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Alpha-band power in the left frontal cortex discriminates the execution of fixed stimulus during saccadic eye movement

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HIGHLIGHTS

- ► Alpha band in the left frontal cortex discriminates the execution of a SEM task.
- ► The random condition requires a greater demand for attention.
- ► The post-stimulus moment is related to greater attention control.

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ABSTRACT

Introduction: The saccadic paradigm has been used to investigate specific cortical networks involving attention. The behavioral and electrophysiological investigations of the SEM contribute significantly to the understanding of attentive patterns presented of neurological and psychiatric disorders and sports performance. *Objective*: The current study aimed to investigate absolute alpha power changes in sensorimotor brain regions and the frontal eye fields during the execution of a saccadic task. *Methods*: Twelve healthy volunteers (mean age: 26.25; *SD*: ±4.13) performed a saccadic task while the electroencephalographic signal was simultaneously recorded for the cerebral cortex electrodes. The participants were instructed to follow the LEDs with their eyes, being submitted to two different task conditions: a fixed pattern versus a random pattern. *Results*: We found a moment main effect for the C3, C4, F3 and F4 electrodes and a condition main effect for the F3 electrode. We also found interaction between factor conditions and frontal electrodes. *Conclusions*: We conclude that absolute alpha power in the left frontal cortex discriminates the execution of the two stimulus presentation patterns during SEM.

1. Introduction

Saccadic eye movement (SEM) induces specific changes in cortical electrical activity and can be indentified through quantitative eletroencephalography (qEEG). Previous studies investigated the relationship of the attention process and SEM using qEEG

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[2,8,24,26]. The alpha band has shown to be strongly correlated with SEM and attention [6]. Traditionally, this band covers a frequency of 8–12 Hz [4,14], and is related to alertness and cognitive tasks involving attention [9,19,26].

Skrandies and Anagnostou [24] detected that cortical increase in alpha power directly influences the preparation and efficiency of eye movements [13]. Kastner et al. [16] and Astafiev et al. [2] suggest that the frontal and parietal cortex influence the initial environmental scanning process and function as the primary sources in the process of voluntary attention. The central and frontal areas contribute to the beginning of the saccades, wherein each play a different role in the type of movement to be executed [6,22].

The behavioral and electrophysiological investigations of the SEM contribute significantly to the understanding of possible parameters of neurological and psychiatric disorders and sports performance. Studies have shown changes in behavioral patterns of the saccades of high performance athletes [3] and of Parkinson disease and Schizophrenia patients. Thus, the studies of electrophysiological patterns generated by SEM in health control subjects are important to establish electrophysiological parameters, and could be further considered as a baseline for researches involving clinical areas and sports.

In this context, the current study aimed to investigate absolute alpha power changes in sensorimotor brain regions and the frontal eye fields during the execution of two stimulus presentation patterns: fixed and random condition. The hypothesis of the present study is that the specific attention processes during a fixed and a random stimulus presentation pattern in a SEM task will lead to different states of adaptation and cortical activities over the frontal and central regions, as measured by respective alpha band changes over the sensorimotor regions and frontal eye field using qEEG.

2. Materials and methods

2.1. Subjects

Twelve healthy volunteers (3 males and 6 females), mean age: 26.25 (*SD* 4.13) were recruited for this study. All participants had normal or corrected-to normal vision and no sensory, motor, cognitive or attention deficits that would affect SEM. Subjects signed a consent form which thoroughly described the experimental procedure. The experiment was approved by the Ethics Committee of the Psychiatric Institute of the Federal University of Rio de Janeiro (IPUB/UFRJ) (Number 81 Liv2-09).

2.2. Tasks and procedures

Subjects were seated on a comfortable chair in a darkened and sound-protected room in order to minimize sensory interference. At the participants' eye level, a bar composed of 30 light emitting diodes (LEDs) was positioned with 15 of these LEDs located on the left side of fixation, and 15 on the right side. The bar had a length of 120 cm. The distance between participants' eyes and the LED bar was standardized to 100 cm for all points in the LEDs bar. Computer software controlled the LED bar and determined the presentation of the stimulus. Participants were asked to keep their eyes fixed on the center of the bar, and to shift their eyes when they perceived one of the diodes lighting up. Participants were instructed to follow the LEDs with their eyes in such way that their heads remained static.

The SEM paradigm consisted of two different conditions: (i) a Fixed Pattern – the target LED always appeared at a pre-defined position, i.e., LED 12, of either the left or right side (alternating between left and right); (ii) a Random Pattern – randomized series of target LEDs at completely unpredictable spatial positions, the light could appear at any of the 30 LEDs. In both conditions, each LEDs remained lit for 250 ms, with a inter-LED-time of 2 s. Each participant underwent 12 consecutive blocks, 6 blocks fixed SEM and six blocks random SEM, with 20 trials per block. The probability of a light to appear on the left or right side was counterbalanced within and across blocks, so were both SEM conditions [7,27].

2.3. EEG data acquisition

The International 10/20 EEG electrode system [15] was used with a 20-channel EEG system (Braintech-3000, EMSAMedical Instruments, Brazil). The 20 electrodes were arranged on a nylon cap (ElectroCap Inc., Fairfax, VA, USA) yielding monopolar derivations using the earlobes reference. Impedance of EEG and EOG electrodes was kept between 5 and 10 kΩ. The data recorded had total amplitude of less than 70 μV. The EEG signal was amplified with a gain of 22,000, analogically filtered between 0.01 Hz (high-pass) and 80 Hz (low-pass), and sampled at 200 Hz. The software Data Acquisition (Delphi 5.0) at the Brain Mapping and Sensory Motor Integration Lab was employed with the following digital filter: notch (60 Hz).

2.4. SEM acquisition

Four additional electrodes of 9 mm in diameter mounted in a bipolar form were used to measure the electrooculogram (EOG). Electrodes were arranged horizontally from the outer canthi of both eyes to determine the horizontal EOG (hEOG) and vertically above both eyes to determine the vertical EOG (vEOG).

2.5. Data processing and analysis

We applied a visual inspection and independent component analysis (ICA) to remove possible sources of artifacts produced by the task (i.e., blink, muscles and saccade-related artifacts). The data were collected using the bi-auricular reference and they were transformed (re-referenced) using the average reference after we conducted the artifact elimination using ICA. We removed by visual inspection all the trials which clearly showed a blink and a saccade-related artifacts "influence", and through ICA we removed the components that showed blink and saccade-related artifacts "contamination". A classic estimator was applied for the power spectral density (PSD) performed by MATLAB 5.3 (Matworks, Inc.). Eight hundred (4 s × 200 Hz) samples with rectangular windowing were analyzed. We extracted Quantitative EEG parameters within a time frame of 500 ms before the stimulus presentation (moment 1) and 500 ms after the target stimulus (LEDs) (moment 2). The Fourier transform resolution was 1/4 s–.25 Hz (FFT). The "Run-test" and "Reverse-Arrangement test" were applied to examine a stationary process, which was accepted for every 1 s (epoch's duration). In this manner, based on artifact-free EEG epochs, the threshold was defined by the mean plus three standard deviations; epochs which showed a total power higher than this threshold were not included into the analysis.

2.6. Statistical analysis

The statistical analyses of absolute alpha power was performed using a two-way repeated measures ANOVA with the factors SEM condition (2 levels: fixed SEM versus random SEM) and moment (2 levels: pre-stimulus versus post-stimulus epoch) as the two within-subject factors for each electrode (i.e., C3, C4, F3, F4, P3 and P4). We also performed repeated measures ANOVA two-way with the factors SEM condition and frontal electrodes to verify complement previous analysis.

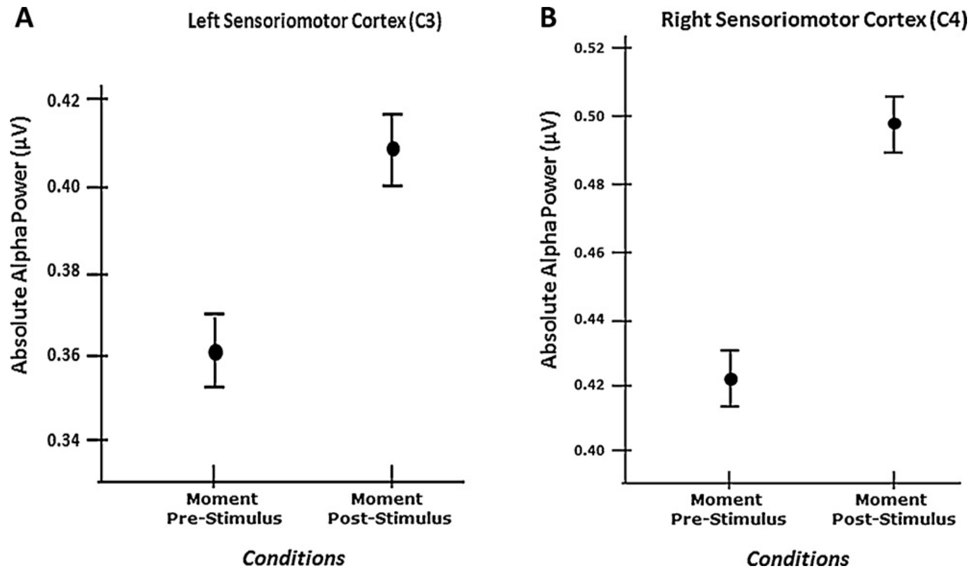

Fig. 1. Mean and standard deviation (*SD*) absolute alpha power on the primary sensorimotor cortex. (a) Main effect for moment at C3 ($p < 0.001$). (b) Main effect for moment in C4 ($p < 0.001$).

3. Results

First, we analyzed the C3 electrode. A main effect was observed for moment ($p < 0.001$; $F = 14.952$; $\eta_p^2 = 0.004$), wherein a significant increase was found from pre- to post-stimulus (Fig. 1a). The same effect was noted in the two-way ANOVA at the C4 electrode ($p < 0.001$; $F = 28.282$; $\eta_p^2 = 0.008$), and a significant increase was also observed between pre- and post-stimulus (Fig. 1b). Two main effects were identified at the F3 electrode: one for moment ($p < 0.001$; $F = 23.449$; $\eta_p^2 = 0.006$) (Fig. 2a) and another for condition ($p < 0.001$; $F = 19.740$; $\eta_p^2 = 0.005$) (Fig. 2b). We observed a significant increase in power from pre to post-stimulus moment,

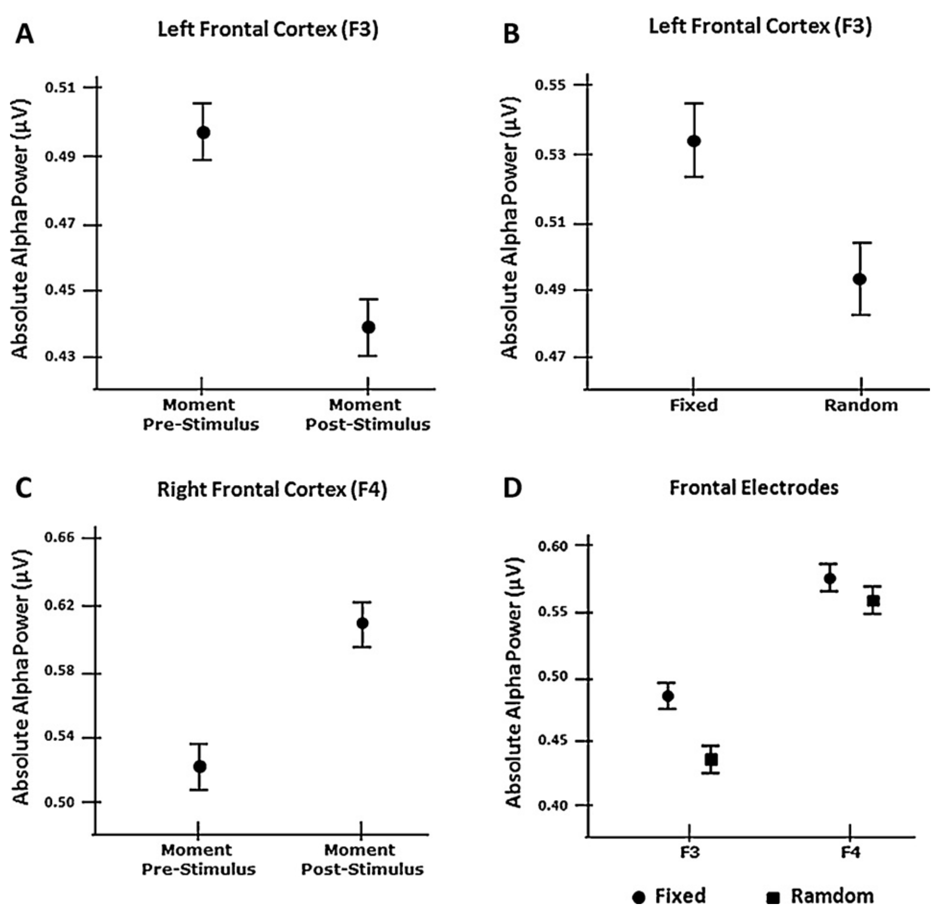

Fig. 2. Mean and *SD* absolute alpha power on the frontal cortex. (a) Main effect for moment in the F3 electrode ($p < 0.001$). (b) Main effect for condition in the F3 electrode ($p < 0.001$). (c) Main effect for moment in the F4 electrode. (d) Interaction between conditions and electrodes ($p < 0.005$).

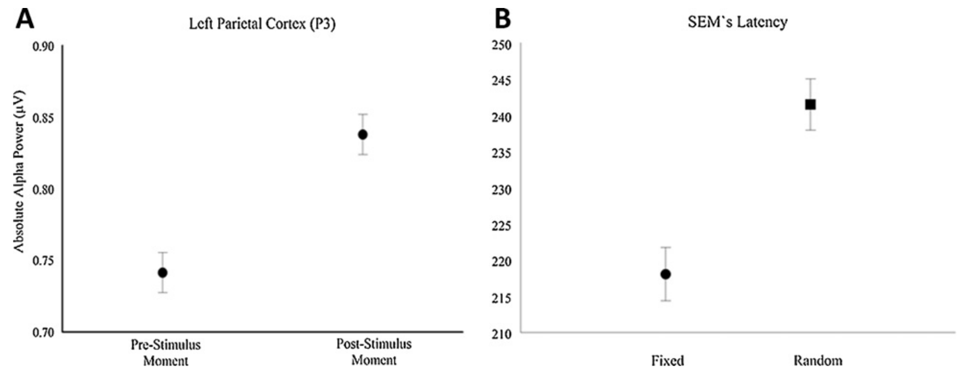

Fig. 3. (a) Mean and *SD* absolute alpha power between on the P3 electrode. Main effect for moment ($p < 0.001$). (b) Behavioral data. Saccade latency mean (ms) and standard deviation.

as well as an increase in power in the fixed SEM condition as compared to the Random SEM condition. The F4 electrode was investigated in the analysis and a main effect for moment was noted ($p < 0.001$; $F = 30{,}428$; $\eta_p^2 = 0.008$), wherein there was a significant increase between the pre- and post-stimulus moments (Fig. 2c). The ANOVA two-way between SEM condition and electrode revealed an interaction between factors ($p < 0.05$; $F = 5{,}135$), wherein there was a significant increase in the F3 electrode in the two conditions (Fig 2d). The P3 electrode was analyzed and a main effect for moment was observed ($p < 0.001$; $F = 22{,}606$) (Fig. 3a). In the analysis at P4 electrode no significant result was found. We also performed a *t*-test between conditions for saccade latency, duration and amplitude. We verified that the fixed condition latency was lower compared to the random one ($p < 0.05$; $F = 4{,}753$) (Fig 3b). Table 1 summarizes all the results.

4. Discussion

Our hypothesis was that the attention process associated with different stimulus presentation patterns causes different values in alpha power indicating states of adaptation over the central and oculomotor field. Based on our results and the areas assessed, the absolute alpha power over the left frontal cortex differentiated between fixed stimulus versus random stimulus presentation during SEM. It is important to consider that the alpha rhythm reflects the attenuation of cortical activity; therefore, the amplitude of this rhythm is inversely proportional to the activity of a given population of neurons in a given cortical region [10,25].

Our saccade latency findings clearly revealed a significant difference between SEM conditions, demonstrating that the saccade latency is lower for a fixed SEM condition when compared to a random one. The decrease in saccade reaction time for the fixed condition is mainly associated with an increase of attention levels or with a memorization. Such finding was expected due to the static nature of the stimulus location and timing under the fixed condition, potentially leading to a respective decrease in latency [23]. For saccade duration and velocity, we did not find significant difference between conditions. These results demonstrate that the stimulus localization on the LEDs bar (i.e., peripherally or centrally) did not influence the saccade amplitude and duration. This confirms that the latency results occurred because of the task nature, predictable or not predictable, and not because of the LEDs location (i.e., peripherally or centrally). In other words, predictability (i.e., memory) is the factor that really influences the task.

4.1. *The sensorimotor cortex*

In the analysis of the C3 (left hemisphere) and C4 (right hemisphere) electrodes, we observed a main effect for moment, where an increase in alpha power was observed in the post-stimulus moment. These results suggest that learning occurred due to the consolidation of competences related to a task with specific demands. In other words, the task became automatic, making high levels of alertness less necessary in order to execute the same task, or rather, the necessity for planning and preparation to execute the task was reduced, thus the task became more routine with practice [1,4,10,25].

The C3 and C4 electrodes are located on cortical areas responsible for motor ability necessary to generate eye movement. Trommershauser's [26] research verified that an improvement in task performance is exhibited after training with repetition, and that perceptual learning has been seen in various perception and motor tasks such as visual discrimination. The author reports that after extensive practice, subjects gradually learn to deploy

Table 1
Summary of the main results.

	Moment		*F*	*p*	Condition		*F*	*p*
	Pre stimulus, mean (*SD*)	Post stimulus, mean (*SD*)			Fixed, mean (*SD*)	Random, mean (*SD*)		
Saccade latency	–	–			218.05 (±2.12763)	241.46 (±2.82572)	4.753	<0.05
C3	0.36029 (±0.0080)	0.40579 (±0.0080)	14.952	<0.001	–	–	–	–
C4	0.42623 (±0.0090)	0.49597 (±0.0090)	28.282	<0.001	–	–	–	–
F3	0.49297 (±0.0090)	0.43738 (±0.0090)	23.449	<0.001	0.53408 (±0.0090)	0.49452 (±0.0090)	19.740	<0.001
F4	0.52256 (±0.0110)	0.60793 (±0.0110)	30.428	<0.05	–	–	–	–
P3	0.74149 (±0.014)	0.83787 (±0.014)	22.606	<0.001	–	–	–	–

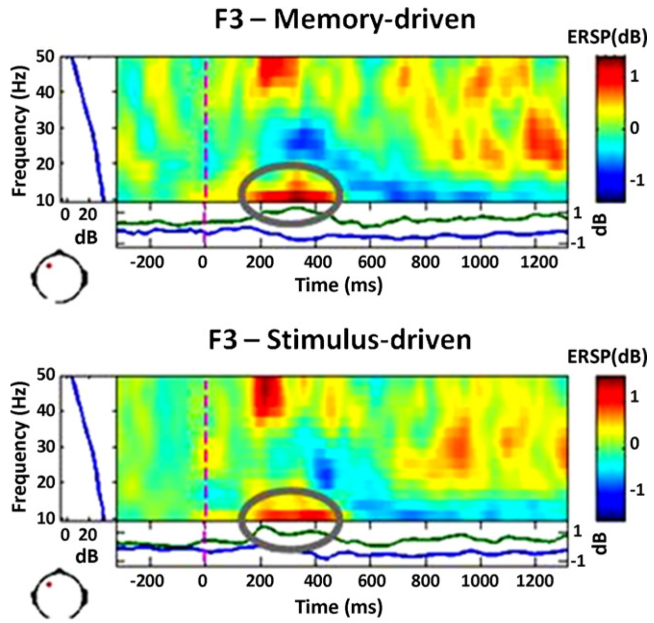

Fig. 4. Event related spectral perturbation for the electrode F3. Time–frequency maps qualitatively representing the difference found between the fixed and random conditions. The circle demonstrates the difference of alpha activity between conditions.

attention to the relevant characteristics of stimuli. In conclusion, the analysis of the cortical areas involved with the tasks demonstrated that the practice provided a lower neuronal recruitment during the task. Based on these findings, we can assume that learning and adaptation have occurred.

4.2. The frontal and parietal cortex (eye field)

The analysis of the F3 electrode demonstrated a main effect for condition and moment. An increase of alpha power in the post-stimulus moment was verified. Additionally, activity under the fixed condition was higher compared to the random condition (Fig. 4). The left frontal area is involved in preparation and execution of voluntary SEM tasks involving repetition of sequences [12,21] and in attention involving visuomotor processes [17]. Under the fixed pattern, predictability allows for learning to occur faster with less need to maintain an elevated level of focus during the execution. The fixed condition thereby resembles a guided saccade, which is conducted by memory. In contrast, under the random SEM condition the LEDs illuminate at a different site on the light bar in each moment, requiring a higher level of engagement in order to perform the task, thus a higher level of alertness.

We observed an alpha increase that can be explained by the involvement of the left frontal cortex for repeated sequences [2]. Repetition strategies were developed so that only the neuronal population directly involved with the task was recruited [20]. Examining the main effect for condition only for F3 electrode and the role of the left frontal cortex in condition discrimination, we verify an interaction between condition and frontal electrodes factors. This result confirms the relevance of alpha power in the left frontal cortex in discriminating the execution of fixed stimulus versus random stimulus presentation pattern. We also identified a greater activation in F3 for the two conditions. The increase in activity fluctuations in the left area can also be explained by the fact of that area being responsible for saccades movements control and for updating the recorded information [23].

The analysis of F4 demonstrated a main effect for moment. We found that alpha power increased from the pre- to post-stimulus moment. Therefore, the difference between moments can be explained by the different forms of brain accommodation for different cognitive processes involving attention used to establish a motor response. This suggests that an increase in the post-stimulus moment is due to the retention of the visual stimuli representation related to eye movements that are executed by these cortical areas for greater attention control.

The frontal cortex is supported by the parietal cortex during the execution of saccades [18]. Our results demonstrated a main effect for moment for the left parietal cortex (P3) with an increase of the alpha absolute power in the post-moment when compared to the pre-moment. No significant results were observed for P4. These results point out a higher activation of the left parietal cortex facing the stimulus presentation. This moment requires a visual research with integration between the stimulus and the spatial location in order to control and execute the saccade. When we compare the pre and post-stimulus presentation moments, we expect more engagement in the pre-moment, since this moment is related to the information acquisition and retention [5,11].

When the subject is exposed to the random condition a greater engagement requiring greater attention occurs. We found that specific attention processes during a fixed and a random stimulus presentation pattern lead to different states of adaptation and cortical activities on the frontal cortex, in contrast to the central regions, where there was no difference between conditions. The random condition demonstrated a greater need to engage in the task requiring more attention demand for execution when compared to the fixed condition. Therefore, the hypothesis was supported. Despite these findings, more detailed studies to better understand the complex processes involved in this type of activity are needed.

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