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Validation of the Karolinska sleepiness scale against performance and EEG variables

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Abstract

Objective: The Karolinska sleepiness scale (KSS) is frequently used for evaluating subjective sleepiness. The main aim of the present study was to investigate the validity and reliability of the KSS with electroencephalographic, behavioral and other subjective indicators of sleepiness.

Methods: Participants were 16 healthy females aged 33–43 (38.1 ± 2.68) years. The experiment involved 8 measurement sessions per day for 3 consecutive days. Each session contained the psychomotor vigilance task (PVT), the Karolinska drowsiness test (KDT—EEG alpha & theta power), the alpha attenuation test (AAT—alpha power ratio open/closed eyes) and the KSS.

Results: Median reaction time, number of lapses, alpha and theta power density and the alpha attenuation coefficients (AAC) showed highly significant increase with increasing KSS. The same variables were also significantly correlated with KSS, with a mean value for lapses ($r = 0.56$).

Conclusions: The KSS was closely related to EEG and behavioral variables, indicating a high validity in measuring sleepiness.

Significance: KSS ratings may be a useful proxy for EEG or behavioral indicators of sleepiness.

Keywords: The psychomotor vigilance task (PVT); The Karolinska drowsiness test (KDT); The alpha attenuation test (AAT); The Karolinska sleepiness scale (KSS); The Japanese version of the Karolinska sleepiness scale (KSS-J)

1. Introduction

Sleepiness is involved in a large part of the accidents in transportation and in other areas of industry (Maycock, 1996). Subjective reports are a convenient way of gathering information about sleepiness in field and laboratory studies. For reports of habitual sleepiness, the Epworth sleepiness scale (Johns, 1991) is frequently used. For reports of instantaneous sleepiness (across the day and night), visual analogue scales (Monk, 1989) or Likert scales, like the 7-graded Stanford sleepiness scale (Hoddes et al., 1973) or the 9-graded Karolinska sleepiness scale (KSS) (Åkerstedt and Gillberg, 1990), are often used.

The KSS was originally developed to constitute a one-dimensional scale of sleepiness and was validated against alpha and theta electroencephalographic (EEG) activity as well as slow eye movement electrooculographic (EOG) activity (Åkerstedt and Gillberg, 1990). It has been widely used and provided reasonable results in studies of shift work (Axelsson et al., 2004; Gillberg, 1998; Härmä et al., 2002; Ingre et al., 2004; Sallinen et al., 2004, 2005), jet lag (Suhner et al., 1998), driving abilities (Åkerstedt et al., 2005; Belz et al., 2004; Horne and Baulk, 2004; Kecklund and Åkerstedt, 1993; Otmani et al., 2005; Philip et al., 2005; Reyner and Horne, 1998a,b), attention and performance (Gillberg et al., 1994, 1996; Kräuchi et al., 2004; Reyner and Horne, 1998) and clinical settings (Schwartz, 2005; Söderström et al., 2004).

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In terms of validation, there have been several studies showing relatively strong positive intra-individual correlations between the KSS and alpha and theta EEG activity (Åkerstedt and Gillberg, 1990; Horne and Baulk, 2004). Reyner and Horne (1998) also demonstrated that falling asleep at the wheel in a driving simulator was always preceded by increased KSS score. While these results indicate a relatively good intra-individual relationship between the KSS and electrophysiological and behavioral variables, we know rather little about the 'meaning' of different levels of the KSS in terms of electrophysiology or behavior. This concerns the characteristics of electrophysiology or as well as behavior at different levels of the KSS, giving an impression of the shape of the relationship.

The only study looking at the characteristics of electrophysiology at different levels of the KSS used the Karolinska drowsiness test (KDT) (Åkerstedt and Gillberg, 1990) to evaluate electrophysiological sleepiness. This test is based on the power density of the EEG during 'eyes-open' or 'eyes-closed'. In the study mentioned, alpha and theta power density increased with sleepiness in the eyes-open condition, whereas alpha power density decreased and theta power density increased during the eyes-closed condition. During 'eyes-open' in normal alertness, brain activities are dominated by waves within the beta band (>13 Hz). With increased drowsiness in 'eyes-open', the proportion of alpha and theta activity is increased. During 'eyes-closed' and alertness, brain activity is dominated by alpha activity (8.0–12.0 Hz) which is replaced by theta activity with increasing sleepiness.

Another EEG-based approach for sleepiness is alpha attenuation test (AAT) (Stampi et al., 1995). In the AAT, the feature of alpha activity during normal alertness is used. The alpha activity tends to *decrease* as an 'eyes-closed' participant gets sleepier. On the other hand, in an 'eyes-open' individual, the alpha activity normally *increases* as a function of increased sleepiness. Usage of the ratio between 'eyes-closed' and 'eyes-open' alpha activity would discriminate a difference between levels of sleepiness and minimize inter-individual variability in alpha activity.

It would be also important to describe commonly used performance variables at different levels of the KSS. One such measure is the psychomotor vigilance task (PVT), which seems sensitive to sleep loss (Dinges et al., 1997). Although the PVT is frequently used in sleepiness or sleep deprivation studies, the correlation between the PVT performances and EEG parameters has not ever been reported (Drummond et al., 2005).

Another interesting point is that all previous studies have, for natural reasons, involved both high and low levels of sleep loss. It seems a reasonable assumption that intra-individual correlations would be stronger if sleep loss and/or the circadian trough are included in the study since this would likely increase the intra-individual variation. Thus, it is an interesting question whether measurements made under conditions of normal night sleep would provide a reasonable covariation between the KSS and electrophysiological and behavioral variables.

The purpose of the present study was to investigate the relation between the KSS and electrophysiological and behavioral measures of sleepiness under conditions of several days and with relatively normal night sleep. In the original validation study (Åkerstedt and Gillberg, 1990), only 7 measurements were made per individual, thus limiting the stability of the computed correlations. Clearly, there is a need for an increased number of measurements, either with a higher density than the 4-hourly ones in the previous study or through inclusion of several days of measurements. The variables chosen for validation was the alpha attenuation test (Stampi et al., 1995), the psychomotor vigilance task (Dinges and Powell, 1985), and a visual analogue scale for sleepiness (Monk, 1989). In addition, the Karolinska drowsiness test (Åkerstedt and Gillberg, 1990) should be included for comparison with the previous study.

The main focus was on the form of the relation between the KSS and the other variables, but also intra-individual correlations were computed. Other results from the present study have been presented in the form of effects of light treatment on sleepiness (Kaida et al., 2006).

2. Methods

2.1. Participants and design

Participants were 16 healthy female paid volunteers aged 33–43 (38.1 ± 2.68) year. It was extremely hard to find a male participant who met with the selection criteria, so only females were selected for the present study. All participants met the following criteria: (1) a normal sleep-wake cycle classified as 'intermediate type' according to the Morningness–Eveningness questionnaire (Horne and Ostberg, 1976; Ishihara et al., 1986), (2) no report of any physical or mental health problems, and a score <15 on the Center for Epidemiological Studies-Depression Scale (CES-D) (Ladloff, 1977), (3) no experience of shift work within the 3-month prior to the experiment, (4) no travel to a different time zone within the 3-months prior to the experiment, (5) not using any medication, (6) being a non-smoker, and (7) a body mass index less than 25 (calculated as weight in kilograms divided by the square of the height in meters; BMI). The participants' ME-score, CES-D score and BMI (mean ± standard deviation) scores were 53.8 ± 4.38, 7.2 ± 5.99 and 21.6 ± 2.71 kg/m^2, respectively.

The study (Kaida et al., 2006) involved one preparatory day and 3 experimental days. The preparatory day was used for practicing and making participants accustomed to the experimental circumstances. During the preparatory day, the participants followed the same schedule for the experimental day as explained below, except for the explanation of the experiment and the signing of the forms of informed consent, which took place during the first session (i.e. from 10:30 to 11:00). The obtained data from the preparatory day were excluded from the analyses.

During the experimental days, participants arrived at the laboratory at 10:30 a.m. and had electrodes applied. From 11:00 to 12:00 a set of tasks (behavioral/elecrophysiological-see below) was repeated twice (sessions 1 and 2, i.e. S1 and S2) at a light level below 100 lux. During a break from 12:00 to 12:40, lunch was served by the experimenters.

From 12:40 to 13:10 (S3) the participants went through an experimental condition, which differed, between the 3 days. It involved performance of a set of tasks under two different lighting levels or a nap-each on a separate day. On day 1, lighting was <100 lux, on day 2 >2000 lux (bright light), and on day 3, a 20 min nap opportunity was given (with lighting <5 lux). Because of the different light conditions during the task, the data from 12:40 to 13:10 (i.e. S3) were analyzed separately and were not included in the present paper.

From 13:10 to 16:10, the tasks were repeated 6 times (i.e. S4–S9) with baseline lighting (<100 lux). Thus, the participants carried out the same task 26 times across the 3 experimental days, and the data from the 24 times (sessions) carried out in less than 100 lux were used for the main analyses.

Participants returned home after the experiment and returned to the laboratory the next morning. A detailed experimental schedule is shown elsewhere (Kaida et al., 2006). The participants were requested to abstain from beverages containing caffeine and alcohol during the days of preparation and the experimental days. They were also requested to keep a normal sleep–wake cycle during the experimental days, and their sleep–wake cycles at home were monitored using the Actiwatch (Mini Mitter Co., Inc., Bend, Oregon, USA) and a sleep diary.

The lunch served contained (mean ± standard deviation) carbohydrates: 200±0 g, protein: 16.8±3.49 g, fat: 23.2±5.77 g, and caloric value: 765.4±63.8 Kcal. The meal was adjusted for the weight of the participants (52.2±7.42 kg).

The experimental protocol was reviewed and approved by the Ethical Committee in Research Involving Humans at the National Institute of Industrial Health, Japan.

2.2. Procedure

The set of tasks for measuring performance and arousal level consisted of the psychomotor vigilance task (PVT) (Dinges and Powell, 1985) using the Psychomotor Vigilance Task Monitor (PVT-192, Ambulatory Monitoring, Inc., USA), the Karolinska drowsiness test (KDT) (Åkerstedt and Gillberg, 1990), the alpha attenuation test (AAT) (Stampi et al., 1995), a 100 mm visual analogue scale (VAS) scale for sleepiness (Monk, 1989) and the Japanese translation of the Karolinska sleepiness scale (KSS-J). The time schedule of the series of tasks was 10 min for the PVT, 1 min for the KSS-J and VAS, 7 min for the KDT, 8 min for the AAT and 4 min for rest (total: 30 min).

2.3. Rated sleepiness

The 9-point KSS (Åkerstedt and Gillberg, 1990) was used: 1 = very alert, 3 = alert, 5 = neither alert nor sleepy, 7 = sleepy (but not fighting sleep), 9 = very sleepy (fighting sleep). In the present study, the original KSS was translated into Japanese by the research team and it was back-translated by an independent translator living in the US for over 10 years. The back-translated scale was verified by a native English speaker. The original expression of 'but not fighting sleep' was omitted in the Japanese version, because this moderate expression is not meaningful in Japanese (Appendix A). The participants rated their current subjective sleepiness, not sleepiness during the task (i.e. during the last 5 min).

The VAS was a 100 mm line, with 'not sleepy' on the left end of the line and 'sleepy' on the right end of the line. Participants were asked to view the line as representing their personal range of feelings and to place a mark on the line indicating their feeling at the moment.

2.4. Electroencephalogram (EEG)

Electrodes were attached at C3 and O1 scalp sites for an electroencephalogram (EEG) referenced to A2, and outside both canthi for an electro-oculogram (EOG). In addition, a bipolar submental electromyogram (EMG) was recorded. The sampling rate was 500 Hz (16-bit AD conversion) and the time constants were 0.3 s for the EEG, 3.2 s for the EOG and 0.03 s for the EMG. Electrode impedance was maintained below 5 kΩ. The low pass filter was set at 30 Hz. Electrophysiological data were recorded with a portable digital recorder (Polymate AP1000, Digitex Laboratory Co., Ltd, Japan).

2.5. Psychomotor vigilance task (PVT)

The PVT uses a simple visual reaction time (RT) paradigm with inter stimulus intervals ranging from 2 to 10 s. Performance indices (e.g. mean of the RTs, fastest 10% of the RTs, slowest 10% of the RTs, median RTs, lapses, i.e. >500 ms) were delivered automatically by standard software (PVTcmmW, version 2.71/REACT, version 1.1.03, Ambulatory Monitoring, Inc., USA).

2.6. The Karolinska drowsiness test (KDT)

During the 5 min of eyes-open in the KDT, the participants were seated on a chair in a quiet room and were asked to focus on a postcard on the wall. Then they were asked to close their eyes for additional 2 min while seated in the same position. Alpha (8.0–12.0 Hz) and theta (4.0–7.9 Hz) power spectra during eyes-open (5 min) and eyes-closed (2 min) conditions were calculated using the fast Fourier transform (FFT) with a Hamming window. Power spectra were calculated for every 15 s epoch of EEG data on a single central derivation (C3–A2). Artifacts in the

EEG were removed using high-pass (0.5 Hz) and low-pass (30 Hz) digital filters.

2.7. The alpha attenuation test (AAT)

During the AAT (Stampi et al., 1995), participants opened (eyes-open) and closed (eyes-closed) their eyes alternately every 2 min for a total of 12 min while staring at a small postcard on the wall. The first eyes-closed (2 min) and eyes-open (2 min) conditions overlapped with the KDT procedure described above. Power spectra were calculated using FFT for every 5 s epoch of artifact-free EEG data on a single occipital derivation (O1–A2). The alpha attenuation coefficients (AAC) per each 12 min test session were calculated as the ratio of mean power in the alpha frequency band during eyes-closed conditions to the mean alpha power during eyes-open conditions. Thus, the higher the AAC, the higher the arousal level.

2.8. Statistical analysis

Differences between days and between KSS-J scores were tested using repeated-measures analysis of variance (ANOVA). The differences were also evaluated using the Friedman's non-parametric test. To control for the type 1 error associated with violation of the sphericity assumption, degrees of freedom greater than one were reduced by the Huynh–Feldt ε correction. As post-hoc analysis, the multiple pared t test with Bonferroni correction was applied for KSS-J bins. The purpose of the present analysis was to demonstrate covariation in the variable pairs. For this purpose, longitudinal product–moment correlations were calculated for each individual. The correlations were then averaged across individuals and tested for significant correlation using a one-sample t test. All the statistical analyses were performed with the SPSS system for Windows, version 11.5 (SPSS Japan, Inc., Japan).

3. Results

Total sleep/rest time measured by the actiwatch prior to the experimental days was 362.2 (±52.56) min for day 1, 365.3 (±49.17) min for day 2, 359.8 (±53.86) min for day 3, respectively. The variation across days was not significant [$F(2, 30)=1.09$, $P=0.92$, $\varepsilon=0.92$].

Table 1

Mean, standard deviation and range of all variables

		Mean (SD)	Range
KSS-J		5.7 (2.01)	1–9
VAS		63.0 (25.73)	0–100
KDT	Open α (μV^2)	4518.6 (2199.38)	1529.2–11472.4
	Open θ (μV^2)	3948.6 (1271.15)	1658.2–8126.2
	Close α (μV^2)	6309.2 (2886.09)	2495.6–17639.2
	Close θ (μV^2)	4863.6 (2003.77)	2036.9–10772.4
AAC		1.5 (0.42)	0.8–3.0
PVT	Mean RT (ms)	317.3 (70.59)	215.5–729.6
	Slowest RT (ms)	561.2 (327.32)	293.5–3105.6
	Fastest RT (ms)	211.1 (23.20)	159.6–285.0
	Median RT (ms)	281.4 (38.67)	198.0–407.0
	Laps (times)	4.7 (5.39)	0–25

Parentheses show standard deviations.

Mean values, standard deviations (SD), and the range of the original data are shown in Table 1.

In order to study the form of the relation between the KSS-J and the other parameters, the KSS-J was divided into bins (1–3, 4–5, 6, 7 and 8–9) since all individuals did not provide ratings at all levels of the KSS-J (i.e. from 1 to 9). Then, for each variable and participant, the values for a certain bin were averaged to represent that bin. These values were then used as each individual's input to the ANOVA. The total numbers of observations in each bin were 75, 89, 68, 90, 62, respectively (Fig. 1).

Fig. 2 shows the mean values for VAS, PVT (lapses and median RT), EEG (alpha and theta power) and AAT (AAC) variables for the different bins of KSS-J. The effects of KSS-J score were statistically significant for VAS: [$F(4, 60)=207.20$, $P<0.01$, $\varepsilon=0.84$; $\chi^2(4)=62.5$, $P<0.01$], lapses: [$F(4, 60)=15.0$, $P<0.01$, $\varepsilon=0.83$; $\chi^2(4)=39.52$, $P<0.01$], median RT: [$F(4, 60)=19.39$, $P<0.01$, $\varepsilon=0.67$; $\chi^2(4)=38.00$, $P<0.01$]; alpha power with eyes-open: [$F(4, 60)=5.15$, $P<0.01$, $\varepsilon=0.61$; $\chi^2(4)=23.65$, $P<0.01$], theta power density with eyes-open: [$F(4, 60)=6.64$, $P<0.01$, $\varepsilon=0.53$; $\chi^2(4)=31.35$, $P<0.01$], alpha power with eyes-closed: [$F(4, 60)=6.90$, $P<0.01$, $\varepsilon=0.84$; $\chi^2(4)=16.35$, $P<0.01$] and AAC: [$F(4, 60)=8.73$, $P<0.01$, $\varepsilon=0.58$; $\chi^2(4)=26.05$, $P<0.01$]. There was no significant effect for theta power with eyes-closed [$F(4, 60)=0.42$, $P=0.73$, $\varepsilon=0.72$; $\chi^2(4)=5.85$, $P=0.21$].

Applying linear and quadratic contrasts to the variables with significant F-ratios, only the linear component was significant [$F(1,15)=454.33$ for VAS; $F(1,15)=32.66$ for

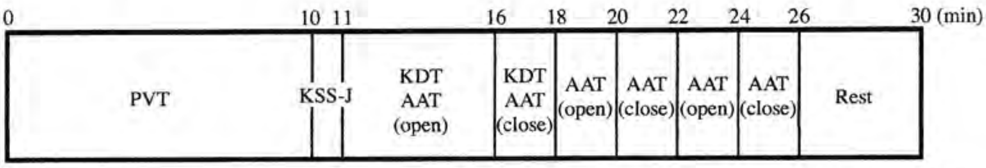

Fig. 1. Schedule for each session PVT, psychomotor vigilance task; KSS-J, the Japanese Karolinska sleepiness scale; KDT, the Karolinska drowsiness test; AAT, the alpha attenuation test; open, eyes-open; closed, eyes-closed.

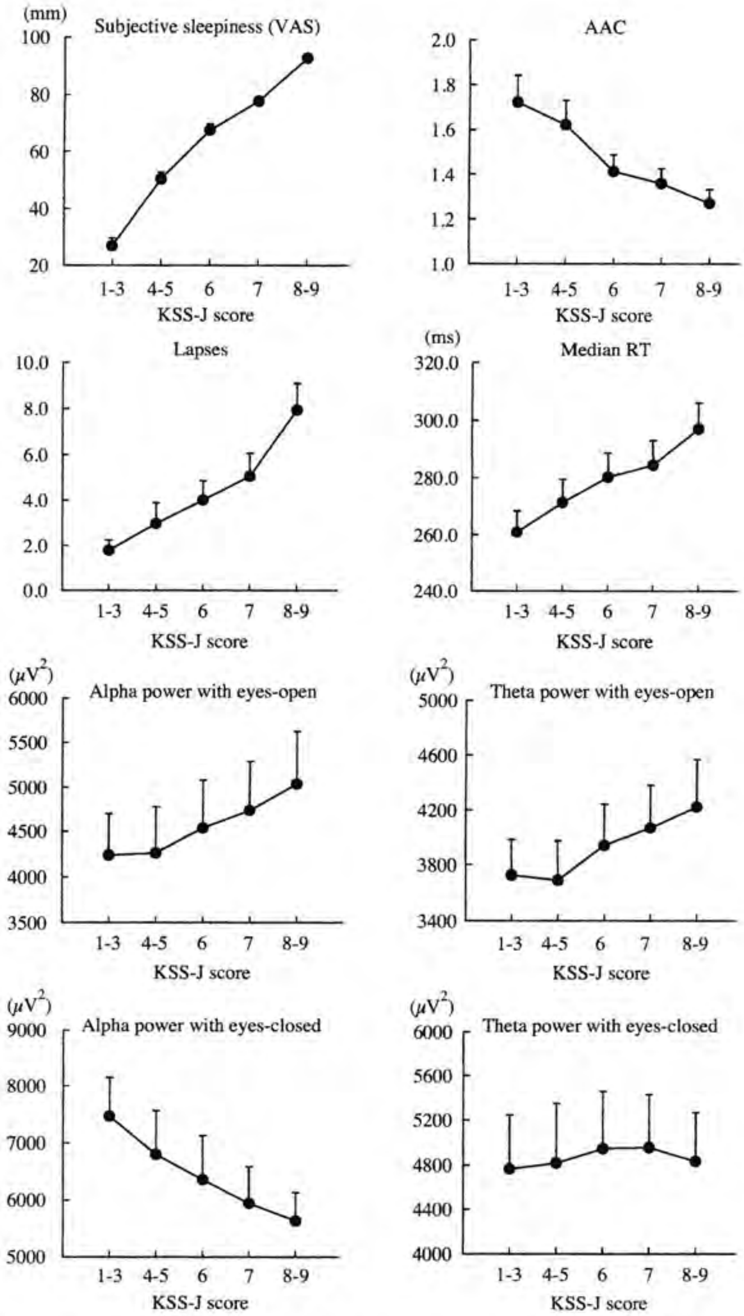

Fig. 2. Mean ± standard error for variables at different bins of KSS-J, VAS, visual analogue scale; Median RT, response time; AAC, alpha attenuation coefficient; KSS-J, the Japanese version of the Karolinska sleepiness scale. The number of observations in the bins was of each bin (i.e. 1+2+3, 4+5, 6, 7, 8+9) was 75, 89, 68, 90, 62, respectively.

lapses; $F(1,15)=33.38$ for median RT; $F(1,15)=32.66$ for lapses, $F(1,15)=10.27$ for alpha power density with eyes-open, $F(1,15)=9.32$ for theta power density with eyes-open, $F(1,15)=18.43$ for alpha power density with eyes-closed, $F(1,15)=17.12$ for AAC results]. There was no significant effect for theta power with eyes-closed.

Following up on the linear contrast, post-hoc comparisons (two tailed pared t test with Bonferroni correction, i.e. $P<0.013$ in this case) were performed. The difference between bin 1–3 and the other bins did not become significant until bin 6 for lapses (bin 6: $t(15)=3.75$, bin 7: $t(15)=3.85$, bin 8–9: $t(15)=5.91$), median RT (bin 6:

Table 2
Averaged Pearson's product–moment correlation coefficient (*r*)

		VAS	KDT				AAC	PVT				
			Open (α)	Open (θ)	Close (α)	Close (θ)		Mean RT	Slowest RT	Fastest RT	Median RT	Lapses
KSS-J		**0.89** (0.07)	**0.40 (0.34)**	**0.38 (0.35)**	**−0.26 (0.31)**	0.18 (0.36)	**−0.37 (0.29)**	**0.57 (0.25)**	**0.57 (0.22)**	**0.30 (0.32)**	**0.49 (0.26)**	**0.56 (0.21)**
VAS			0.36 (0.34)	0.36 (0.34)	**−0.30 (0.28)**	0.17 (0.35)	**−0.41 (0.29)**	**0.52 (0.25)**	**0.51 (0.22)**	**0.26 (0.33)**	**0.44 (0.26)**	**0.51 (0.21)**
KDT	Open (α)			0.64 (0.27)	−0.10 (0.30)	**0.29 (0.34)**	**−0.51 (0.20)**	**0.36 (0.25)**	**0.34 (0.27)**	0.14 (0.33)	**0.33 (0.24)**	**0.32 (0.24)**
	Open (θ)				−0.20 (0.34)	**0.27 (0.37)**	**−0.45 (0.23)**	**0.41 (0.26)**	**0.38 (0.30)**	**0.22 (0.24)**	**0.38 (0.22)**	**0.33 (0.31)**
	Close (α)					0.01 (0.46)	**0.64 (0.25)**	**−0.32 (0.19)**	**−0.30 (0.20)**	**−0.20 (0.26)**	**−0.31 (0.24)**	**−0.27 (0.20)**
	Close (θ)						−0.19 (0.45)	0.20 (0.33)	0.20 (0.36)	0.06 (0.19)	**0.20 (0.25)**	0.17 (0.33)
AAC								**−0.44 (0.16)**	**−0.44 (0.16)**	**−0.22 (0.26)**	**−0.40 (0.24)**	**−0.38 (0.18)**
PVT	Mean RT								**0.90 (0.07)**	**0.57 (0.18)**	**0.84 (0.10)**	**0.79 (0.15)**
	Slowest RT									**0.35 (0.20)**	**0.64 (0.15)**	**0.85 (0.08)**
	Fastest RT										**0.71 (0.16)**	**0.33 (0.24)**
	Median RT											**0.60 (0.23)**

Bold type = significant at $P < 0.01$. Parentheses show standard deviations.

$t(15) = 4.37$, bin 7: $t(15) = 4.49$, bin 8–9: $t(15) = 5.41$) and AAC (bin 6: $t(15) = 2.93$, bin 7: $t(15) = 3.37$, bin 8–9: $t(15) = 4.40$), until bin 7 for alpha power with eyes-closed (bin 7: $t(15) = 3.46$, bin 8–9: $t(15) = 4.17$) and until bin 8–9 for alpha power with eyes-open (bin 8–9: $t(15) = 2.80$). VAS showed significant differences between bins 1–3 and all other bins (bin 4–5: $t(15) = 8.88$, bin 6: $t(15) = 13.57$, bin 7: $t(15) = 15.63$, bin 8–9: $t(15) = 22.22$). No significant differences were detected between the bins for theta power with eyes-open and eyes-closed.

Table 2 shows the averaged data of the Pearson product–moment correlation coefficient (i.e. *r*) between the indices. The KSS-J was highly correlated with the VAS and the PVT measures except for the fastest RT. The correlations were also rather high and significant with alpha and theta power in the KDT for the eyes-open condition, but rather poor for eyes-closed alpha activities and non-significant for theta activities. In addition, a correlation was observed between the KSS-J and AAC. The AAC showed significant correlations with the KDT, the PVT measures and the VAS. The VAS showed a similar pattern of correlations to the KSS-J, but slightly weaker.

4. Discussion

All variables except for theta power density with eyes-closed showed clear relations to the KSS-J despite the fact that the range of variation of sleepiness probably was lower than it would have been if sleep deprivation had been involved. It is notable that the correlations between EEG and PVT performances would be the first report to our best knowledge.

The results are similar to a number of other studies showing relatively high correlations between performance measures and subjective sleepiness (Åkerstedt et al., 2005; Gillberg et al., 1994; Hoddes et al., 1973). In the present study, we also look at the pattern of the relation, which is essentially linear. It appears that lapses may occur at low level of sleepiness and median reaction time is linearly delayed as KSS-J score increased. These results cannot be generalized to other groups as absolute values, but may give an impression of what high levels of sleepiness might influence normal alert performance levels.

According to Jewett et al. (1999), the PVT performance deteriorates exponentially as levels of sleep deprivation increase. It means that moderate sleep deprivation (<6 h) does not much influence lapses and median response time, although subjective sleepiness (measured by the Stanford sleepiness scale) linearly increases with levels of sleep deprivation. The results of the present study, however, clearly showed a correlation between the KSS-J and PVT even after relatively normal night sleep. It suggests that sleep deprivation (i.e. sleep propensity) may not necessarily play a substantial role in the correlation between subjective sleepiness and performance but situational contexts may be important.

As has been pointed out (Dinges et al., 1987), the correlations between sleepiness and performance are not perfect and subjective sleepiness cannot be regarded as a substitute for performance. On the other hand, one performance measure cannot substitute for another one (Van Dongen et al., 2003). Recently, it has been suggested that making the subjective rating after a minute of sitting in quiet in a controlled situation will improve the subjective/performance correlations (Yang et al., 2004). This emphasizes the need for carrying out the rating in a context similar to that of the performance test.

The KSS-J correlated highly with the other subjective sleepiness scale (the VAS) and showed a very strong linear relation in the ANOVA, with extremely small standard errors. This clearly argues for a considerable reliability and concurrent validity. The KSS-J also correlated well with the alpha and theta power of the KDT with eyes-open. Similar observations have been made in previous studies (Åkerstedt and Gillberg, 1990; Horne and Baulk, 2004; Kecklund and Åkerstedt, 1993; Otmani et al., 2005; Strijkstra et al., 2003; van den Berg et al., 2005).

The alpha and theta power density do not start to deviate significantly from low KSS-J levels. This is almost exactly the same result as was obtained in the original study (Åkerstedt and Gillberg, 1990), but in the present study the resolution was one level higher. This pattern is clearly different from that of VAS ratings, lapses and median response time, all of which showed significant deviations from the lowest KSS-J been at earlier levels. Interestingly, the alpha attenuation coefficient also showed a deviation from the lowest KSS-J and the correlation with the KSS-J is stronger than alpha densities in the KDT. Usage of the ratio between 'eyes-closed' and 'eyes-open' alpha activity might minimize inter-individual variability in alpha activity.

The consequence of later rise of alpha and theta power density with KSS-J is suggesting that high correlations cannot be expected unless high-levels of sleepiness occur within the study. In the light of these observations and of the fact that the subjects received relatively normal night sleep, the correlations in the present study between the KSS-J and the alpha and theta activity must be considered relatively high.

The correlations were low with the amount of alpha and theta activity with eyes-closed. This is similar to previous results (Åkerstedt and Gillberg, 1990). It is reminiscent of the difficulties of finding high correlations between the multiple sleep latency test (MSLT) and other sleepiness indicators (Danker-Hopfe et al., 2001). These observations indicate that alpha and theta activity with eyes-closed have less in common with subjective sleepiness than similar variables obtained with the eyes-open. This may be related to the observation, mainly anecdotal, that the perception of sleepiness is related to perceptions of heaviness of the eye lids, difficulties of keeping one's eyes open, feeling 'gravel-eyed', etc. Upon closing one's eyes, all these phenomena will presumably disappear. Thus, one may expect weaker relations between subjective sleepiness with EEG variables during conditions of eyes-closed than with eyes-open.

The KSS, originally presented in English, was translated into Japanese in the present study. The KSS has been used in many other languages but it has not been translated into Japanese and used in Japan in despite of increasing awareness of sleep problems in the country. In a society, which never stops work operations day and night, the assessment of sleepiness is even more a pertinent issue, and it usually needs to be made in its local language. The results of this study demonstrate that KSS-J shows a relation to EEG including AAT and performance measures, which is very similar to that of the original KSS. It is, therefore, a reasonable conclusion that KSS-J reflects other indicators of sleepiness in a way that does not differ from what the original KSS does.

In conclusion, the validity of the Karolinska sleepiness scale was confirmed. Although there are some limitations in our study, such as a small number of the participants, KSS or KSS-J appears to be a convenient and reliable tool for evaluating subjective sleepiness.

Appendix A

The Japanese version of the Karolinska Sleepiness Scale (KSS-J)

あなたの眠気の状態をもっともよく表した数字に○をつけてください.

1 非常にはっきり目覚めている

2

3 目覚めている

4

5 どちらでもない

6

7 眠い

8

9 とても眠い（眠気と戦っている）

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