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Regional scalp EEG slow-wave synchronization during sleep cyclic alternating pattern A1 subtypes

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Abstract

The levels of EEG synchronization, in the 0.25–2.5 Hz band, during the A1 subtypes of the sleep "*cyclic alternating pattern*" (CAP) were measured in five healthy subjects by means of the synchronization likelihood (SL) algorithm. SL was measured for seven electrode pairs (F4-F3, C4-C3, P4-P3 for the analysis of interhemispheric SL and F4-C4, C4-P4, F3-C3, and C3-P3, for the analysis of intrahemispheric SL). During the A1 CAP subtypes, SL tended to be highest between pairs of electrodes situated over different hemispheres; in particular, SL obtained from F4-F3 was the highest, followed by that of P4-P3. These results indicate that the transient high level of synchronization in the slow-wave EEG range, during the sleep A1 CAP subtypes, is a phenomenon involving mostly the anterior parts of the brain and is probably based on interhemispheric interactions, possibly mediated by transcallosal connections.

Keywords: Sleep; Synchronization likelihood; Detrended fluctuation analysis; Cyclic alternating pattern; Slow-wave activity; Slow oscillation; EEG; Human

Sleep phasic EEG events show during nonREM (NREM) stages a peculiar structure which has also been described as "cyclic alternating pattern" or CAP [30,35]. According to Terzano et al. [32] CAP is a periodic EEG activity of NREM sleep characterized by repeated spontaneous sequences of transient events (phase A) which clearly breaks away from the background rhythm of the ongoing sleep stage, with an abrupt frequency/amplitude variation, recurring at intervals up to 1 min long. The return to background activity identifies the interval that separates the repetitive elements (phase B).

CAP sequences are defined as three or more A phases separated from each other by no more than 60 s. The percentage of NREM occupied by CAP sequences defines the CAP rate. All the remaining NREM sleep, not occupied by CAP sequences is called NCAP.

CAP A phases have been subdivided into three subtypes: [32] A1 – A phases with synchronized EEG patterns (intermittent alpha rhythm in stage 1; sequences of K-complexes or delta bursts in the other NREM stages), associated with mild or trivial polygraphic variations; A2 – A phases with desynchronized EEG patterns preceded by or mixed with slow high-voltage waves (K-complexes with alpha and beta activities, k-alpha, arousals with slow wave synchronization), linked with a moderate increase of muscle tone and/or cardiorespiratory rate; A3 – A phases with desynchronized EEG patterns alone (transient activation phases or arousals) or exceeding 2/3 of the phase A length, and coupled with a remarkable enhancement of muscle tone and/or cardiorespiratory rate. The most common subtype of CAP is the A1, which accounts for up to 90% of all CAP A phases during normal sleep, occurring approximately 200–400 times per night [5,6,19]. Fig. 1 shows an example of CAP period, formed by A1 subtypes, in NREM sleep. CAP A1 subtype power spectrum is characterized by a predominant peak in the frequency range of 0.25–2.5 Hz; [8,11] these frequencies, during CAP events, are likely to be generated at the level of the frontal areas of the brain, as we have shown [11] by means of the low-resolution brain electromagnetic tomography method [20,21].

Despite the fact that EEG aspects of CAP [30,33,35] and its clinical correlations [17,18,31,36] have been extensively studied, its underlying neurophysiological aspects are still unclear. In

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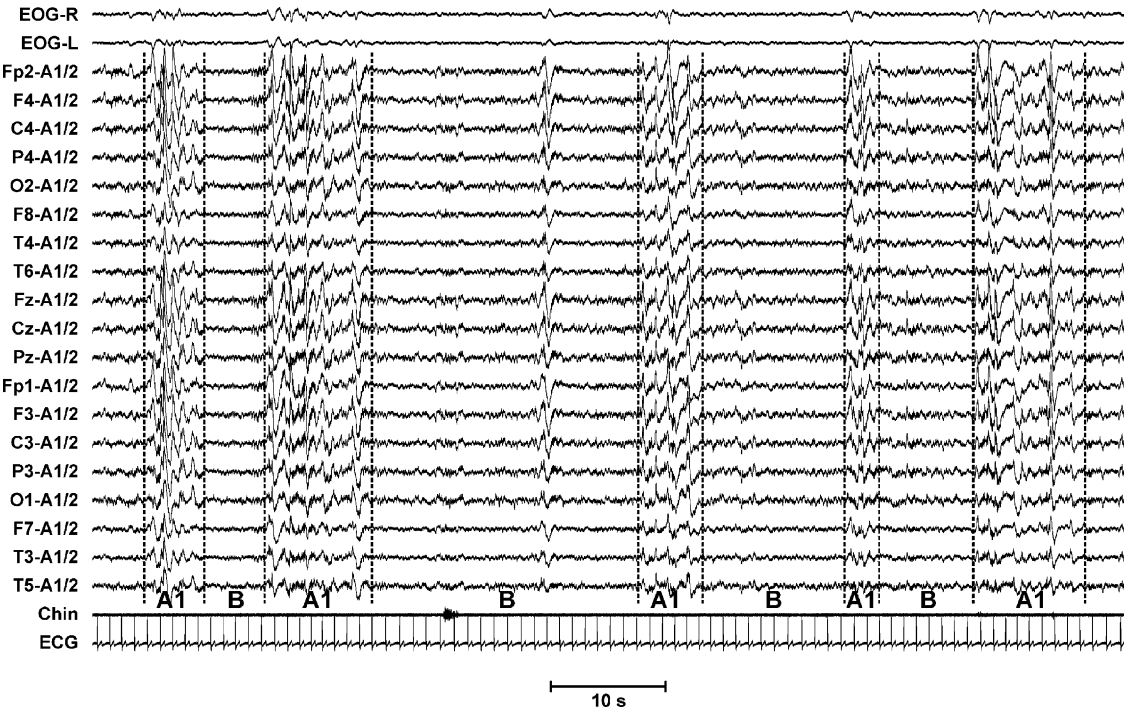

Fig. 1. Example of CAP period in NREM sleep.

particular, sleep EEG shows nonlinear structure only for briefs periods during NREM sleep [23] which are strictly correlated with the occurrence of delta waves [29] of CAP subtypes A1, in particular [12]; we have suggested that, probably, nonlinearity in the EEG corresponds to a particular brain state during which synchronizing mechanisms are able to lower brain complexity [12].

The fluctuations in EEG synchronization during sleep might be one of the important factors playing a role in the recently hypothesized importance of EEG slow waves during sleep for cognitive processing [14,15,38] and the role of sleep slow-wave activity in the consolidation of memory and learning processes is the subject of different studies in animals and humans [27]. Functional relationships between different EEG derivations during sleep have been explored mostly by means of the coherence with unclear results [1,2,7,10].

Recently, we have analyzed EEG slow-wave spatial synchronization during sleep by means of the synchronization likelihood (SL) algorithm [26], a general measure of the dynamical interdependencies between a time series (EEG channel) and one or more other time series, in order to test the hypothesis that the occurrence of CAP subtypes A1 during sleep induces high levels of synchronization in the slow-wave sleep EEG activity. The results of that study [13] indicate a different role for each sleep stage and CAP condition in the EEG slow-wave synchronization processes of sleep which show a complex time structure correlated with its neurophysiological mechanisms. We only considered the global synchronization level, expressed as SL averaged over all possible electrode pairs; however, similarly to the EEG power spectrum [11], also slow-wave SL might show regional differences. These differences might be of crucial importance for the understanding of the functional meaning of EEG synchronization mechanisms during sleep. For this reason, the aim of this study was to analyze the eventual regional differences in slow-wave EEG synchronization during the A1 subtypes of CAP which we have already shown to be accompanied by the highest levels of global synchronization during sleep [13], with the hypothesis that the synchronization between the anterior (frontal) areas of the scalp is higher than the synchronization between these areas and other scalp locations.

Five healthy subjects (4 females and 1 male, aged 20–32 years) were included in this study. These subjects are the same we included in our previous study on SL, mentioned above [13]. They all had regular life routine, did not smoke and did not take any alcohol drink in the 3 days preceding the study. The Oasi Institute ethics committee approved the study and all recordings were performed with the informed and overt consent of each participant, in line with the Declaration of Helsinki.

All subjects underwent one overnight polysomnographic recording, after one adaptation night, which comprised EOG (2 channels), EEG (19 channels, Ag/AgCl electrodes placed according to the 10–20 International System referred to linked earlobes: Fp2, F4, C4, P4, O2, F8, T4, T6, Fz, Cz, Pz, Fp1, F3, C3, P3, O1, F7, T3, T5), EMG of the submentalis muscle and ECG. Recordings were carried out using a Brain Quick Micromed System 98 recording machine and signals were sampled at 256 Hz and stored on hard disk for further analysis. EEG signals, in particular, were digitally band-pass filtered at 0.1–120 Hz, 12-bit A/D precision.

Sleep stages were scored by the first author following standard criteria [22] on 30-s epochs. Subsequently, each CAP A phase was detected in each recording (on the C3/A2 or C4/A1 derivation), during NREM sleep, and classified into three subtypes (A1, A2, and A3), according to the rules defined by