Increasing the Temporal Resolution and Stage Specificity by Visual Adaptive Scoring (VAS) - A Preliminary Description

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The scoring system of Rechtschaffen and Kales (1968) is practically the only method of visual sleep analysis in spite of its serious drawbacks. The most important ones are the fixed, long epochs, the insufficient number of sleep stages and the ignorance of EEG topography. In this preliminary work a method to overcome these limitations in visual scoring is presented. Segments of variable length and more stage categories than in the standard system were used. The method was preliminarily applied to the analyses of multiple sleep latency tests (MSLT) from three subjects. All recordings were classified both by the standard method of Rechtschaffen and Kales (RKS, 1968) and by visual adaptive scoring (VAS). VAS was more sensitive to short sleep spells than RKS and gave a shorter and according to our opinion a more accurate sleep onset latency. The rating of two subjects changed from borderline to pathological. One became more normal because of different scoring of one segment. The percentages of stages obtained by VAS were only slightly different from those obtained by RKS and did not reach statistical significance. Yet, the infrastructure, short lapses of alertness, short sleep episodes and arousals, were more precisely revealed. Although VAS is sometimes more time consuming than traditional scoring it is a model that fits the sleep/wake process more closely than RKS and can therefore be regarded as a better model. The improved temporal resolution gives electrophysiologically more stationary epochs. This will be especially important with computer analysis. When used for scientific work VAS helps to provide more profound understanding of underlying mechanisms of sleep and arousal as well as their correlates. Sometimes VAS is also easier to apply because many of the problems with RKS are due to the epoch boundaries and landmarks not fitting the stage categories. (Sleep and Hypnosis 1999;1:22-28)

Key words: visual scoring, sleep stages, adaptive segmentation, sleep analysis.

INTRODUCTION

In spite of the limitations and criticism presented, the scoring system of Rechtschaffen and Kales (1) is practically the only method of visual sleep analysis. The major drawbacks are: 1. The segment which has to be classified into a single stage is, in physiological terms, rather long (2). 2. The number of stage categories is limited so that some episodes cannot be unambiguously classified (3). 3. Only a single EEG derivation is used so that events on other channels are ignored (4). Previous work in the field is limited consisting only of adaptive segmentation performed for the development of computer analysis (5-8) and a preliminary attempt of adaptive scoring (9).

In the present paper a method to overcome the limitations in visual scoring is described. Segments of variable length and more stage categories than in the standard system were used. The method was preliminarily applied to the analyses of the multiple sleep latency test (MSLT).

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METHODS

Subjects and Recordings

MSLTs from three subjects were utilised. Each test

Table 1. Characteristics of Stages in Visual Adaptive Scoring (VAS)

Wake Low	WL	Low-voltage mixed-frequency EEG with fast eye movements or no eye movements
Wake Alpha	WA	Posterior alpha in EEG, no eye movements
Drowsy Alpha	DA	Posterior or diffuse alpha in EEG with eye movements (SEM, blink, saccade or OEM) Frontal alpha in EEG + SEM
Drowsy Low	DL	Low-voltage mixed-frequency EEG + SEM
S1	S1VAS	Theta in EEG
S2	S2VAS	Spindles and/or K complexes in EEG
Arousals From S2:		
Alpha-Arousal	Ar-Alpha	Appearance of alpha activity in EEG
K/K-Alpha-Arousal	Ar-K	Intermittent sequences of K-complexes or K-complex with alpha activity in EEG
Delta-Arousal	Ar-Delta	Hypersynchronous slow-waves in EEG
EEG Attenuation	Ar-Desyn	Phases with desynchronized EEG-patterns
EMG-Activity	EMG	Elevated muscle activity
Movement	MT	Muscle activity with cable artifacts

consisted of four nap recordings. Two subjects were male aged 35 and 57 years and one was female aged 63 years. All three suffered from sleep apnoea syndrome with apnoea-hypopnoea indexes of 21, 43 and 26, respectively. The four 20-32 min naps were recorded at app. 10:00 a.m., 12:00 p.m., 14:00 p.m. and 16:00 p.m. The recordings were made in a sound-attended laboratory room in a controlled environment with a temperature of about 22 ºC. A 16-channel portable Embla sleep recorder (Flaga) with a dynamic range of 16 bit and a sampling rate of 200 Hz was utilised. This gave a bandwidth of approximately 90 Hz by using a completely digital flat filter. The MSLT naps were terminated 20 min after lights out if there was no sleep at all. If the subject fell asleep, the recording was continued for 15 minutes from the first S1 epoch. The minimum length of one nap recording was 20 min.

The guidelines provided by the Association of Sleep Disorders Centers Task Force on Daytime Sleepiness (10) were followed with slight modifications, which do not have an effect on the present work. Seven EEG derivations Fp1-M2, C3-M2, O1-M2, Fp2-M1, C4-M1, O2-M1, M2-M1, two EOG-channels EOG P8-M1, EOG P18-M1 (11) and submental muscle tonus were recorded. In addition the following parameters were measured: m. tibialis anterior muscle tonus by surface electrodes, body position, electrocardiogram, nasal airflow by thermistor, chest and abdominal respiratory movements by piezo transducers and blood oxygen saturation by oximetry.

Visual analysis

All recordings were analysed both by the standard method (RKS) of Rechtschaffen and Kales (1) and by visual adaptive scoring (VAS). All scorings were made by using the Somnologica program version 1.6 (Flaga). For the purpose of VAS a special tool made by the aid of the developers toolkit provided by the manufacturer was utilised. By this tool the end of each segment was marked. This opened a window for choosing the stage. Special computer programs were also developed for comparison of the scorings as well as display of the hypnograms. The PC computer used for analysis had a 21" screen with a 1280 x 1024 resolution.

The VAS stages with their descriptions are shown in Table 1. Electrophysiological stage changes shorter than 1 sec were not scored separately. This is in line with the recommendation of the Comac BME task force (12).

All recordings were first scored by the same experienced neurophysiologist (S-LH). Thereafter they were re-examined by another neurophysiologist (JH). Parts of disagreement (approximately <5% of the time) were discussed in order to get a mutual decision about the state. Before the first recording was analysed the scorers practised adaptive scoring together in order to develop the stage categories and have the same view about the characteristics defining the states. An example with original tracing and VAS is presented in Figure 1.

RESULTS

The results from the whole material with the 3 MSLTs consisting of 4 naps each are presented in Table 2. The shortest segment scored by VAS was 1 sec and the longest 4:37 (min:sec). The total duration of the recordings was 269:15. The mean length of the naps was 22:26, range 19:59 to 31:58. There was no significant difference between total sleep times (TST, 8:12 for RKS vs. 8:59 for VAS p= 0.0843, Wilcoxon matched-pairs signed-ranks test). Sleep efficiency index (SEI) calculated from time in bed (TST/TIB) was somewhat higher by VAS (34.3% vs. 38.1 %) but the difference did not reach statistical significance (p=0.0597). This may be due to the small material. Sleep onset latencies (SOL) calculated both to adaptively scored S1 (S1VAS) and drowsy-low (DL) were significantly shorter than the latencies to Rechtschaffen-Kales scored S1 (S1RKS, 4:59 and 2:16 vs. 5:35, respectively, p values 0.0342 for both). The relatively small difference in values between S1RKS and S1VAS is due to nap 3C where a segment with a SOL of 1:30 was scored S1 by RKS even if small eye movements were visible in the frontal leads indicating wakefulness. This segment was classified wake low (WL) by

Figure 1. 27 sec of polygraphic tracing with part of the channels recorded. In the beginning the subject is drowsy with diffuse alpha activity and slow eye movements (drowsy-alpha). This is followed by a short episode of S1 with disappearance of the alpha and increasing theta activity. There is an apnoea during which the subject wakes up again. The alpha episodes seen on the occipital channels during wake-low are less than 1 sec and therefore ignored.

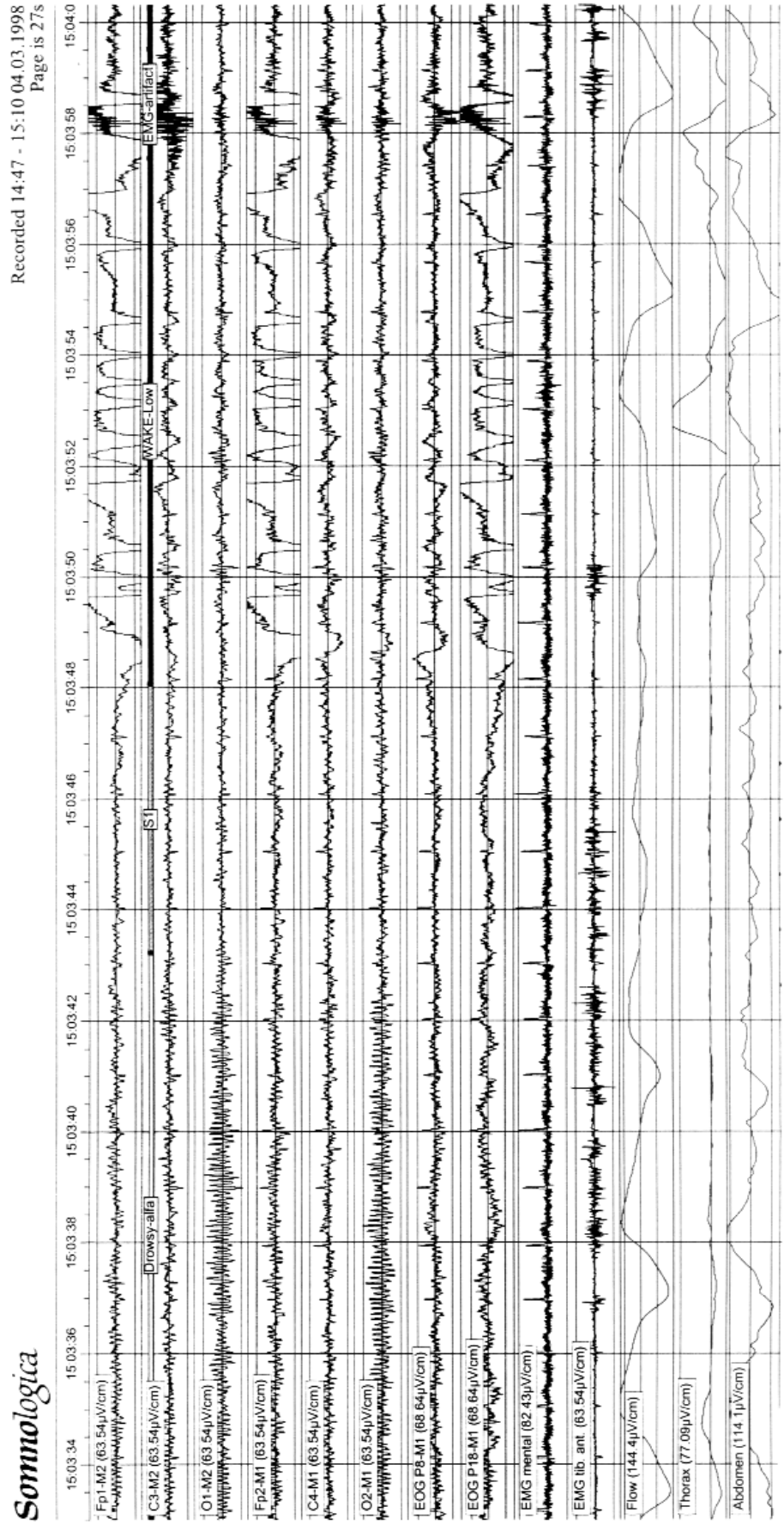


Table 2. Sleep Parameters from the 3 MSLTs with 4 Naps Each

NAP	TIB	SEI RKS	SEI VAS	SOL RKS	SOL S1VAS	SOL DL	LatS2RKS	LatS2VAS	%S0RKS	%S0VAS	%S1RKS	%DL+S1VAS	%S2RKS	%S2VAS+Ar
	min:sec	%	%	min:sec	min:sec	min:sec	min:sec	min:sec	%	%	%	%	%	%
1A	20:00	7.5	11.4	7:00	5:01	0:39			92.5	88.5	7.5	11.5	0.0	0.0
1B	20:00	40.0	45.3	6:30	3:45	0:57	18:30	18:24	60.0	54.6	32.5	37.5	7.5	7.9
1C	19:59	5.0	11.9	3:30	3:08	0:17			95.0	88.1	5.0	12.0	0.0	0.0
1D	19:59	5.0	13.1	7:30	1:34	1:19			95.0	86.8	5.0	13.2	0.0	0.0
2A	22:59	28.3	33.9	6:30	4:57	1:16			71.7	66.0	28.3	34.0	0.0	0.0
2B	19:59	20.0	29.1	8:30	7:22	1:36	12:00	11:53	80.0	70.8	15.0	23.6	5.0	5.6
2C	19:59	40.1	52.5	1:30	0:33	0:36	5:00	3:27	59.9	47.3	20.1	29.3	20.1	23.4
2D	20:29	34.2	39.8	7:00	5:42	2:28			65.8	60.1	34.2	35.2	0.0	4.7
3A	25:44	81.6	76.4	2:00	0:19	0:11	6:00	6:53	18.4	23.4	29.1	24.6	52.5	52.0
3B	24:44	64.7	73.5	6:00	2:43	0:17	7:00	6:54	35.3	23.4	10.1	12.6	54.6	61.0
3C	23:28	32.0	12.7	1:30	17:45	11:47			68.0	87.3	32.0	12.8	0.0	0.0
3D	31:58	53.2	57.7	9:30	6:53	5:53	15:30	11:21	46.8	42.2	23.5	27.8	29.7	30.1
MEAN	22:26	34.3	38.1	5:35	4:59	2:16	10:40	10:35	65.7	61.5	20.2	22.8	14.1	15.4
SD	3:40	23.9	23.6	2:46	4:38	3:23	5:33	5:13	23.9	24.1	11.3	10.0	20.7	21.6
MIN	19:59	5.0	11.4	1:30	0:19	0:11	5:00	3:27	18.4	23.4	5.0	11.5	0.0	0.0
MAX	31:58	81.6	76.4	9:30	17:45	11:47	18:30	18:24	95.0	88.5	34.2	37.5	54.6	61.0
p-value			0.0597		0.0342	0.0342		0.1730		0.0597		0.0844		0.0630

VAS. Latencies to S2VAS and S2RKS were almost equal.

The mean sleep latencies of each MSLTs are shown in Table 3. Two subjects had mean latencies of about six minutes by RKS. This is considered as borderline value (10). With VAS these latencies became markedly shorter and could be interpreted as pathological. Subject 3 had the latency to S1RKS initially pathological (<5 min). The latency to S1VAS was borderline. This was due to the one segment interpreted as WL by VAS because of eye movements visible only on the frontal leads. However, latency to DL remained <5 min.

Table 3. Mean Sleep Latencies (min:sec) from each MSLT.

Subject	SOL RKS	SOL S1VAS	SOL DL
	min:sec	min:sec	min:sec
1	6:08	3:22	0:48
2	5:53	4:39	1:29
3	4:45	6:55	4:32

In six nap recordings SOL RKS was longer than SOL VAS because of arousals caused by apnoea/hypopnoea. In one subject this took place in all four naps and in another subject in two of the naps. It is expected that without the respiratory disturbances the sleep latencies by RKS and VAS would have been more equal.

There were also differences in percentages between %S0VAS and %S0RKS, %DL+S1VAS and %S1RKS and %S2VAS+arousals and %S2RKS but none of those were statistically significant in this rather limited material (p= 0.0597, 0.0844 and 0.0630, respectively). In these calculations S1VAS and DL were combined into a single stage. This corresponds to the rules of Rechtschaffen and Kales by which disappearance of alpha is interpreted as S1 sleep. Arousals from S2 were included into S2VAS.

Only about half of the S0RKS was scored as clear wakefulness (WL and wake-alpha, WA) by VAS (44.3 % and 3.7 %, respectively, Table 4a). One third constituted of drowsiness with occipital alpha activity (drowsy-alpha, DA). About 15 % of time scored S0RKS was actually sleep (DL, S1VAS, S2VAS + arousals). Conversely 91.7% of VAS WL was scored S0 by RKS. 7.9% was scored S1and 0.4 % S2 (Table 4b). A remarkable thing was that 78.7 % of DL

Table 4a. Percentages of VAS Stages in RKS Stages.

	WL	WA	DA	DL	S1VAS	S2VAS	Ar-alpha	Ar-K	Ar-Desyn	EMG	MTV	sum%
S0	44.3	3.7	33.4	5.7	8.5	0.6	0.2	0.5	0.0	2.5	0.7	100.0
S1	11.7	2.4	11.2	4.1	58.4	7.9	0.4	1.5	0.0	1.3	0.1	100.0
S2	0.7	0.0	0.9	0.8	6.0	83.0	3.2	4.6	0.0	0.8	0.0	100.0

Table 4b. Percentages of RKS Stages in VAS Stages.

	WL	WA	DA	DL	S1VAS	S2VAS	Ar-alpha	Ar-K	Ar-Desyn	EMG	MTV
S0	91.7	81.6	87.9	78.7	29.0	2.3	13.5	21.2	100.0	79.7	63.6
S1	7.9	18.4	11.4	18.7	65.8	10.6	12.6	23.2	0.0	13.9	36.4
S2	0.4	0.0	0.8	2.6	5.3	87.1	73.8	55.6	0.0	6.4	0.0
sum%	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Figure. 2a. Only two S1 epochs are obtained by RKS. By VAS several periodic S1 sleep episodes can be seen. Abbreviations: See Table 1.

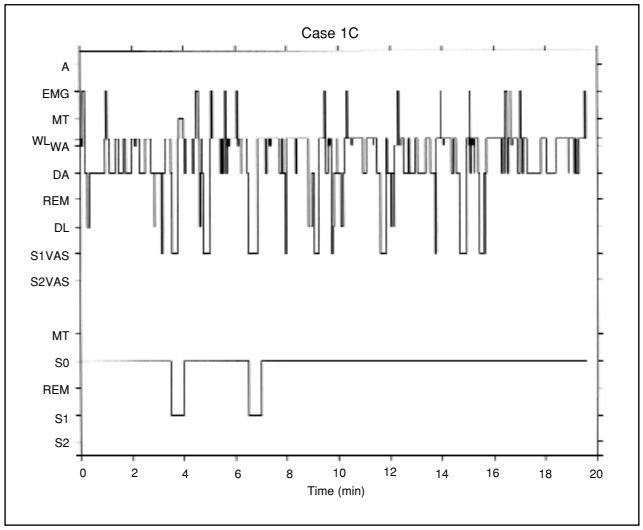


Figure 2b. Most of the repetitive arousals visible by VAS are ignored by RKS.

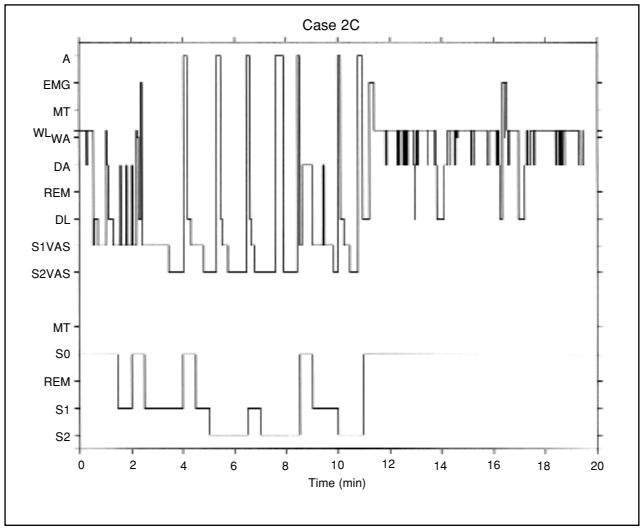
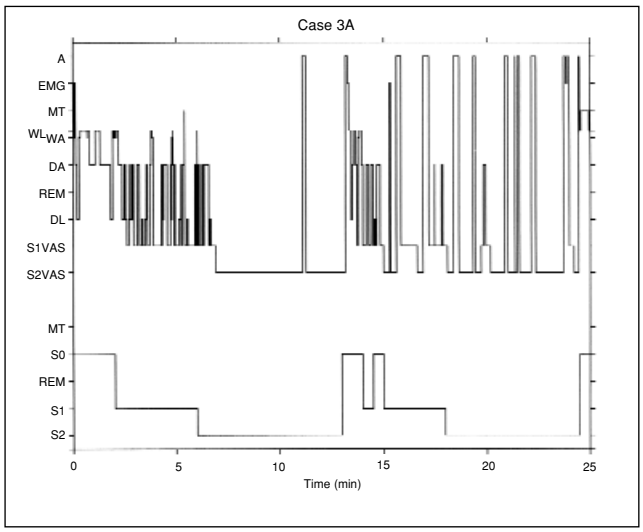


Figure 2c. A rather rapid sleep onset and two major sleep episodes with some wakefulness in between are seen. By VAS sleep onset is disturbed until S2. The second sleep episode is constantly interrupted by repetitive arousals.



which according to standard rules should correspond to S1 sleep was scored S0RKS. One fourth of S1RKS was scored wakefulness or drowsiness by VAS (WL, WA, DA). 62.5 % was scored similarly as S1 (DL included) by both methods. Ten percent of S1RKS was actually S2 sleep (arousals included). Conversely 29.0% of S1VAS was scored wakefulness (S0) by RKS, 65.8.% was scored S1 and 5.3% S2. 83.0 % of S2RKS was scored S2 by VAS. If arousals from S2 are included the percentage increases to 90.8 %. 6.8% was scored S1VAS+DL and 1.6 % as wakefulness. Conversely 87.1 % of S2VAS was S2 in RKS, 10.6% S1 and 2.3 % S0.

The effects of the increase in temporal resolution are clearly visible in the hypnograms illustrated by Figures 2a-c. Short sleep episodes are in many cases overlooked by RKS but revealed by VAS. Likewise intervening repetitive arousals are ignored by RKS but clearly visible by VAS.

DISCUSSION

The MSLT was chosen as the first application for visual adaptive scoring (VAS) because it is particularly sensitive to small differences in stage determination. The latency is the main parameter used, and often the only one. With traditional scoring by the manual of Rechtschaffen and Kales (RKS) the epoch is assigned to the stage which forms the majority. Thus a sleep episode of almost 30 sec can be overlooked if it is evenly divided between two consecutive 30 sec epochs. However, the real sleep and wake episodes do not usually coincide with the fixed epochs. There can be epochs containing wakefulness, drowsiness and stage 1, sometimes also stage 2. This is especially the case with sleep apnoea patients who fall asleep and arouse repetitively. In many cases it is more or less a coincidence which stage the epoch will be scored. With VAS the epoch boundaries can be placed exactly where the real stage changes occur. In apnoea patients VAS might be expected to provide clear benefits as compared to RKS. It might also increase inter-scorer reliability because 1-2 sec differences do not result in different scorings of whole 30 sec epochs.

Already in this small material it could be shown that VAS is more sensitive to short sleep spells than RKS. VAS gives a shorter and according to our opinion a more accurate sleep onset latency. By VAS the rating of two subjects changed from borderline to pathological. One became more normal because of different scoring of one segment.

One can argue, whether VAS is too sensitive. However, in two out of three subjects sleep would probably have continued if the subjects would not have been aroused by an apnoea/hypopnoea. Thus it is evident that RKS provides sometimes erroneous information as compared to VAS. To our knowledge adjustments are used in some laboratories for sleep apnoea patients so that sleep latencies are calculated to sleep episodes shorter than half the epoch if they are terminated by apnoeas. For clinical purpose more studies are needed to determine reference values for VAS. For scientific studies with a control group VAS could be applied immediately.

The percentages of stages obtained by VAS were only slightly different from those obtained by RKS. However, the

infrastructure, short lapses of alertness, short sleep episodes and arousals were more precisely revealed. This is due to improved temporal resolution with electrophysiologically more stationary epochs. The benefit is a more stable and biologically accurate analysis. This will be especially important with computer analysis. EEG spectra have overlapping characteristics in different sleep stages (2). It is expected that if analysis is based on VAS instead of RKS more unique results for each stage would be obtained.

In RKS drowsiness is completely overlooked. Drowsiness should, however, be scored separately because it is known that performance is impaired already when electrophysiological characteristics correspond to drowsy-alpha and even more to drowsy-low (13, Kinnari et al., in preparation). Further impairment takes place with increasing theta activity. It is remarkable that in the present work most of DL was S0RKS. The drowsiness stages show electrophysiological differences and their separation is essential because most computer analysis methods require stationary segments.

It seemed that the stage categories used in this work were suitable for MSLT. By visual estimation rather stationary segments with unique characteristics were obtained. The choice of categories is supported by previous work where it has been shown that the electrophysiological characteristics correlate to performance (13). The arousals were defined roughly according to the cyclic alternating pattern (CAP) definitions of Terzano et al. (14). It is possible that for whole-night sleep recordings the number of stages and their characteristics have to be re-evaluated.

The interpretation of low-amplitude EEG activity is a special problem. It is sometimes difficult to tell whether the subject is becoming more drowsy or more alert if there are no clear fast eye movements to tell that the eyes are opened or slow eye movements indicating drowsiness. Especially the disappearance of background alpha with appearance of blinks without any signs of eye opening can be difficult to interpret. This is a problem both with the RKS system and VAS. In the RKS rules there are no clear guidelines for these episodes. Nap 3C is a rather good example showing how difficult it is to interpret segments with flat EEG. By RKS the segment is scored S1, by VAS as WL. The reason was that there were fast eye movements visible on EEG leads which were not utilised by the RKS.

Also with alpha activity and blinks it is often difficult to tell, whether drowsiness is increased or if the subject is simply blinking her/his eyelids when lying with eyes closed. Regardless of the scoring system interpretation ought to be made according to the context depending on, whether the eyes are presumed to be open or closed. One good possibility would be to take into account the slow eye movements as well as theta activity even more strongly than in the present work. There is evidence that slowing of eye movements might be more important indicators of impaired performance than EEG changes (15, Hirvonen et al., in preparation, Kinnari et al., in preparation). As interpretation of the meaning of electrophysiological activity is dependent on whether the eyes are open or closed video monitoring might be of help.

Onset of S2 is still obscure. Spindles can be asynchronous at sleep onset (16). By RKS the beginning of S2 is dependent on which one of the two central channels has been chosen for scoring. By VAS it is not yet clear when onset of S2 should take place: is it when the first sleep spindle or K complex appears on any channel or is it dependent on synchronous spindling at least when no K complexes are present? More knowledge about sleep physiology is needed. One problem constitutes of subjects who have lacking or poor spindles.

In this preliminary, methodological work all recordings were classified by one scorer, re-examined by a second and finally discussed in order to get a common view about the stages and their boundaries. This was preceded by a training period where the two scored recordings together. Usually a more complicated procedure is applied with two independent scorers and one consensus scorer. This will be necessary in future work in order to evaluate the usefulness and reliability of the scoring system. If inter-scorer agreement is too low and the procedure too time-consuming then it cannot be applied for usual clinical and experimental work.

A stage scoring system can be regarded as a model of the actual, biological processes associated with vigilance. Usually a model which fits and explains the functions best should be chosen. When more information is obtained by scientific work the model should be improved. This has, so far, not been the case with sleep stage scoring. The disadvantages are obvious. Although VAS is sometimes more time consuming than traditional scoring it is a model that fits the sleep/wake process more closely than RKS and can therefore be regarded as a better model. When used for scientific work VAS helps to provide better understanding of underlying mechanisms of sleep and arousal as well as their correlates. Sometimes VAS is also easier to apply because many of the problems with RKS are due to the epoch boundaries and landmarks not fitting the stage categories.

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