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One-class classification of temporal EEG patterns for K-complex extraction*

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***Abstract*— The purpose of this study was to detect one of the constituent brain waveforms in electroencephalography (EEG), the K-complex (KC). The role and significance of the KC include its engagement in information processing, sleep protection, and memory consolidation [1]. The method applies a two-step methodology in which first all the candidate KC waves are extracted based on fundamental morphological features imitating visual criteria. Subsequently each candidate wave is classified as KC or outlier according to its similarity to a set of different patterns (clusters) of annotated KCs. The different clusters are constructed by applying graph partitioning on the training set based on spectral clustering and exhibit temporal similarities in both signal and frequency content. The method was applied in whole-night sleep activity recorded using multiple EEG electrodes. Cross-validation was performed against visual scoring of singular generalized KCs during all sleep cycles and showed high sensitivity in KC detection.**

I. INTRODUCTION

EEG has been widely used as a diagnostic tool in sleep studies since it provides the means for analysis of sleep macrostructure which includes the identification of the different sleep stages (referred to as sleep scoring [2]) and microstructure which refers to the identification of the conspicuous and quite repeated individual brain waves and rhythms. One of these waveforms is the K-complex (KC), which was first described by Loomis et al. [3]. KCs have been suggested to protect sleep and also to provide gating functions in idiopathic generalized epilepsies or sleep disorders [1]. They happen mainly during the non-rapid eye movements (NREM) sleep stage and are one of the hallmarks of sleep stage 2 [2]. They are also considered precursors of delta waves and their frequency of appearance in EEG is one of the key features for sleep scoring. Due to the extreme size of all night sleep EEG, visual recognition of KCs is almost prohibitive in a routine setting, thus the necessity of an automatic detection method becomes apparent.

Apart from labor-intensive, visual marking is also highly scorer dependent mainly due to high intra- and inter-subject variability of KC characteristics and variation in human perception. KCs have been defined by standardized scoring rules [2][4] based on the visual appearance of the signal. The American Association of Sleep Medicine (AASM) gives the following definition: "a K complex is a well delineated negative sharp wave immediately followed by a positive component standing out from the background EEG with total duration ≥0.5 sec. It is usually maximal in amplitude over the frontal regions" [4]. Due to the close similarity of KCs and other waves, such as delta waves, and the high variation of KC appearance (large range of amplitudes and durations), the development of a reliable detection method is not easy.

Several pattern analysis algorithms have been reported in the literature for automated extraction of KCs. A continuous density hidden Markov model was used in [5] to model the background EEG and the phases of the KC, while in [6] the EEG wave patterns were modeled as the sum of two sinusoidal curves with piece-wise linear amplitude. Hjorth parameters activity and complexity and fuzzy decision making were used to create a single channel detector [7]. Also joint linear filtering in time and time-frequency domains was introduced in [8] for classification of KCs and delta waves. All these methods have been applied for classification of isolated waveforms, such as segments of KCs or non-KCs, delta waves and background, and have not been assessed for detection of KCs in whole night EEG.

Devuyst et al. [9] proposed a KC detection algorithm based on features reflecting visual criteria of scoring and the use of likelihood thresholds. The likelihood thresholds were determined by the distribution of the features as calculated from a training set of KCs. Although the results of the method are promising (details are provided in the discussion section), detection methods that apply thresholding of features with experimentally defined thresholds on the dataset used for testing, may have poor performance when applied on different datasets derived from multiple subjects or institutes due to lack of cross-validation and overfitting. Erdamar et al. [10] suggested a detection method based on Teager Energy Operator and wavelet decomposition. The detection algorithm achieved high sensitivity with low false positive (FP) rate but was tested only on NREM stage 2 epochs from a single subject. Likewise, Saccomandi et al. [11] proposed a two-step algorithm based on multiple channels for the detection of transient events such as KCs, delta waves and cycling alternating patterns in sleep stage 2 and 3 occurring in the descending branch of the 2nd sleep

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