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Sleepiness on the job: continuously measured EEG changes in train drivers [1]

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Summary Eleven train drivers participated in the study during 1 night and 1 day journey (4.5 h) over the same route. Their EEG, EOG and ECG were recorded on portable tape recorders. The EEG records were subjected to spectral analysis (FFT) and the EOG was scored visually for slow eye movements (SEMs). The results showed that rated sleepiness increased sharply during the night journey. A similar pattern was seen for spectral power density in the alpha band, SEM and, to a lesser extent, also for power in the theta and delta bands. Heart rate was low during the entire night drive. The day journey showed low values without any trend for all variables. The intra-individual correlations were very high between rated sleepiness and, particularly, alpha and theta power density, as well as SEM. Further analyses showed that most of the night time increases in EEG/EOG parameters were confined to the 6 most sleepy subjects. Among these, 4 admitted to dozing off during the night drive and 2 of these 4 subjects failed to act on signals while exhibiting large bursts of alpha activity. It was concluded that EEG and EOG parameters closely reflect variations in sleepiness on the job and that these parameters, together with self-ratings, demonstrate that severe sleepiness may occur in train drivers during night work.

Key words: Sleepiness, Circadian rhythm, Monitoring

Sleepiness (or fatigue) is a frequently reported phenomenon in night work (cf., Åkerstedt et al. 1982). It is also suspected to play an important role in the occurrence of night-time accidents (Prokop and Prokop 1955; Kogi and Ohta 1975, Harris 1977, Hamelin 1981). To our knowledge, however, there exist no studies in which sleepiness has been continuously and objectively measured during normal work. The present paper describes an attempt to carry out such a study.

Sleepiness is a relatively new and diffuse concept in science. It has been suggested, however, that it involves the physiological tendency to fall asleep and that it may be measured by the time it takes to go to sleep (Carskadon and Dement 1982). The latter refers to the time from the intention to fall asleep to the occurrence of stage 1 sleep in the EEG. In relaxed subjects with closed eyes sleep onset involves the substitution of EEG theta (4–8 Hz) activity for the alpha (8–12 Hz) activity of relaxed wakefulness (Rechtschaffen and Kales 1968). Frequently, this transition is characterized also by slow rolling eye movements (SEMs).

In active subjects with their eyes open also alpha activity appears to indicate cessation of wakefulness (Daniel 1967, Horváth et al. 1976, O'Hanlon and Beatty 1977). Similarly, both alpha and theta activities are increased in connection with sleep-inducing situations (Lecret and Pottier 1971; O'Hanlon and Kelley 1977; Fruhstorfer et al. 1977). In our own experiments with subject-worn EEG recorders and subsequent spectral analysis we have found that dozing off during a task is associated with increased alpha and theta power density as well as with increased SEM activity (Torsvall and Åkerstedt 1985). We have also demonstrated that the same variables correlate closely with self-rated sleepiness (Åkerstedt et al. 1985).

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The studies cited above suggest that it should be possible to use EEG/EOG parameters to demonstrate sleepiness at work Two studies have monitored such parameters during work but the results are difficult to interpret with respect to sleepiness since that concept was not explicitly investigated (Chéliout et al. 1979; Lille and Chéliout 1982). The purpose of the present study was to bring the parameters described above into a normal job setting, validate them against perceived sleepiness and performance, and to test hypotheses about the sleep-conducing properties of night work. The group concerned was one of train drivers working irregular schedules covering the whole 24 h period This occupational group had, in a nation-wide questionnaire, reported severe fatigue during night work, including incidents of dozing off while driving at night (Åkerstedt et al 1983).

Methods

Twenty drivers of electric locomotives were asked to participate in the study. The selection was based only on the intuitive assumption that they would accept to participate. Three refused and for six their very irregular work schedules could never be made to fit all the requirements of the study The latter involved the occurrence of a proper night journey (i.e., between 21.00 h and 07.00 h) and a proper day journey, over a predetermined route (same for all subjects), without any extremes in weather conditions or train composition. This left 11 drivers, aged between 27 and 58 years (mean 42 years). They were recorded during 1 day journey and 1 night journey

The recordings lasted about 4.5 h and were made continuously over a 340 km long route in southern Sweden. The route was divided into 7 segments of approximately the same length (35 min), separated by major stations. The journeys were normally occurring duties in the work schedule of the drivers. The night and day journeys were recorded in a balanced order across the drivers. On each trip the driver was accompanied by an observer, whose task was to record the occurrence of all signals along the route as well as possible failures to respond to them This observer was sitting (without communicating) in the seat beside the driver (Recently the traditional system with co-drivers had been abandoned and thus the driver normally worked alone) The drivers were instructed to follow their habitual routines of resting, eating, etc., but to record these behaviors in a special diary

The EEG (O_2-P_4), EOG (vertical) and ECG were registered on a 4-channel Medilog tape recorder worn by the subject on a belt The fourth channel contained an event marker and a 60 Hz time signal (transferred to 0 1 Hz at write-out). The EEG and EOG signals were amplified by miniature preamplifiers a few centimeters from the electrodes The ambulatory recording method is relatively widespread but involves a risk of loosing records due to various artifacts (Blumhardt and Oozeer 1982) To reduce this risk particular care was taken to apply electrodes and preamplifiers securely and to obtain an electrode impedance of less than 3 kΩ.

The 4 channels were replayed at 30 times the recording speed with the mingograph speed set to either 2 5 mm/sec to provide a compressed overview or to 250 mm/sec to allow visual analysis of the EOG and of the quality of the records. The EOG was scored for proportion of 1 min intervals containing slow eye movements (SEMs) The latter were defined as slow ($< 3/4$ Hz), rolling excursions (> 100 μV) of the EOG, lasting for more than 1 sec.

The EEG records were subjected to spectral analysis (FFT) using a special purpose spectrum analyzer (Princeton Applied Research, Model 4512). The tape was replayed at 30 times the recording speed with a time window of 0 25 sec (512 samples), yielding analysis intervals of 7 5 sec of real time and a corresponding sampling rate of 68 Hz The resulting spectra were stored and further analyzed by a PDP 11/10 computer. The gain of the system was calibrated using a 1.7 Hz sine wave with a 50 μV amplitude

The frequency response of the Medilog system appears adequate between 1 and 25 Hz (Declerck et al 1982) which should be sufficient for the present purpose The reliability was checked by FFT analysis of the calibration signal at the beginning and end of each recording Furthermore, tape speed was checked by visual inspection of the write-out from the time channel.

In the computer 8 successive spectra were averaged to form 1 min means, and also smoothed and integrated across the delta (0.5–3.9 Hz), theta (4–7.9 Hz) and alpha (8–11.9 Hz) bands. Intervals with artefacts or tape speed irregularities were few (5%) but, when occurring, eliminated Since the inter-individual differences in power density were considerable, the results are presented as log % with the first segment of the day journey as the reference

Heart rate (HR) was derived from the ECG by computer analysis. Subjective sleepiness was rated after each of the 7 segments of the route. The ratings were made on a scale from 1 (very, very alert) to 13 (very, very sleepy). One hour before and after each journey a 10 min sleep latency test (Carskadon and Dement 1982) was carried out in a quiet and darkened room All results were subjected to analyses of variance (Winer 1971), using the Greenhouse-Geisser (1959) correction for repeated measures where appropriate.

Results

Results from the statistical analysis are presented in Table I and Fig. 1. Since rated alertness differed greatly between individuals the group was divided at the median into those who experienced most and least sleepiness, respectively, during the night journey. The former included 4 subjects (36%) who reported having dozed off The 3-factor (segment by condition by group) analysis of variance indicates that rated sleepiness, SEM and alpha and theta power behaved in a similar way They all increased across segments of the journey The interaction of segment by condition (i.e., night/day) was significant, however, indicating different developments over the two conditions Fig. 1 demonstrates that the increase was confined to the night journey This is also supported by the fact that a separate analysis (not in the table) for each condition demonstrated a significant (at least $P < 0.01$) increase across the night journey for all variables except HR No significant effects of segment were seen across the day journey.

The group effect and group by condition interaction were significant only for rated sleepiness, both apparently direct effects of the criteria for selection into groups. Delta power showed a similar but weaker pattern compared to the other EEG variables.

Heart rate showed a very different pattern from that of the other variables. Thus, the effect of condition was significant but not that of segment Heart rate during the night varied between 64 and 67 beats/min in comparison to the 74–78 beats during the day drive

As indicated above, the group effects were negligible for all variables, except for the sleepiness ratings. In order to pursue possible inter-individual differences we still carried out a 2-factor analysis of variance for each group separately.

TABLE I

F ratios and associated probability levels from the 3-factor analysis of variance group by condition by segment The degrees of freedom (*df*) entered in the table are the original ones The asterisks indicate the level of significance after the Greenhouse-Geisser correction for repeated measures

	Segment	Condition	Group	S×C	C×G	G×S
'Sleepy'	11.5 ***	22.0 ***	5.2 *	6.9 **	16.9 ***	2.5
Alpha	10.0 ***	1.7	1.3	8.6 **	4.9	2.3
Theta	7.4 **	0.9	0.2	5.4 **	1.0	2.1
Delta	4.9 **	2.8	0.0	2.6	0.0	1.3
SEM	3.5 *	7.4 *	3.5	4.1 *	3.1	1.2
HR	2.9	13.9 **	0.5	0.5	2.7	1.1
df	6/54	1/9	1/9	6/54	1/9	6/54

* $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$

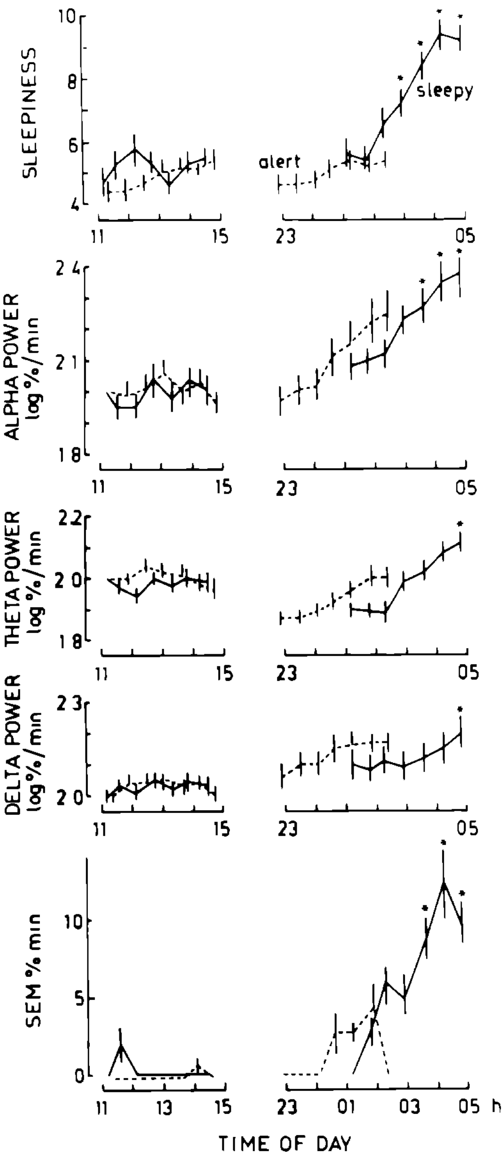

Fig. 1 Means and standard errors (±1 S E) for 35 min segments of the day and night journeys for the sleepy (———) and alert groups (— — —). The values are plotted at the midpoint of each segment of the journey The asterisks indicate the point at which the night value significantly (at least $P < 0.05$) exceeded the corresponding day value

Table II demonstrates that the alert group showed no increase across segments, except for delta power, and no interaction with condition. In contrast, the sleepy group showed significant increases for all variables except for delta power and heart rate In addition, the interaction effects were significant for ratings, alpha power and theta power. Heart rate showed a significant effect of condition for both groups. Towards the end of the night journey the sleepy group showed significant elevations (Fig 1) above corresponding day values for all variables, except heart rate

The effects of night work on sleepiness are exemplified in Figs. 2 and 3. The former illustrates the changes in the EEG spectrum across the journeys for the most sleepy subject (52 years old). During the day no activity in the theta or alpha range is observable, except for a small alpha burst during a stop. The 4 bursts of activity in the delta band represent artefacts due to snacks. In contrast, during the night journey alpha activity starts to appear after approximately 75 min and continues to appear in repeated bursts for the remainder of the journey, except for the portion of time when the driver is in the vicinity of major stations The theta activity is less pronounced but shows a similar pattern.

The first asterisk in Fig. 2 indicates the point at which the driver failed to respond to a stop signal. This incident is further illustrated in Fig. 3 In that figure is indicated the position of the main signal and of the presignal. Both were set to 'stop ' The driver approaches the presignal at 90 km/h and should see the presignal about 1.5 min before he reaches it, at which point breaking must commence. During the approach, however, the driver exhibits a rolling EOG accompanied by bursts of alpha activity and does not respond to the signal. This pattern continues for approximately 20 sec, after which a normal waking EEG and EOG pattern appears and the driver starts breaking. This is accompanied by a more than doubling of heart rate When reaching the main stop signal 20 sec later the train is still breaking, but at this point the signal changes to green and the driver releases the breaks and continues without having come to a stop. As indicated in Fig 2 the same driver experienced a second incident which involved a failure to reduce speed. This failure was accompanied by continuous alpha activity.

During the 10 min sleep latency tests only one subject fell asleep in connection with the day journey. Before the night journey no subject fell

TABLE II

F ratios and probabilities from two-factor analyses of variance for each group separately

	Sleepy group			Alert group		
	Segm	Cond.	S×C	Segm	Cond	S×C
'Sleepy'	9 2 **	28 4 **	10 9 **	4 1	0.4	0 0
Alpha	8 5 **	6 0	7 4 **	3 7	0 5	3 2
Theta	8 2 **	0 0	5 3 *	1 6	1 2	1 7
Delta	2 2	2 2	2 3	6 2 *	1 0	1 3
SEM	3 6 *	6.9 *	4 3	1 0	1 6	1 1
HR	1 9	9 5 *	0.5	1 9	11 5 *	1 6
df	6/30	1/5	6/30	6/24	1/4	6/24

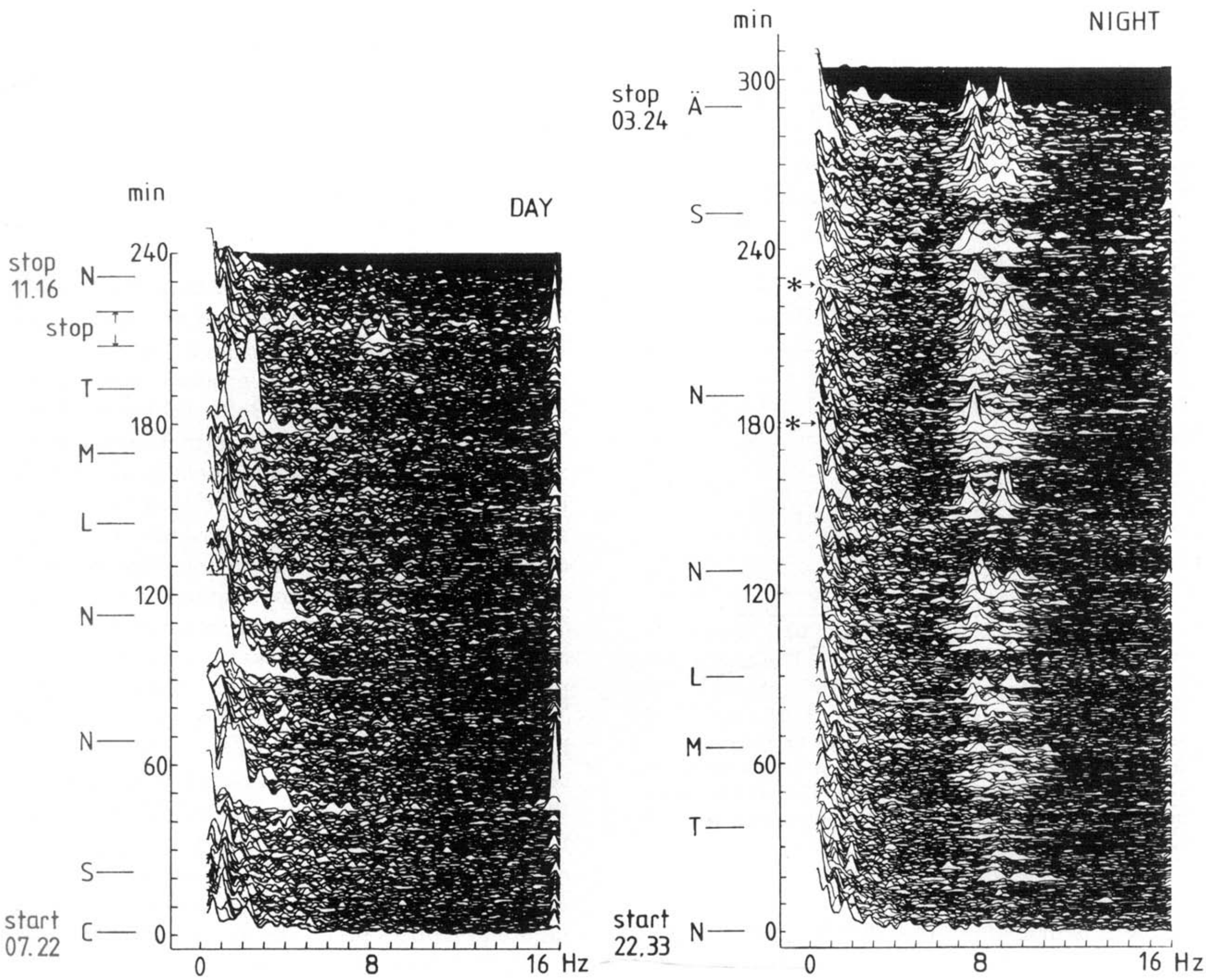

Fig. 2. Compressed spectral array of the EEG from the sleepiest driver during his day and night journey Each spectrum represents 7 5 sec The asterisks indicate the points where performance lapses were observed The letters indicate the major stations The activity in the 16 66 Hz region derives from the engine

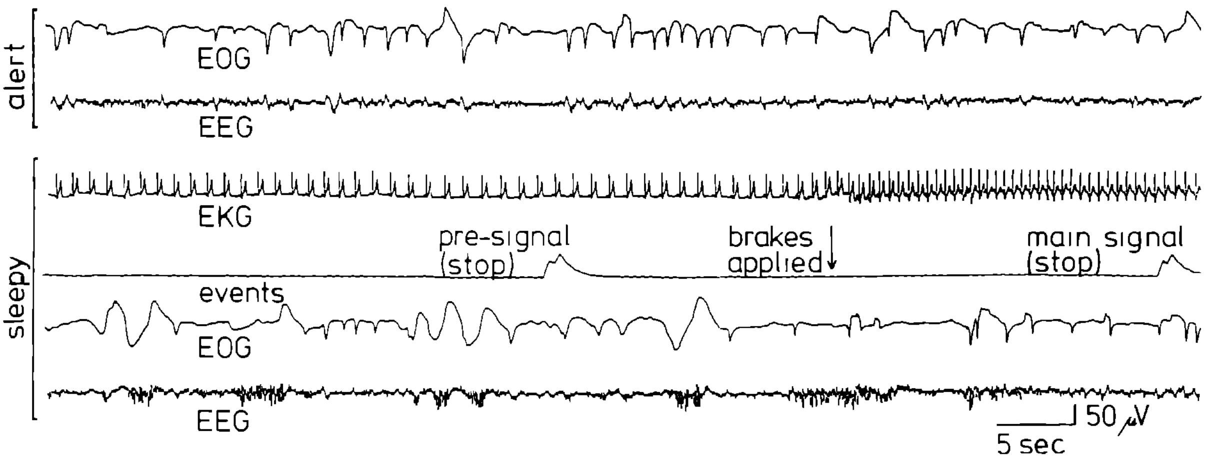

Fig 3 Above detail of the EEG and EOG (ECG added) record during an alert part of the night journey Below detail of the record around the first performance lapse See text

asleep (i.e., mean latency = 600 sec), whereas 9 subjects did so after the journey (mean latency = 375 ± 45 sec), the difference being highly significant ($P < 0.001$) The two groups (alert and sleepy) did not differ significantly, although the sleep latency after the night journey was slightly shorter (343 ± 42) for the sleepy group than for the alert group (413 ± 80).

Table III shows the mean intra-individual correlation coefficients across each condition For the night journey rated sleepiness correlated significantly with all variables except HR, but particularly with alpha and theta power. The spectral parameters also showed high correlations among themselves. Alpha power, in addition, correlated significantly with SEM. For the day journey the spectral parameters correlated significantly between themselves Otherwise no correlations reached significance. Correlations did not differ significantly between the two groups.

Two of the 11 subjects (one in each group) did not have a visually detectable alpha activity The alert subject showed no change in alpha activity during the night journey, whereas the subject in the sleepy group reached a value of log 2.38 towards the end of the night journey, i.e., more than twice the baseline level (log 2.00).

The two groups were also investigated for clues to their differences in sleepiness. Most background variables did not, however, differ significantly (t test) between the groups The age ranged between 27 and 57 years in the sleepy group and between 35 and 58 years in the alert group One subject in each group smoked Both groups consumed 1.2 cups of coffee per person during the night journey. The sleepy group had a slightly

TABLE III

Mean ($\bar{r}$) intra-individual correlation coefficients for each journey The decimal point has been left out Asterisks indicate level of significance according to the zero mu test

		Sleepy	Alpha	Theta	Delta	SEM	HR	
Day	Sleepy		71 ***	58 ***	43 *	54 *	−08	Night
	Alpha	−01		82 ***	56 ***	39 *	−04	
	Theta	−22	79 ***		55 **	30	−02	
	Delta	−17	53 ***	59 ***		04	29 *	
	SEM	−07	−23	−11	−02		−10	
	HR	−21	−15	−18	30	04		

longer prior main sleep period (7 0 h against 5.6 h), a slightly shorter prior nap (2.9 against 3 5 h), and a slightly higher amount of total prior sleep (10.0 against 9 1 h). The sleepy group finished their nap slightly later than the alert group (21 21 h against 18.21 h) and drove the train for a slightly longer time (4 7 against 4 3 h). Finally, the sleepy group started their night journey later (24 10 h against 22.26 h) and finished it later (04.52 against 02.44). The latter was the only significant difference among those tested ($t = 2.3$, $P < 0.05$).

Discussion

As expected, night work was associated with an increase of subjective sleepiness, particularly towards the end of the journey. This was also reflected in the reduced sleep latency after the night journey Clearly, however, some drivers were more affected than others, 4 drivers (36%) reported that they had dozed off while driving. This may be compared to the 11% in the questionnaire who reported such experiences for many or most of the night journeys (Åkerstedt et al 1983), or to the 70% who had experienced such an incident at least once

The continuously monitored EEG and EOG variables paralleled the development of rated sleepiness. This was particularly pronounced for alpha power and SEM, but also theta and delta power followed this pattern. The intra-individual correlations further emphasize this parallelism. These results closely agree with the results of several laboratory studies (O'Hanlon and Beatty 1977; Åkerstedt et al. 1985). Alpha activity was clearly most sensitive to sleepiness, followed by theta and delta activity. As O'Hanlon and Beatty have suggested, this ranking may be directly related to the severity of the sleepiness, delta and theta being more related to the occurrence of sleep proper. Heart rate showed no relation to sleepiness.

Interestingly, the occurrence of slow eye movements covaried with sleepiness There are some related previous observations in narcoleptics who fall asleep involuntarily (Guilleminault et al. 1975; Valley and Broughton 1983). Also, Henn et al. (1984) have pointed out that the first 'slow saccade' indicates the transition from wakefulness to sleep and that this indicator is more easily discernible than EEG changes In our previous laboratory studies we found a close correlation between SEM (with open eyes) and sleepiness (Åkerstedt et al. 1985; Torsvall and Åkerstedt 1985). It should be emphasized, however, that the concept of SEM usually refers to horizontal eye movements. In the present study we recorded the vertical EOG which mainly represents the downward movement of the upper eyelid (Stern et al. 1984) This derivation is less frequently used, but Simon et al. (1980) have demonstrated somewhat related patterns in the vertical EOG to herald 'severe tiredness.' In the present study SEM correlated significantly with alpha activity and Fig. 3 illustrates the simultaneous appearance of SEMs and alpha bursts that was very characteristic for all episodes of dozing off. Together with our laboratory studies we interpret this combined pattern of alpha burst and SEM as part of a process of dozing off and as representing transient failure in fighting off sleep.

In contrast to the night work results, those from the day work condition did not contain any correlation between ratings and EEG/EOG parameters This lack of correlations appears logical, however, since very low sleepiness was reported for the day journey and since the EEG/EOG variables for that journey never reached the levels associated with sleepiness during night work. Thus, as Townsend and Johnson (1979) have pointed out, there exists a certain amount of variation in alpha and theta activity that bears no relation to variations in wakefulness This variation seems minor, however. In the previous study we demonstrated that very high subjective sleepiness, i e , to the extent of 'fighting sleep,' had to be present before significant EEG/EOG changes could be observed (Åkerstedt et al. 1985).

The relation between the EEG/EOG parameters and sleepiness is further brought out by the inter-individual differences Even if the interaction effects between group and condition were significant only for subjective sleepiness, the two alertness groups clearly differed with respect to how pronounced the night work effect was The t tests of background variables showed that lack of sleep, length of journey, coffee consumption and age did not differ between the groups. The sleepy group did, however, finish their duty later at night than the alert group Fig 2 suggests that it was precisely during these later hours (03.00 h–05 00 h) that the most severe sleepiness occurred. This time coincides with the time when the circadian trough of alertness or peak of sleepiness usually appears (Froberg et al. 1975). Thus, although not conclusive, the results suggest that the circadian phase may have been a major source of the sleepiness observed.

Remarkably, the alpha poor subject in the sleepy group showed a strong increase of alpha power during the night journey. The corresponding alert subject showed no such change. Previously, Johnson et al. (1965) observed that computer analysis of the EEG may reveal alpha activity that is not detectable by the naked eye It is, however, premature to decide whether these observations mean that computer detectable alpha activity will appear during perceived sleepiness for all alpha poor subjects

As indicated in the introduction, subjective sleepiness is a well-known phenomenon during the night shift To our knowledge, however, it has never been demonstrated with objective measures that sleep-like EEG/EOG patterns characterize this subjective sleepiness Clearly, such patterns may indicate not only reduced well-being on the night shift, but also increased accident risks. It is tempting to speculate that accident risk, to some extent, may be monitored through EEG/EOG methods Even if the present results do indicate strong night work sleep tendencies for many subjects it is still unclear how precisely these tendencies can predict behavioral lapses, and even less clear how well associated accident risks may be predicted. A reliable estimation of risk would require much larger samples of subjects and much greater numbers of monitored journeys and situations.

The recording and analysis methods seem to have worked satisfactorily. The artefacts were few and easily identified despite the interference from the surrounding electrical equipment. The successful recordings were probably due to careful application of electrodes, to the amplification of the EEG close to the source and to the frequencies of the interfering sources which were mostly outside the 1–16 Hz range.

Finally, it should be emphasized that, although we have used the concept of sleepiness to denote the tendency to enter sleep-like states, we have used it in two slightly different ways. One refers to the sleep latency test before and after the journey This involves falling asleep under optimal sleep inducing conditions, i e., lying down with closed eyes in a dark and quiet room (Carskadon and Dement 1982). The other usage refers to the occurrence of sleep or sleep-like states under any condition that may happen to be at hand This latter usage involves sleepiness that manifests itself openly against a background of other influences The former reflects a 'purer' form of sleepiness with external influences excluded, thus measuring more of some basic or latent potential for sleepiness (Carskadon and Dement 1982) Nevertheless, our data from the sleep latency tests after the drive roughly agree with the sleep tendency during the drive but a formal comparison of the two forms is not possible and, as far as we know, no such comparison has been made elsewhere Which of the two types of sleepiness measure should be used will depend on the particular question asked Frequently, however, both may be used.

In conclusion, the results demonstrate that slow eye movements and EEG power density in the alpha and theta bands reflect sleepiness/wakefulness, and that night work in many individuals is associated with a strongly increased sleepiness that may be not only uncomfortable and taxing, but also potentially hazardous. The results also demonstrate that the recording of EEG/EOG parameters is quite feasible in ambulatory subjects in their normal work situation.

Résumé

Somnolence au travail. modifications de l'EEG mesuré en continu chez des conducteurs de trains

Onze conducteurs de trains ont participé à cette étude pendant un voyage d'une nuit et d'une journée (4,5 h) sur le même trajet Leurs EEG, EOG et ECG furent enregistrés sur un enregistreur magnétique portable. Les enregistrements EEG furent soumis à une analyse spectrale (FFT) et les EOG subirent une estimation visuelle pour les mouvements lents des yeux (SEM) Les résultats ont montré que la somnolence estimée augmentait brutalement pendant le voyage de nuit. Une configuration similaire a été observée pour la densité de puissance spectrale de la bande alpha, pour les SEM et, dans une moindre mesure, pour la puissance dans les bandes thêta et delta. Le rythme cardiaque était bas pendant l'intégralité de la nuit de conduite. Le voyage de jour présentait des valeurs basses sans aucune tendance pour toutes ces variables. Les corrélations intraindividuelles ont été très hautes entre la somnolence estimée et, en particulier, les densités de puissance de l'alpha et du thêta, comme les SEM. D'autres analyses ont montré que la majorité des augmentations dans les paramètres EEG/EOG avaient lieu chez les 6 sujets les plus somnolents. Parmi ceux-ci, quatre admirent s'être assoupis durant la conduite de nuit et deux de ces 4 sujets ne pas agir sur les signaux alors qu'ils présentaient de grandes bouffées d'activité alpha. On en conclut que les paramètres EEG et EOG reflètent fidèlement les variations de somnolence pendant le travail et que ces paramètres, joints à une auto-estimation, démontrent que des assoupissements profonds peuvent intervenir chez les conducteurs de trains pendant le travail de nuit.

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