Sleep Staging with Frontopolar EEG Derivation

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Fastening an electroencephalography (EEG) electrode to the forehead with a disposable self-adhesive electrode in ambulatory polysomnographic recordings is a tempting option. The aim of the present study was to clarify, whether the sleep parameters change if sleep stage scoring is based on the frontopolar EEG derivation instead of the commonly used central EEG derivation. Ten healthy subjects and ten patients with sleep disorders were studied.
The scoring agreements between the two EEG derivations were close to previously observed inter-scorer agreements. In addition, it was found that using frontopolar scoring would not have caused any changes in the clinical diagnosis of the patients as compared to the standard scoring method. Interestingly, higher percentage of slow wave sleep and a lower amount of sleep stage 2, as expected, was obtained by frontopolar scoring in healthy subjects but such difference was not found in frontopolar scoring of the patients. This might implicate a deficit in the synchronization producing mechanisms in the frontal cortex of the patients. In ambulatory studies with a limited number of channels frontopolar EEG recording could be used as a single electrode because of its simplicity and probable sensitivity to changes in nocturnal brain activity. **(Sleep and Hypnosis 2004;6(2):48-54)**

Key words: *sleep EEG, sleep stage scoring, frontal lobe, frontal sleep EEG*

INTRODUCTION

Patients suffering from sleep disorders, especially respiratory disorders, are often investigated by all-night ambulatory home recordings instead of extended polysomnographic in-laboratory studies. Reasons for this are lower costs and long waiting lists to sleep laboratories. Special ambulatory recording equipment has been developed for these home recordings (1). In some instances sleep electroencephalography (EEG) is not recorded. However, even one EEG electrode could be of substantial aid in differentiating non-REM (NREM) from REM sleep, estimating the quality and depth of NREM sleep and measuring in a reliable way the amount of sleep during the night.

Unfortunately, the EEG electrode might become detached during the night in home recordings. Often a skilled technician is required for attaching the most commonly used central EEG-electrode (C3 or C4). Because of

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this, fastening an electrode to the forehead with a disposable self-adhesive electrode is a tempting option. Attaching the electrode to the forehead is not complicated and the patient or the spouse would be able to attach a replacement electrode themselves. In addition, the electrode in this location probably would not disturb the sleeper too much. One single frontal EEG derivation would also be easy to add on to the recording system.

The frontal derivation has not been used in visual sleep stage scoring, because it is not included in the rules of the standardized sleep staging manual in which a central EEG derivation is recommended (2). However, it has recently been reported that an additional frontal recording channel (Fz) added to the standard montage significantly improved the recognition of arousals in apnea patients (3). It was therefore recommended as an extra EEG derivation. In one automatic sleep staging system the analysed channel can be selected from central, frontal or electro-oculogram (EOG) derivations (4,5).

The aim of this methodological study was to find out how sleep stage scoring with frontopolar EEG differs from sleep stage scoring with the standard electrode montage in normal healthy subjects and in patients with sleep disorders. As the most important waveforms of sleep EEG are quite visible also in the EOG, we performed a few additional scorings in a small group of both healthy subjects and patients with sleep disorders by using only the EOG and submental electromyography (EMG) channels. Previously visual scoring with a periorbital electrode has been presented with healthy subjects (6).

SUBJECTS AND METHODS

Subjects and Recordings

Ten healthy subjects (control group) and ten patients with sleep disorders (eight patients with sleep apnea, one with narcolepsy, one with psychophysiological insomnia) were studied by frontopolar scoring. Both groups consisted of three females and seven males. Mean age was 30.5 years (range 20–59 years) in the control group and 40.5 years (range 27–50 years) in the patient group. EOG scoring was made on four healthy subjects (one female, three male) and four patients (one female, three male; three patients with sleep apnoea, one with psychophysiological insomnia). The mean age of these subjects was 35.5 years (range 21-52 years).

None of the subjects had any other primary medical or psychiatric disorder or medication. The healthy subjects had no history of excessive daytime sleepiness or any sleep complaints. The patients were regular clinical outpatients and the recordings of the control subjects were part of two larger studies. The recordings were carried out in the laboratory. All subjects retired to bed between 10 and 12 p.m., according to their habitual bed times.

Four EEG derivations Fp2-A1, C3-A2, C4-A1, O1-A2, two EOG-channels (EOG P8-A1 and EOG P18-A1) (7), and submental EMG were recorded. This recording protocol has been routinely used in our laboratory, as the number of the recording channels is limited. In addition, the electrocardiogram, oro-nasal airflow by thermistor or nasal pressure transducer, thoracic and abdominal respiratory movements, body position, blood oxygen saturation and tibialis anterior muscle activity were recorded.

Visual analysis

The Somnologica, program (Flaga/Medcare, Iceland) was used for visual analyses. All sleep recordings were classified into sleep stages by the standard scoring method (2) in epochs of 30 s by an experienced clinical neurophysiologist. In standard sleep stage scoring (central scoring) all recorded EEG-derivations with the two EOG-channels and submental EMG were visible on the screen. Scoring was based on the C4-A1–derivation. In frontopolar scoring only the Fp2-A1-derivation, the two EOG-channels and

submental EMG were visible. In EOG scoring only the two EOG channels with submental EMG were utilized. The time intervals between scoring sessions of the same subject were at least one week. The apnea-hypopnea index (AHI) was calculated as the hourly rate of cessations or diminutions >50% of airflow lasting over 10 s.

Statistics

The SPSS for Windows version 10.0® (SPSS Inc.) program was used in statistical analyses. Nonparametric tests were used, as all the variables were not normally distributed. Wilcoxon signed-rank test was used for comparisons between dependent variables. P values <0.05 were considered statistically significant.

RESULTS

The median scoring agreement between the central and frontopolar sleep stage scorings was 86 % (range 80-90%) in the control group and 89% (84-94%) in the patient group. The agreement between central and EOG scoring was 86% (72-91%).

The agreement between central and frontopolar scoring was high (around 90 %) in wakefulness epochs, in stage REM (SREM) and in sleep stage 2 (S2) and moderate (>60%) in sleep stage 1 (S1) in both healthy subjects and patients (Table 1). The agreement in sleep stage

Table 1. Agreements in percentage between different scoring methods

	Central vs. frontopolar		Central vs. EOG
Sleep stage	**Control group**	**Patient group**	**Study group**
Wake	87	95	91
REM	92	91	92
S1	62	62	59
S2	89	94	89
S3	43	52	39
S4	93	32	87

Table 2. The sleep parameters of the night recordings with the central and frontopolar scoring methods in the healthy subjects

	Central scoring			Frontopolar scoring			
Parameter	**Median**	**Min**	**Max**	**Median**	**Min**	**Max**	**p value**
TIB, min	494.3	438.0	525.0	494.3	438.0	525.0	
SPT, min	483.8	434.5	519.0	483.5	435.5	515.0	0.13
WASO, min	5.5	1.0	47.0	4.3	0.5	48.0	0.72
TST, min	472.5	421.5	514.0	475.5	422.0	514.0	0.87
SL, min	4.0	0.5	30.5	4.8	1.0	29.5	0.13
SEI, %	99.0	90.5	99.8	99.2	90.3	99.9	0.55
Awakenings	2.0	0.0	6.0	2.5	0.0	6.0	0.89
MT	3.0	1.0	11.0	3.0	2.0	8.0	0.48
REML, min	71.5	61.0	162.0	73.8	55.0	169.0	0.44
AHI	1.3	0.0	4.4	1.3	0.0	4.4	0.32
ODI4	0.0	0.0	38.9	0.0	0.0	38.4	0.07
Stage shifts	87.0	57.0	129.0	76.5	49.0	130.0	0.36
%S1	3.3	0.6	6.3	3.3	0.6	5.8	0.73
%S2	59.3	49.8	72.0	56.8	44.9	66.2	0.017
%S3	8.1	1.0	12.1	7.0	5.1	10.9	0.88
%S4	8.5	0.0	21.5	11.7	0.0	19.6	0.038
%SWS	18.9	1.0	28.1	20.2	6.4	29.8	0.021
%SREM	21.5	12.0	26.5	20.4	10.5	31.0	0.55

TIB=time in bed; SPT=sleep period time; WASO=wakefulness time after sleep onset; TST=total sleep time; SL=sleep latency: SEI=sleep efficiency index; Awakenings=number of awakenings > 30 s: MT=number of movement time epochs; REML=REM sleep latency; AHI=apnea-hypopnea index; ODI4=number of >4 desaturations per hour of sleep; Stage shifts=number of sleep stage shifts %S1-%SREM=percentage of sleep stage referred to total sleep time.

3 (S3) was relatively low (approximately 40-50%). A pronounced difference between the groups was seen in sleep stage 4 (S4), in which the agreement was 93 % in the healthy group but only 32 % in the patient group. In general, similar results were obtained in comparison between central and EOG scoring.

The sleep parameters derived from the night recordings with the central and frontopolar scoring methods in the groups of healthy subjects and patients are shown in Tables 2 and 3 respectively. In the healthy subjects less S2 and more S4 or slow wave sleep (SWS=S3+S4) were obtained by frontopolar scoring. In the

Table 3. The sleep parameters of the night recordings with the central and frontopolar scoring methods in the patient group

	Central scoring			Frontopolar scoring			
Parameter	**Median**	**Min**	**Max**	**Median**	**Min**	**Max**	**p value**
TIB, min	506.5	395.5	565.5	506.5	395.5	565.5	
SPT, min	482.5	373.5	553.0	483.8	373.5	552.5	1.00
WASO, min	89.5	19.0	266.5	97.8	19.0	263.0	0.58
TST, min	410.5	185.0	492.0	395.8	188.5	491.5	0.77
SL, min	15.0	5.5	114.0	16.8	4.5	114.0	1.00
SEI, %	83.1	41.0	96.0	80.9	41.7	96.0	0.62
Awakenings	16.0	7.0	28.0	15.5	9.0	27.0	0.47
MT	0.0	0.0	2.0	1.0	0.0	3.0	0.06
REML, min	149.0	55.5	301.5	154.0	56.5	297.0	0.57
AHI	23.4	0.0	43.3	23.4	0.0	43.7	0.62
ODI4	30.1	0.0	82.7	29.5	0.0	81.5	0.06
Stage shifts	110.0	63.0	171.0	100.5	64.0	141.0	0.07
%S1	7.5	1.9	25.1	7.9	3.5	25.5	0.96
%S2	67.1	56.4	72.7	66.2	58.7	75.9	0.24
%S3	7.2	0.0	13.3	4.4	1.5	16.4	0.20
%S4	0.0	0.0	2.1	0.6	0.0	3.9	0.25
%SWS	7.3	0.0	13.4	5.4	1.5	16.9	0.28
%SREM	17.8	3.2	23.2	16.9	4.0	22.0	0.96

For abbreviations see Table 1.

Table 4. The sleep parameters of the night recordings with the central and EOG scoring methods

	Central scoring			EOG scoring			
Parameter	**Median**	**Min**	**Max**	**Median**	**Min**	**Max**	**p value**
TIB, min	483.0	425.0	515.0	483.0	425.0	515.0	
SPT, min	473.3	420.0	495.0	471.8	386.0	495.0	0.06
WASO, min	34.8	2.0	127.0	43.0	4.0	133.5	0.18
TST, min	442.0	323.5	481.0	440.8	293.0	479.5	0.035
SL, min	9.0	2.5	33.0	13.3	6.5	38.5	0.06
SEI, %	92.6	73.2	99.6	91.1	71.7	99.2	0.08
Awakenings	12.0	1.0	18.0	11.0	2.0	19.0	0.62
MT	3.0	0.0	11.0	1.5	0.0	8.0	0.17
REML, min	109.5	32.0	440.5	108.8	21.0	210.5	0.06
AHI	0.4	0.0	50.6	0.4	0.0	50.0	1.00
ODI4	11.1	0.0	60.0	10.9	0.0	58.5	0.043
Stage shifts	107.0	70.0	128.0	73.5	58.0	122.0	0.028
%S1	5.2	1.9	16.2	6.8	3.2	18.5	0.16
%S2	63.3	50.1	70.8	60.5	55.3	72.5	0.78
%S3	8.2	2.1	13.0	4.3	2.8	8.9	0.33
%S4	1.8	0.0	14.4	3.4	0.0	25.2	0.40
%SWS	12.1	3.5	24.1	11.0	3.7	28.0	0.67
%SREM	18.0	5.1	31.3	19.3	4.4	33.9	0.67

For abbreviations see Table 1.

patient group no statistically significant differences between any sleep parameters obtained by central or frontopolar scoring were found. The outcome of EOG scoring is shown in Table 4. Statistically significant differences in the number of stage shifts per hour, total sleep time (TST) and number of desaturations per hour (ODI4) were obtained. The number of stage shifts was clearly reduced in EOG scoring, but the actual differences in TST and ODI4 were minimal.

DISCUSSION

To the best knowledge of the authors this is the first study dealing with comparison of sleep stage scoring with frontopolar EEG electrodes in patients. When comparing frontopolar scoring to standard scoring with a central electrode, the agreement obtained was, as expected, high (>86%) for stages wake, SREM and S2 in both groups. Between the groups there was only one major difference in the agreements. Whereas the agreement for S4 was high in the healthy subjects, a low agreement was obtained in the patient group. This is probably due to the low amount of S4 in the patient group.

These results correspond to inter-scorer agreements obtained for standard visual sleep stage scoring. In general, high inter-scorer agreements have been obtained for stages S2 and SREM, whereas the agreements for S1 and S3 have been low (8-11). The stages S1/S2 and S3/S4 are often prone to disagreement as they are transitional stages sharing same features (12). The findings have recently been confirmed in a European sleep laboratory study including both healthy subjects and patients with sleep disorders (13,14).

It is also important to notice that using frontopolar scoring would not have caused any changes in the clinical diagnosis of the patients when compared to the standard scoring method. This indicates that frontopolar scoring seems suitable for the clinical work, especially when the alternative in many ambulatory settings would be having no EEG recording at all.

The results obtained by EOG scoring are close to those obtained by frontopolar scoring. This was expected since the location of the EOG electrode above the eye is not far from the frontopolar recording site. Previously in a small group of healthy subjects EOG scoring was found to be usable in order to obtain the main sleep parameters and to reveal the dynamics of low-frequency sleep EEG (6). The results of our study create a similar impression, but as the EOG study group was small, a larger study with patients having different sleep disorders is still needed.

Previously attention has been paid to the finding that the delta waves are highest frontally and therefore the frontal delta activity may show S4 sleep pattern at the same time as delta waves in central leads are too low to be scored as S4 (15). A similar pattern could be seen in the healthy subjects in the present study. In other words, a higher percentage of SWS and a lower amount of S2 was obtained by frontopolar scoring in subjects with normal sleep. Interestingly, no such difference was found in frontopolar scoring of the patients. This might implicate a deficit in the mechanisms producing synchronization in the frontal cortex in these patients, as the increasing synchronization of the brain can be seen as an increase in slow waves and amplitudes in the cortical EEG (16). It is worth noticing that there is a ten year difference in the mean age of the control group and the patient group. The reduction in central delta activity increases with age (17), which might bias our results. However, as the derivative comparisons of SWS were made within the groups, the results should remain unbiased.

Sleep deprivation and fragmentation of sleep are known to increase the amount of slow wave activity in the frontal cortex (18). Quite recently cumulative evidence of the importance of recording sleep EEG from the left frontal area

has been presented. After sleep deprivation delta power was noticed to enhance in the left fronto-central (F3-C3), but not in the right fronto-central lead (18). In another study significant association between performing tasks specific to the left prefrontal cortex and very slow delta activity (0.5-1.0 Hz) in the left frontal EEG channel was found (19). In our previous study it was shown that women have higher sleep spindle density in the left frontal area than men (20). In the present work the frontopolar sleep stage scoring was based on the Fp2-A1 -derivation. Comparison between Fp2-A1 and Fp1-A2 –derivations could not be conducted as only Fp2 was recorded. Taken into account the new results of all the above-mentioned reports, we have to consider changing our recording protocol to include Fp1-A2 instead of Fp2-A1 in those instances in which the number of channels is too limited to include both frontopolar electrodes.

It has been recently concluded that impairment of sleep seems to affect performance on tasks of frontal lobe (21). Our study, together with recent reports, implicate that adding the frontopolar or possibly frontal EEG channels to standard polygraphy might give valuable additional information about the effects of sleep disorders or alterations in sleep schedules on electrophysiological brain activity during sleep. Changes in frontopolar EEG during sleep might explain better the cognitive impairment found in some sleep disorders, particularly, if future studies can confirm that the changes in local electrophysiological activity during NREM sleep correspond to the vulnerability of the brain regions due to sleep fragmentation. In ambulatory studies with a limited number of channels frontopolar EEG recording could be used as a single electrode because of its simplicity and probable sensitivity to changes in nocturnal brain activity.

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