AUTOMATIC ESTIMATION OF WAKEFULNESS AND SLEEP USING ELECTRO-OCULOGRAPHY

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ABSTRACT

There are large development efforts directed toward unobtrusive methods for the monitoring of wakefulness and sleep. When testing these devices also the reference testing method should be easy to use and analyse. It is known that frontopolar electroencephalographic (EEG) and electro-oculography (EOG) electrodes outside the hairline can be used for sleep staging. We have recently demonstrated the use of standard two channel sleep electro-oculography in automatic detection of sleep stages. Here we studied further the use of electro-oculography in the automatic estimation of wakefulness and sleep.

KEYWORDS

sleep, sleep stage, electro-oculography, ambulatory, analysis, automatic, automated, computerized

INTRODUCTION

In standard criteria sleep is defined using central EEG, EOG and submental EEG [1]. For the use in ambulatory screening the major limitations of the use of standard criteria are central electrode placement and visual analysis. Already in 1970's possibility of using electro-oculography as an easier alternative for automatic analysis was studied by Hilbert and Natoh [2]. Later Dyson et al. did visual scoring where the central EEG electrode was replaced by a frontopolar EEG electrode on the forehead [3]. Werth et al. observed similar 0.75-4.5 Hz slow wave activities (SWA) using EOG when compared to central EEG [4]. Visual scoring of sleep apnoea patients is also possible using frontopolar EEG, EOG and EMG [5]. Independent component analysis has been used to separate EEG and EOG using frontopolar electrodes [6]. There are some automatic devices which use frontopolar EEG [7].

We have recently studied the use of only two channel electro-oculography in automatic estimation of wakefulness and sleep. Substantial accuracy (Cohen's Kappa >0.60) for automatic slow wave sleep detection [8], unintentional sleep onset [9] and separation of wakefulness, SREM, S1, S2 and SWS [10] was achieved when compared to the standard visual sleep scoring.

SUBJECTS

We used the same training (n=133) and validation (n=132) data sets as in our previous study [8]. Data sets are described in Table 1.

Table 1 - Number of subjects, age and sleep parameters in the training and validation group

	Subjects (males)	Age mean (range)	Epochs	Wake	SREM	S1	S2	SWS	AHI (SD)
Training	133 (118)	43 (26-61)	135752	16.0 %	17.0 %	12.7 %	41.9 %	12.4 %	8.3 (12.4)
Validation	132 (121)	43 (28-60)	135880	15.8 %	17.8 %	12.2 %	42.0 %	12.2 %	5.8 (12.1)

AHI data of five training and one validation subject was unavailable

METHODS

Instead of using the two channel EOG L-M1, EOG R-M1 [8-10], we analysed only the difference between the two EOG channels (EOG L-R). The standard EOG placement [1] as indicated in Figure 1 was applied.

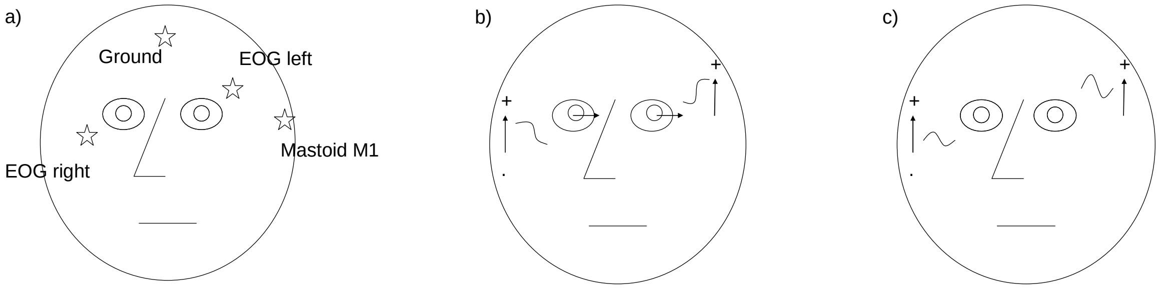

Figure 1 - a) used EOG, mastoid reference and ground electrode location. b) schematic horizontal eye movement c) schematic synchronous slow wave activity

Using overlapped 2 s segments, the peak to peak amplitude in 0.5-6 Hz band and beta power in 18-30 Hz band were calculated. To exclude eye movements and artefacts, the 0.5-6 Hz band amplitude in each segment had to be in a fixed range to indicate SWS or NREM. The number of accepted segments in every 30 s epoch was calculated and there had to be at least 20% accepted segments for SWS and 50% for NREM. Additionally, large amplitude difference (assumed as eye movements, artefacts) in any three adjacent epochs indicated wakefulness or SREM. The use of automatically determined subject specific beta threshold was also studied for offline applications. Beta threshold was based on mean beta values when the amplitude was in the fixed range.

RESULTS

With the use of both channels (including cross-correlation information), the accuracy of slow wave sleep (SWS) detection (Cohen's Kappa) was 93.3% (0.70) [8] and NREM detection 84.4% (0.66). With the same algorithm without cross-correlation, the agreements were for SWS 90.8% (0.58) and for NREM 73.0% (0.40) respectively.

With the use of single-channel algorithm developed in this study (optimal amplitude ranges were 32-50 μV and 11-45 μV), the results were 92.3% (0.64) and 77.2% (0.50). With the three epoch rule (optimal amplitude range 34-70 μV and 9-60 μV with maximum amplitude difference in 90 s window <155 μV and <140 μV), the results improved for SWS to 92.7% (0.65) and for NREM 82.6% (0.61). With the addition of subject specific beta threshold, the final results were 92.7% (0.65) and 83.9% (0.65). Subject specific beta threshold for NREM was < (4 μV^2/Hz + 1.3 (Calculated mean beta in segments with amplitude >9 μV and <60 μV) - 2.5 μV^2/Hz). Results are summarized in Table 2.

Table 1 - Comparison of two channel algorithm results with single channel algorithm results

Binary SWS detection	Agreement	Cohen's Kappa
Two channel	93.3 %	0.70
Single channel	90.8 %	0.58
and amplitude in range	92.3 %	0.64
and with three epoch rule	92.7 %	0.65
and with subject specific beta	92.7 %	0.65
Binary NREM detection		
Two channel	84.3 %	0.66
Single channel	73.8 %	0.40
and amplitude in range	77.2 %	0.50
and with three epoch rule	82.6 %	0.61
and with subject specific beta	83.9 %	0.65

DISCUSSION

Using the difference between EOG L and EOG R means that only three electrodes (including the ground) are needed. All electrodes can be placed in the facial area, enabling the use of self-applicable self-adhesive electrodes. Reducing the channels from two to one reduced the accuracy especially for SWS detection with the current algorithms. For EOG electrode placement there are different recommendations [1, 11, 12]. In this study the standard EOG placement [1] was used.

When testing unobtrusive methods, e.g. actigraphs, the use of automatic analysis of signals recorded by EOG electrodes should be considered as an easy alternative to be used as the reference method. Easily applied EOG could also be used as part of objective ambulatory screening devices. By combining EOG analysis with activity or heart rate analysis is likely to improve the accuracy of automatic analysis [13-15].

CONCLUSION

The importance of developing novel technologies that assess wakefulness and sleep onset for long periods in the actual work environment has been pointed out, for instance, by Wise [16]. Also recently stated by Knutson et al. "Lastly, additional epidemiologic studies, specifically designed to address the role of sleep duration in weight gain and metabolic disturbances, should involve objective measures of sleep duration and quality" [17]. Our method provides possibilities for carrying out these types of studies.

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