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Effect of Day Length on Sleep Habits and Subjective On-Duty Alertness in Irregular Work Schedules

June J. Pilcher, Heather M. Teichman, Stephen M. Popkin, Krista R. Hildebrand, and Michael K. Coplen

The human circadian system is sensitive to environmental conditions, such as those created by shift work, that affect the timing and duration of sleep. Previous research on the effects of shift work, however, has focused primarily on regularly scheduled shifts. Few studies have focused on irregular and unpredictable on-call shift systems, such as those found in much of railroad operations. The purpose of the current study was to examine the effect of irregular shift systems experienced by locomotive engineers on the length of sleep-wake periods and the effect of different length sleep-wake periods on self-reported sleep quantity, sleep quality, and on-duty alertness. A total of 179 locomotive engineers provided information on work times, sleep habits, and on-duty alertness as part of a 14-day activity log. Sleep-wake periods were first divided into three categories: short (<22 h), normal (22 to 26 h, inclusive), and long (>26 h). A one-way analysis of variance for multiple variables was completed on sleep quantity, sleep quality, and on-duty alertness by using the three sleep-wake period categories as the factor. The results indicated that normal-length periods occurred in less than half of the sleep-wake periods. The remaining sleep-wake periods were divided approximately equally between short and long periods. In addition, short sleep-wake periods resulted in less sleep and generally poorer sleep than normal length sleep-wake periods. Long sleep-wake periods resulted in more sleep but poorer sleep and lower levels of on-duty alertness than normal sleep-wake periods. Furthermore, on-duty alertness followed a circadian rhythm with the most well defined rhythm seen in normal length sleep-wake periods and less pronounced rhythms seen in short and long sleep-wake periods. The current data indicated that the range of sleep-wake periods caused by irregular working conditions negatively impacted sleep habits and on-duty alertness in locomotive engineers.

The human circadian system affects virtually all internal drives in humans, including such parameters as hormonal levels, body temperature, and performance (1). In addition, the circadian system brings about a natural drive to be awake during the day and to sleep at night. Although this system is for the most part endogenously driven, it is sensitive to environmental conditions (e.g., light exposure) and behavioral activity (e.g., working at night) that affect the

sleep-wake cycle. For example, the negative impact of shift work on sleep and on-duty alertness has been shown in a variety of regularly scheduled shifts, such as fixed night shifts and regularly rotating shifts (1-6).

Not all shift work, however, results in regularly scheduled shifts. Many occupations require flexible working arrangements that can result in irregular work times. One example of a schedule requiring irregular work times is seen in locomotive engineers. Locomotive engineers work under less regular and less predictable schedules than many other occupations, such as police officers and factory workers (7). For instance, locomotive engineers in France, Australia, and the United States report work periods spread approximately evenly over the 24-h day (8-10). In the United States, most locomotive engineers work under an on-call system in which they are typically provided with a 2-h notice of when they must report for duty. Another component of the work schedule experienced by many locomotive engineers in the United States is two work shifts surrounding a relatively short off-duty period. This happens most often when an engineer reports to work at his home terminal, takes a train to a distant location (away terminal), and then has to wait at the away terminal for an often unpredictable amount of time for a train to be prepared for the return trip home. This often results in the engineers sleeping at the away terminal.

Similar to more regularly scheduled shift-work systems, irregular and unpredictable work schedules such as those experienced by most locomotive engineers often result in decreased sleep quantity and feelings of fatigue (11, 12). In addition, workers on irregular work schedules report more problems with health and less positive feelings of well-being than workers on regular work schedules (13). A further problem associated with irregular shift-work schedules and one that is indicative of their degree of schedule irregularity occurs when the worker is required to report back to work before 24 h has elapsed since the start of the last work episode. A previous report found that 33% of the work days reported by locomotive engineers had less than 24 h elapse between work onset times (14). Moreover, engineers reported less sleep on the shorter-than-24-h days than on days where at least 24 h elapsed between work onset times.

In addition to the negative effect on sleep and perceived well-being, the type of irregular scheduling experienced by most locomotive engineers may have a negative impact on the endogenous circadian system. For example, some researchers have concluded that without a regular "anchor" sleep during a specified period each day (usually at night), free-running circadian rhythms can develop (15). Other studies have also shown that individuals working on irregular schedules may develop a free-running circadian rhythm of greater than 24 h

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(16, 17). In general, the literature suggests that displaced sleep, a common consequence of irregular schedules, can lead to phase shifting of the circadian rhythms (18, 19). Irregular schedules may also result in the engineers' trying to sleep at times when sleep is not easily accomplished. Previous research has shown that sleep is virtually impossible between 8 and 10 p.m., a period called the "forbidden zone" (20).

One purpose of the current study was to examine sleep-wake period lengths as defined by major sleep times under irregular and unpredictable work schedules. Sleep-wake period length was chosen as the factor variable to logically describe the effects of irregular schedules in locomotive engineers on the endogenous circadian cycle. Dividing their sleep-wake periods into logical categories permitted data analyses to be conducted for each individual category. Thus, the results could be displayed for categories that relate directly to the endogenous circadian rhythm. As such, the effect of different sleep-wake period lengths (short, normal, and long, defined below) on sleep quantity, sleep quality, and on-duty alertness could be examined. Sleep quantity, sleep quality, and alertness were expected to vary by sleep-wake period length. More specifically, we anticipated that sleep-wake periods of about 24 h would result in the most stable sleep patterns and increased on-duty alertness in that these periods would more easily fit the endogenous circadian day. As an additional indication of the relationship between irregular schedules and circadian rhythms, the current study examined the impact of irregular schedules on the circadian rhythm in on-duty alertness as well as sleep onset times. It was expected that the circadian rhythms seen in on-duty alertness and time of sleep onset would be negatively affected by the irregular work schedules.

METHODS

The current study is part of an ongoing fatigue research effort supported by the Federal Railroad Administration's Human Factors Program in the Office of Research and Development. The data were initially gathered and reported by the Volpe National Transportation Systems Center (21).

Participants

The participants were volunteer locomotive engineers from six major U.S. railroads. The data from 179 engineers (mean age \pm standard deviation, 43.6 ± 6.5 years) were collected during 1992 and 1994. The engineers worked under a variety of irregular schedules, though most were on call 24 h a day. Typically, the engineers were notified by a phone call from their employer 2 h prior to the time when they were expected to report for duty.

Materials

Participants provided information on their work times, sleep times, sleep quality, and on-duty alertness as part of a 14-day activity log. The activity log has been described in more detail in a previous report (21).

Procedures

The participants completed the activity log for 14 days, including work days and days off. All participants provided information on

time going to work, time getting off of work, time that their employer called them with their duty report time, commuting time, time not at work (personal time), time getting into bed, and time getting out of bed. The participants also provided information on two sleep-quality measures: ability to stay asleep (1 = easily to 5 = not at all) and feeling well rested upon awakening (1 = well rested to 4 = not at all rested). In addition, 124 of the 179 engineers (mean age \pm standard deviation, 44.1 ± 6.2 years) provided information on another sleep-quality measure, ability to go to sleep (1 = easily to 5 = not at all), and on subjective on-duty alertness (1 = fully alert to 4 = fighting sleep). Subjective on-duty alertness was assessed at the start of each work period and every 2 h while working.

The original activity logs were designed such that the participants entered data for each 24-h day defined as midnight to midnight. This method of defining days resulted in the activities spanning midnight being split into two separate days, and consequently confounding data analysis. To control for this unanticipated limitation of the original log design, the days in the original data set were redefined as sleep-wake periods, with each period defined from wake-up time to the next wake-up time following a major sleep episode. Major sleep episodes were generally classified as 4 h or more of reported continuous sleep. In a few cases, decisions had to be made when there were either two or more similar-length sleep episodes or when no sleep episode of at least 4 h was reported for 36 h or more. In those cases, major sleep episodes were defined as the sleep episode that occurred at night. Sleep occurrences that were not classified as major sleep episodes were classified as naps. For the purposes of the current study, sleep time was calculated as the total duration of all sleep episodes (main sleep episodes and naps) during each sleep-wake period.

The modified data set contained 2,020 sleep-wake periods in contrast to the 2,506 midnight-to-midnight days in the original data set. This difference is due to two major causes. First, some days were dropped from the data set due to missing data. If a record contained incomplete sleep data resulting in an inability to determine sleep length or sleep-wake period length, it was dropped from the data set. Second, the irregular sleeping patterns maintained by many of the locomotive engineers resulted in some days that were substantially longer than 24 h.

Data Analyses

The data were analyzed in Statistical Package for the Social Sciences. The first step of the analysis was to calculate the length of each sleep-wake period. The sleep-wake periods were then divided into three categories: short (<22 h), normal (between 22 and 26 h, inclusive), and long (>26 h). The endpoints for the normal day-length category, 22 and 26 h, were chosen because a change in day length of 2 h or less requires little or no adaptation of the endogenous circadian system. In contrast, day length changes of more than 2 h typically result in some degree of adaptation. To illustrate the effect that irregular work schedules have on work and sleep times in locomotive engineers, the frequency with which the engineers reported going to work and to sleep throughout the 24-h day was calculated and plotted across all days and for each of the sleep-wake period categories. Mean work duration, total sleep time, sleep and napping time at home, sleep and napping time away from

home, ability to go to sleep, ability to stay asleep, feeling rested upon awakening, and on-duty alertness were then calculated across all days and for each of the three sleep–wake period length categories. Because all participants did not respond to all questions for each day of the activity log, many of the variables contain data averaged across a different number of sleep–wake periods. A one-way multiple analysis of variance (MANOVA) was completed using sleep–wake period category as the factor. A Tukey’s studentized range statistic, which accounted for the different number of sleep–wake periods in each factor grouping, was completed as a post-hoc analysis to identify the source of significant main effects. An alpha (α) of .05 was used for all post-hoc analyses. Finally, to further examine the relationship between on-duty alertness and day length, the average alertness rating was calculated for each on-duty hour by actual 24-h clock time. These data were then double plotted across all sleep–wake periods and for each of the sleep–wake period categories.

RESULTS

The distribution of the data across the different sleep–wake period categories for all locomotive engineers is shown in the top half of Table 1. The bottom half of Table 1 is the same information for the subset of the engineers who also provided information on subjective on-duty alertness and ability to go to sleep. When averaging across the sleep–wake periods in each data set (the All line in Table 1), the engineers appeared to be living under a relatively normal 24-h schedule. However, when the sleep–wake period lengths were divided into the three categories, not quite half of the sleep–wake

periods were about 24 h in duration. The remaining sleep–wake periods were split approximately equally between the short and long categories.

The sleep data reported by the engineers are presented in Table 2. When averaged across all sleep–wake periods, locomotive engineers reported a total sleep time of about 8 h. However, the amount of total sleep varied significantly across the three sleep–wake period categories ($F_{2,2017} = 170.92, p < .001$). Post-hoc analyses indicated that the engineers reported significantly less sleep during short sleep–wake periods than in either normal or long sleep–wake periods and significantly more sleep during long sleep–wake periods than in either short or normal length sleep–wake periods.

As an additional means of examining sleep habits in locomotive engineers, the sleep data were divided into sleep episodes and naps that took place at home versus away from home. As shown in Table 2, the engineers reported sleeping and napping more at home than away from home. There was a significant difference between the three sleep–wake categories in all four conditions: sleep at home ($F_{2,2017} = 37.51, p < .001$), nap time at home ($F_{2,2017} = 210.56, p < .001$), sleep away from home ($F_{2,2017} = 41.73, p < .001$), and nap time away from home ($F_{2,2017} = 39.18, p < .001$). Post-hoc analyses showed that significantly more sleep at home was reported under normal sleep–wake periods than either short or long periods, whereas more sleep away from home was reported under long sleep–wake periods than either short or normal periods. In contrast, the engineers reported longer naps both at home and away from home under long sleep–wake periods than either short or normal periods.

TABLE 1 Data on Length of Sleep–Wake Periods

Sleep–Wake Period Category	Number of Days	Percent of Total	Mean Length	SD
All ^a	2020	--	24.8 h	6.0
Short (< 22 h) ^a	511	25.3%	18.4 h	2.8
Normal (22 – 26 h) ^a	953	47.2%	24.0 h	1.0
Long (> 26 h) ^a	556	27.5%	31.9 h	5.8
All ^b	1391	--	24.9 h	6.2
Short (< 22 h) ^b	358	25.7%	18.4 h	2.8
Normal (22 – 26 h) ^b	635	45.6%	24.0 h	1.0
Long (> 26 h) ^b	398	28.6%	32.1 h	6.0

^aData based on all participants (N=179).

^bData based on subset of participants (N=124) that provided information on subjective on-duty alertness and ability to go to sleep.

TABLE 2 Average Sleep and Nap Durations

Sleep–Wake Period Category	Total Sleep ^a ± SD	Sleep ^a at Home ± SD	Nap Time ^b Home ± SD	Sleep ^a Away ± SD	Nap Time ^b Away ± SD
All	8.05 ± 2.26	5.67 ± 3.8	19.7 ± 59.42	1.88 ± 3.32	10.98 ± 48.1
Short (< 22 h)	6.78 ± 2.05	5.23 ± 3.26	5.63 ± 32.87	1.38 ± 2.74	4.74 ± 33.95
Normal (22 – 26 h)	8.08 ± 1.07	6.41 ± 3.57	3.93 ± 24.27	1.53 ± 3.11	5.52 ± 32.46
Long (> 26 h)	9.15 ± 2.72	4.8 ± 4.35	59.78 ± 92.9	2.95 ± 3.88	26.1 ± 72.34

Data based on all participants (N=179).

^aSleep time in hours.

^bNap time in minutes.

The locomotive engineers in the current study reported work onset times throughout the day and night. As shown in Figure 1, when averaging across all sleep-wake period categories, for each sleep-wake period, and all participants, work onset times remained relatively stable, with about 1.7% to 4.8% of the engineers reporting to work each hour across the 24-h day. However, the work onset times varied across the three sleep-wake period categories. Work onset times in normal length sleep-wake periods were more likely to occur during the day, whereas work onset times in long sleep-wake periods were more likely to occur late at night and in the early morning hours. In spite of having to report to work at all times of the day and night, engineers reported sleeping at night whenever possible (Figure 1). This effect was most pronounced in those sleep-wake periods approximating normal days, in which over 70% of the participants reported going to bed between 9 p.m. and 1 a.m., and least pronounced in the long sleep-wake periods in which less than 40% of the participants reported going to bed between 9 p.m. and 1 a.m.

As seen in Figure 2, there was a trend toward a decrease in ability to go to sleep, a decrease in ability to stay asleep, and a less well-rested feeling upon awakening in both short and long sleep-wake periods in comparison with normal length sleep-wake periods. The

MANOVA results indicated that there was a significant difference across the three sleep-wake period length categories in reported ability to go to sleep ($F_{2,1245} = 11.46, p < .001$), in reported ability to stay asleep ($F_{2,1801} = 15.68, p < .001$), and in a well-rested feeling upon awakening ($F_{2,1812} = 28.61, p < .001$). Post-hoc analyses showed that engineers reported more difficulty going to sleep on long sleep-wake periods than on short or normal-length sleep-wake periods. Furthermore, both short and long sleep-wake periods resulted in more difficulty staying asleep than on normal sleep-wake periods and in more difficulty staying asleep on long sleep-wake periods than on short sleep-wake periods. Post-hoc analyses also indicated that engineers reported a significantly less well-rested feeling upon awakening on both short and long sleep-wake periods than on normal sleep-wake periods.

Feelings of subjective on-duty alertness (Figure 3) differed significantly across the three sleep-wake period categories ($F_{2,905} = 53.28, p < .001$). Post-hoc analyses indicated that long sleep-wake periods resulted in significantly less feelings of alertness while on duty than either short or normal sleep-wake periods. However, subjective on-duty alertness showed a strong circadian rhythm when examined hourly across the 24-h day for each of the sleep-wake period categories, based on responses from the subset

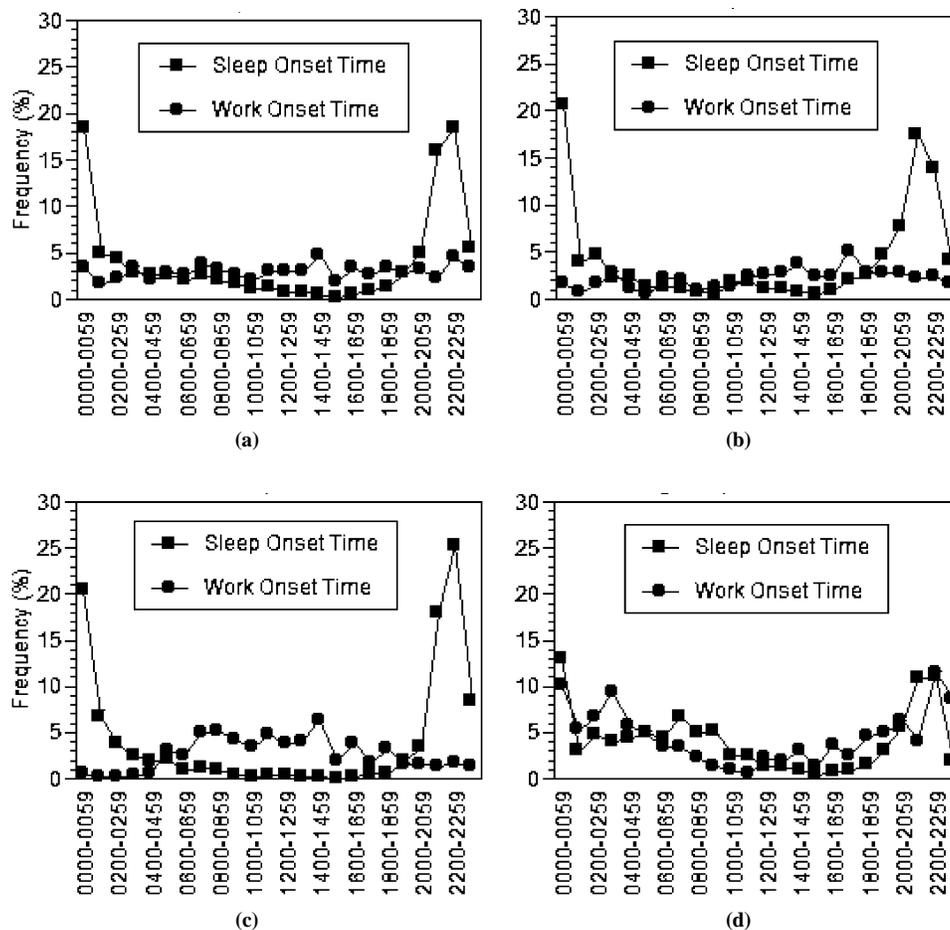


FIGURE 1 Percentage of time that locomotive engineers reported going to work (work onset time) or going to sleep (sleep onset time) throughout 24-h day: (a) all sleep-wake periods, (b) short sleep-wake periods, (c) normal sleep-wake periods, and (d) long sleep-wake periods.

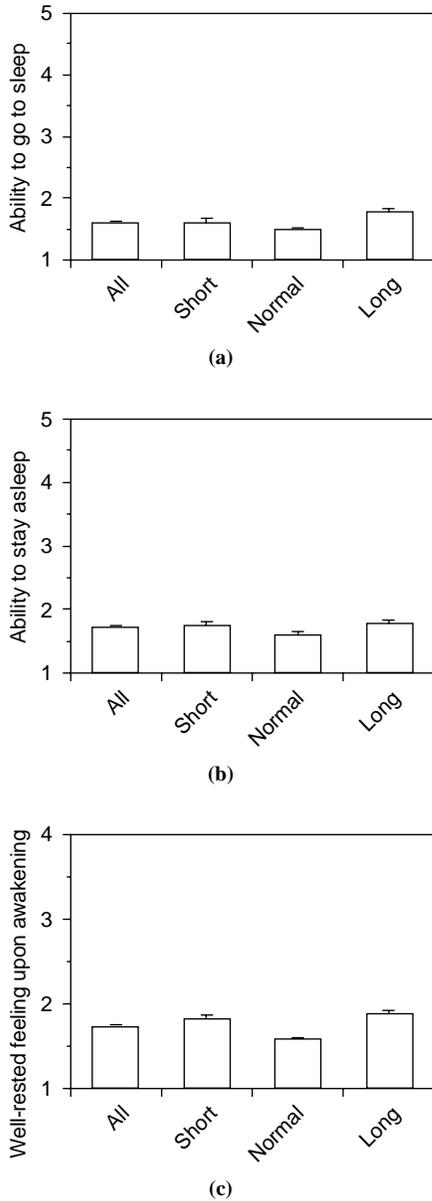


FIGURE 2 Sleep quality results. Means (+ standard errors) across all sleep-wake periods and for each sleep-wake period category. Data on the ability to stay asleep [1 (easily) to 5 (not at all)] and well-rested feeling upon awakening [1 (well rested) to 4 (not at all rested)] were based on all participant responses. Data on the ability to go to sleep [1 (easily) to 5 (not at all)] were based on responses from the subset of 124 participants.

of 124 participants. Figure 4 presents data averaged across all sleep-wake periods and for each sleep-wake period category. Alertness ratings [1 (fully alert), 2 (moderately alert), 3 (drowsy), 4 (fighting sleep)] are inversely plotted to illustrate the decrease in alertness at night. The data are also double plotted to illustrate the circadian rhythm. The circadian rhythm is most pronounced for normal sleep-wake periods, with the lowest levels of alertness reported

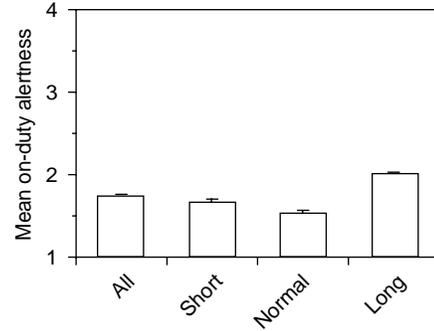


FIGURE 3 Mean subjective on-duty alertness results. Means (+ standard errors) across all sleep-wake periods and for each sleep-wake period category. Subjective on-duty alertness was assessed with a 4-point scale [1 (fully alert), 2 (moderately alert), 3 (drowsy), 4 (fighting sleep)]. Data are based on the responses of the subset of 124 participants.

during the early morning hours and highest levels of alertness reported in the afternoon. In contrast, the long sleep-wake periods resulted in overall less reported alertness in the afternoon hours, and the short sleep-wake periods resulted in a flattened circadian rhythm with more variance associated with the means.

DISCUSSION OF RESULTS

The results presented here indicate that the locomotive engineers in the current study reported a wide range of sleep-wake period lengths associated with their irregular work schedules. When defined by main sleep episodes, less than half of the days were classified as normal sleep-wake periods (22 to 26 h long). The remainder of the days in the data set were divided approximately evenly between short and long sleep-wake periods. Furthermore, had the category for normal sleep-wake periods been more conservatively defined (e.g., 23 to 25 h long), even fewer of the days recorded by the locomotive engineers would have been classified as normal in length.

Despite working under irregular and unpredictable conditions, locomotive engineers maintained some degree of normal circadian rhythmicity in their sleep-wake cycles. The participants in the current study reported sleeping at night when possible as well as a decrease in on-duty alertness when working at night. These results are consistent with previous literature on shift work. For example, Parrot and Petiot (22) also found that locomotive engineers preferentially sleep at night even when working under irregular schedules. Furthermore, a decrease in subjective alertness while working at night has been demonstrated in a number of shift-work studies (23-26) and specifically in locomotive engineers (27). However, the circadian pattern in sleep onset times and subjective on-duty alertness reported here varied across the three sleep-wake period categories. Long sleep-wake periods were associated with an increase in work onset times at night, with a corresponding decrease in nighttime sleep onset. This resulted in long sleep-wake periods having the least well-defined circadian rhythm in sleep onset times of the three categories as well as significantly lower subjective ratings of on-duty alertness. Short sleep-wake periods also had a strong negative impact on sub-

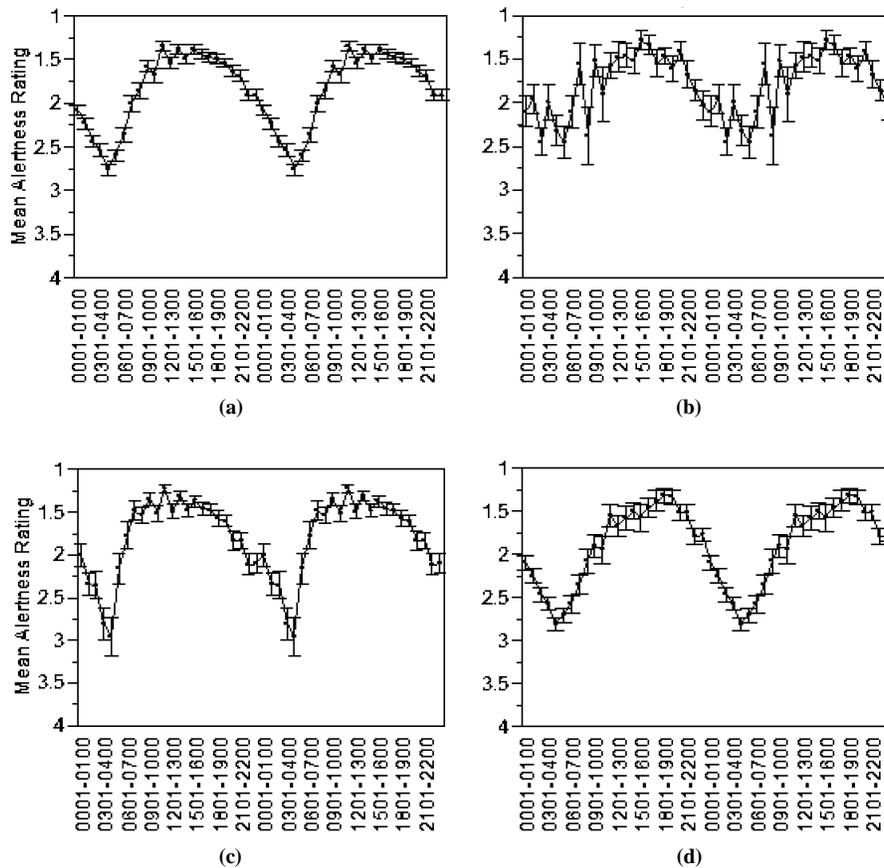


FIGURE 4 Mean subjective on-duty alertness (means \pm standard errors) across the 24-h day: (a) all sleep-wake periods, (b) short sleep-wake periods, (c) normal sleep-wake periods, and (d) long sleep-wake periods.

jective on-duty alertness. Although a circadian rhythm in on-duty alertness was discernable in short sleep-wake periods, the circadian curve was blunted and was associated with greater variability around the means. Thus, the current results indicated that both short and long sleep-wake periods had a negative impact on the engineers' sleep-wake and alertness rhythms.

The data on sleep onset times and subjective on-duty alertness suggest that, as a group, locomotive engineers did not experience free-running circadian rhythms in response to working under irregular and unpredictable schedules. This disagrees with the conclusions from earlier studies that free-running rhythms can develop under these conditions (16, 17). The current results indicated that the engineers were capable of maintaining a circadian pattern even under short and long sleep-wake period lengths. This was most evident in the obvious increase in engineers' sleep onset times in the late evening hours. Although the engineers reported going to sleep late in Lavie's "forbidden zone" (20), they avoided sleeping earlier in the evening, suggesting that the early evening hours were not conducive for sleeping. This could have been due to the endogenous circadian rhythm or to external social events (e.g., family duties). As previously mentioned, the engineers' schedules had a negative impact on circadian rhythms, albeit not as dramatic as a free-running rhythm. Hence, the current data suggest that the underlying endogenous circadian rhythm is quite robust and is not dramatically altered by changing work schedules.

The current data also indicated that sleep quantity and quality varied across the three sleep-wake period lengths. Not surprisingly, the engineers reported less sleep under short sleep-wake periods than under normal or long sleep-wake periods. In addition, they reported more difficulty staying asleep and a less well-rested feeling upon awakening in short sleep-wake periods than normal sleep-wake periods. These data agree with those reported in an earlier study (14), which also found a decrease in sleep quantity and poorer sleep quality in shortened work-rest periods where less than 24 h elapsed between work onset times.

The engineers reported more sleep under long sleep-wake periods than either short or normal sleep-wake periods. However, in spite of sleeping more in long sleep-wake periods, the engineers did not report feeling better rested upon awakening and reported difficulty with going to sleep and staying asleep. This suggests that although long sleep-wake periods may seem to provide an opportunity for the engineers to return to a normal sleeping pattern and perhaps catch up on any accumulated sleep debt that may have occurred in previous days, the engineers did not benefit from the opportunity as much as might have been expected. One reason for this that has been previously discussed is that long sleep-wake periods are outside of our normal 24-h circadian rhythm and as such may counter the expected beneficial effects of longer sleep episodes. Another possible reason is one example of how irregular and unpredictable schedules in the railroad industry are implemented. Many of the long

sleep-wake periods reported here were actually associated with two working episodes. As described earlier, this happened when the engineers were required to wait at an away terminal before returning home. At the away terminal, they could and did sleep, perhaps accounting for some of the increase in sleep quantity seen in long sleep-wake periods. However, they typically did not get more than 4 h of sleep at one time; hence, the increase in sleep was largely due to an increase in what was defined here as naps. In addition, perhaps because they were not sleeping at their home, their sleep quality reports were not as positive as might be expected in response to the additional sleep time.

The findings presented here are of interest in a variety of occupational settings, including many in the transportation industry, where irregular shift-work schedules occur. The expected decrease in subjective on-duty alertness during nighttime duty across all sleep-wake periods is of concern in that increased sleepiness is related to increased accident occurrence and other occupational safety risks (28, 29). Those in management responsible for scheduling decisions should be educated about the robustness of the circadian rhythm and its impact on nighttime alertness. Such countermeasures as limiting the number of nighttime assignments and altering the work environment to improve on-duty alertness may be warranted. It is of particular interest that both short and long sleep-wake periods resulted in less reported alertness when working during the day than normal sleep-wake periods. This result suggests that short and long sleep-wake periods could increase the likelihood of safety risks throughout the day and night. As such, management and labor should avoid creating circumstances in which engineers work under days that are either shorter or longer than the normal 24-h circadian day.

The data and conclusions in the current study are limited primarily by the method used to gather the data. Because of the nature of self-reported data, it was impossible to get every participant to complete every question every day. However, the difference in response rates for the different variables reported here was accounted for in both the MANOVA results and the post-hoc analyses. Another concern was that the participants were volunteers and may not have been representative of the entire locomotive engineer population. In an effort to account for this potential concern and to broaden the data set, data were gathered from as many engineers as possible from six major U.S. railroads and at two different times (1992 and 1994). Finally, research in occupational settings is usually limited to self-reported data and to those individuals who volunteer to participate.

In summary, the current results indicate that irregular schedules brought about a wide range of sleep-wake period lengths in locomotive engineers. Sleep quantity, sleep quality, and on-duty alertness varied across the three sleep-wake periods (short, normal, and long). Less sleep was reported in short sleep-wake periods and more sleep was reported in long sleep-wake periods than in normal-length sleep-wake periods. There was also generally less alertness and poorer sleep quality reported in both short and long sleep-wake periods in comparison with normal sleep-wake periods. In addition, the results indicated the importance of better understanding of the effects of irregular work schedules on the human circadian system. The fact that over 50% of the days in the current data set were well outside the normal circadian range suggests that the current scheduling systems agreed upon by labor and management do not attempt to control the hours worked by locomotive engineers in an effort to complement our endogenous circadian system. Additional research on irregular and unpredictable schedules could provide information

to help improve scheduling practices, especially in those industries where irregular schedules are currently used. In addition, research on the effects of work schedule irregularity and unpredictability on safety and health risks is needed so that effective countermeasures can be developed and implemented in many different transportation industries.

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