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Case report

Case comparison of sleep features from ear-EEG and scalp-EEG

I. Zibrandtsen [a,*], P. Kidmose [b], M. Otto [c], J. Ibsen [a], T.W. Kjaer [a]

[a] Neurophysiology Center, Dept. of Neurology, Zealand University Hospital, Roskilde, Denmark
[b] Dept. of Eng., Aarhus University, Aarhus, Denmark
[c] Dept. of Clinical Neurophysiology, Aarhus University Hospital, Aarhus, Denmark

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ABSTRACT

Background: We investigate the potential usability of a novel in-the-ear electroencephalography recording device for sleep staging.
Methods: In one healthy subject we compare simultaneous earelectroencephalography to standard scalp EEG visually and using power spectrograms. Hypnograms independently derived from the records are compared.
Results: We find that alpha activity, K complexes, sleep spindles and slow wave sleep can be visually distinguished using earelectroencephalography. Spectral peaks are shared between the two records. Hypnograms are 90.9% similar.
Conclusion: The results indicate that ear-electroencephalography can be used for sleep staging.

1. Introduction

We present a case trial of sleep stage detection using a novel electroencephalographic (EEG) recording platform placed in the ear (ear-EEG). In current practice, polysomnography (PSG) during hospitalization is the gold standard for diagnosing sleep disorders. However, PSG is also a relatively resource intensive investigation, which limits its use. Home PSG as a less expensive alternative has been investigated finding unsatisfactory recordings in 13 of 48 patients, the main cause of unsatisfactory recordings being loss of EEG data [1]. We envision that ear-EEG fills this gap.

The ear-EEG devices are customized to each user similar to hearing-aid earplugs. This secures tight contact between the recording electrodes and the skin. Ear-EEG as a method has been tested in awake, healthy subjects using a variety of known EEG paradigms [2]. Compared to scalp EEG it maintains a similar signal-to-noise ratio, being less contaminated by electro-muscular artifacts albeit at a cost to signal amplitudes [3]. Correlation analysis between ear-EEG and scalp-EEG shows the highest degree of similarity for scalp electrodes near the temporal region decreasing towards the midline [4]. Thus one can make reasonable assumptions that sleep related phenomena predominantly found near the midline, such as vertex sharp waves, would be less likely to be resolved with ear-EEG.

We present novel data showing identification of sleep specific graphoelements using ear-EEG and demonstrating that ear-EEG performs comparably to standard extracranial recordings for sleep staging purposes.

We envision a number of future applications for small non-intrusive biomedical devices such as ear-EEG for long term monitoring of brain electrophysiology.

2. Methods

The ear-EEG device consists of four recording electrodes embedded in a solid cast made from individually fitted ear impression moulds. We used two ear-EEG devices simultaneously. The recording electrodes are labelled E, I, B and A (Fig. 1).

We recorded simultaneous scalp EEG for comparison. Scalp electrode configuration followed the international 10–20 system with 25 electrodes including inferior temporal chain and EOG. For sleep staging, we used electrode positions F3, C3, O1, F4, C4, O2 contralaterally referenced to M1 and M2 on the mastoid processes as recommended by The American Academy of Sleep Medicine [5]. The study has been approved by the National Board of Health and the Local Ethics Committee.

We explored the ear-EEG channels by varying the choice of active electrode and reference electrode.

The validation setup is 3 fold:

* Corresponding author.
E-mail address: icz@regionsjaelland.dk (I. Zibrandtsen).
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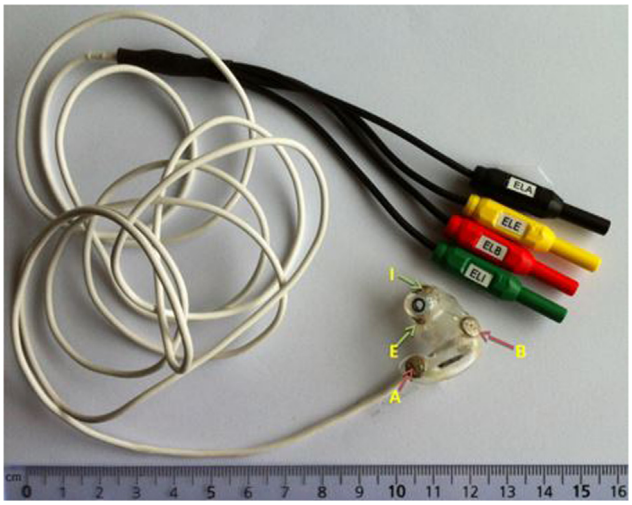

Fig. 1. Ear-EEG prototype. The four recording electrodes, I, E, B and A with connector cables labelled with 3-letter combinations. EL prefix stands for Ear-Left and ER for Ear-Right. The third letter refers to one of the four recording electrodes. Electrode I and E (green arrows) rest in the outer external acoustic meatus. B and A (red arrows) in the concha.

1) "Ear-scalp" referencing ERI (ear-right-I) to M1 to approximate C4-M1 for comparative reasons.
2) In "inter-ear" referencing each ear electrode is referenced to the contralateral homologue electrode, thus ELE (ear-left-E) is referenced to ERE (ear-right-E) and so on.
3) "Intra-ear" referencing uses electrode A referenced to electrode I. Bipolar intra-ear referencing can be expected to yield low voltages given the proximity of the electrodes used.

The subject was a 30 y.o. male with no known medical problems who participated after giving informed consent. Ear-EEG and simultaneous scalp EEG were recorded for 21 h including one night's sleep. The amplifier used was a Nicolet wireless 64-channel system sampling at 256 Hz. Both scalp and ear-EEG electrodes was connected to the same amplifier. For visual inspection of raw data we used proprietary software (Nervus reader v.5.93.424, from Cephalon, Denmark). For frequency analysis of the EEG we calculated power spectrograms in Matlab using the pwelch function. Ear-EEG signals have smaller amplitudes compared to standard EEG. To compensate we displayed scalp signals at 100 μV/cm and ear-EEG signals at 30 μV/cm. This preferentially amplified low frequency noise in ear-EEG channels making parts of the EEG difficult to read due to high-amplitude waveforms. To offset this effect we displayed duplicates of ear-EEG channels with different low cut filters, one at 2.0 Hz and the other at 0.5 Hz. Using the latter is necessary for identification of the slow waves of N3 sleep, but using a low cut at 2.0 Hz improved the readability of parts of the EEG where faster frequencies predominated. We found this approach to be more efficient than dynamically altering the sensitivity throughout the sleep staging process.

Two experienced sleep scorers (one board certified) evaluated seven hours of recording. The recording contained 6 h and 45 min of sleep preceded by 15 min of wakefulness. Both scorers analysed first the standard EEG channels then repeated the process looking exclusively at the intra-ear and inter-ear channels and EOG. Each 30 s period was scored as either wake, N1, N2, N3 or REM. If the scores in an epoch differed it was jointly rescored and consensus reached (less than 10% of periods). Scalp referenced EEG (ERI-M1) was not evaluated to avoid mixing the two types of EEG signal. Submentalis EMG was lost due to electrode failure.

Scorers followed AASM criteria for sleep scoring [5]. This requires an amplitude above 75 μV in stage N3. Since signals had to be magnified by a factor of 5 in order to appear similar this cut-off was reduced to 15 μV in the ear-EEG. The resulting hypnograms for standard and ear EEG were compared.

3. Results

Visual comparison of short EEG epochs revealed striking similarities (Fig. 2). The ear-EEG amplitudes are reduced compared to the scalp channels, but the individual waveforms can be identified and appear similar between scalp and ear EEG channels. To ease the visual comparison of signals we displayed ear-EEG with increased sensitivity. Sensitivity adjustments in the intra-ear channel make the use of low-cut filters at 2 Hz necessary in order to keep some parts of the record visually interpretable. Panel B shows a K-complex. In panel C a sleep spindle is observed. Whereas the K-complex is less distinct in the ear-EEG channels than in standard EEG, the rapid oscillating morphology of the sleep spindle is fairly distinct in the intra-ear channel.

Spectral density estimates of the signals (Fig. 3) in two different states: wakefulness with closed eyes (75 s) and slow wave sleep

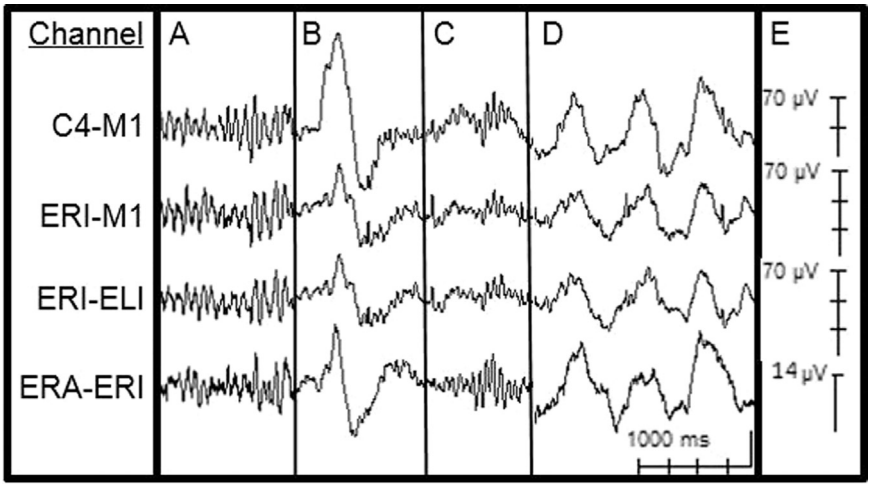

Fig. 2. Combined EEG montage showing scalp-channel C4-M1 (top) with three different ear-EEG channels (below). ERI-ELI is the inter-ear referenced Ear-EEG and ERA-ERI is the intra-ear referenced Ear-EEG channel. A) Resting alpha with closed eyes. B) K-complex. C) Sleep spindle during N2 D) N3, slow wave sleep. Discontinuities in the record are marked with vertical lines. Note use of different sensitivity settings throughout as indicated in panel E. Low cut filtering in the Intra-Ear channel, 2 Hz in A, 1 Hz in B and C, 0.5 Hz in D.