Discriminatory analysis of the EEG in sleep stage 2 prior to and following evoked K-complexes

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ABSTRACT:

Contradictory results of several authors which investigated the EEG immediately before and after stimulus presentation in order to evoke K-complexes (KC) during sleep have lead us to the question if methodological extensions in the biosignal analysis can clarify the picture. We applied several methods of parametric and non-parametric power spectral density estimation, two types of wavelet filter banks and a recently introduced phase space method, namely the Delay Vector Variance. In the next step we utilized supervised learning algorithms, especially Support Vector Machines, in order to find optimal discriminant functions which separate all samples of KC elicitation against all of non-elicitation. Parameters of all steps were empirically optimized in a multiple hold-out cross validation scheme. Results show no differences in the EEG prior to the stimuli and in intervals following the evoked responses. Only in the time interval of 2 sec immediately after stimulus, we were able to detect EEG changes which means nothing else than solving the KC detection task. Therefore, we can not give further support to the hypothesis of brain microstates in sleep which control the elicitability of KC and which influence the arousal system.

INTRODUCTION:

KCs are multimodally induced evoked potentials during non-REM sleep lasting between 0.5 and 1.0 sec. Their potential field is widely spread over frontal and central areas and shows largest amplitudes among all sleep EEG patterns.

Their functional significance is still under discussion. On the one hand, they are indicative for non-REM sleep and therefore, for a brain state in which arousals are less likely to occur. Possibly, a KC protects the sleeper from awakening. On the other hand, any response to a stimulus is indicative of some form of an arousal process.

Peculiarly, at one time KCs are elicitable by a stimulus and when the same stimulus is later presented again, KCs are no longer elicitable. Pál et al. [1] hypothesized that the elicitability of KC corresponds to "finely graded microstates" of the arousal system.

Such microstates, if they exist, might influence the EEG. The characteristics of the EEG prior to the stimulus should to some degree depend on the observation if a KC is elicited or not. Bastien et al. [2] investigated this question utilizing power spectral density estimation and performing ANOVA. They reported no significant EEG changes when a KC is elicited compared to non-elicitation. In this paper we want to address the question if an extended biosignal analysis framework can reach higher sensitivity and can detect possibly smaller, but characteristic EEG changes.

Another question concerns the change of brain microstates caused by KC elicitation. Following the hypothesis of many authors that KC are part of arousal reactions, one should detect EEG changes post stimulus. Bastien et al. [2] reported that this is not generally the case. After KC elicitation no significant changes were detected. Otherwise, after non-elicitation of KC they found a significant overall increase in theta, alpha, sigma, and beta frequency bands. This is in some conflict to other findings [3] reporting on small, but significant changes lasting between 10 and 15 sec post stimulus.

We again ask if an extended biosignal analysis, overcoming some quantitative and qualitative limitations, can detect generalizable differences in post stimulus EEG depending on the elicitability of KC.

MATERIAL:

24 healthy volunteers (13 women, 11 men; mean age: 25.3 years, SD 7.2, range 18-47) spent a single night in the sleep laboratory. Pairs of tone clicks [65 dB(A)] with an inter-stimulus-interval of 3 sec were presented every 20 to 30 sec randomly (Fig. 1). Compared to single tones, tone pairs can give us deeper insight to factors influencing the elicitability, like the short and long inter-stimulus-interval condition [4].

METHODS:

Sleep stages were scored visually by an expert. Only in stage 2 four elicitability responses (00, 10, 01, 11) were classified regarding occurrence (1) or non-occurrence (0) of KC on the first and second stimuli respectively. The decision if a KC occurred in the EEG was again done by an expert, because

KC have an extremely variable morphology. The elicitability of these four responses differed largely between subjects [5].
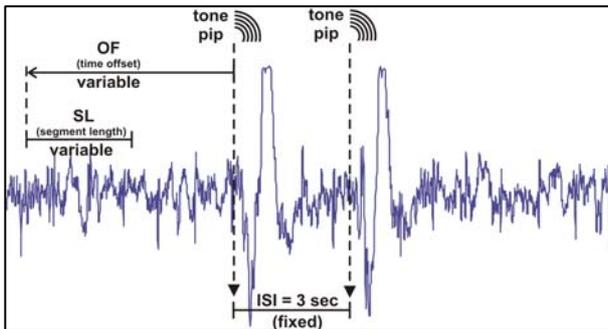
Figure 1: One example of KCs elicited on both tone pips („11" response). Pre- and post-stimulus intervals of EEG were segmented using variable time offset and variable segment length.

EEG segments with variable length and variable time offset to the stimulus (Fig. 1) were analyzed utilizing the following transformations:

- spectral domain: maximum entropy method, multi-taper method, periodogram
- wavelet domain: wavelet decomposition tree, wavelet packet decomposition tree
- state space: delay vector variance (DVV) [6]

Discriminant analysis was performed by several types of neural networks [5] and Support Vector Machines (SVM). Here, we only report on results of SVM because they outperformed all other methods.

RESULTS:
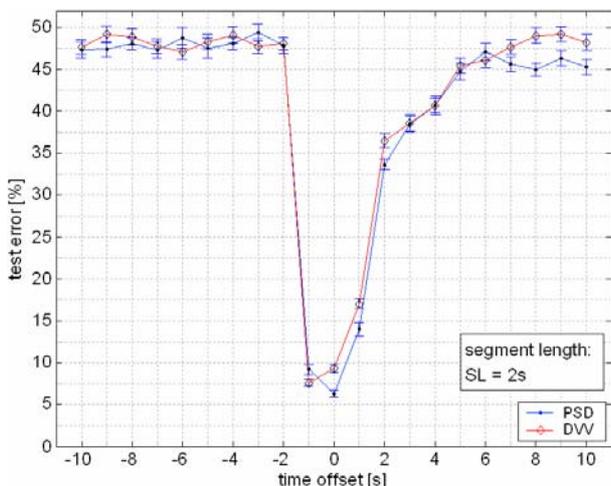
Figure 2: Mean and standard deviation of test errors of SVMs versus the segmentation parameter OF (offset). Results are nearly the same for power spectral density (PSD) and delay vector variance (DVV) features.

Test set errors of the SVM were computed according to the multiple hold-out cross validation para-digm. The time offset (OF) turned out to be the most influencing parameter (Fig. 2). Values lower or equal to -2 sec result in very high test errors, almost as high as the 50% error of random choice. Values of $-1 \leq OF \leq 0$ and $2 \leq OF \leq 3$ lead to EEG segments containing also KC responses on the first and the second stimulus, respectively. Here, low errors are achievable. Also immediately after KC responses (OF = 1, OF = 4) lower errors are achievable. But if the segment is shifted more than 1 sec away of KC responses (OF $\geq$ 5 sec) high errors result. This picture is unchanged if we take DVV instead of periodogram features (Fig.2), and also if we take wavelet domain features. Equivalent results arise for other segment length.

DISCUSSION:

Results demonstrate on a relatively large data set, compared to other authors, and utilizing several techniques of signal transformation that no EEG changes prior to stimulus are detectable. The hypothesis of microstates controlling the KC elicitability cannot be supported, but also meets no refusal, because the EEG is dominated by cortical activity and obscures thalamic and sub-thalamic activities.
EEG changes lasting up to 10 – 15 sec post stimulus [3] can not be confirmed by our methodology. Immediately after KC responses EEG changes are detectable which should be a matter of concern for future research.

REFERENZEN:

[1] Pál I, Simon G, Halász P. K-Complex formation as a function of the ongoing EEG activity. In Koella et al. (eds.), Sleep'84, 1985.

[2] Bastien C, Ladouceur C, Campbell KB. EEG characteristic prior to and following the evoked K-complex. Canad J Exp Psych, 54 (2000) 4, 255-265.

[3] Halász P, Ujszászi J. Spectral features of evoked micro-arousals. In Terzano et al. (eds.), Phasic events and dynamic organization of sleep. Raven Press, New York, 1991.

[4] Kurella B, Heitmann A, Golz M, Dormann U. The probability of eliciting K-complexes during sleep; J Sleep Res 1 (1992) Suppl. 1, 322.

[5] Kurella B, Sommer D, Golz M. A Neural Network based analysis of the electroencephalogram in sleep stage 2 concerning the elicitability of evoked K-complexes. Sleep Medicine 6 (2005) Suppl. 2, S102-S103.

[6] Gautama T, Mandic D, Van Hulle M. The Delay Vector Variance Method for Detecting Determinism and Nonlinearity in Time Series", Physica D 190 (2004) 167-176.