Association of subjective sleepiness scores and EEG spectra during prolonged wakefulness

A.M. Strijkstra, B. Drayer, N. Halbesma, D.G.M. Beersma, S. Daan
Department of Animal Behavior, University of Groningen, Haren, The Netherlands

INTRODUCTION

Subjective sleepiness is part of the system controlling the decision to go to sleep. Feelings of sleepiness are related to effects of prior wake duration, in interaction with effects related to time of day, which are mediated by the internal biological clock. Subjective sleepiness is associated with the cortical EEG during waking. Alpha (8-12 Hz) and theta (4-8 Hz) frequencies in the wake EEG are of particular interest.1 During active wake with eyes open, alpha activity is usually low, unless the subject is severely fatigued.2 However, with eye closure alpha activity increases, also when the subject is not fatigued. Furthermore, during the transition from quiet wake with eyes closed to sleep, a gradual reduction of alpha activity and a gradual increase in theta activity occurs.3 Reduced alpha activity and increased theta activity during wake with eyes closed may thus indicate an increased drive to sleep, and may reflect subjective sleepiness. Here, we report on the association of subjective sleepiness (measured with four different sleepiness/fatigue scales) and the overall cortical wake EEG (averaged over 28 locations on the scalp) recorded with eyes closed during prolonged wakefulness.

METHODS

The ten participating healthy young subjects (20-35 years) did not smoke nor use drugs, and abstained from consumption of alcohol and coffee throughout the experiment. They did not rate as extreme morning or evening types. Subjects signed an informed consent form. The experiment was approved by the Medical Ethics Committee of the Academic hospital of the University of Groningen. Subjects were awake for 40 hours, from 8:00 h in the morning of day 1 to 24:00 h on the evening of day 2. At predetermined times between 8:30 h on day 1 to 22:30 h on day 2, subjects performed 21 test series, during which sleepiness was scored and wake EEG was recorded. Subjective sleepiness was measured by means of the Karolinska sleepiness score (KSS)4, a Visual Analogue Score (VAS-f, fatigue)5, a sleep score (THR-s, deactivation/sleep)6 and the fatigue factor of the profile of mood state (POMS-f).

EEGs were recorded using a cap system with Ag/AgCl electrodes (Electro-Cap International, Inc., Eaton, Ohio, USA), on 28 positions on the scalp (Fp1, Fp2, F7, F3, Fz, F4, F8, FC5, FC1, FC2, FC6, T3, C3, Cz, C4, T4, CP5, CP1, CP2, CP6, T5, P3, Pz, P4, T6, O1, Oz, O2). The left earlobe was used as reference, and the inion was used as ground. Data were sampled at 100 Hz, and bandpass filtered between 0.16-40 Hz. EEG was recalculated to average reference before fast Fourier transformation was applied to artifact-free 5-sec intervals. EEG power was calculated per 0.2 Hz frequency bin. During wake EEG recordings, subjects were sitting in a chair for three min with their eyes closed.

For each subject, the data of the 21 recording sessions were normalized to standard normal distributions (mean=0, SD=1) to correct for inter-individual variation (z-transformation). The within subject correlation coefficients were combined to an average, of which the z-statistic was calculated for statistical evaluation.7

RESULTS

The similarity between subjective sleepiness scores within subjects was high, with correlation coefficients r ranging from 0.27 to 0.95, and on average between subjects highly significant (z-statistic >13.8, p<0.0001). The statistical significance of the similarity of the sleepiness scores ranked KSS/VAS-f (z-statistic 19.1), THR-s/VAS-f (z-statistic 18.4), KSS/THR-s (z-statistic 17.5), VAS-f/POMS-f (z-statistic 15.7), KSS/POMS-f (z-statistic 14.9) and THR-f/POMS-f (z-statistic 13.8).

Figure 1 shows the z-statistic of the average individual correlation between subjective sleepiness scores and the overall average cortical EEG activity in 0.2 Hz bins. All data were z-transformed before individual correlations were made. Correlations were calculated within individuals and later combined to an average value, of which the z-statistic is calculated for statistical evaluation.7

The patterns of correlation of the four subjective sleepiness scores and the wake EEG activity over the whole spectrum were similar, obviously in line with the similarity of the sleepiness scores during the 40 h wake period. Significant negative correlations were found in the alpha range and the beta-1 (15-22 Hz) range, and positive correlations were found in the sub-delta (<0.5 Hz) range, the theta range and the beta-2 (22-30 Hz) range.
DISCUSSION

The data show that a high level of similarity exists between four standardized subjective sleepiness and fatigue scores in their reaction to prolonged wakefulness, and (consequently) in their association patterns with EEG spectra averaged over a large cortical area. Several frequency ranges of the resting (eyes closed) wake EEG correlate negatively (alpha, beta-1) or positively (sub-delta, theta, beta-2) with subjective sleepiness during prolonged wakefulness. It seems paradoxical that a decrease in alpha power would predict sleepiness, since a reduction in alpha power in many testing environments is related to an increase in cortical activity, rather than a decrease. Indeed, occurrence of high alpha activity in the wake EEG relates to decreased performance. In contrast, alpha activity recorded with eyes closed and without any performance require-

Increased theta activity is associated with sleepiness and decreased performance. Additionally, the increase in wake EEG theta activity correlates with the increase in slow-wave activity during sleep after 16 h or 40 h of wakefulness, suggesting a likeness of theta activity to the need for sleep. An increased theta activity may be related to a decreased cortical and thalamic glucose uptake, which may indicate reduced cortical and thalamic function. During resting wake with eyes closed, theta activity and the inverse of alpha activity may represent the level of subjective sleepiness during prolonged wakefulness. These correlations may indicate the drive for sleep, since they resemble the alpha activity decrease and theta activity increase during sleep entry. Perhaps an interaction between processes underlying alpha activity decrease and theta activity increase are responsible for subjective feelings of sleepiness, guiding humans in their decision to go to sleep.

REFERENCES