

Spectral Features of EEG Alpha Activity in Human REM Sleep: Two Variants with Different Functional Roles?

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Abstract: Evidence suggests that an important contribution of spectral power in the alpha range is characteristic of human REM sleep. This contribution is, in part, due to the appearance of well-defined bursts of alpha activity not associated with arousals during both tonic and phasic REM fragments. The present study aims at determining if the REM-alpha bursts constitute a different alpha variant from the REM background alpha activity. Since previous findings showed a selective suppression of background alpha activity over occipital regions during phasic REM fragments and, on the other hand, the density of alpha bursts seem to be independent of the presence or absence of rapid eye movements, one expects to find the same spectral power contribution of alpha bursts in tonic and phasic REM fragments.

The results indicated that REM-alpha bursts showed a similar power contribution and topographic distribution (maximum energy over occipital regions) both in tonic and phasic REM fragments. This suggests that two variants of alpha activity with different functional roles are present during the human REM sleep: i) background alpha activity, modulated over occipital regions by the presence of rapid eye movements, which may be an electrophysiological correlate of the visual dream contents; and ii) REM-alpha bursts, independent of the presence of rapid eye movements, which could be facilitating the connection between the dreaming brain and the external world, working as a micro-arousal in this brain state.

Key words: Alpha activity; REM sleep; REM-alpha bursts; dreams; visual imagery; micro-arousals; humans.

INTRODUCTION

HUMAN RAPID EYE MOVEMENT (REM) SLEEP SHOWS AN IMPORTANT SPECTRAL POWER CONTRIBUTION IN THE ALPHA RANGE (7.5-12.5 HZ). Recently, this has been proposed to be mainly caused by the spontaneous presence of transient bursts of alpha activity during tonic and phasic REM fragments¹ (Figure 1). These alpha bursts are clearly detectable by visual inspection of the REM sleep electroencephalogram (EEG), and they do not comply with two of the essential criteria for scoring arousals during REM sleep since their duration is shorter than three seconds and are not associated with concurrent increases in the amplitude of submental electromyographic activity².

Alpha activity suppression over specific brain areas has been typically interpreted as an activation index of those cortical regions involved in the information processing of an specific sensory modality, both in active wakefulness³⁻⁵ and mental imagery.^{6,7} More surprisingly, Hong et al.⁸ obtained an alpha power attenuation over Broca's and

Wernicke's area during REM sleep when the reported dreams were composed predominantly of expressive and receptive language, respectively. In addition to this, there is experimental evidence that the rapid eye movement density is strongly associated with visual imagery in dreaming,⁹ as well as that the same cortical areas are involved in eye movements generated during REM sleep and wakefulness.¹⁰ On the bases of these findings, a study was designed to explore the spectral contribution of alpha activity over occipital brain regions during tonic (without rapid oculomotor activity) and phasic REM fragments (with prominent bursts of rapid eye movements). The results obtained in that work revealed that the spectral power of REM background alpha activity decreased selectively over occipital areas in phasic, in comparison with tonic, fragments. This finding suggested that occipital regions are much more active when the oculomotor activity is present, which may be due to the intense and complex mental imagery generated in these brain periods.¹¹ Taken together, these studies support the hypothesis that alpha activity shows a selective power suppression over cortical areas specific of a sensory modality, not only in wakefulness but also in REM sleep, and in the latter brain state such suppression might be dependent on the dream contents.

However, there is no information available about the spectral power contribution of the above-mentioned REM-alpha bursts over specific cortical areas during tonic or pha-

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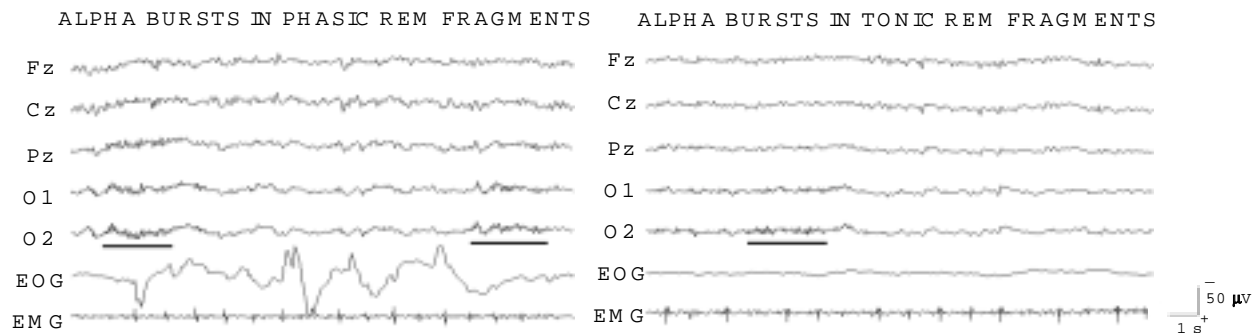


Figure 1—REM-alpha bursts clearly defined (solid black lines) and non-associated with body movements and/or EEG arousals in phasic (left) and tonic (right) REM sleep fragments.

phasic fragments. A previous study showed that this sleep phasic event appears with the same density in tonic and phasic REM fragments.¹ Therefore, it does not seem hazardous to hypothesize that alpha-burst spectral power is independent of the presence or absence of rapid oculomotor activity in human REM sleep.

The purpose of the present work was to explore whether the REM-alpha bursts show spectral power attenuation over specific brain regions associated with the simultaneous presence of prominent rapid eye movements. A power suppression of alpha bursts over occipital areas during phasic fragments would support the hypothesis that REM oculomotor activity is able to modulate any variant of alpha activity present in visual cortical areas, whereas a similar amount of energy over these areas in tonic and phasic fragments would be consistent with the proposal that there exist two variants of alpha activity during REM sleep possibly playing different functional roles.

METHODS

Subjects

Ten healthy subjects (19-25 years) were selected to participate in this study. Each one was evaluated by interview and questionnaires and selected when no medical and/or psychological disorders were present. They gave informed consent after a full explanation of the experimental protocol. All subjects slept for two nights (first for adaptation) in the sleep laboratory. Pre- and post-sleep questionnaires were used to screen for events that might have influenced the sleep quality.

Recording Protocol

Polysomnographic recordings included 28 EEG derivations (Fp1, Fp2, F1, F2, F3, F4, F7, F8, Fz, pF1, pF2, pF3, pF4, pFz, C1, C2, C3, C4, Cz, P3, P4, Pz, T3, T4, T5, T6, O1, and O2) with a linked mastoid reference, vertical and horizontal electrooculogram (EOG), and submental electromyography (EMG). All-night data were recorded with a Medid 4 system (Neuronic). EEG and EOG filters were

set between 0.5 and 40 Hz (-3 dB points of a 24 dB/octave roll-off curve), and EMG between 5 and 70 Hz. In all cases, electrode impedances were kept below 5 Kohms. Electrophysiological measurements were digitized with a sampling rate of 200 Hz (12-bit resolution). Three different sleep technologists performed visual sleep scoring according to standard criteria.¹² The experimental night (second night) was monitored by video synchronized with the EEG sleep recording in order to manually reject those EEG epochs with alpha activity caused by transient body movements and/or EEG arousals. Only those spontaneous alpha activity bursts inherent to REM sleep stage were included in the subsequent analyses.

EEG Analysis

EEG segments (2.56s) containing REM-alpha bursts were selected by three experienced sleep technologists considering all REM periods contained in the experimental night, and using the following criteria: i) Presence of a clearly defined alpha burst (7.5-12.5 Hz) with an amplitude above 20 μ V in any scalp region; ii) absence of a simultaneous increase in the EMG amplitude; iii) total absence of sleep spindles over fronto-parietal regions; and iv) the appearance of clear electrophysiological REM signs at least one minute before, and on continuing in REM stage one minute after the selected EEG segment.

Total number of EEG segments containing REM-alpha bursts through the night varied between subjects (mean=40.7 bursts; S.D.=10.2). They were classified in those appearing simultaneously with rapid oculomotor activity (phasic) and without rapid eye movements (tonic). Variability between subjects ranged from 12 to 28 (mean=18.9; S.D.=5.6) and from 11 to 32 (mean=21.8; S.D.=5.6) REM-alpha bursts in tonic and phasic fragments, respectively. All subjects participating in the present study showed REM-alpha bursts in each REM period through the night.

An FFT analysis was carried out on each EEG segment (512 samples) previously selected, the power spectrum being computed with a resolution of 0.39 Hz. Absolute

power values (μV^2) were obtained via a broad band spectral model in the range of alpha activity (7.5-12.5 Hz) for tonic and phasic REM EEG segments, separately.

Frequency brain maps were designed by using a linear interpolation algorithm from the three nearest electrodes. Each brain map was built with the averaged absolute power values from 10 subjects.

Statistical Analysis

Absolute power data of alpha band were analyzed using a two-way analysis of variance (ANOVA) with repeated measurements (REM period x scalp area). This analysis was carried out to study the spectral contribution and topographic distribution (frontal, central, parietal, and occipital) of REM-alpha bursts occurring within phasic and tonic REM fragments, separately. Electrodes of the same cortical region were collapsed in order to obtain a representative power value from each scalp area.¹³ Spectral power data were transformed to logarithm scale for using parametric statistic with more reliability.

RESULTS

No significant difference was observed to compare spectral power of REM-alpha bursts in tonic (desynchronized EEG without ocular activity) and phasic (with prominent rapid ocular movements) REM fragments. A significant main effect of the scalp area factor [$F(3,27)=51.62$; $p<0.0001$, $\epsilon=0.43$] suggested that the alpha bursts are not homogeneously distributed over the scalp. Tukey post-hoc tests indicated that the spectral power was significantly higher over occipital regions [$F(3,36)=12.07$; $p<0.0001$]. No REM period x scalp area interaction was obtained.

Topographic distributions of REM-alpha bursts in tonic and phasic REM fragments are displayed in Figure 2 (upper part). Brain maps of the REM background alpha activity extracted from tonic and phasic REM are represented in the lower part of the same figure. One can observe that REM-alpha bursts showed a similar topographic distribution both in tonic and phasic fragments, with a maximum power over occipital regions. In contrast, REM background alpha activity displayed the highest spectral power over occipital regions in tonic REM fragments, and an alpha suppression over visual areas simultaneously with the presence of

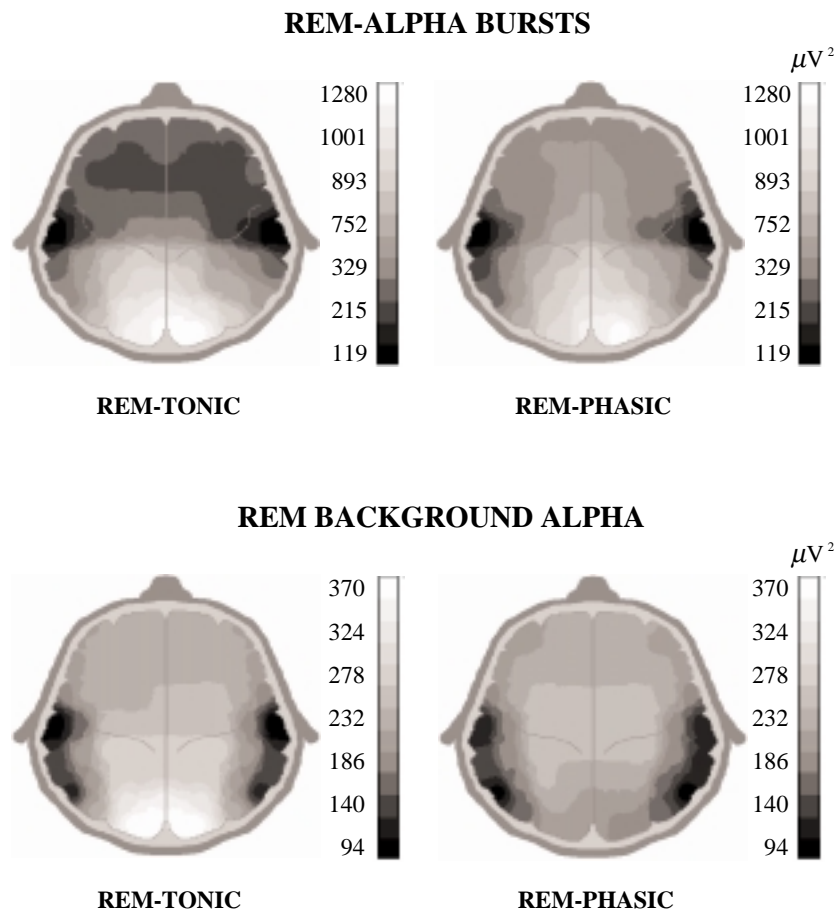


Figure 2—Topographic distribution of REM-alpha bursts (upper part) and REM background alpha activity (lower part) in tonic (left maps) and phasic (right maps) REM fragments, separately. A similar topographic distribution of REM-alpha bursts in both REM fragments contrasts with the suppression of REM background alpha power over occipital regions simultaneously with the presence of prominent rapid eye movements. μV^2 : spectral power unit.

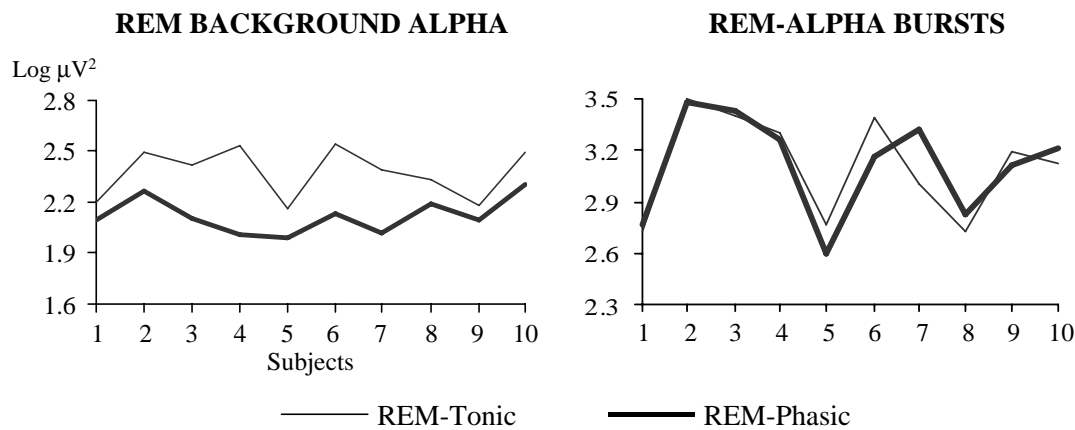


Figure 3—Individual contribution of occipital alpha power in tonic and phasic REM fragments for each variant of alpha activity.

prominent rapid eye movements.¹¹

The individual spectral power contribution over occipital areas in the range of alpha activity was represented in tonic and phasic REM fragments for background alpha activity and REM-alpha bursts, separately (Figure 3). A different occipital region behavior in both alpha variants is apparent when rapid oculomotor activity periods were compared with REM tonic fragments.

DISCUSSION

Results obtained in the present study provide evidence that short alpha bursts appearing spontaneously during REM sleep show the same power contribution and topographic distribution when they appear in tonic and phasic REM fragments. These results, together with the background alpha suppression previously observed over occipital areas during phasic fragments,¹¹ suggest that two variants of alpha activity with different functional roles coexist during human REM sleep.

Previous studies have reported a power attenuation of REM-alpha activity over selective brain regions according to the dream content,⁸ and its usefulness to discriminate pre-lucid (higher power) from non-lucid and lucid dreams.¹⁴ However, no effort has been made to separate the power contribution of REM-alpha bursts from that of REM background alpha activity. Since spectral analysis technique does not allow one to dissociate contributions of background alpha activity and REM-alpha bursts, the question arises whether those electrophysiological changes that might be associated with visual imagery contained in dreams are evidenced indiscriminately in both alpha variants during REM sleep. The present results suggest that alpha burst pattern should be functionally different from REM background alpha activity studied by Cantero et al.,¹¹ since only the latter variant seems to be affected by the appearance of rapid oculomotor activity typical of this sleep stage (Figure 2 and 3). Furthermore, this finding adds further support to the proposal that visual imagery during

REM sleep uses the same neural systems as in wakefulness,¹⁰ and suggests that the background alpha suppression over occipital areas during phasic REM fragments may be an electrophysiological correlate of the visual dreams in human subjects.

The fact that spontaneous alpha bursts were systematically present in all subjects and with the same density in tonic and phasic REM fragments indicates, on the one hand, that they may constitute a phasic event characteristic of human REM sleep,¹ and on the other, that this alpha variant is independent of the presence or absence of rapid eye movements. Alpha activity during stage 2 of sleep, usually accompanied by K-complexes, has been interpreted as a typical micro-arousal during NREM sleep.¹⁵ REM-alpha bursts could be also considered as a micro-arousal which might be facilitating the dreaming brain the connection with the external world. This would explain the relatively high level of information processing during this sleep state,¹⁶⁻¹⁸ and the possibility to incorporate external stimuli in the dream contents.^{19,20}

Additionally, REM-alpha bursts have shown different electrophysiological features as compared with alpha rhythm of relaxed wakefulness, as well as with alpha activity present in the drowsiness period at sleep onset. Findings obtained in several previous works pointed out that the spectral structure differed between the different alpha activities.²¹ A significant decrease in fronto-occipital and inter-frontal coherence values in the alpha range was also observed with the falling of the arousal level,²² as well as a different duration and number of brain spatial microstates contained in alpha activity depending on the brain state.²³ These results support the hypothesis that REM-alpha bursts index different brain processes from those associated with other alpha activities in wakefulness and light drowsiness, and that most likely their cortical generation mechanisms are not exactly identical.²⁴

In conclusion, two variants of alpha activity with different functional roles seem to coexist during human REM

sleep: one of them, background responsive alpha—blocked over occipital regions when rapid eye movements are present—which may be an electrophysiological correlate of the visual imagery in dreams;¹¹ the other, well-defined bursts of spontaneous alpha activity showing the same spectral features in tonic and phasic REM fragments. The systematic appearance of these alpha bursts in each REM period through the night could be facilitating the connection between the dreaming brain and the external world, working as a micro-arousal during this brain state.

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