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Sleep–wake rhythm in an irregular shift system

MIKAEL SALLINEN[1], MIKKO HÄRMÄ[1], PERTTI MUTANEN[2], RIIKKA RANTA[2], JUSSI VIRKKALA[1] and KITI MÜLLER[1]
[1]Brain and Work Research Units, and [2]Department of Epidemiology and Biostatistics, Finnish Institute of Occupational Health, Helsinki, Finland

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SUMMARY Sleep in shift work has been studied extensively in regular shift systems but to a lesser degree in irregular shifts. Our main aim was to examine the sleep–wake rhythm in shift combinations ending with the night or the morning shift in two irregular shift systems. Three weeks' sleep/work shift diary data, collected from 126 randomly selected train drivers and 104 traffic controllers, were used in statistical analyses including a linear mixed model and a generalized linear model for repeated measurements. The results showed that the sleep–wake rhythm was significantly affected by the shift combinations. The main sleep period before the first night shift shortened by about 2 h when the morning shift immediately preceded the night shift as compared with the combination containing at least 36 h of free time before the night shift (reference combination). The main sleep period before the night shift was most curtailed between two night shifts, on average by 2.9 and 3.5 h among the drivers and the controllers, respectively, as compared with the reference combination. Afternoon napping increased when the morning or the day shift immediately preceded the night shift, the odds being 4.35–4.84 in comparison with the reference combination. The main sleep period before the morning shift became 0.5 h shorter when the evening shift preceded the morning shift in comparison with the sleep period after a free day. The risk for dozing off during the shift was associated only with the shift length, increasing by 17 and 35% for each working hour in the morning and the night shift, respectively. The results demonstrate advantageous and disadvantageous shift combinations in relation to sleep and make it possible to improve the ergonomy of irregular shift systems.

KEYWORDS dozing off, naps, railway traffic controllers, shift work, sleep, train drivers

INTRODUCTION

Sleep and alertness are known to be disturbed by shift work, particularly while working on early morning and night shifts (for a review see Åkerstedt 1988, 1995; Kecklund and Åkerstedt 1995). The main sleep period is usually reduced by 2–4 h in connection with these shifts (Åkerstedt *et al.* 1991; Kecklund *et al.* 1997; Tilley *et al.* 1982; Torsvall *et al.* 1981). In addition, sleep deficit together with the circadian factor of alertness leads to severe sleepiness at work, especially during night shifts (Åkerstedt *et al.* 1983; Härmä *et al.* 2002; Torsvall and Åkerstedt 1987).

Sleep in shift work has mainly been studied in regular shift systems. These studies show that a sleep period before the morning shift is curtailed as the starting time of the shift is advanced and the length of day sleep between two night shifts decreases when the ending time of the night shift is delayed (Kecklund *et al.* 1997; Rosa *et al.* 1996). Similar findings have also been reported in studies on railway personnel working on irregular shift systems (Foret and Lantin 1972; Hak and Kampman 1981). Also the free time before a shift affects sleeping. It is estimated that 16 h of free time is needed to ensure a sleep duration of 7–8 h (Kecklund and Åkerstedt 1995; Kurumatani *et al.* 1994).

Correspondence: Mikael Sallinen, Brain and Work Research Units, Finnish Institute of Occupational Health, Topeliuksenkatu 41 a A, 00250 Helsinki, Finland. Tel.: +358-9-47472735; fax: +358-9-5884759; e-mail: mikael.sallinen@occuphealth.fi

Severe sleepiness in irregular shift systems has been studied especially in railway personnel (Åkerstedt *et al.* 1983; Härmä *et al.* 2002; Ingre *et al.* 2000; Torsvall and Åkerstedt 1987). Their shift systems often include early morning shifts and quick changeovers (e.g. Foret 1987; Hak and Kampman 1981; Ingre *et al.* 2000; Kolmodin-Hedman and Swensson 1975). Sleep attacks at work occur especially during night shifts. In a study by Åkerstedt *et al.* (1983), 11% of train drivers reported dozing off on most night shifts. In a later study, Torsvall and Åkerstedt (1987) showed that four of 11 train drivers had electroencephalograph-defined microsleeps on night journeys. On day journeys, no corresponding signs of sleep attacks were observed. In our recent study, sleepiness at work was associated with long working hours, short sleep prior to the shift, but not consistently with the time-off period before the shift (Härmä *et al.* 2002).

Sleep in irregular shift systems has been examined only in few studies. Hak and Kampman (1981) studied railway personnel working on either a very irregular or a relatively regular shift systems. The differences in the duration and quality of sleep between the groups were small and the main finding was a short main sleep before shifts starting at 6:00 a.m. or earlier. The results of a study by Aguirre and Foret (1994) were in line with those of Hak and Kampman in relation to sleep duration, but not in relation to sleep quality. Aguirre and Foret found that workers on an irregular shift system reported sleep disturbances more frequently than regular three-shift workers on both working and rest days. Furthermore, the difference in self-reported sleep quality between work and non-work days was larger in the regular three-shift workers than in the workers on the irregular system. The authors concluded that the workers on the irregular system did not have enough days off for recovery. Kurumatani *et al.* (1994) studied the effect of various shift combinations on sleep in hospital nurses. The nurses had more sleep when the free time between two shifts increased. Unfortunately, the authors did not take into account nocturnal sleep, before the first night shift. In addition, only little could be said about sleep before the morning or the night shift because most of the shift combinations ended with either the day or the evening shift.

Afternoon napping is a common feature with night shifts. According to Rosa (1993), 54% of the first night shifts and 28% of the following night shifts are preceded by an afternoon–evening nap. In our earlier report, afternoon napping prior to the night shift was closely associated with the free time between the shifts (Härmä *et al.* 2002). When the free time was less than 8 h 63% of the train drivers took a nap, but only 25% when the free time was at least 16 h.

As a whole, there are a plenty of studies on sleep in regular shift systems, but studies examining sleep in shift combinations typical of irregular shift systems are lacking. Our main aim was to study the effect of various shift combinations of irregular shift systems on the main sleep length, afternoon napping and dozing off at work. The focus was on those shift combinations that ended with either the morning or the night shift as sleep is known to be most disturbed in connection with these shifts. In addition, our sample of Finnish train drivers and traffic controllers gave us the opportunity to examine the occurrence of various shift combinations in these occupational groups.

MATERIALS AND METHODS

Subjects

The data of the present study was based on a random sample of all professional train drivers (drivers, $n = 1277$) from East and South Finland and traffic controllers (controllers, $n = 453$) from South, East and West Finland. The sample consisted of 230 drivers and 270 controllers. Of all allotted drivers and controllers 139 (60.4%) and 138 (51.1%), respectively, gave an informed consent to participate in the study. Main reasons for refusal of the study were unwillingness to participate, retirement, a long sick leave, and a change to another job. Twelve percent of the drivers mainly worked in local traffic and 42% in long-distance traffic. For rest of the drivers, the work was more mixed and included driving a local or long-distance train, service driving, duties at a railway depot or a railway yard as well as office work. Unfortunately, it was not possible to control for the type of the work task because the subjects reported their duty-specific work tasks only infrequently.

Prior to statistical analyses a total of 47 subjects were removed. Two subjects were excluded because of acute sickness absence during the data collection period and 12 subjects because they were not working on an irregular three-shift work. The data of 11 subject were too incomplete for analyses because of on-call shifts, sick leave or training courses. In addition, the data of 26 women were removed because the number of women was too small to examine the gender effect and secondly, all of them were traffic controllers, which would have complicated the comparisons between the occupational groups. After these exclusionary criteria, which partially overlapped, 126 drivers and 104 controllers were included in the statistical analyses. The two occupational groups were comparable in terms of age (drivers: mean 42.3 years, range 33–55 years, controllers: mean 44.2 years, range 26–61 years), shift work experience (drivers: mean 22 years, range 14–36 years, controllers: mean 19 years, range 0–38 years), and percentage of subjects who had children at the same household (drivers: 32%, controllers: 18%).

Study protocol

The study contained a field and a laboratory part, but only the data from the field part are included in this study. During the first visit in a sleep laboratory, subjects answered a shift work and sleep questionnaire and a nurse instructed them on the use of a sleep diary. Individual sleep need was ascertained with the following question: 'How many hours of sleep do you need per day (if you could sleep as long as you like)? In other words, how much sleep do you need to be alert and in good shape at

Shift combination	N	%	Main sleep N	h (SD)	Nap %	Dozing off %
D+N	23	8	18	8.0 (1.2)	91	9
M+N	45	16	39	6.0 (1.2)	73	31
N I N	14	5	14	5.7 (1.3)	43	14
N	103	37	93	8.4 (1.3)	59	13
Undefined	95	34	93	7.3 (1.7)	65	19
All	280	100	257	7.4 (1.7)	65	18
D+N	67	30	55	6.5 (0.9)	81	36
M+N	64	29	57	6.3 (0.9)	70	28
N I N	10	5	10	4.6 (1.4)	10	50
N	30	14	28	8.3 (1.6)	33	30
Undefined	50	23	48	6.6 (1.0)	66	28
All	221	100	198	6.7 (1.3)	65	32

Figure 1. The mean timing of sleep and work periods in shift combinations ending with the night shift among train drivers and traffic controllers. For the drivers, 13% of the Day + Night combinations, 20% of the Morning + Night combinations and 16% of the Night combinations were preceded by either the day or the evening shift (ending time before 9:31 p.m.) on the previous day. For the controllers, the corresponding values were in the same order 69, 56, and 23%. White dots inside the night shifts stand for the mean timing of dozing-off at work.

work the next day?' The subjects started to keep the diary on the same day and continued with it for 3 weeks. The subjects were told to keep the diary with them all the time and to record the starting and ending of all shifts, sleep periods, dozing-offs and experienced sleepiness. The total amount of coffee, alcohol, and drugs used within the past 24 h was marked in the sleep diary at bedtime. The sleep period started and ended upon switching lights off and on, respectively. Subjects were also instructed to report sleep latency, number of awakenings and sleep quality upon awakening. The number of sleep periods marked for 1 day was limited to three. When a morning or a night shift was preceded by at least two sleep periods, which ended after 10:00 p.m., the main sleep period was the longest of these sleep periods. In 44 cases the length of the main sleep period could not be determined because of missing data (35 cases) and too fragmented sleep–wake rhythm containing no main sleep period (nine cases).

Definitions of the shifts

The shifts were identified according to the following criteria: night shift – at least 3 h of the shift, or the whole shift, is between 11:00 p.m. and 6:00 a.m.; evening shift – ends between 7:00 p.m. and 1:59 a.m. and is not a night shift; morning shift – commences between 3:01 a.m. and 6:59 a.m. and is not a night or an evening shift; day shift – starts between 7:00 a.m. and 1:59 p.m. and is not an evening or a night shift.

Shift combinations

A computer program was developed to organize the data into a visual form that allowed the identification of shift combinations. A total of four shift combinations ending with the night shift contained enough cases for separate shift combination groups. The combinations have been shown in Fig. 1. Because we had not enough data to examine all possible shift combinations ending with the night shift, we concentrated on the shifts preceding the night shift within the past 24 h. To make the shift combinations comparable in terms of preceding sleep, two criteria were applied to the sleeping conditions before the day of the first night shift. If there was a shift within 24–42 h before the night shift, the shift had to start after 6:59 a.m. and end before 9:31 p.m. These criteria ensured that nocturnal sleep before the night shift was not affected by sleep deprivation resulting from an early shift or by a delayed bedtime resulting from a late shift. When these criteria were applied, the identified shift combinations encompassed 71% of all the cases. The rest of the combinations formed their own group called undefined combinations. Four separate shift combination groups could be formed from the cases ending with the morning shift (Fig. 2). These cases covered 89% of all the observations.

Statistical methods

The association between the shift combinations and the length of the main sleep period was tested with a linear mixed model for repeated measurements (Brown and Prescott 1999; Littell *et al.* 1996). The mean values were compared in the linear mixed model as in classical analysis of variance models. Our model for dichotomous variables (afternoon napping and dozing-off at work) was a generalized linear model for repeated measurements. It can be considered as a logistic regression model for repeated measurements data, although it uses the generalized estimation equations method instead of the maximum likelihood method. Both models can be used with unbalanced and missing data whereas in the classical multivariate analysis of repeated measurements, all subjects

Shift combination			Main sleep		Dozing off
	N	%	N	h (SD)	%
E I M	78	22	77	5.5 (0.8)	6
D I M	32	9	32	6.0 (1.1)	6
M I M	52	15	50	5.7 (1.0)	10
F I M	144	41	127	5.7 (1.1)	10
Undefined	48	13	47	5.8 (1.1)	10
All comb.	354	100	333	5.7 (1.0)	9
E I M	90	39	87	5.8 (1.0)	4
D I M	13	6	12	5.1 (1.6)	15
M I M	30	13	28	6.1 (1.3)	0
F I M	83	36	71	6.3 (1.0)	1
Undefined	17	7	17	5.9 (1.3)	0
All comb.	233	100	215	6.0 (1.6)	3

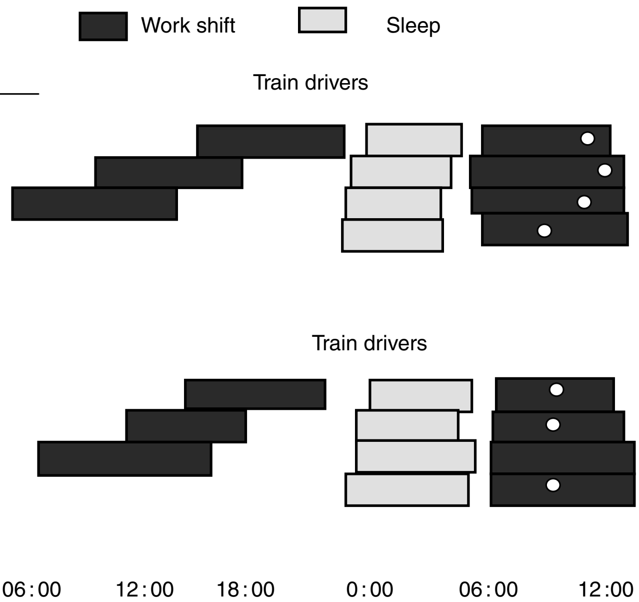

Figure 2. The mean timing of sleep and work periods in shift combinations ending with the morning shift among train drivers and traffic controllers. White dots inside the morning shifts stand for the mean timing of dozing-off at work.

with missing data are simply deleted. In addition, the models allowed us to study and fit different covariance structure models (compound, linear, power, gaussian, and spherical) for repeated observations. For both continuous and dichotomous response variables, the correlation structure of the repeated measures was compound symmetry, i.e. the correlation was equal regardless of the time length between the measurements from the same individual. We concluded in this solution after finding that the residual log-likelihood reached its minimum in case of the compound symmetry.

Before statistical analysis we examined associations between potentially relevant explanatory variables. Spearman correlation was used at this preliminary phase of the statistical analysis, because the crude distributions of the variables were not always normal. Experience in shift work was excluded from the model because it correlated closely with age (Spearman correlation coefficient = 0.63, $P < 0.001$ in the night shift combinations and 0.67, $P < 0.001$ in the morning shift combinations). All models contained the following explanatory variables: age (< or > = 45 years), occupation (driver, controller), shift combination type, children in the same household (at least one child < 7 years, at least one child between 7 and 17 years but no younger ones or no children) and self-reported sleep need. In addition, the model included either the starting time of the shift or its duration. When afternoon napping was explained, we included the length of the main sleep period in the model. Similarly, when dozing-off at work was studied, we included the length of the main sleep period and afternoon napping as explanatory variables.

The Shapiro–Wilk test showed that the residuals were not normally distributed when the length of the main sleep period was studied. To correct the residuals, four deviating observations were removed from the data containing shift combinations ending with the night shift. The same was carried out for six observations of the data ending with the morning shift. After this procedure, the skewness and kurtosis of residuals were −0.27 and 0.21, respectively, when the main sleep before the morning shift was studied. The corresponding values were 0.02 and 0.15 for the main sleep prior to the night shift. The level of significance was set at $P < 0.01$.

All the statistical analyses were carried out using the Statistical Analysis System (SAS Ver. 8, SAS Institute Inc., 1999). The SAS-procedures mixed and genmod were used for the continuous and dichotomous variables, respectively.

RESULTS

Shift combinations ending with the night shift

Among the drivers, the most common shift combination was the one, where the night shift was not preceded by any other shift on the same day (Fig. 1). This combination covered more than one-third of all the combinations. The Morning + Night combinations were also quite common (16%). The mean length of the night shift was 7 h 52 min (standard deviation (SD): 2 h 28 min) and it occurred between 10:20 p.m. (SD: 2 h 37 min) and 6:10 a.m. (SD: 2 h 28 min).

Among the controllers, the most prevalent combinations were the Day + Night and the Morning + Night encompassing more than half of all the combinations (Fig. 1). The mean length of the night shift was 9 h 40 min (SD: 1 h 10 min) and it was scheduled between 9:00 p.m. (SD: 44 min) and 6:40 a.m. (SD: 59 min).

Shift combinations ending with the morning shift

Among the drivers, the Free | Morning and the Evening | Morning combinations were the most common ones encompassing 63% of all the combinations (Fig. 2). The mean length of the morning shift was 7 h 47 min (SD: 2 h 15 min) and the it was timed between 5:20 a.m. (SD: 53 min) and 1:10 p.m. (2 h, SD: 30 min).

Among the controllers, the Free | Morning and the Evening | Morning combinations were the most prevalent ones covering 75% of all the combinations (Fig. 2). The mean length of the morning shift was 7 h 23 min (SD: 1 h 51 min) and it was scheduled between 6:00 a.m. (SD: 43 min) and 1:25 p.m. (SD: 1 h 50 min).

Sleep in shift combinations ending with the night shift

Main sleep period before the night shift

The mean length of the main sleep period in the four shift combinations has been shown in Fig. 1. As a whole, the length of the main sleep period varied greatly between the shift combinations as well as between the occupational groups. The sleep period before the first night shift was shortest in the Morning + Night combination in both occupational groups. Among the controllers, the mean length of the main sleep period was also short (6.5 h) in the Day + Night combination. Of all the combinations, the main sleep period was shortest between two successive night shifts among both drivers and controllers. The mean length of the main sleep period calculated over all combinations (including the undefined combinations also) was 0.7 h shorter for the controllers than for the drivers.

The results of the linear mixed model for repeated measurements showed a significant Occupation × Shift combination interaction ($F_{4,413} = 5.43$, $P < 0.001$) indicating that the effect of shift combination on the main sleep period differed in the occupational groups. Among the drivers, the Morning + Night and the Night | Night combinations were associated with shortening of the main sleep period by 2 h 12 min to 2 h 56 min as compared with the reference combination including no shift within 24 h before the night shift (Table 1). Among the controllers, all shift combinations were significantly associated with the shortening of the main sleep in comparison with the reference combination (Table 1). The estimated curtailment of main sleep varied between 1 h 50 min (Day + Night) and 3 h 32 min (Night | Night) among the defined combinations. Self-reported sleep need was also associated with the length of the main sleep period. A 1 h increase in sleep need prolonged the main sleep period by 21 min (Table 1).

Because the main sleep periods of the occupational groups differed greatly in the Day + Night and the Night | Night combinations, we analyzed whether the timing of the shifts also differed in these combinations between the groups. The mean starting time of the day shift preceding the night shift was clearly earlier for the controllers (7:01 a.m., SD: 0.1) than for the drivers (9:43 a.m., SD: 2.1). In the Night | Night combination, the main difference between the occupational groups was in the ending time of the first night shift. It was much earlier for the drivers (4:10 a.m., SD: 1.9) than for the controllers (7:40 a.m., SD: 1.8).

Table 1 A linear mixed model for repeated measurements for the length of the main sleep period prior to the night shift. All explanatory variables are included in the model when the effect of one explanatory variable on the main sleep period is tested. A total of 443 observations has been included in the analysis

Explanatory variable	*Categories/units*		*Estimate*	*SD*	*DF*	*P-value*
Intercept			5.7	0.85	318	< 0.001
Age	≥45 years		0.03	0.16	151	0.85
	< 45 years		Reference	–		–
Children at home	< 7 years		−0.32	0.19	147	0.09
	7–17 years		0.09	0.16	148	0.57
	No children		Reference	–		–
Sleep need	Hour		0.35	0.07	156	< 0.001
Starting time of night shift	Time in hours		0.00	0.03	426	0.89
Occupation × shift combination	*Occupation*	*Shift combination*				
	Driver	Undefined	−0.9	0.17	420	< 0.001
		D + N	−0.3	0.3	424	0.24
		M + N	−2.2	0.23	401	< 0.001
		N | N	−2.9	0.33	395	< 0.001
		N	Reference	–		–
	Controller	Undefined	−1.7	0.29	472	< 0.001
		D + N	−1.8	0.29	423	< 0.001
		M + N	−2.0	0.28	406	< 0.001
		N | N	−3.5	0.45	407	< 0.001
		N	Reference	–		–

Driver, train driver; controller, traffic controller; M, morning shift; D, day shift; N, night shift; |, the dividing line between 2 days; +, no night between the shifts; SD, standard deviation; DF, degrees of freedom.

Afternoon napping before the night shift

In both occupational groups, 65% of the night shifts were preceded by an afternoon nap (Fig. 1). The mean length of the nap was 2 h 20 min (SD: 1 h 10 min) and its' mean starting and ending times were 4:50 p.m. (SD 3 h) and 7:20 p.m. (SD: 3 h 30 min), respectively. Shift combinations, where both drivers and controllers took an afternoon nap in more than half of the cases, were the Morning + Night and the Day + Night combinations. The generalized linear model for repeated measurements showed that afternoon napping was significantly associated with the shift combinations [$\chi^2(4) = 27.53$, $P < 0.001$] and the starting time of the night shift [$\chi^2(1) = 27.26$, $P < 0.001$], but not with the length of the main sleep period. The effect of the length of the main sleep period remained non-significant even when the shift combination factor was dropped from the model [$\chi^2(1) = 0.34$, $P = 0.56$]. The odds for afternoon napping were significantly increased in the Morning + Night and Day + Night combinations as compared with the reference combination containing no work within 24 h before the night shift (OR: 4.36–4.84, Table 2). When the starting time of the night shift was delayed by 1 h, the odds for taking an afternoon nap was elevated by half (Table 2). Descriptive statistics showed that the mean starting time of the night shift was 1 h 25 min later on the nap days than on the non-nap days (10:15 p.m. versus 8:50 p.m). Eighty-three percent of the night shifts starting after the midnight were preceded by an afternoon nap, whereas afternoon napping occurred only in 17% of the night shifts starting no later than 6:00 p.m.

Dozing off during the night shift

On average, dozing off at least once was reported in 24% of all the night shifts and it occurred at about 3:00 a.m., but the variation was great (SD: 2 h 10 min) (Fig. 1). The occurrence of dozing-off at work varied greatly between the shift combinations in both occupational groups (9–31% among the drivers and 28–50% among the controllers), but the effect of shift combination was non-significant. The generalized linear model for repeated measurements revealed that only the shift length was associated significantly [$\chi^2(1) = 8.73$, $P = 0.003$] with dozing off (OR: 1.17 for each hour of the shift, 95% confidence interval 1.05–1.30, $P = 0.003$). In a telephone interview conducted afterwards, drivers were asked about the situation in which dozing-off occurred. According to this interview, all events of dozing-off took place in a rest room or in the train cabin while the train was waiting at traffic lights or at a station.

Sleep in shift combinations ending with the morning shift

Main sleep period before the morning shift

The mean length of the main sleep period in the four shift combinations has been shown in Fig. 2. Among the controllers, the main sleep period was shortest in the common Evening | Morning combination whereas among the controllers, the main sleep period was most curtailed in the rare Day | Morning combination. All in all, sleep periods less than 6 h were frequent: 57% of the sleep periods of the divers and 44% of the sleep periods of the controllers were less than 6 h.

The results of the linear mixed model for repeated measurements revealed that the effects of shift combination type ($F_{4,476} = 12.26$, $P < 0.001$), the starting time of the shift ($F_{1,519} = 278.18$, $P < 0.001$), and self-reported sleep need ($F_{1,178} = 8.70$, $P = 0.004$) were significant. The only shift combination differing significantly from the other combinations was the common Evening | Morning one having the mean free time of 8 h 20 min between the shifts (Table 3). The estimated length of the main sleep period (5 h 28 min) was about 30 min shorter in this combination than in the other combinations. In 30% of the Evening | Morning combinations the free time between the shifts was less than the average sleep

Table 2 A generalized linear model for repeated measurements for afternoon napping prior to *the night shift*. All explanatory variables are included in the model when the effect of one explanatory variable on afternoon napping is tested. A total of 447 observations has been included in the analysis

Explaining variable	*Categories/units*	*Odds ratio*	*CI: 95%*	*Limit*	*P-value*
Intercept		0.00	0.00	0.02	< 0.001
Age	≥45 years	0.63	0.28	1.38	0.24
	< 45 years (reference)	1	–	–	–
Occupation	Driver	1.15	0.61	2.17	0.66
	Controller (reference)	1	–	–	–
Shift combination	Undefined	1.86	1.08	3.21	0.03
	D + N	4.84	2.30	10.18	< 0.001
	M + N	4.35	2.09	9.03	< 0.001
	N | N	0.55	0.19	1.67	0.30
	N (reference)	1	–	–	–
Children at home	< 7 years	0.40	0.19	0.85	0.017
	7–17 years	0.96	0.46	2.00	0.91
	No children (reference)	1	–	–	–
Sleep need	Hour	0.90	0.64	1.28	0.56
Main sleep period	Hour	1.00	0.84	1.20	0.95
Starting time of night shift	Time (h)	1.51	1.34	1.71	< 0.001

Driver, train driver; controller, traffic controller; M, morning shift; D, day shift; N, night shift; |, the dividing line between 2 days; +, no night between the shifts.

Table 3 A linear mixed model for repeated measurements for the length of the main sleep period prior to the morning shift. All explanatory variables are included in the model when the effect of one variable on the main sleep period is tested. A total of 534 observations has been included in the analysis

Explaining variable	*Categories/units*	*Estimate*	*SD*	*DF*	*P-value*
Intercept		0.65	0.51	266	0.20
Age	≥45 years	0.06	0.13	177	0.62
	< 45 years	Reference	–		–
Occupation	Driver	0.09	0.12	196	0.45
	Controller	Reference	–		–
Shift combination	Undefined	−0.10	0.11	488	0.33
	E | M	−0.53	0.08	504	< 0.001
	D | M	0.09	0.12	465	0.44
	M | M	0.03	0.09	435	0.75
	F | M	Reference	–		–
Children at home	< 7 years	−0.003	0.15	174	0.99
	7–17 years	0.11	0.13	175	0.37
	No children	Reference	–		–
Sleep need	Hour	0.15	0.05	178	0.004
Starting time of morning shift	Time (h)	0.73	0.04	519	< 0.001

SD, standard deviation; Driver, train driver; controller, traffic controller; F, free day; M, morning shift; D, day shift; E, evening shift; |, the dividing line between 2 days.

need of the subjects (7 h 40 min). In these cases, the subjects' mean sleep length was 5 h (SD: 56 min). The ending time of the evening shift (before the morning shift) correlated clearly with the main sleep duration (Spearman correlation coefficient −0.22, $P = 0.005$). On average, a 1 h increase in self-reported sleep need prolonged the main sleep period by 9 min and a 1 h delay in the starting time of the morning shift extended the main sleep by 44 min (Table 3). Descriptive statistics showed that more than half of the main sleep periods were 6 h or more in length only when the shift starting time was later than 6:00 a.m. Twenty-nine percent of the morning shift starting times fell within this range.

Dozing-off during the morning shift

Dozing-off at work was clearly more infrequent in the morning shift than in the night shift (Fig. 2). The events of dozing off were most common in the Morning | Morning and the Free Morning combinations among the drivers and in the Day | Morning combination among the controllers.

The generalized linear model for repeated measurements showed that neither the shift combinations nor the length of the main sleep period were significantly associated with the occurrence of dozing-off. The same was true for the occupation factor although it came up to the level of significance ($P = 0.06$). Only the length of the morning shift was significantly associated with dozing off [$\chi^2(1) = 9.69$, $P = 0.002$]. The odds for dozing off at work increased as the time spent in shift increased (OR = 1.35 for each hour of the shift, 95% confidence limits 1.15–1.59).

DISCUSSION

The present study showed that both the train drivers and the traffic controllers had many shift combinations that were associated with the shortening of sleep prior to the morning and the night shift. For the length of the main sleep period prior to the night shift, the Night | Night and Morning + Night combinations were most disadvantageous. In the case of the morning shift the same was true for the common Evening | Morning combination. Afternoon napping before the night shift clearly increased in the Morning + Night and Day + Night combinations. The events of dozing-off during the morning or the night shift were associated only with shift length, not with shift combinations. The generalization of the results may be limited because 39.6% of the allotted drivers and 48.9% of the allotted controllers did not participate in the study. We do not know the reasons for the refusers' unwillingness to participate, but can at least speculate that they might have considered the study too time-consuming.

Sleep in connection with the night shift

The possibility for a normal nocturnal sleep of 7–8 h before the first night shift was particularly at risk when the night shift was immediately preceded by an early shift (starting time before 7:01 a.m.). The shortening of nocturnal sleep in connection with an early rising time is understandable because of physiologically determined difficulty to fall asleep between 7:00 and 9:00 p.m. (Lavie 1986). Thus, a normal night sleep before the first night shift could be promoted by avoiding preceding early shifts, and if this is not possible, by postponing the starting time of the preceding shift to later than 7:00 a.m.

Our results are in accordance with the finding that sleep is curtailed by 2–4 h between two night shifts as compared with the normal sleep length (Åkerstedt *et al.* 1991; Tilley *et al.* 1982; Torsvall *et al.* 1981). The curtailment of the main sleep period between two night shifts was especially marked among the controllers whose first night shift ended 3.5 h later than the drivers' first night shift. This finding is consistent with the study of Rosa *et al.* (1996) in which already a 1-h delay in the ending time of the night shift (from 06:00 to 07:00) led to a 0.5-h reduction in the length of day sleep. Three obvious reasons for this finding are the rising circadian rhythm of alertness, changes in sleeping conditions (e.g. noise) and social factors during daytime. On the basis of these results, it is recommendable that the first of the two consecutive night shifts would end no later than 7:00 a.m., preferably before, to increase possibilities for a daytime sleep to last at least 5 h.

A way to compensate insufficient sleep and prepare for extended wakefulness is napping (Bonnet *et al.* 1995; Dinges *et al.* 1987). In the present data, the length of the main sleep period was not a significant determinant of afternoon napping. This finding is in line with the study of Rosa (1993), in which the length of nocturnal sleep before the first night shift was similar on the nap and no-nap days. Although the chance for afternoon napping was not associated with the length of the main sleep period, it was elevated in those shift combinations where the main sleep was most curtailed before the first night shift, i.e. in the Day + Night and the Morning + Night combinations. One explanation for this finding may be that workers take an afternoon nap regardless of how long nocturnal sleep they have had because they have often experienced sleep deficit in these combinations. Another possibility is that especially drivers have favourable conditions for afternoon napping in these combinations. Many of the Day + Night and Morning + Night combinations are round trips and drivers have an opportunity to sleep in terminal station's rest rooms while waiting for the start of the night shift.

Also, the starting time of the night shift was an important determinant of the afternoon napping: the later the starting time, the greater the likelihood for the napping. In practice, social reasons may make mid-afternoon napping difficult and unattractive, although the mid-afternoon peak of sleep propensity makes it physiologically easy to take a nap (Lavie 1986; Lavie and Weler 1989). In addition, a mid-afternoon nap has been shown to be less effective in improving alertness during the early morning hours compared with a nap taken at 7:00 p.m. (Lavie and Weler 1989). Also our previous study showed that a nap of 30–50 min taken during the night shift was an effective countermeasure to the drop in vigilance during the late part of the shift (Sallinen *et al.* 1998). Together these findings suggest that the temporal closeness of a nap to the early morning hours is important for the effectiveness of a nap to reduce a high sleep pressure at night work.

The workers' need for sleep as indicated by dozing off during the night shift was only affected by the length of the night shift, but not by the shift combinations or previous sleep periods. Each working hour increased the risk for dozing off by 17%. In our earlier report, which was based on the same sleep diary data as the present study, each working hour increased the risk for severe sleepiness by almost the same probability (15%) (Härmä *et al.* 2002). The occurrence of dozing off in 18–32% of the night shifts is comparable with the results of previous studies on train drivers (Åkerstedt *et al.* 1983; Kogi and Ohta 1975; Torsvall and Åkerstedt 1987). Also its mean temporal placement (3:00 a.m.) is in accordance with the nadir of circadian rhythm of alertness during the early morning hours, although the variation of timing was great (Åkerstedt *et al.* 1977; Folkard *et al.* 1978). In our poststudy interview, the drivers reported that they dozed off in either a rest room or the cabin when the train was stopped. The absence of dozing off while driving is a somewhat surprising finding in the light of previous results (Åkerstedt *et al.* 1983; Härmä *et al.* 2002; Kogi and Ohta 1975). Possible explanations for the fact that dozing off during train driving was not reported are that the subjects were not aware of dozing off (see Torsvall and Åkerstedt 1987) or the subjects considered dozing-off as an indication of poor work performance. It seems that the drivers have marked dozing-offs only when they have more or less voluntarily fallen asleep for a short period of time during a break in driving. The timing of these short periods of sleep indicates that the drivers have mainly used them to cope with an increased sleep pressure, not in a prophylactic sense.

Sleep in connection with the morning shift

Our results are in accordance with the previous findings that the main sleep period before the morning shift starting before 7:00 a.m. is about 5.5–6 h in length (Hak and Kampman 1981; Kecklund *et al.* 1997; Rosa *et al.* 1996). In the present study, a 1 h delay in the starting time of the shift was associated with an extension of 44 min of the main sleep period. This increase in sleep duration is comparable with the results of Hak and Kampman (1981) showing that the main sleep period of railway personnel was 65 min longer when the morning shift started between 6:01 and 8:00 a.m. compared with the starting times between 4:00 and 6:00 a.m. In the present study, half of the main sleep periods before the morning shift were at least 6 h in length only when the shift started after 6:00 a.m. Only 29% of all the morning shifts started between 6:01 and 6:59 a.m. As a whole, it seems that the morning shift should not start before 6:00 a.m. in order to have a reasonable chance for at least 6 h of sleep before the shift.

Of all the shift combinations, only the common Evening | Morning was associated with the curtailment of the main sleep period compared with the Free | Morning combination. The mean free time between the shifts was only 8 h 20 min, which is only about half of what has been recommended by Kecklund and Åkerstedt (1995). In 30% of the Evening | Morning combinations, the free time between the shifts was shorter than the subjects' mean sleep need. In these combinations, the mean sleeping time was 5 h. Laboratory experiments suggest that one night with 5 h sleep does not lead to a substantial impairment of vigilance, but two nights with that amount of sleep do (Dinges *et al.* 1997; Jewett *et al.* 1999). These results suggest that two successive Evening | Morning combinations with about 8 h between the shifts leads to a clear impairment of vigilance. However, one has to keep in mind that in the laboratory experiments, vigilance has been measured with only 10-min test sessions, but in real work, train drivers and traffic controllers have to work noticeably longer sessions. This difference in the time-on-task factor may underestimate the effect that one night of only 5 h of sleep has on vigilance at work.

Dozing-off during the morning shift was quite rare as compared with the night shift. This finding is consistent with our earlier result on the difference in the prevalence of severe sleepiness between the night and the morning shift (Härmä *et al.* 2002). As with the night shifts, only the shift length was associated with the occurrence of dozing off. This result suggests that the differences in the sleeping time between the shift combinations were not large enough to become manifested in dozing-off during the breaks at work.

Individual factors: sleep need and age

To our knowledge, the present study showed for the first time that individual sleep need affects sleeping time in an irregular shift system. In the night shifts, a 1 h increase in sleep need prolonged the main sleep period by 17 min and in the morning shifts by 9 min. These findings demonstrate how a high sleep need magnifies the degree of sleep deprivation in an irregular shift system as only a small part of the additional sleep need can be fulfilled.

Age did not affect sleeping before the morning and the night shifts. This finding is consistent with the previous results showing that aging is likely to decrease the sleeping time between the night shifts, but it does not affect the length of a sleep period before the morning shift or the first night shift (Härmä *et al.* 1994; Rosa *et al.* 1996). In the present data, about 95% of the night shifts were first night shifts. It is unlikely that the use of the seniority principle in selection of various shifts could explain the non-significant age effect. Possible differences in age between the shift combinations were controlled for in the statistical models. In addition, our questionnaire revealed that 42% of the train drivers under 43 years of age, and 71% of the 43-year-old train drivers felt that they could at least partially influence the selection of their work shifts. Among the traffic controllers the case was opposite. Thirty-one percent of the younger but only 15% of the older subjects felt they could influence their work shifts. However, the age effect did not differ between the occupational groups.

The absence of an age effect on dozing off during the night shifts was a somewhat surprising finding. For instance, our earlier study showed that the risk of severe sleepiness at work was decreased by 8% for each year of age (Härmä *et al.* 2002). A reason for this discrepancy may be that in the present study, dozing off at work probably included two types of lowered arousal: involuntary shut-eye and voluntary naps.

Table 4 Shift scheduling guidelines particularly for an irregular shift system

1	The first of the two consecutive night shifts should end no later than 7:00 a.m., preferably before, to provide reasonable conditions for a worker to sleep at least 5 h before the second night shift.
2	To obtain a normal nocturnal sleep before the first night shift, double shifts (e.g. Morning + Night) should be avoided, and if this is not possible, the first shift should not start before 7:00 a.m.
3	The morning shift should not start before 6:00 a.m. to provide reasonable conditions for a worker to have a nocturnal sleep of at least 6 h before the morning shift.
4	The shift combination, in which the evening shift immediately precedes the morning shift, should be avoided because the free time between the shifts is often insufficient for the fulfilment of sleep need.
5	To increase napping before the night shift, the starting time of the night shift should preferably be after 10:00 p.m.

CONCLUSIONS

Our results suggest that sleep before the morning and the night shift in an irregular shift system can be improved by shift scheduling (Table 4). There are shift combinations and the starting and ending times of shifts that should be avoided to facilitate the fulfilment of sleep need. Particularly, early shifts before the night shift, morning shifts starting before six o'clock, and evening shifts before the morning shift should be avoided.

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REFERENCES

Aguirre, A. and Foret, J. Irregularity of working hours in railway workers and types of complaints. *Int. Arch. Occup Environ. Health.*, 1994, 65: 367–371.

Åkerstedt, T., Kecklund, G. and Knutsson, A. Spectral analysis of sleep electroencephalography in rotating three-shift work. *Scand. J. Work Environ. Health*, 1991, 17: 330–336.

Åkerstedt, T., Patkai, P. and Dahlgren, K. Field studies of shift work. II. Patterns in psychophysiological activation in workers alternating between night and day work. *Ergonomics*, 1977, 20: 621–631.

Åkerstedt, T. Sleepiness as a consequence of shift work. *Sleep*, 1988, 11: 17–34.

Åkerstedt, T., Torsvall, L. and Fröberg, J. E. A questionnaire study of sleep/wake disturbances and irregular work hours. *Sleep Res.*, 1983, 12: 358.

Åkerstedt, T. Work hours and sleepiness. *Neurophysiol. Clin.*, 1995, 25: 367–375.

Bonnet, M., Gomez, S., Wirth, O. and Arand, D. L. The use of caffeine versus prophylactic naps in sustained performance. *Sleep*, 1995, 18: 97–104.

Brown, H. and Prescott, R. *Applied Mixed Models in Medicine*. John Wiley & Sons Ltd., Chichester, 1999.

Dinges, D. F., Orne, M. T., Whitehouse, W. G. and Orne, E. C. The placement of a nap for alertness: contributions of circadian phase and prior wakefulness. *Sleep*, 1987, 10: 313–329.

Dinges, D. F., Pack, F., Williams, K. et al. Cumulative sleepiness, mood disturbance, and psychomotor vigilance performance decrements during a week of sleep restricted to 4–5 hours per night. *Sleep*, 1997, 20: 267–277.

Folkard, S., Monk, T. H. and Lobban, M. C. Short and long term adjustment of circadian rhythms in 'permanent' night nurses. *Ergonomics*, 1978, 21: 785–799.

Foret, J. Conditions de travail des conducteurs de train: revue des 'etudes physiologiques et psychophysiologiques. *Le Travail Humain*, 1987, 50: 17–33.

Foret, J. and Lantin, G. 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, Diurnal Rhythm and Sleep Loss*. Academic Press, London, 1972: 273–282.

Hak, A. and Kampman, R. Working irregular hours. complaints and state of fitness of railway personnel. In: A. Reinberg and N. Vieux (Eds) *Night and Shift Work. Biological and Social Aspects*. Pergamon Press, Oxford, 1981: 229–236.

Härmä, M., Hakola, T., Åkerstedt, T. and Laitinen, J. Age and adjustment to night work. *Occup. Environ. Med*., 1994, 51: 568–573.

Härmä, M., Sallinen, M., Ranta, R., Mutanen, P. and Muller, K. The effect of an irregular shift system on sleepiness at work in train drivers and railway traffic controllers. *J. Sleep Res*., 2002, 11: 141–151.

Ingre, M., Söderström, M., Kecklund, G., Åkerstedt, T. and Kecklund, L. *Train Drivers Work Situation. Working Hours, Sleep, Stress and Safety*. Stress Research Report no. 292. Institutet för Psykosocial Medicin (IPM), Stockholm, 2000 (Swedish with an English abstract)

Jewett, E., Dijk, D.-J., Kronauer, E. and Dinges, D. F. Dose–response relationship between sleep duration and human psychomotor vigilance and subjective alertness. *Sleep*., 1999, 22: 171–179.

Kecklund, G., Åkerstedt, T. and Lowden, A. Morning work. effects of early rising on sleep and alertness. *Sleep*, 1997, 20: 215–223.

Kecklund, G. and Åkerstedt, T. Timing of shifts on sleepiness and sleep duration. *J. Sleep Res*., 1995, 4 (Suppl. 2): 47–50.

Kogi, K. and Ohta, T. Incidence of near accidental drowsing in locomotive driving during a period of rotation. *J. Hum Ergol*., 1975, 4: 65–76.

Kolmodin-Hedman, B. and Swensson, Å. A field study of Swedish railroad workers with irregular work hours. *Scand. J. Work Environ. Health*, 1975, 1: 254–262.

Kurumatani, N., Koda, S., Nakagiri, S., Hisashige, A., Sakai, K., Saito, Y., Aoyama, H., Dejima, M. and Moriyama, T. The effects of frequently rotating shift work on sleep and the family life of hospital nurses. *Ergonomics*, 1994, 37: 995–1007.

Lavie, P. Ultrashort sleep-waking schedule. III. Gates and 'forbidden zones' for sleep. *Electroenceph. Clin. Neurophysiol*., 1986, 63: 414–425.

Lavie, P. and Weler, B. Timing of naps: effects on post-nap sleepiness levels. *Electroenceph. Clin. Neurophysiol*., 1989, 72: 218–224.

Littell, R. C., Milliken, G. A., Stroup, W. W. and Wolfinger, R. D. *SAS® System for Mixed Models*. SAS Institute Inc., Cary, NC, 1996.

Rosa, R. Napping at home and alertness on the job in rotating shift workers. *Sleep*, 1993, 16: 727–735.

Rosa, R., Härmä, M., Pulli, M., Mulder, M. and Näsman, O. Rescheduling a three-shift system at a steel rolling mill: effects of a 1-hour delay of shift starting times on sleep and alertness in younger and older workers. *Occup. Environ. Med*., 1996, 53: 677–685.

Sallinen, M., Harma, M., Akerstedt, T., Rosa, R. and Lillqvist, O. Promoting alertness with a short nap during a night shift. *J. Sleep Res*., 1998, 7: 240–247.

Tilley, A. J., Wilkinson, R. T., Warren, P. S., Watson, B. and Drud, M. The sleep and performance of shift workers. *Hum Factors*., 1982, 24: 629–641.

Torsvall, L., Åkerstedt, T. and Gillberg, M. Age, sleep and irregular work hours. A field study with electroencephalographic recording, catecholamin excretion and self-ratings. *Scan J. Work Environ. Health*, 1981, 7: 196–203.

Torsvall, L. and Åkerstedt, T. Sleepiness on the job: continuously measured EEG changes in train drivers. *Electroenceph. Clin. Neurophysiol*., 1987, 66: 502–511.