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The effect of an irregular shift system on sleepiness at work in train drivers and railway traffic controllers

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SUMMARY Sleepiness and fatigue are frequent problems in railway transportation with occasional monotony and irregular shift schedules. This study aimed at (1) studying the prevalence of severe sleepiness in shifts and (2) examining which shift and sleep-related factors were associated with the occurrence of severe sleepiness in an irregular shift system. A total of 126 randomly selected male train drivers (Tdrs) and 104 railway traffic controllers (Tcos) were investigated using questionnaires and sleep–wake diaries. A sleep diary was used to collect information on sleepiness at work and sleeping times during the 21 consecutive days of the study. The prevalence of severe sleepiness at work (i.e. Karolinska Sleepiness Scale 7 or higher) was modelled by a logistic regression analysis for repeated measurements (GEE) using different shift schedule related factors and sleep length as explanatory variables. Severe sleepiness was reported in 49% (Tdrs) and 50% (Tcos) of the night shifts and in 20% (Tdrs) and 15% (Tcos) of the morning shifts. The odds ratios showed that the risk for severe sleepiness was 6–14 times higher in the night shift and about twice as high in the morning shift compared with the day shift. Age affected the two occupational samples differently: with Tdrs increased age was associated with an additional 8% reduction of risk for severe sleepiness for each year of age, while the Tcos did not show any age dependency. Shift length increased the risk by 15% for each hour of the shift and main sleep period decreased the risk by 15% for each hour of the main sleep. The risk of severe sleepiness was not consistently related to the time-off period before the shifts. The results indicate that adjustments for shift timing, length and off-duty time, in addition to actions aiming at extending the main sleep period, would probably decrease severe sleepiness in railway transportation.

KEYWORDS age, railway traffic controllers, shiftwork, sleepiness, train drivers

INTRODUCTION

Sleepiness and fatigue at work are frequent problems in many sectors of transportation with night and early morning work (Åkerstedt 1995). Although professional drivers have less fatigue-related accidents than private drivers (Summala and Mikkola 1994), fatigue prevention in road, air and marine transportation has become a large issue in many public and private transportation companies (Dinges 1995).

The train driver's and railway traffic controller's work has special features compared with other professional drivers and controllers. The subjective workload of train drivers is relatively high (Ingre *et al.* 2000). While attentional and information-processing requirements are increasing in many train driving tasks as a result of new technology, the driver's work is often subject to occasional periods of monotony. The driver is often alone in the locomotive cabin. Driving is focused on controlling speed and acceleration (Branton 1979; Foret 1987) but the driver also has to concentrate on the control of different dynamic forces, upcoming terrain, traffic signs and communication. Computerized remote controlling of railway traffic requires constant surveillance of on-going traffic. The work includes intense periods of information encoding and problem solving.

The shift schedules in railway transportation are often irregular and include early morning shifts and relatively short

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time-off intervals between the shifts (Cabon *et al.* 1993; Dekker *et al.* 1993; Foret 1987; Hak and Kampman 1981; Ingre *et al.* 2000; Torsvall *et al.* 1981). Sleeping conditions between consecutive shifts may also be degraded if the train driver is not sleeping at home (e.g. Foret 1987; Hak and Kampman 1981; Ingre *et al.* 2000).

About one-fourth of Swedish train drivers reported chronic fatigue at least once a week (Ingre 2000). Excessive fatigue is most frequent during night and early morning shifts (Dawson *et al.* 1998; Ingre *et al.* 2000; Hak and Kampman 1981; Moore-ede *et al.* 1996). Dozing off while operating the train, an extreme manifestation of sleepiness at work, has been reported by 11 and 26% of train drivers, respectively (Åkerstedt *et al.* 1983; Kogi and Ohta 1975). In an ambulatory electroencephalogram (EEG) study of train drivers, Torsvall and Åkerstedt (1987) showed that objective signs of sleepiness [slow eye movements (SEMs) and EEG power density in the alpha and theta bands] increased steadily during the night shifts. Four of the 11 drivers dozed off during the night shift and one passed two consecutive stop signals while having concurrent rolling eye movements according to the encephalo-oculogram (EOG).

Reduction of fatigue in rail transportation is a safety question. Lack of alertness was the most important single contributor for accidents and near accidents in a recent analysis of more than 100 such cases (Edkins and Pollock 1997). Based on two other separate analysis of near accidents, both Kogi and Ohta (1975) and Kecklund *et al.* (1999) suggest that about 17% of the train incidents are related to severe sleepiness at work. The relationship between sleepiness and human factors-induced accidents is also supported by the finding that both the emergency braking behaviour of the drivers and the frequency of non-operation of the safety switch (a piece of equipment expressly designed to prevent the driver falling asleep) were reported to peak at the same time during the early morning hours when sleepiness is peaking (Hildebrandt *et al.* 1974b; Kogi and Ohta 1975; Verhaegen *et al.,* personnal communication). Accident reports also suggest that fatigue and poor shift schedules have occasionally been reported or identified as major contributors in serious rail accidents (Lauber and Kayten 1988; Moore-ede *et al.* 1996; Onnettomuustutkintakeskus 1999).

In order to prevent fatigue in rail transportation it is important to know the critical characteristics of the work schedules that are related to excessive sleepiness. It is not possible to avoid night and early morning shifts in 24-h rail transportation, but it is possible to adjust shift lengths, time between shifts and shift combinations to minimize fatigue. There is very little objective data on the relationship of shift characteristics and sleepiness in irregular shift systems. Due to the variable intraindividual sleep–wake and shift rhythms, questionnaire studies of irregular shift systems are exposed to memory bias and cannot sufficiently parse out the different causative factors linking the effects of shift work to sleepiness. Although the shift work of train drivers and air traffic controllers (e.g. Luna 1997) has been under research, we are not aware of earlier research on shiftwork and sleep among the railway traffic controllers.

Karolinska Sleepiness Scale (KSS) (Åkerstedt and Gillberg 1990) is widely used for the measurement of subjective sleepiness at work. In this study, severe sleepiness was defined as a KSS rating of 7 (e.g. 'sleepy but not yet fighting sleep') or greater. These perceived bouts of severe sleepiness have been shown to correlate highly with intraindividual neurophysiological signs of sleepiness during train driving (Torsvall and Åkersted 1987). Furthermore, Gillberg *et al.* (1994) found the KSS to correlate to changes in cognitive performance during the night shift. Occasional SEMs and increasing amounts of alpha and theta activity in the EEG usually start to appear at a KSS rating of 7 (Åkerstedt and Gillberg 1990; Gillberg et al. 1994). The appearance of SEMs and alpha and theta activity in the EEG are related to cognitive performance deterioration and lapses in vigilance tasks (Åkerstedt and Gillberg 1990). A rating of 7 on the KSS has also been found to predict steering errors in car simulation studies (Reyner and Horne 1998).

The earlier studies of train drivers do not give exact prevalence rates of sleepiness severe enough to affect operational performance and safety. Therefore, this study aimed at examining the prevalence of severe sleepiness at work in a large random sample of male train drivers and railway traffic controllers. Secondly, the effect of different shift and sleep characteristics (shift timing, shift length, time-off between shifts, sleep length, etc.) on the risk of severe sleepiness at work was studied through multivariate analysis.

MATERIALS AND METHODS

Subjects

Based on an initial randomization among all professional train drivers (Tdrs) and railway traffic controllers (Tcos) of the state railroad in Finland, 139 of 230 allotted Tdrs (60.4%) and 138 of 270 allotted Tcos (51.1%) gave informed consent to participate in this combined laboratory and field study.

Two subjects failed to complete the protocol due to acute sickness absences. Subjects not on irregular three-shift work ($n = 12$) and those with extensive missing information, holidays, on-call shifts, sick-leave or training courses ($n = 11$) were excluded. Twenty-six females, all Tcos, were excluded from the multivariate analysis as gender showed significant effects on sleepiness in an initial multivariate analysis of traffic controllers, that is, to maintain homogeneity of variance within the sample. These exclusionary criteria are not orthogonal and did overlap in some instances. The remaining 126 Tdrs and 104 Tcos were accepted for the current analysis. There were no significant differences in the mean age, body mass index (BMI) and shift work experience between the two occupational groups (Table 1). However, the range of many variables was greater among the Tcos.

Table 1 The characteristics of male subjects. Mean values and ranges

	Train drivers (*n* = *126*)	*Traffic controllers* (*n* = *104*)
Age (years)	42.3 (33–55)	44.2 (26–61)
BMI (kg m^{-2})	25.7 (21–37)	26.2 (18–48)
Shift work experience (years)	22 (14–36)	19 (0–38)
Percentage of subjects who have children under 7 years of age	32%	18%

Study protocol

The subjects visited a sleep laboratory twice separated by a 3-week interval. As participants could only be investigated in couplets, the entire protocol required 2 years to complete. During the first visit a nurse gave instructions on the use of a sleep diary. A health interview and an ophthalmologic and neurophychological screening was also given. The diary was started on the first visit and was completed 21 days later when the subject returned to the sleep laboratory. During this visit the diary was checked for completion and a separate shift work and sleep questionnaire was filled in. A whole-night polysomnography was also registered during this visit. Maintenance of Wakefulness tests and computerized cognitive performance tests were carried out during the following day in the laboratory. These data will be published separately and will not be discussed in this paper.

Sleep diary

The subjects filled in the sleep diary daily for 21 consecutive days. They were instructed to keep the diary available at all times and to record the starting and ending times of all shifts. Information about the total amount of coffee, alcohol and medicine consumed during the past 24 h was also to be provided daily prior to the main sleep period. Upon awaking subjects answered questions concerning the clock time when they got up from bed, sleep latency, number of awakenings and sleep quality. In addition to the main sleep period, a maximum of two other sleep periods were registered during each 24-h period. Main sleep length was calculated as the interval between lights-off and lights-on times. Sleep latency was subtracted out from its base value. In the case of several sleep periods a day, the main sleep period was defined as the longest sleep period ending after 22:00 at the preceding day or the same day of the shift. The main sleep period could thus be a normal night sleep or a day sleep between two night shifts.

Sleepiness was rated using the KSS (Åkerstedt and Gillberg 1990). Scale scores were recorded by the subjects at the beginning and end of each shift, and at any time during the shift when the subject felt 'sleepy' (instructed to indicate a KSS rating of 6 or greater on this 9-point scale). Short nodding-off episodes/naps (i.e. less than 30 min) at any time of the day were marked separately on the sleep–wake diary.

Shift work questionnaire

Participants were asked to report the frequency of severe sleepiness at work in connection with their morning, evening and night shifts (5-point scale, very seldom or never – often or continuously). The survey also asked whether these episodes of severe sleepiness impaired work performance (5-point scale, very seldom or never – often or continuously). The 5-point scale (not at all – very much) was also used to determine the amount of influence the worker had on selecting his shifts.

Shift schedules

Based on the collective agreement, the average working time was 38 h 15 min among the Tdrs and 37 h 30 min among the Tcos. In Tdrs, continuous driving time was limited to 3.5 h with a single driver where breaks shorter than 12 min were accounted. Tcos had a normal office working time with 37 h and 30 min a week without any additional breaks.

The recording of diary data across the 21 consecutive days of the study for the 230 subjects resulted in data from 2482 separate shifts (Table 2). For purposes of data analysis, these highly irregular shifts were assigned as morning, day, evening and night shifts. The definition of night shift was taken directly from the Finnish Working Time Act (night shift: at least 3 h of the shift, or the whole shift, falling between 23:00 and 06:00). Consequently, some very late shifts with less than 3 h after 23:00 were recorded as evening shifts and some very early shifts starting less than 3 h before 06:00 were recorded as morning shifts. The following set of rules was used: *night shift* – at least 3 h of the shift, or the whole shift, falling between 23:00 and 06:00; *evening shift* – ending between 19:00 and 01:59 and not categorized as a night shift; *morning shift* – starting between 03:01 and 06:59 and not recorded as a night or an evening shift; *day shift* – starting between 07:00 and 13:59 and is not a night or an evening shift.

Shift starting and ending times, shift length and time-off periods of the Tdrs were in most cases more variable than those of Tcos. The Tdrs had more morning shifts and less day shifts than Tcos. The morning shifts of the Tdrs started on the average a half an hour earlier but ended later than those of Tcos (Table 2). The median starting and ending times of the Tdr's day shifts were about 2 h later compared with Tcos. The night shifts of Tcos lasted for 10 h on the average, while the night shifts of Tdrs were only about 8 h. In both groups, 25% of the night shifts started not more than 8 h after the end of the preceding shift. Although Tdrs had more very short time-off periods before going back on duty (6 h or less, Fig. 1), the median of the time-off period before the night and morning shifts was lower among the Tcos than among the Tdrs. Night shifts were often followed by day or evening shifts during the same solar day (e.g. 25% of the time-off periods after the night shifts were 9.8 h or less among the Tdrs).

According to the questionnaire, 42% of the Tdrs under 43 years of age and 71% of the 43-year-old or older Tdrs felt they could at least partially influence the selection of their

Table 2 Characteristics of the 2482 shifts during the 3-week follow-up period of the train drivers (Tdrs, $n = 126$) and railway traffic controllers

	Morning shifts N (%)			*Day shifts N (%)*			*Evening shifts N (%)*			*Night shifts N (%)*			*All N (%)*
Train drivers	354 (25.9)			317 (23.2)			409 (29.9)			286 (20.9)			1366 (100)
Traffic controllers	233 (20.9)			339 (30.4)			323 (28.9)			221 (19.8)			1116 (100)
	Med	*25%*	*75%*	*Med*	*25%*	*75%*	*Med*	*25%*	*75%*	*Med*	*25%*	*75%*	
Starting time of the shift													
Tdrs	05.30	05.00	06.00	09.00	08.00	11.00	13.30	12.00	15.50	22.00	21.00	00.30	
Tcos	06.00	05.40	06.30	07.30	07.00	09.00	13.00	12.30	14.00	21.00	20.50	21.20	
Ending time of the shift													
Tdrs	13.30	12.00	14.30	16.00	14.30	17.30	22.00	21.00	23.10	06.00	04.30	07.00	
Tcos	13.00	12.20	14.10	14.00	13.00	16.30	21.00	21.00	21.30	07.00	06.20	07.00	
Shift length (h)													
Tdrs	7.8	6.5	9.0	6.2	4.0	8.0	8.3	7.0	9.7	8.0	6.0	9.3	
Tcos	7.0	6.2	8.0	6.2	5.7	7.8	8.2	7.8	9.0	10.0	9.0	10.2	
Free time before the shift													
Tdrs	16.2	9.7	≥24.0	14.3	7.0	≥24.0	22.5	14.0	≥24.0	15.5	7.7	≥24.0	
Tcos	12.5	9.3	≥24.0	16.0	10.0	≥24.0	≥24.0	16.8	> 24.0	8.0	7.8	9.0	
Free time after the shift													
Tdrs	≥12.0	9.0	≥12.0	≥12.0	11.5	≥12.0	≥12.0	9.0	≥12.0	≥12.0	9.8	≥12.0	
Tcos	≥12.0	8.3	≥12.0	≥12.0	8.0	≥12.0	10.0	9.5	≥12.0	≥12.0	≥12.0	≥12.0	

work shifts. On the contrary, 31% of the younger but only 15% of the older Tcos felt they could influence their work shifts (data not shown).

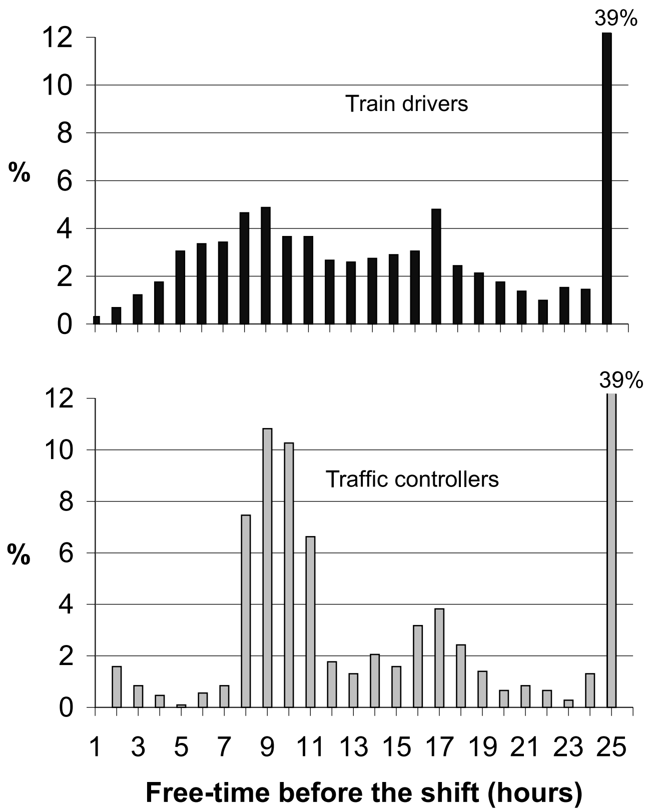

Figure 1. The distributions of free time before the shift (hours) during a 3-week period of the total number of 2482 work shifts among train drivers and railway traffic controllers.

Work demands

The work demands of two Tdrs and Tcos was analysed by a simple task analysis of the different jobs. Most Tdrs were driving both cargo and passenger trains, the system mixing also the high-speed and commuter driving and one or two concurrent drivers, depending on the route. Occasional monotony with fluctuating demands for attention and communication was typical for the work, work demands depending on the time of the day and route. Tcos were working in small and large train stations. In small stations the Tcos had mixed work, traffic controlling being only one of the main tasks and the work being only partly computerized. In large stations the Tcos were doing fully computerized work including constant surveillance of on-going traffic. Work was from moderate to highly information intensive with occasional needs for problem solving and decision making in relation to the overall traffic situation.

Statistical methods

For continuous shift-related variables (e.g. starting and ending times of the shift, shift length, free time before and after the shift, and length of the main sleep period before the shift), descriptive characteristics, such as mean, median, as well as first and third quartiles (Q1 and Q3) were calculated. Frequency and percentage distributions were calculated for the categorical variables.

The prevalence of severe sleepiness at work (KSS 7 or higher at least once at any time during the shift) was modelled through a logistic regression analysis for repeated measurements (Generalized Estimating Equations, GEE) using shift schedule related factors (e.g. shift type, length and interval between shifts), sleep length, age and occupation as explanatory variables (Table 4). The binary responses for repeated measurements were assumed to be equally correlated, i.e. an exchangeable correlation structure in GEE model; also implying one parameter into the statistical model. The logistic regression analysis for repeated measurements accounts thus for both intra- and interindividual variation and gives risk estimates of excessive fatigue for different shift and sleep-related factors. The logistic regression models a probability of severe sleepiness (P) and uses logit as a link function. In this study, the following model was used:

$$\begin{aligned}\text{logit}(P) = \log[P/(1-P)] = {} & Intercept + \beta_{age} \cdot age \\ & + \beta_{occupation} + \beta_{shift} + \beta_{time\_before\_shift} \\ & + \beta_{shift\_length} \cdot shift\_length \\ & + \beta_{main\_sleep\_length} \cdot main\_sleep\_length \\ & + \beta_{shift \times time\_before\_shift} \\ & + \beta_{age \times occupation} \cdot age\end{aligned}$$

In addition to the main sleep length, there was also an attempt to include the time awake (the homeostatic factor) in the model; however, because of its very strong covariation (multicollinearity) with a shift type and shift interval (free time before the shift) it was dropped from the analysis. We also calculated additional logistic models with the interactions of shift type and sleep length and, similarly, shift type and shift length, added to the above model one at the time.

The results of the GEE analysis are presented as odds ratios (OR) and their 95% confidence intervals, along with the associated P-values for each parameter and for each variable in the model. The OR, here precisely the prevalence odds ratio (POR), is used because (1) the data is cross-sectional, (2) of its sound mathematical and statistical properties, and (3) it is typically used on this kind of data. It should be noted, however, that when the studied prevalence rate is common, as it is here, OR overestimates the rate ratio parameter (prevalence rate ratio or risk ratio), when OR is greater than one, and underestimates it when OR is less than one (Zhang and Yu 1998).

Odds ratios and their confidence intervals for the unit of quartile range of the continuous explanatory variables described above were computed in order to compare their effect on severe sleepiness.

All the statistical analyses were performed using the Statistical Analysis System, SAS Versions 6.12 (SAS Institute Inc. 1989) or 8 (SAS Institute Inc. 1999). All statistical tests were two-tailed with a significance level of $P < 0.05$.

RESULTS

Prevalence of sleepiness

Questionnaire

According to the survey, over half of the train drivers and traffic controllers reported severe fatigue during their night shifts (Table 3). Perceived work performance impairment due to fatigue during the night shifts was reported by 21–37% of the Tdrs and 13–19% of the Tcos. In relation to age, younger Tdrs (under 43 years) reported more fatigue during the morning shifts than older (43 years or older) Tdrs. However, older Tdrs rated decreased work performance more often than younger Tdrs during the night shifts.

Table 3 The percentage of subjects having severe fatigue at work (rather often, often or continuously) and who perceive that fatigue impairs their work performance (rather often, often or continuously). The questions were asked separately during morning, evening and night shifts. Statistical difference (χ^2-test) between the younger and older group

	Shift		
Age (years)	*Morning -42, 43- (P)*	*Evening -42, 43- (P)*	*Night -42, 43- (P)*
Severe fatigue (%)			
Train drivers	31, 15 (0.044)	1, 4	51, 57
Traffic controllers	22, 14	7, 9	61, 57
Fatigue impairs work performance (%)			
Train drivers	8, 4	1, 4	21, 37 (0.044)
Traffic controllers	4, 4	0, 4	13, 19

Sleep and work diary

Figure 2 shows the occurrence of severe sleepiness at the beginning, end and throughout (including the beginning and the end) the morning, day, evening and night shift as recorded in the diary. Severe sleepiness was perceived at least once during the shift in 49% (Tdrs) and 50% (Tcos) of the night shifts and in 20% (Tdrs) and 15% (Tcos) of the morning shifts.

The effect of irregular shift system on sleepiness

Table 4 shows the obtained logistic regression model for repeated measurements giving ORs for the studied shift and sleep-related factors associated with the severe sleepiness at work. In order to compare the effects of the continuous variables, such as the main sleep length, shift length and age to each other in respect to their effects on the occurrence of severe sleepiness at work, ORs for the unit of the quartile range of the continuous variables were also calculated (Table 5).

Age and occupation had an interaction with the occurrence of severe sleepiness. Among the Tcos, the risk for severe sleepiness did not change according to age while younger Tdrs had greater risk for severe sleepiness than older Tdrs. Among the Tdrs, age decreased the risk of severe sleepiness by 8% each year, compared with Tcos. As the ORs of Table 4 cannot be interpreted directly for interactions (e.g. OR 26.6 is for zero-old Tdrs compared to zero-old Tcos), the age-dependency of the risk of severe sleepiness of Tdrs compared with Tcos was calculated from the model (Fig. 3). Thirty-four year old Tdrs had about double the risk and 51-year-old Tdrs had half the risk for severe sleepiness compared with Tcos of the same age.

Shift type had a significant effect on the occurrence of severe sleepiness (Table 4) and an interaction with the amount of free time prior to shift. Based on the model, the ORs for night vs. day shifts for severe sleepiness were 6.9, 6.2 and 13.5 for the

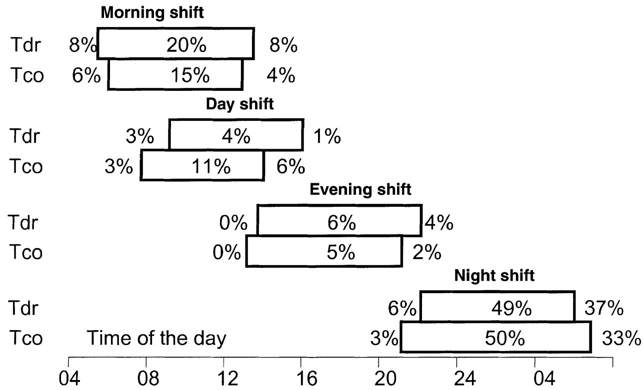

Figure 2. The occurrence of severe sleepiness (KSS 7 or higher) of the train drivers (Tdrs, $n = 126$) and railway traffic controllers (Tcos, $n = 104$) at the beginning, at any time (in the middle of the bar) and at the end of all morning, day, evening and night shifts (total no = 2482) during a 3-week period.

shortest (< 8 h), middle (8–16 h) and longest (≥16 h) free-time periods before the shift. Similarly, the ORs for severe sleepiness during morning vs. day shifts were 2.4, 1.3 and 2.3 for the shortest, middle and longest free-time period before the shift. Free time before shift did not have a consistent effect on severe sleepiness although the interaction with shift type showed that a night shift with a free-time period of 16 h or more prior to beginning the shift was associated with a somewhat higher risk for severe sleepiness than a night shift preceded by 8–16 h of free time. For the remaining three shifts, the shortest analysed time-off period before the shift (< 8 h) tended to be associated with an increased risk for severe sleepiness at work compared with the longest analysed free time before the shift (≥16 h, e.g. Figs 4 and 5).

Shift length increased the risk of severe sleepiness by 15% for each hour of the shift (Table 4). The increase of shift length from 6 to 9 h (from the first to the third quartile of the distribution) increased the risk for severe sleepiness by 51% (Table 5). Similarly, each hour of the main sleep decreased the occurrence of severe sleepiness by 15%. The increase of main

Table 4 Logistic regression analysis (GEE) of variables predicting the risk (odds ratios, OR) of severe sleepiness at work (at least one KSS value of 7 or higher during the shift). The reference groups of classified variables have an OR of 1.0. With the continuous variables shift length and main sleep length, the OR indicates the risk for the each hour of the variable. With age the OR indicates the risk for each year

Explaining variable	*Level 1*	*Level 2*	*OR*	*95% Confidence limits*		*P* variable*	*P** level*
Intercept			0.1	0.0	1.2		0.071
Age			1.0	0.9	1.0	0.011	0.767
Occupation						0.056	
	Tdrs		26.6	1.0	675.2		0.047
	Tcos		1.0	1.0	1.0		
Shift							
	Even.		0.7	0.4	1.4		0.363
	Night		13.5	7.4	24.8		0.000
	Morn.		2.3	1.3	4.1		0.005
	Day		1.0	1.0	1.0		
Time before the shift						0.161	
	< 8 h		1.6	0.7	3.5		0.236
	8–16 h		1.7	0.9	3.0		0.076
	≥16 h		1.0	1.0	1.0		
Shift length			1.1	1.1	1.2	0.000	0.000
Main sleep length			0.9	0.8	0.9	0.003	0.002
Shift × time before the shift						0.263	
	Even.	< 8 h	1.4	0.5	4.1		0.562
	Even.	8–16 h	1.0	0.4	2.9		0.970
	Even.	≥16 h	1.0	1.0	1.0		
	Night	< 8 h	0.5	0.2	1.0		0.130
	Night	8–16 h	0.5	0.2	1.0		0.053
	Night	≥16 h	1.0	1.0	1.0		
	Morn.	< 8 h	1.1	0.4	2.8		0.907
	Morn.	8–16 h	0.6	0.3	1.2		0.132
	Morn.	≥16 h	1.0	1.0	1.0		
	Day	< 8 h	1.0	1.0	1.0		
	Day	8–16 h	1.0	1.0	1.0		
	Day	≥16 h	1.0	1.0	1.0		
Age × occupation						0.055	
	Tdrs		0.9	0.9	1.0		0.45
	Tcos		1.0	1.0	1.0		

**P*-value for the whole variable based on Likelihood ratio Type III test.
***P*-value for the parameter estimates based on Z-scores.

Table 5 Odds ratios for the unit of quartile range of the continuous variables (main sleep length, shift length, and age × occupation–interaction)

Variable	*1st quartile (Q1 = 25%)*	*3rd quartile (Q3 = 75%)*	*Quartile range (Q3–Q1)*	*OR for quartile range*	*Confidence interval for OR*
Main sleep length	5 h 30min	7 h 55min	2 h 25min	0.71	0.57–0.88
Shift length	6 h	9 h	3 h	1.51	1.25–1.84
Age, all (years)	39	47	8		
Train drivers	38	45	7	0.50*	0.33–0.76*
Traffic controllers	39	48	9	0.93*	0.60–1.46*

*quartile range 8 years (all subjects) used in the calculations.

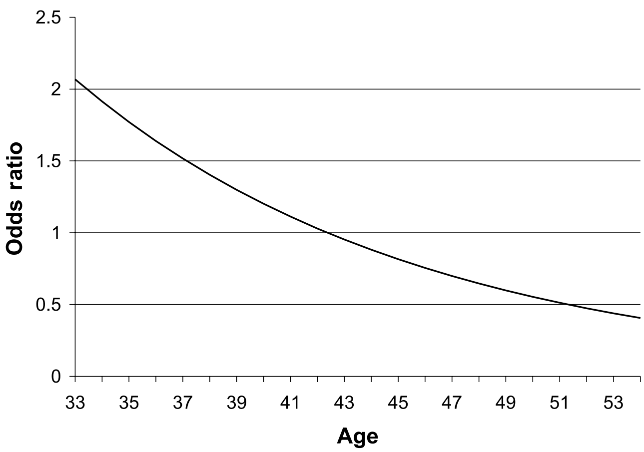

Figure 3. Odds ratio for the occurrence of severe sleepiness at work among train drivers compared with railway traffic controllers. The data are based on the multivariate model in Table 4.

sleep length from 5 h 30 min to 7 h 55 min (from the first to the third quartile of the distribution) decreased the occurrence of severe sleepiness by 41% (Table 5). Figures 4 and 5 show examples of the effects of main sleep length and shift length on the probability of severe sleepiness in different shift and prior-to-shift free time combinations among the Tdrs. Although severe sleepiness was most probable during the night and morning shifts, a long shift and a short main sleep length also seemed to increase the probability for severe sleepiness at work with regard to the day and evening shifts.

Because of the complicated interactions between shift type, time-off period, naps and other explaining factors, we could not add the time-since-sleep effect to the logistic regression model. However, to explain the relatively mild effect of the different free-time period on the occurrence of severe sleepiness during the night shift, napping in different free-time period conditions prior to the Tdrs' night shifts was analysed. When the night shift was preceded by at least 16 h of free time, the length of the preceding main sleep period was, on average, 6.3 h, 25% of the Tdrs took an additional nap, and the mean time since sleep (main sleep or nap) at the beginning of the night shift was 5.9 h. If the night shift was preceded by less than 8 h of free time before the shift, the length of the main sleep period was 6.1 h (mean), 63% of the Tdrs took an additional nap, and the mean time since sleep at the beginning of the night shift was only 3.6 h. Similarly, a short free-time period before the night shift was related to increased napping among the Tcos. Since the effects of different shifts and shift combinations on sleep and napping were very complicate, these data will be published seperately.

The used multivariate model included only one interaction term of the shift type (shift type × time before the shift). To study the possibility that the effect of main sleep length and the effect of shift length would also be modified by shift type, two additional logistic models with the above interaction terms were calculated. The shift length did not have any interaction with shift type. However, in a model where the interaction between sleep length and shift type was added to the model presented in Table 4, the interaction term of sleep length × shift type became significant ($P < 0.0001$). The new interaction shows that in relation to the occurrence of severe sleepiness at work, the possible shortening of main sleep length was important before the morning, day and evening shifts but not before the night shift (Table 6).

The addition of the new interaction term of shift type × main sleep length decreased dramatically the significance of the interaction between shift type and time before the shift in the new logistic model. The other explaining factors did not change substantially (age, $P < 0.014$; occupation, $P < 0.081$; shift, $P < 0.069$; time before the shift, $P < 0.683$; shift length, $P < 0.001$; main sleep length, $P < 0.0001$; shift type × time before the shift, $P < 0.490$; age × occupation, $P < 0.085$; shift type × main sleep length, $P < 0.0001$).

DISCUSSION

These results indicate that fatigue and severe sleepiness at work are very common among personnel responsible for train driving and the control of train traffic. Based on a large and nationally representative sample of subjects, severe sleepiness was perceived in about 50% of all night shifts and in about one-fifth of all the morning shifts during the 3 weeks they participated in the study.

Earlier studies have shown that fatigue and sleepiness are associated with night and early morning shifts among the train drivers (Åkerstedt *et al.* 1980; Dawson *et al.* 1998; Hak and Kampman 1981; Ingre *et al.* 2000; Kolmodin-Hedman and Svensson 1975). In an earlier Swedish study, only 25% of train drivers reported excessive sleepiness 'sometimes or continuously' (Åkerstedt *et al.* 1980). In a later questionnaire study, severe sleepiness during a night shift was reported

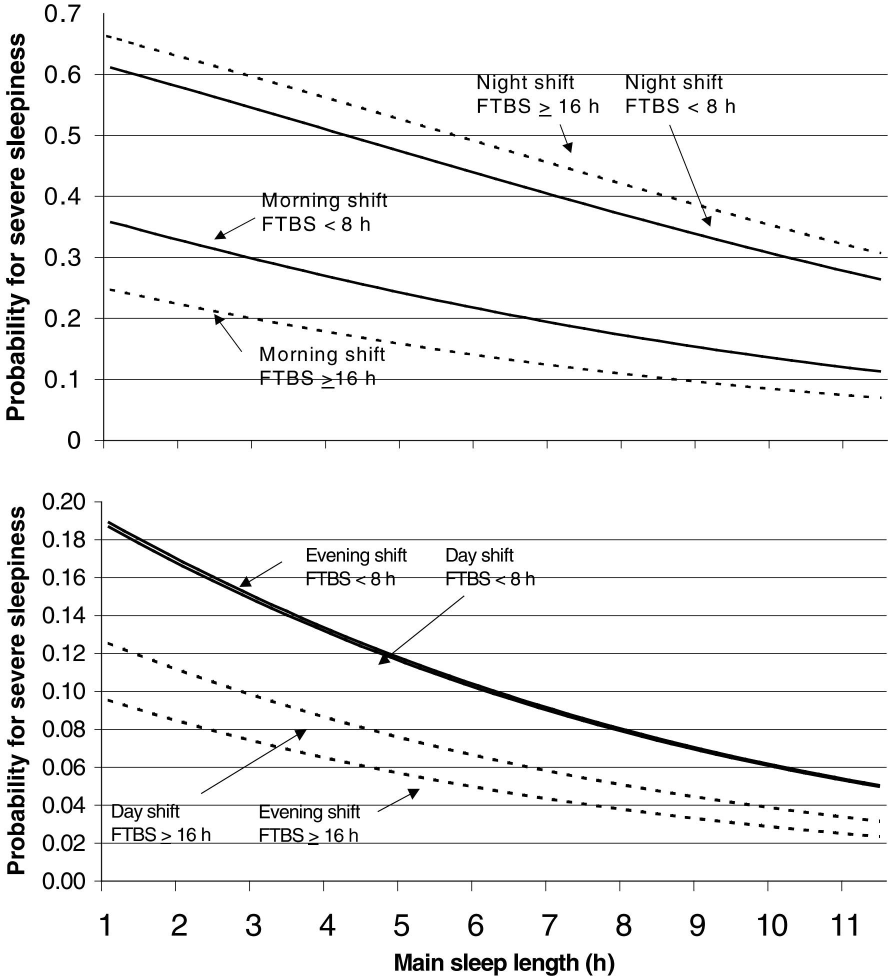

Figure 4. Probability for severe sleepiness according to the shift type and free time before the shift (FTBS, <8 h and ≥16 h) among the train drivers. Data are based on the logistic regression model (Table 4) where a mean value of 43.2 years has been used for age and 7.6 h for the shift length.

monthly by 57% of the train drivers (Ingre 2000), the same exact number found here with the group of 43 or older drivers (57%). Due to different questions, it is still not possible to directly compare the frequencies between these studies. The shift systems in Sweden and Finland are, however, both irregular. The length and timing of the shifts vary strongly making difficult shift combinations and short sleeps common. The problems related to severe sleepiness and fatigue at work are probably also the same.

While there was no age effect among the traffic controllers, age was inversely related to the prevalence of severe sleepiness among the train drivers. The age-related differences between the two occupational groups cannot be explained by seniority-based selection of work shifts or other differences in shift schedules as most of these possible differences in shift characteristics were included in the model. The higher sleepiness ratings of the Tdrs could partly be explained by duties related to the care of small children since Tdrs had more children under 7 years than Tcos who showed no age dependency on sleepiness. Although ageing is negatively related to the sleep quality of train drivers (Torsvall *et al.* 1981), earlier studies of train drivers have not found age-related differences in subjective sleepiness and performance (Hildebrandt *et al.* 1974a; Ingre *et al.* 2000; Torsvall *et al.* 1981). It is possible that the observed interaction between age and occupation reflects a basic problem of young shift workers to maintain wakefulness in a highly monotonous work environment. Young shift workers have been reported to perceive higher levels of sleepiness during early morning shifts (Rosa *et al.* 1996) and during first night shifts (Härmä *et al.* 1994). Furthermore, Summala and Mikkola (1994) found that young drivers have a clear peak in fatigue accidents at night time. Experimental studies also show that younger subjects are even more sensitive to an acute sleep loss than middle-aged or older subjects (Härmä 1995). The present results thus seem to suggest that in monotonous work, young age is related to an increased risk for severe sleepiness at work.

Feelings of fatigue and sleepiness at work are generally unpleasant for the worker. Together with occasional poor sleep as a result of irregular shift schedules (e.g. Ingre *et al.* 2000) a potentially large number of train drivers and traffic controllers have continuous and serious problems with their personal sleep and wakefulness. However, as train driver's sleepiness is also related to human errors and train accidents (Edkins and Pollock 1997; Kecklund *et al.* 1999; Kogi and Ohta 1975), the prevention of severe sleepiness in rail traffic is

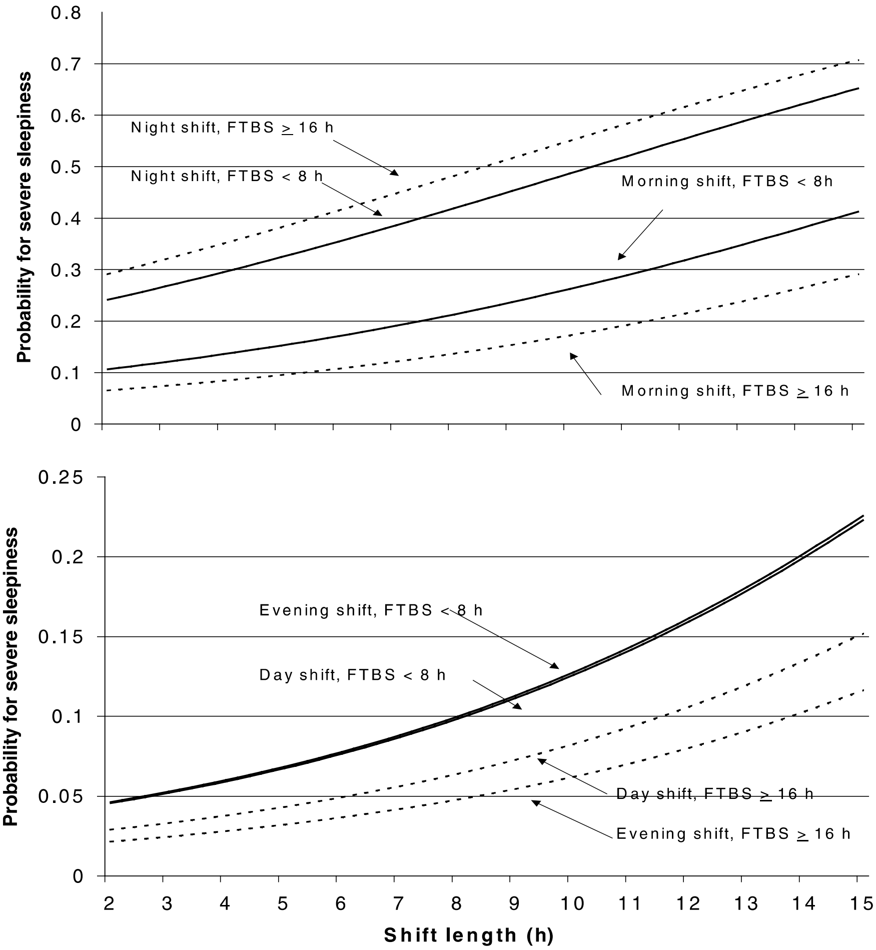

Figure 5. Probability for severe sleepiness according to the shift length and free time before the shift (FTBS, < 8 h and ≥16 h) among the train drivers. The data are based on the logistic regression model (Table 4) where a mean value of 43.2 years has been used for age and 6.61 h for the main sleep length.

Table 6 Odds ratios for the occurrence of severe sleepiness at work among train drivers and railway traffic controllers according to main sleep length and shift type. The selected sleep lengths respond the 25% (Q1), 50% (Q2) and 75% (Q3) quartiles of the distribution of the variable. The odds ratios are based on a logistic regression model (see text) with an interaction term of main sleep length × shift type

Sleep length/shift type	*Morning shift*	*Day shift*	*Evening shift*	*Night shift*
5 h 30 min (Q1)	2.8	4.1	2.4	0.9
6 h 35 min (Q2)	1.8	2.2	1.6	0.9
7 h 55 min (Q3)	1.0	1.0	1.0	1.0

also a public safety question. The existence of severe sleepiness in 50% of the night shifts cannot be explained by individual differences or solved by selecting for particular workers. It is obviously related to the present shift system.

The existence of severe sleepiness was associated with both the shift type and the shift length. Night shift was definitely the most significant single factor, leading to 6–14 times higher risk for severe sleepiness, compared with the day shift. This relationship was dependent upon the amount of free time prior to start of the shift. Morning shift had about double the risk compared with the day shift. Shift length was related to a somewhat smaller effect: the increase of shift length by 3 h increased the risk of severe sleepiness by half. The effect of shift length on the occurrence of severe sleepiness at work was not modified by the shift type. However, if a night shift is extended, the purely additive effects of the two factors yield the greatest occurrence of sleepiness.

Our results on the association of shift length to severe sleepiness at work may not be generalized to occupations with more physical or different work demands. The existing literature on the relationship of shift length with fatigue is inconsistent, some studies supporting (Rosa *et al.* 1989; Rosa and Bonnet 1993) and some studies rejecting (Lowden *et al.* 1998) that long working hours would increase fatigue. Disagreements in the literature may be due to differences in job intensity and monotony, possibilities to control work pace and opportunities to recover before or after the shifts. It should be noted, however, that our approach of using a logistic regression model controls for differences in occupation, age, shift type, time between shifts and sleep length of the current sample.

Earlier studies of rail transportation have reported an increase of sleepiness during the span of a night shift (a combined effect of the night shift and shift length). Non-responding to the secondary task in the train cabin, used generally to prevent falling asleep and to signal possible health emergencies, peaked near the end of the analysed shifts (Hildebrandt *et al.* 1974a). During both simulated and true train driving, physiological sleepiness (alpha and theta activity of the EEG) increases steadily during a night shift (Fruhstoffer *et al.* 1977, Torsvall and Åkerstedt 1987). Similarly, increases in physiological sleepiness and intrusions of normal sleep into periods of wakefulness were most frequent during the second half of a night shift in industrial process operators (Torsvall *et al.* 1989).

The time-off period prior to the shift was not consistently related to the appearance of sleepiness. Shift type had, however, a weak interaction with the time between shifts indicating that a night shift with 16 h or more free time before the shift was associated with a higher risk of sleepiness than a night shift with only 8–16 h of free time before the shift. This indicates that a long time-off period before the night shift, meaning mostly a free day in our sample, is not a good choice compared to a morning shift–night shift combination. Similarly, the risk of accidents in British Rail increased on the first day following a rest day (Sparkes 1994).

Our results also indicate that train drivers and railway traffic controllers adjust their sleeping habits for each shift and time-off period combination. For example, a time-off period of 8 h or less before a night shift was associated with a somewhat smaller risk of severe sleepiness during the shift than a time-off period of 16 h or more. However, 62% of the all subjects took a nap during the shorter time-off period compared with only 27% during the longest time-off period.

Because of the strong interactions between shift type, naps, time-off period and other explaining factors, we could not add the time-since-sleep effect to the logistic regression model. We could thus not directly compare our model with the three-process model of alertness (Åkerstedt and Folkard 1997). Any comparison would also be difficult due to the different nature of our data. We analysed binary response data looking at the prevalence of severe sleepiness during the whole shift (KSS 7 or higher). There was no distinction between severe sleepiness felt once during the shift and severe sleepiness felt throughout the shift. The observed higher sleepiness during the night and early morning shifts would still agree with the circadian component of the three-process model of alertness.

Each hour of main sleep decreased the risk of severe sleepiness by 15%. However, according to the additional interaction model, the length of the main sleep period influenced the occurrence of severe sleepiness at work before the morning, day and evening shifts but not before the night shifts – when the subjects could perhaps compensate the shorter night sleep with additional naps during the day. The observation that the length of main sleep is negatively related with severe sleepiness at work may not be surprising. However, there seems to be no published field studies of shift work where the effects of different sleep lengths have been evaluated (Gillberg 1995). On the average, the increase of sleep length by 2 h 25 min decreased the risk of severe sleepiness by 41%. Thus, our results on sleep–wake diary seem to agree with the laboratory studies suggesting that already 1–3 h curtailment of sleep may introduce higher sleepiness (Gillberg 1995).

In conclusion, fatigue and severe sleepiness at work, the level of which has been shown to decrease work performance, were very common during night and early morning shifts among personnel responsible for train driving and the control of train traffic. The shown relationships between the characteristics of the irregular shift system and severe sleepiness at work indicate that adjustments for shift timing, shift length and time between shifts in addition to actions aimed at improving sleep would probably decrease severe sleepiness at work and, consequently, increase traffic safety. Since the maintenance of safety is a critical prerequisite in public transportation, the observed results call for actions aiming at more ergonomic shift scheduling and better sleep among the personnel responsible for rail safety.

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