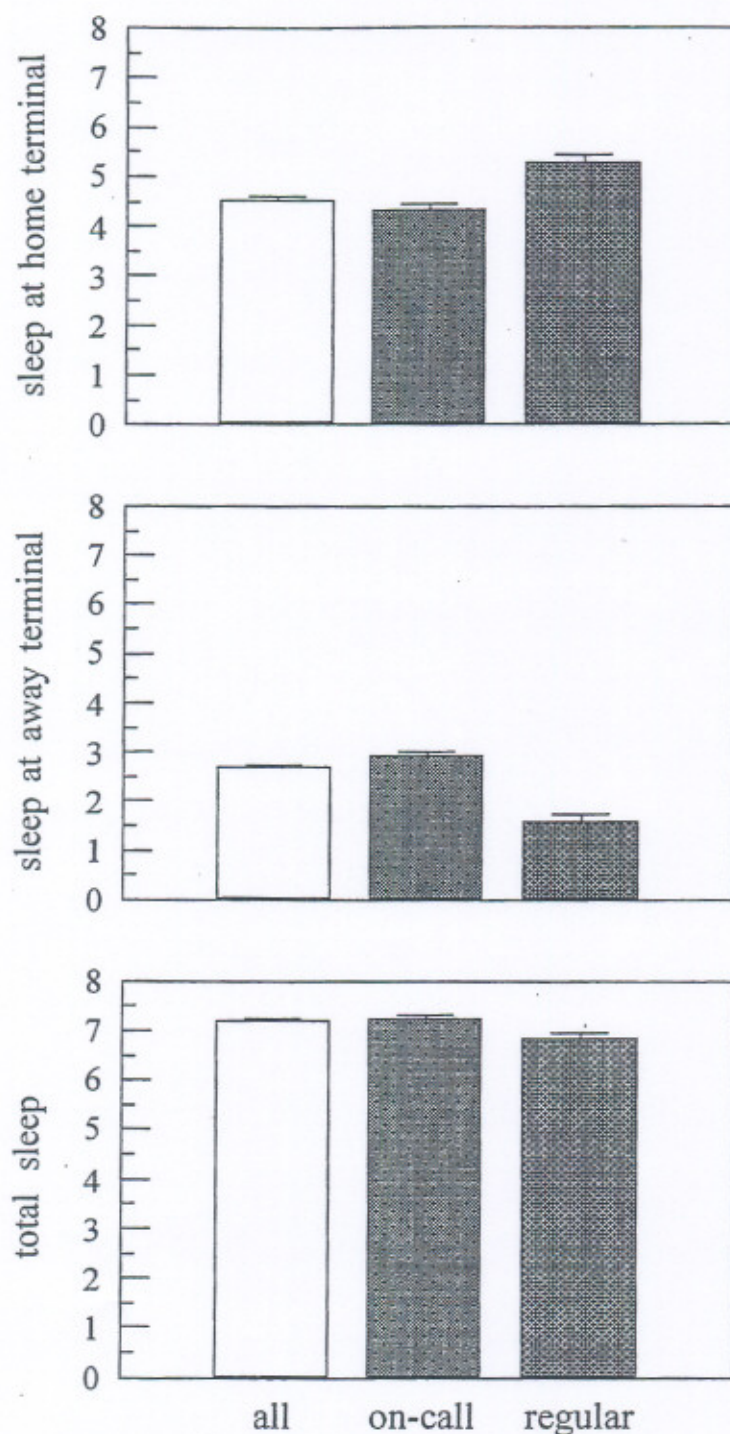


Figure 3. Amount of sleep at the home terminal, sleep at the away terminal, and total sleep by work assignment category. All = data collapsed across work assignment categories; on-call = on-call assignments (road pool and extra board assignments); regular = regular assignments (road and yard/local assignments).

1917) = 126.01, $p < 0.0001$] and less total sleep [$F(1, 1917) = 17.31$, $p < 0.0001$] when working on a ST 24-h work/rest cycle than a GE 24-h work/rest cycle.

As shown in figure 2, ST 24-h work/rest conditions resulted in more difficulty going to sleep and staying asleep in addition to a less rested feeling upon awakening than GE 24-h work/rest conditions. When analysed by a two-factor MANOVA, the participants reported significantly more difficulty in staying asleep [$F(1, 1128) = 4.65$, $p < 0.05$] and a significantly less rested feeling upon awakening [$F(1, 1733) = 18.35$, $p < 0.0001$] under ST 24-h work/rest cycles than GE 24-h work/rest cycles. Although there was a trend for more difficulty in going to sleep under the ST 24-h work/rest conditions than under the GE 24-h work/rest condition, the difference between the two groups was not statistically significant.

3.2. Analysis by work assignment

The amount of sleep as well as where sleep took place differed by the work assignment categories (figure 3). Engineers working on on-call assignments reported less sleep at the home terminal but more sleep at the away terminal than engineers on regular assignments. The participants on on-call assignments obtained more total sleep than workers on regular schedules, due to the increased amount of sleep at the away terminal. When analysed by a two-factor MANOVA, sleep at home [$F(1, 1917) = 8.75$, $p < 0.01$], sleep away from home [$F(1, 1917) = 26.93$, $p < 0.0001$] and total sleep [$F(1, 1917) = 8.26$, $p < 0.01$] differed by work assignment category. Post hoc analysis revealed that on-call assignments resulted in significantly less sleep at the home terminal but more sleep at the away terminal and more total sleep than regular assignments.

The measures of sleep quality for each category of work assignment are shown in figure 4. In general, the engineers on regular schedules reported better sleep quality than those on on-call schedules. When analysed by a two-factor MANOVA, on-call conditions resulted in significantly more difficulty in going to sleep [$F(1, 1743) = 9.15$, $p < 0.01$] and staying asleep [$F(1, 1128) = 11.51$, $p < 0.001$] than regular schedules. In contrast, there was no significant difference between on-call and regular schedules on the feeling rested upon awakening variable. Therefore, although engineers working on on-call schedules were sleeping more than engineers on regular schedules, on-call engineers reported more difficulty in going to sleep and staying asleep than the engineers who were working regular schedules.

The interaction between work assignment category and the ST 24-h work/rest cycle variable was also tested for each of the sleep-related variables. The interaction was only significant for difficulty in going to sleep [$F(1, 1743) = 5.78$, $p < 0.05$], indicating that the effect of the ST 24-h work/rest condition on sleep at home depended upon the work assignment category.

4. Discussion

The current results indicated that shorter than 24-h work/rest cycles occurred in approximately 33% of work days reported by 198 locomotive engineers from several major US railroads. Engineers reported less sleep and poorer sleep when working under shorter than 24-h work/rest cycles than when working under work/rest cycles of at least 24 h. For example, they were more likely to report no sleep when working under shorter than 24-h work/rest cycles than when working under longer work/rest cycles. Furthermore, the current results demonstrated that the frequency of shorter

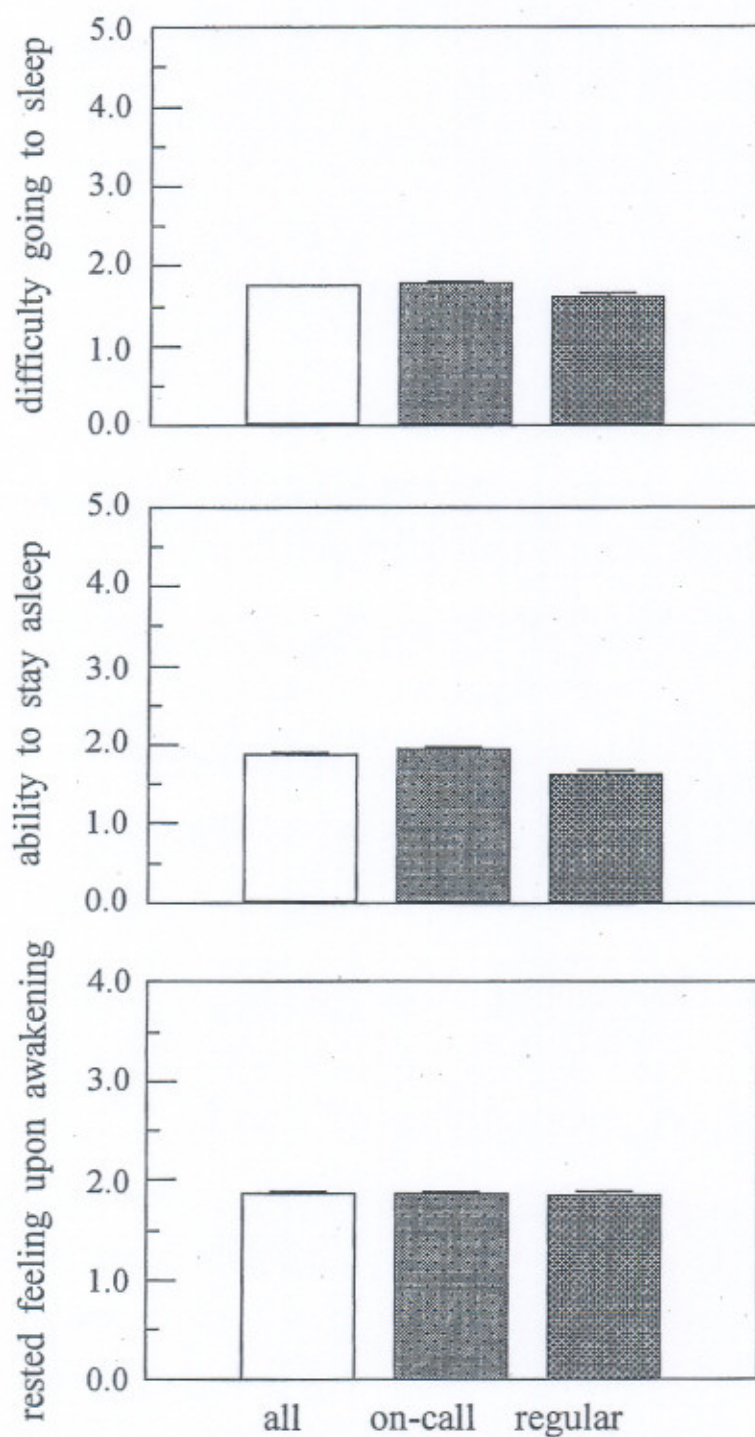


Figure 4. Sleep quality measures of difficulty in going to sleep, ability to stay asleep, and rested feeling upon awakening by work assignment category. All = data collapsed across work assignment categories; on-call = on-call assignments (road pool and extra board assignments); regular = regular assignments (road and yard/local assignments).

than 24-h work/rest cycles depended upon the type of work scheduling. On-call extra board and road pool assignments had a higher frequency of shorter than 24-h work/rest cycles than other, more predictable, on-call or regularly scheduled assignments.

Although the current data are in general agreement with the earlier study by Parrot and Petiot (1978), the prevalence of shorter than 24-h work/rest cycles differed between the two studies. They reported that shorter than 24-h work/rest cycles occurred in approximately 85% of the days reported by their four engineers. This obviously contrasts with the present finding that 33% of work days had shorter than 24-h work/rest cycles. One likely explanation for this discrepancy is that the engineers in the Parrot and Petiot (1978) sample reported regularly scheduled days off, while most of the engineers in the current sample worked under on-call systems that did not permit regularly scheduled days off. Scheduled days off would directly affect the frequency at which engineers are required to work. For example, if the same number of trains were scheduled to run over a specified period using a limited number of engineers, an on-call system with scheduled days off would require engineers to work more often during consecutive work days than an on-call system without scheduled days off, and would therefore have a higher frequency of shorter than 24-h work/rest cycles.

The current data clearly indicate that working under shorter than 24-h work/rest cycles is detrimental to the maintenance of good sleep habits. In general, engineers sleep less when they work a shorter than 24-h work/rest cycle compared to when they work a longer work/rest cycle. Also, they sleep more away from home than they do at home, suggesting a condition of long-term partial sleep deprivation at their home terminal with recovery sleep at their away terminal. Engineers working under a shorter than 24-h work/rest cycle also reported poorer sleep quality than they did when working on a greater than or equal to 24-h work/rest cycle. However, this poorer sleep quality may be a reflection of the fact that the engineers working under shorter than 24-h work/rest cycles are actually sleeping more away from home where they are less likely to sleep as well.

The robust nature of the circadian sleep/wake cycle provides the most plausible explanation for the sleep difficulties experienced by engineers working under shorter than 24-h work/rest cycles. Shorter than 24-h work/rest cycles require the worker to adapt to counterclockwise work schedules that are often outside the range of biological entrainment. The endogenous biological clock approximates a 25-h cycle and is synchronized each day by the exogenous 24-h light/dark cycle and the timing of sleep, therefore adaptation to irregular shorter than 24-h work/rest cycles may be difficult, if not impossible. The current data support this theory, as do several studies using workers from regularly rotating shift work schedules (Mills *et al.* 1978, Czeisler *et al.* 1982, Knauth and Rutenfranz 1982, Orth-Gomer 1983).

In addition to providing information about the frequency and effects of shorter than 24-h work/rest cycles, the current data provide a comparison of on-call and regular shift work schedules used in the US railroad industry. Since on-call schedules resulted in a greater percentage of work days with shorter than 24-h work/rest cycles, one would expect on-call schedules to also result in sleep difficulties. Unexpectedly, the findings reported here show that on-call schedules did not have an effect on mean sleep quantity, although they did have an effect on sleep quality. However, when the results were further analysed it was found that while on-call workers reported more total sleep overall than those on more regular schedules, they had less sleep at their home terminal. These unexpected results are due to the significant increase in sleep

reported at the away terminal by on-call workers. Therefore, on-call schedules appear to result in an inadequate amount of sleep at home, and thus an increased reliance on recovery sleep at the away terminal in comparison to more regular working schedules.

This increased reliance on sleep at the away terminal under on-call conditions may also be encouraged by social factors. Without the presence of family and social obligations at their away terminal, engineers may not only have more time available for sleeping but also fewer sleep disruptions than when they sleep at their home terminal.

The current results suggest a number of practical applications to on-call work scheduling in the railroad industry. First, it is clear that on-call operations in general result in poorer quality sleep than more regular shift work schedules, suggesting a general need to develop improved on-call work/rest systems in the railroad industry. Second, it is also clear that when on-call employees work shorter than 24-h work/rest cycles they get significantly less sleep, suggesting a specific need to consider the frequency of shorter than 24-h work/rest cycles when redesigning or modifying on-call work/rest systems in railroad operations. Since the current Federal Hours of Service Act (1989) allows for shorter than 24-h work/rest cycles to occur in up to 100% of an employee's work days this issue is of particular importance. Extra attention should be paid to extra board and other on-call assignments that are more likely to result in these short cycles. Detailed staffing analysis may also provide helpful predictors of shorter than 24-h work/rest cycles where seasonal conditions and other factors are likely to result in crew shortages, thus intensifying overall work demand and a shortening of average work/rest cycles.

An additional relatively simple, but important, consideration is the sleeping conditions provided at the away terminal. The conditions of the sleeping environment at the away terminal are of particular importance because both the shorter than 24-h work/rest cycles and the on-call schedules require the engineers to obtain much of their daily sleep there. Interventions would include using a cool, dark, and quiet sleeping environment that often can be simply and inexpensively accommodated. For example, room darkening shades, fans or white noise machines, and a functioning heating and air-conditioning system can frequently minimize sleep disturbances in many lodging facilities.

In recent years, the Association of American Railroads formed a work/rest task force to study potential fatigue countermeasures and to evaluate feasible solutions. After the formation of this task force, railroad management began making significant changes to the traditional on-call system of railroad operations. A number of pilot programmes have been implemented, including: calling windows (limited time blocks during which an engineer can be called to duty), scheduled days off systems for on-call employees, on-duty napping policies, and improvements in lodging facilities, among others. However, little available published research documents the effects of these improvements on sleep quantity or quality. Furthermore, reports of research within the railroad industry have usually measured the combined effects of comprehensive programmes, thus limiting the ability to determine the effectiveness of any single programme change.

As the traditional on-call work schedules in the railroad industry evolve toward hybrid on-call work systems with more regular work/rest patterns, it becomes increasingly necessary to develop better fatigue and alertness models to help to guide the development of these innovative scheduling practices. Although the current trend

toward calling windows and scheduled days off in on-call operations will help to improve sleep and reduce fatigue among operating employees, better schedule design guidelines are necessary to maximize overall benefits and minimize any unintentional negative effects. For example, calling windows may help to alleviate the inherent irregularity and unpredictability of existing on-call work schedules in locomotive engineers. However, without basic criteria to help to minimize the frequency of shorter than 24-h work/rest cycles, calling windows can still result in relatively fatigued employees. Similarly, scheduled days off systems may help workers to minimize their cumulative sleep debt during days off, but scheduled days off do little to help the workers to manage their acute sleep and circadian rhythm disruptions during consecutive work days. In fact, scheduled days off systems are likely to shorten the average work/rest cycle under current union work agreements. Consequently, it is possible that the implementation of an on-call system with scheduled days off may reduce cumulative sleep debt, but at the cost of increasing acute sleep debt and other sleep problems by increasing the frequency of shorter than 24-h work/rest cycles during consecutive work days.

As US railroads continue to develop new schedule systems to combat fatigue in on-call operations, better predictors of fatigue are needed to serve as schedule design guidelines. Fatigue and alertness models should not only include factors that account for the effects of sleep deprivation (both acute and cumulative) and circadian time of day, they should also include factors that account for the sleep-related effects of on-call and irregular work hours, particularly shorter than 24-h work/rest cycles.

In conclusion, the current study found that shorter than 24-h work/rest cycles occurred remarkably often among a sample of locomotive engineers and that these work conditions resulted in less sleep and poorer sleep quality. Furthermore, the work schedules that used on-call scheduling resulted in a greater frequency of shorter than 24-h work/rest cycles than the schedules that used more predictable work shifts. Although on-call schedules and shorter than 24-h work/rest cycles are used frequently in the US railroad industry, their effects on alertness and performance are not clearly understood. The effects of on-call schedules and schedules resulting in shorter than 24-h work/rest cycles need to be more thoroughly researched in an effort to establish sleep and alertness models that account for irregular working and sleeping times. With valid predictive models as guides, the railroad industry would have a wide variety of non-prescriptive and non-regulatory options to consider when implementing schedule changes in on-call operations.

Acknowledgements

The authors wish to thank John K. Pollard for his efforts in the collection and initial entry of the data used in the current study.

References

- ÅKERSTEDT, T. 1985, Shifted sleep hours, *Annals of Clinical Research*, **17**, 273-279.
- ÅKERSTEDT, T., TORSVALL, L. and FROBERG, J. 1983, A questionnaire study of irregular work hours and sleep/wake disturbances, *Sleep Research*, **12**, 353.
- ASCHOFF, J. 1978, Features of circadian rhythms relevant for the design of shift schedules, *Ergonomics*, **21**, 739-754.
- ASCHOFF, J., HOFFMANN, K., HERMANN, P. and WEVER, R. 1975, Re-entrainment of circadian rhythms after phase-shifts of the zeitgeber, *Chronobiologia*, **2**, 23-78.

- BABKOFF, H., CASPY, T., MIKULINER, M. and SING, H. C. 1991, Monotonic and rhythmic influences: a challenge for sleep deprivation research, *Psychological Bulletin*, **109**, 411-428.
- COLQUHOUN, W. P. and RUTENFRANZ, J. (eds) 1980, *Studies of Shiftwork* (London: Taylor & Francis).
- CZEISLER, C. A., MOORE-EDE, M. C. and COLEMAN, R. M. 1982, Rotating shift work schedules that disrupt sleep are improved by applying circadian principles, *Science*, **217**, 460-463.
- CZEISLER, C. A., WEITZMAN, E. D. and MOORE-EDE, M. C. 1980, Human sleep: its duration and organization depend on its circadian phase, *Science*, **210**, 1264-1267.
- DECOSTER, F. and FORET, J. 1979, Sleep onset and first cycle of sleep in human subjects: change with time of day, *Electroencephalography and Clinical Neurophysiology*, **46**, 531-537.
- DEKKER, D. K., PALEY, M. J., POPKIN, S. M. and TEPAS, D. I. 1993, Locomotive engineers and their spouses: coffee consumption, mood, and sleep reports, *Ergonomics*, **36**, 233-238.
- DINGES, D. F. and KRIBBS, N. B. 1991, Performing while sleepy: effects of experimentally induced sleepiness. In T. H. Monk (ed.), *Sleep, Sleepiness, and Performance* (Chichester: Wiley), 97-128.
- ELSHAUG, A., REID, K. and DAMSON, D. 1998, The circadian effects of irregular shiftwork, *Sleep*, **21** (Suppl.), 221.
- FOLKARD, S., MONK, T. H. and LOBBAN, M. C. 1978, Short and long term adjustment of circadian rhythms in permanent night nurses, *Ergonomics*, **21**, 783-799.
- FORET, J. and LANTIN, G. 1972, The sleep of train drivers: an example of the effects of irregular work schedules on sleep. In W. P. Colquhoun (ed.), *Aspects of Human Efficiency* (London: English Universities), 273-282.
- HAMELIN, P. 1987, Lorry drivers' time habits in work and their involvement in traffic accidents, *Ergonomics*, **30**, 1323-1333.
- HILDEBRANDT, G., ROHMERT, W. and RUTENFRANZ, J. 1974, Twelve and 24-hour rhythms in error frequency of locomotive drivers under the influence of tiredness, *International Journal of Chronobiology*, **2**, 175-180.
- KNAUTH, P. and RUTENFRANZ, J. 1982, Development of criteria for the design of shiftwork systems, *Journal of Human Ergology*, **11**(Suppl.), 337-367.
- KNAUTH, P., EMDE, E., RUTENFRANZ, J., KIESSWETTER, E. and SMITH, P. 1981, Re-entrainment of body temperature in field studies of shiftwork, *International Archives of Occupational and Environmental Health*, **49**, 137-149.
- KNAUTH, P., LANDAU, K., DROGE, C., SCHWITTECK, M., WIDYNSKI, M. and RUTENFRANZ, J. 1980, Duration of sleep depending on the type of shift work, *International Archives of Occupational and Environmental Health*, **46**, 167-177.
- KRUEGER, G. P. 1989, Sustained work, fatigue, sleep loss and performance: a review of the issues, *Work & Stress*, **3**, 129-141.
- LAUBER, J. K. and KAYTEN, P. J. 1988, Sleepiness, circadian dysrhythmia, and fatigue in transportation system accidents, *Sleep*, **11**, 503-512.
- MILLS, J. N., MINORS, D. S. and WATERHOUSE, J. M. 1978, Exogenous and endogenous influences on rhythms after sudden time shift, *Ergonomics*, **21**, 755-761.
- MINORS, D. S. and WATERHOUSE, J. M. 1992, The impact of irregular sleep-wake schedules on circadian rhythms and the role of 'anchor' sleep. In C. Stampi (ed.), *Why We Nap. Evolution, Chronobiology, and Functions of Polyphasic and Ultrashort Sleep* (Boston: Birkhauser), 82-101.
- MONK, T. 1986, Advantages and disadvantages of rapidly rotating shift schedules—a circadian viewpoint, *Human Factors*, **23**, 553-557.
- National Transportation Safety Board [NTSB] 1991, Railroad accident report: Atchison, Topeka and Santa Fe Railway Company (ATSF) freight trains ATSF 818 and ATSF 891 on the ATSF Railway, Corona, California, November 7, 1990 (Report Nos. PR91-916303, NTSB/RAR-91/03). Washington, DC: National Transportation Safety Board.
- ORTH-GOMER, K. 1983, Intervention on coronary risk factors by adapting a shift-work schedule to biologic rhythmicity, *Psychosomatic Medicine*, **45**, 407-415.
- PARROT, J. and PETIOT, J. 1978, Less than 24 hour pseudo-periodicity in work schedules of train drivers, in relation to their sleep, *International Archives of Occupational and Environmental Health*, **41**, 179-188.

- PILCHER, J. J. and HUFFCUTT, A. I. 1996, Effects of sleep deprivation on performance: a meta-analysis, *Sleep*, **19**, 318-326.
- POLLARD, J. K. 1996, Locomotive engineer's activity diary (Report Nos. DOT/FRA/RPP-9602, DOT-VNTSC-FRA-96-12). Washington, DC: Federal Railroad Administration, US Department of Transportation.
- REID, K., ROACH, G. and DAWSON, D. 1997, The proportion of time spent sleeping and working across the day in train drivers working irregular hours, *Sleep Research*, **26**, 747.
- RUTENFRANZ, J., COLOQUHOUN, W. P., KNAUTH, P. and GHATA, J. N. 1977, Biomedical and social aspects of shiftwork: a review, *Scandinavian Journal of Work, Environment and Health*, **3**, 165-181.
- SMILEY, A. M. 1990, The Hinton train disaster, *Accident Analysis and Prevention*, **22**, 443-455.
- STROGATZ, S. H., KRONAUER, R. E. and CZEISLER, C. A. 1986, Circadian regulation dominates homeostatic control of sleep length and prior wake length in humans, *Sleep*, **9**, 353-364.
- THOMAS, G. R., RASLEAR, T. G. and KUEHN, G. I. 1997, The effects of work schedule on train handling performance and sleep of locomotive engineers: a simulator study (Report No. DOT/FRA ORD-97-09). Washington, DC: Federal Railroad Administration, US Department of Transportation.
- TORSVALL, L. and ÅKERSTEDT, T. 1987, Sleepiness on the job: continuously measured EEG changes in train drivers, *Electroencephalography and Clinical Neurophysiology*, **66**, 502-511.
- TORSVALL, L., ÅKERSTEDT, T. and GILLBERG, M. 1981, Age, sleep and irregular work hours, *Scandinavian Journal of Work, Environment and Health*, **7**, 196-203.
- WINGET, C. M., HUGES, L. and LADOU, J. 1978, Physiological effects of rotational shiftworking: a review, *Journal of Occupational Medicine*, **20**, 204-210.