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RESEARCH ARTICLE

Changes in absolute alpha power during execution, imagination and observation of a finger movement task

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ABSTRACT:

Background: Neurons that fire both during execution and observation of a motor act, called mirror neurons, provide strong evidence of its existence in humans. Real, observed and imagined movements seem to share most of the same neural pathways. However, little is known about the neural mechanisms and functional processes of the different areas and the integration of information between the observation and imagined systems. **Objective:** Compare alpha absolute power levels in sensorimotor areas between real, imagined and observed movement conditions. **Methods:** The sample consisted of a group of 12 healthy young individuals (4 men and 8 women), right-handed and with mean age of 30 ± 10. The task consisted of 4 blocks of 20 trials of rhythmic flexion-extension movements of the index finger by pressing the left button of a mouse properly fixed on a table. The activation level was analyzed by measuring the absolute power of the alpha band (8-13hz). **Results:** ANOVA with repeated measures showed that in the real condition, alpha absolute power was higher in the electrodes Cz, P3 and Pz compared to the electrode C3. In the imagined condition, the electrodes P3 and Pz presented higher alpha absolute power compared to the electrode C3. For the observed condition, electrodes P3, Pz and P4 presented higher alpha power compared to the electrode C3. In addition, higher alpha absolute power was observed in the electrode Pz compared to the electrodes Cz and C4. **Conclusion:** Higher alpha activation was observed on the electrode C3 in all conditions. These findings indicate that the observed movement also shares neural circuits when compared to the real and imagined movements. It was observed that in all conditions there was a significant decrease in alpha power on the C3 electrode, which indicates activation of the motor cortex in a similar way in the conditions.

Keywords: Mirror neurons; motor imagery; EEG; alpha frequency.

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BACKGROUND

The existence of neurons that fire both during execution and during the observation of a motor act provides strong evidence of a functional neural link between perception and action(1). Such neurons are known as mirror neurons (MNS) and were found for the first time in the pre-ventral cortex (F5) and in the intra-parietal groove of monkeys(2). More recently, studies have reported the existence of such neurons in humans(3), through transcranial magnetic stimulation (EMT)(4), electroencephalography (EEG)(5, 6), magnetoencephalography(7) and single cell records(8). MNS in humans are found mainly

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in the inferior frontal cortex, superior temporal groove (STS) and anterior groove intraparietal groove (aIPS)(9), in some limbic and other cortical structures(10).

MNS have been related to many human skills that involve interaction with other people(1, 11), such as imitation(12) and speech perception(13). In addition, by implicitly simulating the actions of the other, the MNS supposedly facilitates the understanding of the other's intentions(12, 14) and emotions(15, 16). Thus, MNS is proposed as an integral part of the formation of social skills(17, 18), as well as being the basis for empathy(19, 20), as well as for learning motor(11).

During the observation of movements performed by other people, visual information is integrated with relevant motor representations, somatosensory and kinesthetic memories, as well as with internal representations of goals, instructions and manual preference(21). In general, the literature points to a "functional equivalence" or "representations" between the cortical processes underlying the observation and execution of movements(22-25) and even motor imagery(26). It is suggested that the MNS would form an innate system that integrates perception with the production of movements(27). In human beings, the cortical mechanisms related to manual gestures and the adequacy of the observation / execution of the movement may be at the basis of the origin of the gesture and spoken language, as indicated by studies that show a high concentration in the left hemisphere of specialized cortical areas for language and control of manual movements(28). These findings raise the issue of hemispheric functionality and asymmetry when observing movements performed by other individuals.

Another important issue is the integration of multisensory and "distant" motor representations that occur during movement observation. The recording of cortical activity as observed in electroencephalogram (EEG) studies can provide important information related to the integration of multisensory and motor representations(29-31). In fact, the postsynaptic asynchronous/synchronous functions that occur in the pyramidal cortical neurons generate a pattern of oscillations in the EEG, known as event-related desynchronization/synchronization (ERD/ERS), very common in the alpha frequency band(29). ERD and ERS represent the opening/closing ("gate function") of bidirectional connection in the connections between the associative cortex and the thalamic reticular nucleus. These circuits can form sets of cortical neurons that represent motor events related to the observed movement(29-32). In addition, EEG studies show a decrease in power (8-12 Hz) in the central and parietal regions during prolonged observed movement(33, 34). Since the alpha frequency band has an inverse relationship to the level of cortical activation, alpha desynchronization can be interpreted as a state of comparatively high excitability, whereas alpha synchronization would be a state of inhibition with comparatively low excitability(35).

Little is known about neural mechanisms and functional processes in different areas and the integration of information between observation systems. Understanding the functioning of the cortical areas related to the process of mental simulation of a motor act is particularly interesting in several practical settings. The analysis of the changes in alpha frequency activity has been associated with the search for accuracy in brain-machine interfaces(36), the development of new neurofeedback protocols(37), and the monitoring of mental states in patients with social-cognitive dysfunctions, such as autism spectrum disorder and schizophrenia(38).

In summary, the objective of the present study was to compare the absolute power levels in the alpha frequency band in sensorimotor areas between the conditions of real, imagined and observed movement. We hypothesized that a functional equivalence between the cortical processes will be found. Thus, a pattern in the levels of alpha absolute power between target areas should be found in the three experimental conditions. Since the movement-related potentials of alpha rhythm show greater excitability of the cortical populations in the M1 than in the parietal(39, 40), we also expect a higher cortical activation in the central area than in the posterior area in all experimental conditions, as well as a more contralateral lateralization.

METHODS

Sample

Twelve healthy (8 male and 4 females; mean age: 30, SD: 10) participants were recruited in graduate courses at the university. All participants were right-handed according to Edinburgh Handedness Inventory(41) and had normal vision (i.e., 20/20). Inclusion criteria were absence of mental or physical impairments and no history of psychotropic substance use (screened by an anamnesis and a clinical examination). Moreover, participants were not included if they had less than 6 to 8 hours of sleep prior to the experiment and/or caffeine 48 hours prior to the experiment. All participants were made aware of the entire experimental protocol and signed a consent form before participating in this study. This study was approved by the Ethics Committee at Federal University of Rio de Janeiro and was conducted according to the ethical declaration of Helsinki.

Experimental procedures

Participants were randomized into three conditions: a) The first condition performed the real action, the second condition performed motor imagery; c) and the third condition performed motor observation. EEG recording was performed in both conditions while participants sat in a dark room with their arms lying on the back of the chair. To reduce artifacts during EEG collection, participants were asked to focus their attention on the monitor placed in front of them at a distance of 1 m to keep the jaw relaxed and avoid blinking. These instructions were given prior to each data collection. A metronome, adjusted to 2 Hz, was used to impose time of movement pattern and to guarantee a similar number of finger contacts per attempt in all conditions and participants. this consistency also ensured similar experimental circumstances in the execution and observation conditions.

In this experiment, twelve participants took part in all conditions, i.e. were submitted to real movement condition (RM), imagined movement condition (IM) and observation movement condition (OM), during different days, using a randomized cross-over methodology. Each session was conducted with an interval of 48 hours between them. During the task, in order to minimize sensory interference, lights were turned off and subjects instructed to concentrate exclusively on the monitor. A 15” Samsung monitor was placed 50 cm in front of the participant. Participants were seated on a comfortable chair to minimize muscular artifacts, while electroencephalography (EEG) data was collected. The visual stimulus (yellow square) was presented on the monitor by the Imagery Acquisition software, developed in DELPHI (Direct electrophysiological imaging). The task consisted of 4 blocks of 20 trials of extension-flexion index finger movements (i.e., rhythmic and standardized movements) pressing the left button of a mouse. Each trial comprised four stages presented to the participant via a video display (Figure 1). In IM, and OM conditions the participants were also instructed not to move the finger during the four stages of the trial. Only in the RM condition there was finger movement.

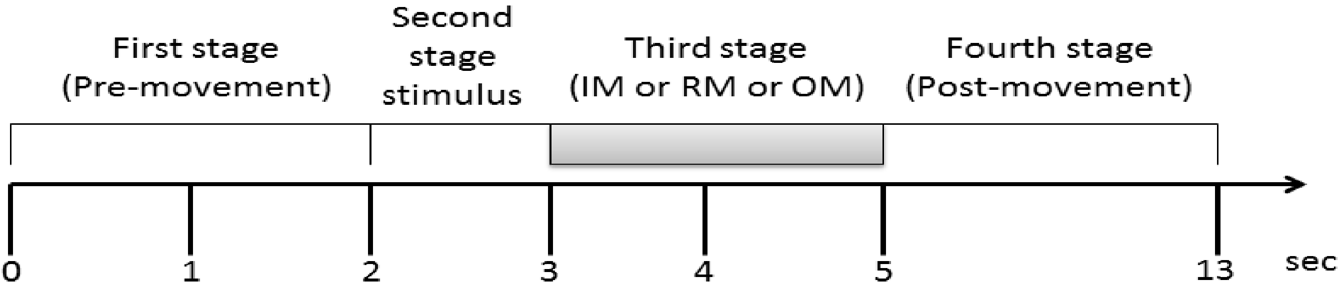

Figure 1. Timeline for each trial

During the first stage of each trial the participant observed an amber monitor warning the participant of the imminent requirement to move. During the second stage, lasting one second, participants must react to a stimulus (yellow square). In the third stage, participants performed the experimental conditions with duration of two seconds. In the RM condition, participants must react to a stimulus (yellow square) with an index finger movement (flexion-extension) clicking the mouse button. In the IM condition, participants must imagine the same task according to the RM condition after stimulus appearance in the PC monitor. In the OM condition, individuals must observe the stimulus appearance and the hand performing the flexion-extension finger movement in the PC monitor. The time interval between the onset of the next trial was 8 seconds (fourth stage).

Motor Task

Participants underwent a task of repetitive index finger movements holding a mousepad. Individuals should flex the right index finger by pressing the button on the mousepad followed by an extension of the right index finger to create a 90° angle between the distal and medial phalanx while the hand remained in the dorsal position holding the mousepad (Figure 1). This simple sequence of index finger movements requires the execution of certain neural networks with particular temporal and spatial sequences. Therefore, this task was chosen because it was performed far from the head, preventing the detection of possible artifacts in the EEG, besides being an object-oriented task.

Data acquisition

EEG was recorded from 20 electrodes arranged according to the 10-20 system(16) in a nylon cap (ElectroCap Inc, Fairfax, VA, USA) yielding monopolar derivations referred to linked earlobes. In addition, two 9-mm diameter electrodes were attached above and on the external corner of the right eye, in a bipolar electrode montage, for eye-movement

(EOG) artifact monitoring. Impedance of EEG and EOG electrodes was kept on 10 KΩ. The data acquired had total amplitude of less than 100 μV. The EEG signal was amplified with a gain of 22,000, analogically filtered between 0.01 Hz (high-pass) and 100 Hz (low-pass), and sampled at 240 Hz. Data Acquisition software (Delphi 5.0) was employed with the following digital filters: notch (60 Hz), high-pass of 0.3 Hz and low-pass of 25 Hz. In order to obtain signals from the accelerometer, the MMA7340 model of Freescale semiconductors was used to aid to identify the beginning of index finger movements. This system is a microelectronics mechanism, which explores the mechanical properties of silicone to create movable structures and to detect distinct movement directions. The movement capture was conducted in actual time system, with the interaction of EEG software signal acquisition. As the movement was performed, the accelerometer showed a curve with acceleration variability providing information about velocity and time.

Data processing and analysis

In order to quantify reference-free data, a visual inspection and independent component analysis (ICA) was applied to identify and remove any remaining artifacts, i.e., eye blinks and ocular movements, produced by the task(18). Data from individual electrodes exhibiting loss of contact with the scalp or high impedances (10 kΩ) were discarded, and data from 10 single-trial epochs exhibiting excessive movement artifacts (±100 μV) were also deleted. ICA was then applied to identify and remove any artifacts after the initial visual inspection. ICA is an information maximization algorithm to blind the EEG signals related to the artifacts(18). Independent components resembling eye-blink or muscle artifacts were removed and the remaining components were then projected back onto the electrode data by multiplying it by the inverse matrix of the spatial filter coefficients derived from ICA, using established procedures. The ICA-filtered data were then reinspected for residual artifacts using the same rejection criteria described above. Then, a classic estimator was applied for the power spectral density, or directly from the square modulus of the Fourier Transform, performed by MATLAB (Matworks, Inc.). Quantitative EEG parameters were reduced to 2 s periods (the selected epoch 2 s after the trigger). In this study we will analyze only post stimulus time, i.e. 2 s after the trigger, being considered the phase during the conditions. Thus, channel 21 created to use the accelerometer was excluded, in order to avoid any type of artifact.

Spatial location of electrodes

The electrodes C3 and C4 are located on the pre-central rotation, representing the primary motor cortex (M1) in each hemisphere that are functionally related to motor preparation, perception and execution of movements(42, 43). The CZ electrode represents the M1 of both hemispheres and the supplementary motor area (AMS), which is functionally related to temporal organization and movement coordination(43, 44). The electrodes P3, Pz and P4 represent the parietal cortex (CP), functionally related to the integration of information such as, tactile recognition, object manipulation(45, 46), intention and preparation for the movement(47-49), coding spatial information and directing spatial attention(50, 51) and allocation of attention in relation to the control of limb movements(48, 52).

Statistical analysis

For descriptive analysis, the mean and standard deviation values were reported for absolute alpha power. For inferential statistics, an ANOVA of repeated measures with two factors, with input for condition (Observed x Imaged x Real) and electrode (C3 x Cz x C4 x P3 x Pz x P4) was performed on the alpha power measurement. The sphericity assumptions were verified by the Mauchly test and the Greenhouse-Geisser was used as a correction factor if the sphericity was violated. Follow-up analysis was performed using the Bonferroni correction factor. The level of statistical significance was established with $p \leq 0.05$. Statistics were performed using the Statistical Package for the Social Sciences (SPSS) version 23.0.

RESULTS

The sphericity assumptions were not violated, according to Mauchly's test. Anova of repeated measurements demonstrated interaction between condition x electrode (F (10, 110) = 1.943; p = 0.047), no main effect for condition (F (2, 22) = 1.048; p = 0.367) and main effect for electrode (F (5, 55) = 7,201; p = 0.000) in the absolute power of alpha. Still on the main effect for electrode, Bonferroni's follow-up analysis showed that the absolute alpha power of electrode C3 was lower compared to electrodes P3 (p = 0.000), Pz (p = 0.001) and P4 (p = 0.01). In addition, the C4 electrode also had a lower absolute alpha power compared to the Pz electrode (p = 0.048). Specific interactions are shown in figure 2.

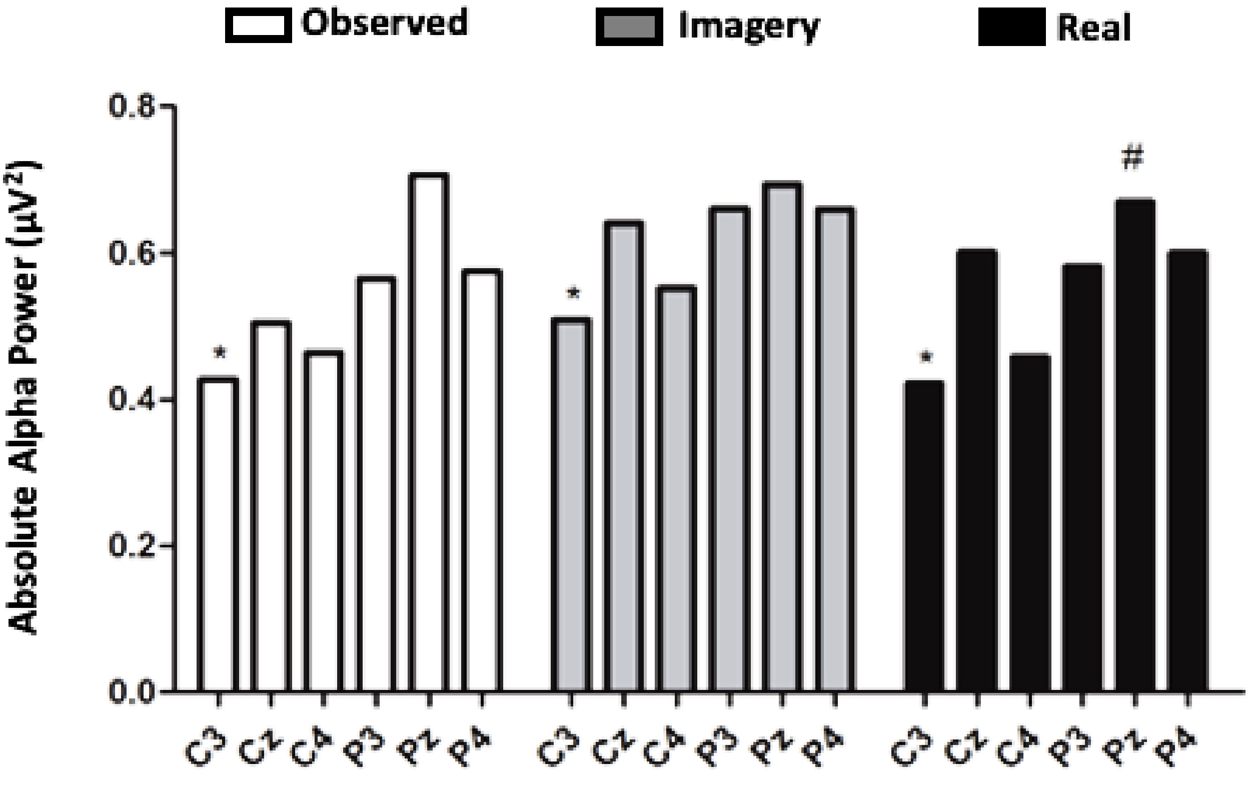

Figure 2. Absolute alpha power for observed, imagery and real conditions

*Real condition: C3 < Cz (p = 0.008), P3 (p = 0.002) and Pz (p = 0.000); Imagined Condition: C3 < P3 (p = 0.002) and Pz (p = 0.034); *Observed Condition: C3 < P3 (p = 0.007), Pz (p = 0.009) and P4 (p = 0.026); *#Observed Condition: Pz > Cz (p = 0.009) and C4 (p = 0.030).

DISCUSSION

The aim of the study was to compare the conditions RM, OM and IM, on the absolute power in the alpha frequency band in sensorimotor areas. Interaction between condition and electrode was observed, with the following results: 1) in the condition of real movement less absolute power was observed in electrode C3 when compared to electrodes Cz, P3 and Pz; 2) in the condition of imagined movement, less absolute power was observed in electrode C3 when compared to electrodes P3 and Pz; 3) in the observed movement condition, less absolute power was observed in electrode C3 when compared to electrodes P3, Pz and P4 and also greater absolute power in electrode Pz when compared to electrodes Cz and C4 ($p = 0.030$). Therefore, the discussion will be divided into sections.

Real Movement Condition

As observed in the results, a lower absolute power was observed in the C3 electrode when compared to the Cz, P3 and Pz electrodes. The activity of the alpha frequency band topographically represents sensory functions when recorded in sensory areas(53) and motor responses when recorded in areas involved in voluntary motor control(6). Increased absolute alpha potency would result from a consistent cortical conduction from the thalamus to the cortex coinciding with the lack of other sensory inputs. Alpha is considered a mechanism to increase signal-to-noise ratios within the cerebral cortex by inhibiting unnecessary or conflicting processes for a task to be performed(54-56). The oscillation of the alpha frequency band is now increasingly considered to reflect a global inhibition of the cortex in order to exercise cognitive control of final performance(35). In this context, two apparently opposite functions are operational. In the first function, the synchronization of alpha oscillations seems to integrate the multisensory factors in segregated blocks of information necessary to link the bonds of perception of interpersonal action. In the second function, the increase in alpha power can have a "windscreen wiper" effect through pulsed inhibition to select or control the signals received(56).

In this sense, when compared to electrodes Cz, P3 and Pz, electrode C3 showed less absolute power. This finding means greater activation of the primary motor area of the left hemisphere during the execution of the movement. This result is not surprising, since the real movement is mainly controlled by the M1 contralateral to the limb used(57). Therefore, there seems to be a neurophysiological mechanism that increases the focused activation of specific cortical areas and decreases the activity in areas that are not relevant to the completion of the task(58). This assumption is similar to ERD / ERS. ERD means a reduction in power in specific cortical areas, induced by some event, reflecting an increase in cortical activity, which can be considered an electrophysiological correlate of an activated neural network, prepared to process information with an increase in the excitability of cortical neurons, as well as a state of readiness during imagination or observation tasks(59), while the ERS means an increase in potency in specific cortical areas, also induced by some event, reflecting the decrease in cortical activity that seems to represent an inhibition or deactivation of areas less involved in the task(30).

The greater alpha activity in M1 seems to reflect the reception of proprioceptive and sensory information from the parietal areas that are disabled, to perform targeted movements(34). Lower absolute alpha power was observed during the execution of a movement directed towards an objective. The alpha activity in the parietal cortex greater than in M1 indicates a lower participation in this area, possibly due to the low complexity of the task, thus not requiring a large participation of the areas most involved in task planning.

Imagery Condition

According to the results, a lower absolute alpha power was verified in the C3 electrode when compared to the P3 and Pz electrodes. As in the real movement and observing the parietal areas, they were less active in the sensory-motor integration during the kinesthetic imagined movement.

The realization of motor imagery in different modalities has demonstrated activation of different areas of the cortex. Slodkin et al.(60) compared a real motor execution, visual motor imagery and kinesthetic motor imagery, through functional image magnetic resonance, finding differences. However, there was a wide overlap of areas between real motor execution and kinesthetic motor imagery. Motor area (M1) facilitated during the actual execution of the movement, with the opposite effect during kinesthetic motor imagery. In addition, the parietal lobe played an important role during motor, visual and kinesthetic imagery.

Within this context, the kinesthetic motor imaging modality used in our study directly interferes with the integration and processing of the motor task. Callow and Hardy(61) demonstrated functional differences when the subject is the “agent” of mental representation, showing a significant relationship between external visual images and kinesthetic images. It seems that the focus of activity during kinesthetic imagery is concentrated in the sensory-motor area of the hand, while visual motor imagery does not clearly demonstrate a spatial neural pattern(62).

Reinforcing the participation of the parietal area in imagined motor tasks, Stecklow et al.(63) aimed to investigate the contribution of the EEG alpha band during visual and kinesthetic motor imaging, in athletes and non-athletes. Alpha power in the left parietal cortex (i.e., P3 electrode) had greater reductions in kinesthetic motor imagery compared to visual motor imagery. However, the results suggest that the greatest reduction in alpha power, in the left parietal hemisphere, was more seen in subjects with real knowledge of the task (athletes) and in the kinesthetic motor imaging modality. Other authors who also found a difference in activation in relation to the type of MI, especially individuals with some type of lesion in the parietal lobe, seem to have difficulty in forming quality images, which can be attributed to the planning function of the parietal lobe(25, 64).

Familiarization with the situation may also influence cortical activity, because when kinesthetic motor imaging was performed by athletes and non-athletes of the modality, a higher left hemisphere alpha (ie, P3 electrode) was observed in non-athletes compared to athletes(63). Another research conducted by Stecklow et al.(65) also demonstrated that alpha power was lower in athletes during the kinesthetic motor imaging modality. It seems that the least cognitive effort in a motor imaging task demands less participation from the parietal cortex. Reinforcing this hypothesis, Nair et al.(57) investigated neural connectivity, through functional magnetic resonance imaging, in different conditions: opposition of fingers (thumb and index) performed in real and imagined, with one hand (uni-manual) and bimanual. The activation of the parietal cortex occurred in both real and imagined tasks, but it was more present during bimanual action sequences, whose need for greater attention and memory resources are more associated.

Our results showed that the alpha power was greater in parietal areas (P3 and Pz electrodes) compared to the M1 area (C3 electrode), but with no difference between the actual and observed execution conditions. It is speculated that the non-occurrence of real movement, represented by kinesthetic motor imagery, reduced the effective participation of the left parietal cortex in the planning of the motor task. This would indicate a specific alpha modulation in the parietal cortex for the proprioceptive and sensory transformation processes related to the execution of the movement(30, 39, 66).

Observed Movement Condition

According to the results, a lower absolute power was verified in electrode C3 when compared to electrodes P3, Pz and P4, and a higher absolute power in electrode Pz when compared to electrodes Cz and C4. These results point to greater activation in M1 and less in the parietal region of both hemispheres.

The greater activation of M1 suggests that human beings have a motor resonance system capable of encoding the details of the observed action, allowing its subsequent reproduction. Calmels et al.(67) compared the cortical activity between actual and observed execution. The results showed that there were no significant differences in the alpha frequency band (10-13Hz) in 19 electrodes investigated (Fp1, Fp2, Fz, F3, F4, F8, Cz, C3, C4, Pz, P3, P4, T3, T4 , T5, T6, O1 and O2). The type of motor action observed seems to influence EEG behavior, as observed Muthukumaraswamy et al.(68), when comparing a directed action (load cell pressed by the index and thumb fingers) and an undirected action (when there was no load cell and something empty was pressed by the index and thumb). The results showed that the directed action caused a greater reduction in the power of the alpha band compared to the non-directed one.

Int this study, the flexion and extension movement of the finger, shown on the screen for the observed condition, was similar to that performed on a computer mouse. Thus, we assume that, due to familiarization with the motor gesture used in the study, there was greater stimulation of the sensorimotor areas in the observed condition compared to the actual execution, which may also explain the lesser activation of the parietal cortex during the observed action, since the fundamental role of this is in the planning and understanding of the movements observed, so that a simple movement and already present in the motor repertoire of the practitioners, did not require much activation in this region.

CONCLUSION

In all experimental conditions, less absolute alpha power was observed in the C3 electrode, area M1, reflecting greater activation in that area. These findings indicate that these three conditions, real, imagined and observed, share similar neural circuits. This was also reflected by the greater alpha power in the parietal electrodes for the three conditions, demonstrating a lower activation in this area due to the less need for planning, according to the simplicity of the proposed task.

The changes that occurred in the absolute power of the alpha band were subordinated to visuo-somatomotor transformations that accompanied the execution of real movement (with feedback), imagination and observation of movements. The results are in favor of a functional equivalence of alpha in the M1 area, since there was a significant decrease in the alpha potency in this area in all conditions. We suggest that new studies perform more complex tasks, using non-dominant limbs, as well as samples composed of individuals affected by psychiatric disorders such as autism, schizophrenia, who have motor disorders related to the neural circuit of the MNS system or even individuals with some type of deficit motor.

Authors' contribution: ASSF, AY and SM contributed equally in all phases of the project; DCS, TA, JLL, DP and PAI participated in the collection and part of the writing of the final document; PSL, RALM participated in multiple revisions and the writing of the final document; ACR and DAC are scientific initiation students and participated in some phases of the project, as well as the presentation of the work in the format of a congress summary.

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