Accuracy of automated sleep staging using signals from a single forehead site

Article *in* Sleep · January 2008

CITATIONS
10

READS
60

3 authors, including:

Djordje Popovic
Advanced Brain Monitoring
54 PUBLICATIONS **726** CITATIONS
SEE PROFILE

Daniel J Levendowski
Advanced Brain Monitoring
138 PUBLICATIONS **2,416** CITATIONS
SEE PROFILE

Accuracy of Automated Sleep Staging Using Signals from a Single Forehead Site

Djordje Popovic[1], Indu Ayappa[2], Peter Hauri[3], Daniel Levendowski[1], Vladislav Velimirovic[1], Omar Burschtin[2], David M. Rapoport[2], Philip Westbrook[1]

Advanced Brain Monitoring[1], NYU School of Medicine[2], Mayo Clinic[3]

Introduction: Portable devices used for diagnosing obstructive sleep apnea (OSA) do not monitor or stage sleep, which can lead to underestimation of severity of OSA. We present a validated algorithm for automated sleep staging using a forehead portable recorder (ARES™ Unicorder).

Methods: Automated sleep staging with ARES is accomplished in two steps as shown in Figure 1. The first step differentiates awake from sleep using a combination of signals available from the Level III Unicorder. Further classification of sleep into REM vs. NREM is accomplished from a single bi-polar channel obtained with two electrodes placed at Fp1 and Fp2. A-EEG, A-EOG and A-EMG signals were extracted from the composite frontal signal by time-frequency analysis (Figure 2) and used for staging sleep in 30 second epochs. The software enables visual inspection of the signals and manual editing of automated sleep staging.

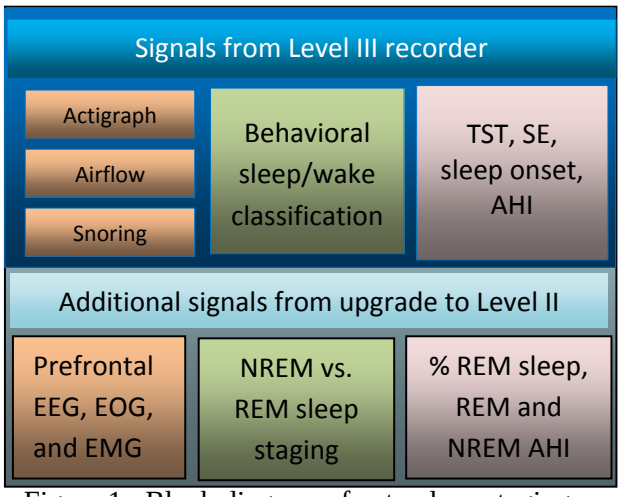

Figure 1: Block diagram of auto-sleep staging routine.

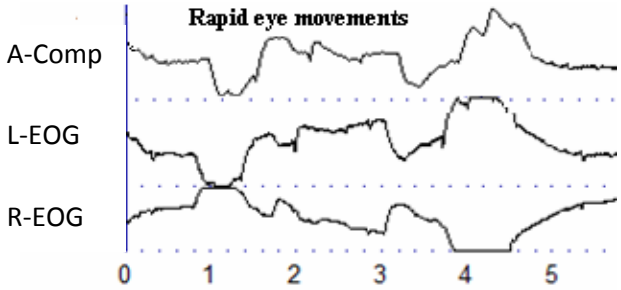

Figure 2.a. 5-sec comparison of composite frontal signal compared to conventional left and right EOG

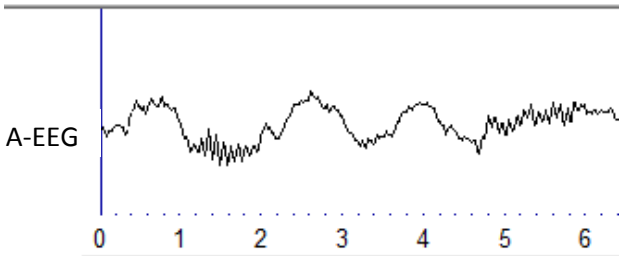

Figure 2.b. Example of the derived EEG signal showing sleep spindles during NREM sleep.

Five healthy subjects (AHI=1.3±1.2) and 19 OSA patients (AHI=16.2±7.1) underwent concurrent overnight recording with PSG and ARES Level II Unicorder. PSG records were scored manually according to the AASM criteria. Once scored using the standard criteria, epochs where sleep disordered breathing triggered arousals were reclassified as sleep. The auto-staging algorithms were applied to the Unicorder signals using modified ARES software. Epoch-by-epoch comparisons yielded sensitivity and positive predictive value (PPV) per class; kappa statistics assessed significance of above-chance agreement. Sleep latency (SL), total sleep time (TST) and sleep efficiency (SE) were analyzed by Bland-Altman plots, and their significance tested by Wilcoxon signed rank test.

Results: Overall agreement between the manual PSG and automated ARES sleep staging was 84% (kappa=0.57) (Tables 1 and 3), which is comparable to the performance of systems for automated staging of PSG records. The behavioral sleep/wake classifier outperforms non-EEG based sleep/wake classifiers described in the literature (overall agreement if NREM and REM sleep are lumped reaches 91%). The REM detector had difficulties in distinguishing between Wake, REM and Stage 1 sleep, which resulted in a low PPV. With visual inspection/editing of periods detects as REM (which took approximately 15 minutes per record), the overall accuracy improved substantially (Tables 2 and 3).

Sleep 2008; 31:332

Table 1: PSG vs. auto-scoring

	Wake	Sleep		Totals
		NREM	REM	
Wake	2,463	620	78	3,161
NREM	609	10,340	319	11,268
REM	176	1,030	1,458	2,664
Totals	3,248	11,990	1,855	17,093

Table 2: PSG vs. auto-scoring with manual edits

	Wake	Sleep		Total
		NREM	REM	
Wake	2,777	433	51	3,261
NREM	405	10,946	239	11,590
REM	66	611	1,565	2,242
Total	3,248	11,990	1,855	17,093

Table 3: Overall accuracy of sleep staging

	Auto-scoring		With manual edits	
	Sensitivity (%)	PPV (%)	Sensitivity (%)	PPV (%)
Wake	76	78	85	86
REM	79	54	84	70
NREM	86	91	91	94

Bland-Altman analysis showed a good agreement between PSG and ARES estimates of sleep latency, total sleep time and sleep efficiency (Figure 3). In all three plots the bias is negligible (SL: -0.25min, p=.132; TST: -5.7min, p=.567; SE: -2%, p=.224) and the variability is (except for SL) within a clinically acceptable range. For example, 70% of the subjects had the difference in TST and SE less than 30 minutes and 5% respectively. The disagreement between ARES and PSG increased with severity of OSA but the relation was not statistically significant (TST: r=0.27, p=0.26; SE: r=0.37, p=0.17).

ARES significantly underestimated SL in five subjects with a long sleep onset phase during which they oscillated between wakefulness and Stage 1 (per PSG) while lying still in bed. In three of five cases, visual inspection of A-EEG would have provided a more precise estimate of SL, had this option been implemented for this analysis.

Conclusion: Automated sleep staging is accurate and can aide in screening and routine follow-ups of patients with OSA. The EEG sensors can be applied with little preparation by the patient in minimal amount of time. The A-EEG and A-EOG signals contain familiar features (i.e., theta and delta waves, sleep spindles, k-complexes, cortical arousals, beta trains, and rapid eye movements) which enables manual editing of the auto-sleep staging. Accurate recognition of awake vs. sleep can be achieved using signals available on the Level III Unicorder.

Support: NIH SBIR Grant 5R44HL068463-05

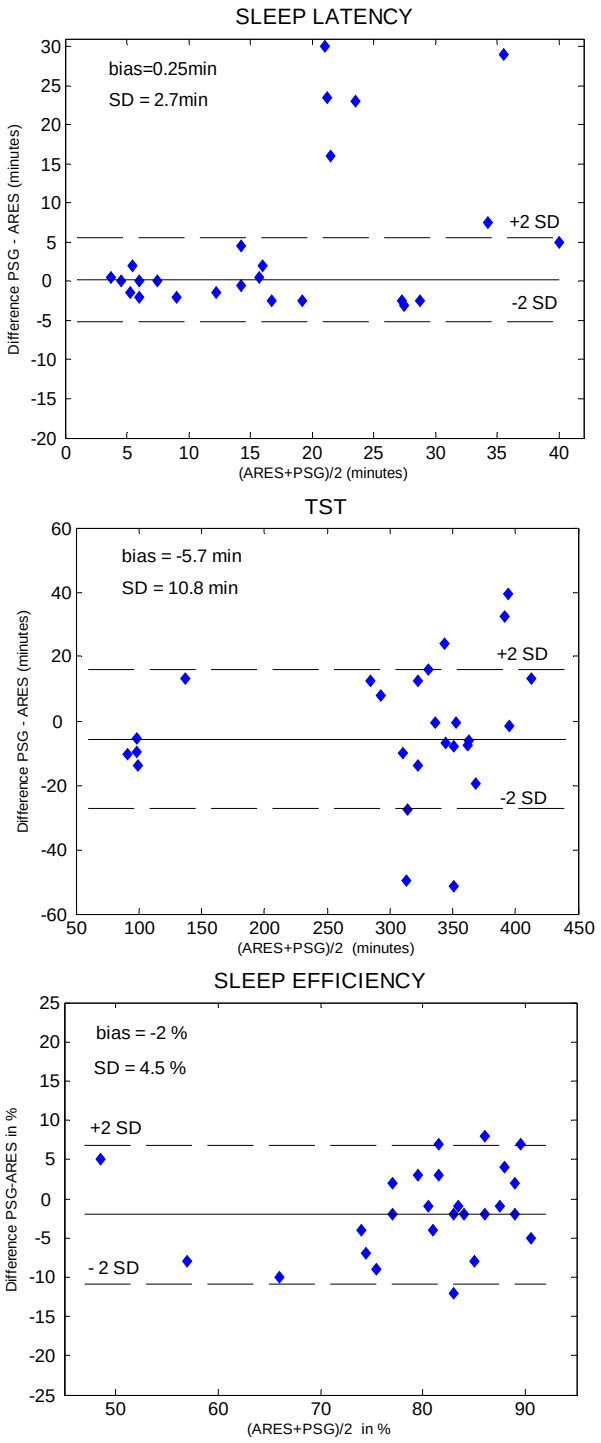

Figure 3. Bland-Altman plots between ARES and PSG for: a. Sleep latency, b. Total sleep time (TST), c. Sleep efficiency.