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Electroencephalographic (EEG) Coherence during Imagery in Young Men

Coherencia Electroencefalográfica (EEG) durante la imaginería en hombres jóvenes

Jahaziel Molina del Rio [1]
https://orcid.org/0000-0001-9670-4114

Rosa María Hidalgo Aguirre [2]
https://orcid.org/0000-0001-8413-5671

Miriam Nathaly Reyes Cardiel [3]
https://orcid.org/0009-0005-7628-2651

Marisela Hernández González [4]
https://orcid.org/0000-0002-2356-9561

Claudia del Carmen Amezcua [5]
https://orcid.org/0000-0001-8975-6012

[1,2,3] Laboratorio de Neuropsicología, Universidad de Guadalajara, Centro Universitario Los Valles, Guadalajara, México
[4,5] Instituto de Neurociencias, Universidad de Guadalajara, Guadalajara, México

[1] ✉ jahaziel.mdelrio@academicos.udg.mx [2] ✉ rosa.hidalgo@academicos.udg.mx [3] ✉ nathaly.reyca@gmail.com
[4] ✉ marisela.hgonzalez@academicos.udg.mx [4] ✉ delcarmen.amezcua@academicos.udg.mx

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Abstract. *Objective*. The objective of the study was to characterize the electroencephalographic coherence pattern during mental imagery elicitation in young men. *Method*. EEG activity was recorded during two conditions, Retention (RET) and Imagery (IMG). A series of ten geometric figures were presented. Participants were asked to storage the images (RET), and to create new images based on the figure (IMG). Then, coherence values were compared between conditions. *Results*. Increased Coherence was presented in left and right posterior-anterior regions during mental imagery, which could be related to cognitive manipulation of stimuli in creative processes.

Keywords. Functional connectivity, EEG, coherence, imagery, male participants

Resumen. *Objetivo*. Caracterizar el patrón de coherencia electroencefalográfica durante la elicitación de imágenes mentales en hombres jóvenes. *Método.* Se registró la actividad del EEG durante dos condiciones, retención (RET) e imágenes (IMG). Se presentó una serie de diez figuras geométricas. Se pidió a los participantes que almacenaran las imágenes (RET) y que crearan nuevas imágenes basadas en la figura (IMG). Luego, se compararon los valores de coherencia entre las condiciones. *Resultados*. Se observó un aumento de la coherencia en las regiones posterior-anterior izquierda y derecha durante la imaginería mental, lo cual podría estar relacionado con la manipulación cognitiva de los estímulos en los procesos creativos.

Palabras clave. Conectividad funcional, EEG, coherencia, imágenes mentales, participantes masculinos

Introduction

Mental imagery is a cognitive process involved in retention and evocation of perceived stimuli, and is considered as a subjective phenomenon (Martínez, 2014), to be the internal or mental representation of information (Kosslyn, 1980), as any image created in the mind without the presence of the real object or event, linked to senses and feelings (Jenkins, 2009), being not exclusively a visual activity (Campos & González, 2017). It has been a process linked to learning, retrieval and solving problems, and describes that mental imagery has properties of quality, length, clarity, and intensity (Heidbreder, 1960).

There are some subjective evaluations techniques that have been employed to study mental imagery, some of them are the Visual Images Vividness Questionnaire (Beato, et al., 2006), Mental Imagery Questionnaire (Sheehan, 1967), Spontaneous Use of Images Scale (SUIS; Reisberg et al., 2003), and the Movement Imagery Questionnaire (MIQ; Hall & Pongrac, 1983), those are questionnaires and self-reports that represent a personal interpretation without considering the physiological response during mental imagery.

There is evidence that cognition is formed largely thanks to perception, in other words, it is highly based on the sensorial properties and on mental imagery attributed thereto and to a set of perceptions related to a variety of high-level cognitive functions. This is a complex process which is believed to occur thanks to the re-experience of material prior to sensory input (Zhang et al., 2018).

Hence, studies suggest that the primary visual area (PVA) and the default mode network (DMN) are involved in the mental generation of visual images, finding a relation between the brain activity in these areas with the mental images, suggesting that PVA is inextricably linked to the elicitation of mental images in rest (Amedi et al., 2005; Bergmann et al., 2016; Bar, 2007; Bar & Neta, 2008; Binder et al., 2009; Daselaar et al., 2010).

It is worth mentioning that Mellet et al. (1992), by using positron emission tomography (PET), found significant activations of the occipital external left area, in the precuneus (bilateral), in the motor supplementary area, and the left precentral gyrus (unilateral), during the generation of mental visual images (Mellet et al., 1992), through a study in healthy subjects performing a task involving the generation of visual mental images. The results allow to consider the involvement of frontal areas in the conscious generation and voluntary control of mental visual images.

Vera et al. (2006) explain that the visual process and the generation of visual mental images have been attributed to the function of the post-rolandic cortex with a probable lateralization of the left hemisphere, postulated also by Farah et al. (1985).

Along this line, the participation of certain brain regions that could allow the creation of mental images has been suggested. Pearson et al. (2015) propose that early visual areas (primary visual cortex) and secondary visual areas (ventral stream) activation are correlated to the complexity of the elements. Other studies such as Kosslyn et al. (2001) found that visual imagery activates brain regions related to visual perception, while internal speech activates regions related to auditory perception, but not the visual areas. Otherwise, external stimulus processing by the brain has been described as evidence of thoughts, which demonstrates that images or word cognitive processing activates brain regions implicated in visual and auditory perception (Villena-González, 2016).

Another technique used to study cognitive processing is the electroencephalogram (EEG), through which the electrical activity of a group of neurons responding simultaneously is registered by placing an electrode on the scalp. This technique allows to record activity with great temporal resolution, as well as to know the participation among brain areas during a cognitive task (Holczberger, 2011).

Farah (1989) identified the act of generating a mental image from memory and proposes that forming a mental image has noticeable effects in event related potentials (ERP). In this study, word-recordings were made under two instruction conditions: the first consisted of the subject being able to encode the word; in the second, the subject is expected not only to encode the word, but also to form an image related to that word. The results of the ERP reflect an electric activity synchronized with the generation of mental images, with the participation of occipital regions for the words presented in visual format and posterior temporal regions for the auditory mode.

Farah (2000) managed to identify the implication of mental images in the efferent activation of visual areas in the pre-striate occipital cortex, parietal and temporal cortex, and to recognize that those areas manage to represent the same types of specialized visual information in images as in perception. Within his study, Farah also identified the different components that allow the assessment of images, which appear to be lateralized in different manners.

Even though the studies have considered EEG activity during imagery tasks, they do not make an analysis of the synchronous participation of brain regions during the task, which could be obtained through a coherence analysis. Taking as a reference the coupling between the different bands measured by the waves generated on the brain areas, we can obtain by the coherence, which can be interpreted as a way of measuring how similar two signals are, between regions spatially separated, explained by "the square root of the correlation between sinusoidal components of the EEG of two regions and in a certain frequency range" (Silva, 2011, p. 34). When two areas can develop the same brain waves in amplitude and frequency, they are identified as value 1 coherence, while when two areas have amplitude and frequency completely different, their coherence value is 0. And, although two areas are involved with brain activity, it does not mean that they start that activity at the same time, which means that there can be certain delay in the region that initiates the activity and in the one that follows the activity (Guevara & Corsi-Cabrera, 1996).

Besides, it is important to note that coherence in sinusoidal activity allows reflect morphological or functional interconnectivity, that is, the coherence of two distant areas is high only if both areas have direct, indirect connections or if they are involved in the execution of the same task (Silva, 2011). Coherence measures when signals are related as a linear transformation and time invariant, it has a constant amplitude reason and phase shift (Esqueda et al., 2016).

The analysis of how multiple areas interact during a cognitive process brings forth an approach to understand the functional organization of the brain, useful to many disciplines in neuroscience and neuroinformatic, like cognitive neurosciences, cognitive modeling, cognitive architectures, among others. According to this, we established the next research question, which are the characteristics of the electroencephalographic coherence pattern during mental imagery elicitation in young men? Considering the previous research and literature about the topic we hypothesized that mental imagery elicitation in young men will have a pattern of increased synchronization in fast bands (Beta1, Beta2 and Gamma), among occipital and frontal regions. Thus, the aim of this research is to characterize the electroencephalographic coherence pattern during mental imagery elicitation in young men.

Method

Quasi-experimental, quantitative, cross-sectional study with a correlated groups design.

Participants

Twenty-three young men with an average age of 19.91 (min = 19, max = 26) participated in this study. Previous studies have shown differences between men and women (Campos & Lustres, 2018; Subirats et al., 2018) in different imagery tests. Particularly, considering the type of mental imagery test used in this study, as a motor rotation task, we decided to invite only men as participants, all of which are right-handed, healthy, with no prior history of neurological or psychiatric disorders, learning disabilities, drug abuse, or chronic illness. Also, they had normal attentional levels according to parameters of specific subtest (retention of digits in progression, visual detection, digit detection and successive series), tasks used to evaluate visual an auditive attention part of the neuropsychological battery NEUROPSI memory and attention (Ostrosky et al., 2003) and I.Q. equal or greater than 90 according to intelligence test Shipley-2 (Shipley, Gruber, Martin, & Klein, 2014). They were required to attend the Neuropsychology Laboratory in the Centro Universitario de los Valles, with at least 12 hours without prior consumption of caffeine or any energy drink before the EEG recording session. All procedures involved in the present experiment were approved by the institutional committee and performed strictly in accordance with the code of Ethics of World Medical Association (Declaration Helsinki, 1964) and its later amendments, or comparable ethical standards, as well as APA ethical standards. All participants signed an informed consent with general information about the procedure and were free to leave the experiment at any moment that they wanted.

Instrument

Experimental task

The experimental task consisted of two consecutive phases, a retention (RET) and an imagery phase (IMG). In all cases, participants were seated on a comfortable chair in front of a 32-inch monitor where stimuli were presented. The first screen contained the general instructions, requesting them to avoid head or eye movements, even excessive blinking. Afterwards, an EEG recording of a two-minute basal period was taken, where they had to look at a central white point over a black screen. The retention phase began with the next instruction displayed on the screen: "Next, a series of images will be presented, one at a time. First, you must watch each image attentively. Second, storage the figure in your memory, during the black screen. Third, draw the figure on the provided sheet. Do the same steps with each figure". Next, a white geometric figure over a black screen was displayed for two seconds, followed by an entirely black screen for six seconds. Finally, a screen prompts the participant to draw the memorized figure, with no time limit. The participants have a 20 second rest between each figure presentation. Once this time lapsed, the evaluator pressed a button, so the next figure would appear. This sequence was repeated for ten geometric figures.

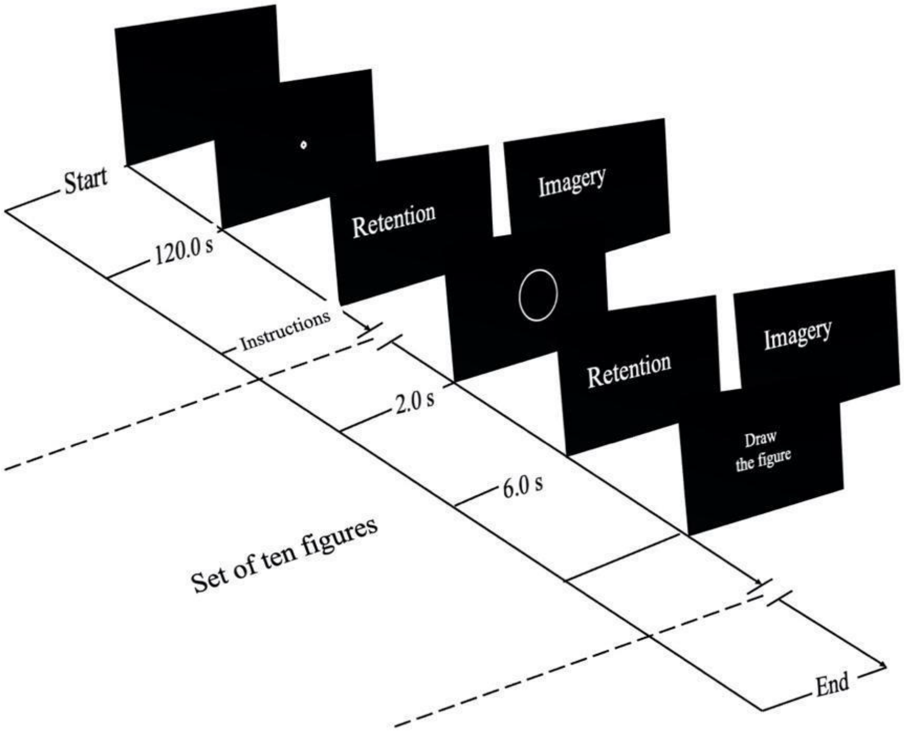
The imagery (IMG) phase began with the next instruction displayed on the screen: "Next, a series of images will be presented, one at a time, first, you must watch each image attentively. Second, you have to imagine something that includes the figure that you just saw during the black screen. Third, draw what you imagined on the provided sheet, and repeat the same steps with each figure". The following sequence was the same as the one in the previous phase. The experiment ended once the two phases were completed (see Figure 1).

EEG recording and processing

The electroencephalographic activity was recorded continuously over all the experimental tasks with a Nexus 32 device at 24 bits resolution with filters set at 1-50 Hz, with impedance for EEG electrodes below 10 Kohms. Electrodes were placed following the 10-20 international system (Jasper, 1958) over frontal (dorsolateral: F3, F4), temporal (T3, T4), parietal (P3, P4) and occipital (O1, O2) regions, referred ipsilaterally with the ground electrode placed on the forehead. BioTrace+ software was used to process 256 samples per second and store the EEG data for offline processing. To decrease eye-movement and muscle artifacts during and after drawing, we gave each participant 20 second rest before displaying the next figure.

After recording, the data were extracted and processed in EEGLAB (Delorme & Makeig, 2004) for the six seconds that lasted on the black screen for the ten figures for each participant in each condition (Retention and Imagery). A pre-processing visual

Figure 1. Sequence of screens in the experimental task



inspection was made to reject the segments with signal noise by eyeblink. A digital filter (FieldTrip toolbox) was implemented to reduce muscle movement. An average of 22.6 two-second segments per subject for each condition was obtained. Low band pass filter was set to 1 Hz and High band pass filter to 50Hz. Electrodes were referenced ipsilateral to mastoids (A1-A2). EEGBands program (Guevara et a., 2014) was used to apply the fast Fourier Transform to calculate the absolute power for each band (Delta, Theta, Alpha1, Alpha2, Beta1, Beta2 and Gamma). The auto-spectrum and crossed-spectrum in each band where obtained to calculate de interhemispheric (F3-F4, T3-T4, P3-P4, O1-O2) and intrahemispheric (F3-T3, F3-P3, F3-O1, T3-P3, T3-O1, P3-O1, F4-T4, F4-P4, F4-O2, T4-P4, T4-O2, P4-O2) coherence values, and finally, applies parametrical statistical analysis to these spectral parameters calculated for wide frequency EEG bands.

Data analysis

To get a normal distribution, the EEGBands program (Guevara et al., 2014) transforms the coherence values into Fisher's *z*. Based on this data, a comparison of means between conditions (RET versus IMG) was used employing a t-test and considering a significant level $p \leq .05$. The effect sizes were obtained for each comparison using Cohen's *d*. According to the multivariate analysis, a correction of the *p* using the False Discovery Rate method was applied to all the global comparisons. Statistical power was obtained post hoc using G*Power software.

Results

Next tables summarize the EEG coherence data obtained for each comparison, grouped in interhemispheric coherence (Table 1), left intrahemispheric coherence (Table 2) and right intrahemispheric coherence (Table 3). Significant findings are detailed.

Table 1. Interhemispheric coherence values

Bands	RET	*SD*	IMG	*SD*	*t*	*p*
Frontal derivations (F3-F4)						
Delta	0.663	0.059	0.613	0.046	0.98	.33755
Theta	0.649	0.059	0.657	0.046	-0.199	.84421
Alpha1	0.593	0.05	0.656	0.042	-1.468	.15636
Alpha2	0.584	0.049	0.578	0.039	0.162	.87302
Beta1	0.567	0.053	0.549	0.038	0.490	.62875
Beta2	0.517	0.05	0.518	0.036	-0.005	.99612
Gamma	0.477	0.047	0.48	0.034	-0.086	.9322
Temporal derivations (T3-T4)						
Delta	0.371	0.033	0.368	0.033	0.125	.90137
Theta	0.339	0.028	0.383	0.028	-1.611	.1215
Alpha1	0.331	0.024	0.36	0.027	-0.857	.40071
Alpha2	0.306	0.022	0.365	0.027	-1.953	.0636
Beta1	0.312	0.022	0.331	0.019	-0.747	.46277
Beta2	0.311	0.02	0.324	0.018	-0.569	.57517
Gamma	0.293	0.02	0.316	0.018	-0.951	.35202
Parietal derivations (P3-P4)						
Delta	0.660	0.044	0.632	0.039	0.848	.40582
Theta	0.632	0.045	0.641	0.042	-0.314	.75659
Alpha1	0.569	0.039	0.592	0.043	-0.706	.48758
Alpha2	0.502	0.038	0.539	0.042	-0.903	.3764
Beta1	0.510	0.044	0.515	0.043	-0.141	.88948
Beta2	0.482	0.042	0.493	0.036	-0.307	.76205
Gamma	0.490	0.045	0.469	0.034	0.583	.56593
Occipital derivations (O1-O2)						
Delta	0.615	0.044	0.606	0.041	0.257	.79948
Theta	0.626	0.051	0.631	0.043	-0.128	.89945
Alpha1	0.657	0.047	0.668	0.051	-0.268	.79118
Alpha2	0.674	0.059	0.686	0.044	-0.249	.80573
Beta1	0.596	0.052	0.575	0.042	0.501	.62152
Beta2	0.561	0.051	0.565	0.039	-0.089	.92997
Gamma	0.556	0.054	0.534	0.039	0.598	.55563

Note. Interhemispheric coherence mean values for each condition for the seven frequencies band with their standard deviation, statistical comparation from Student *t* test with 22 degrees of freedom and his correspondent *t* in each pair of electrodes. RET = Retention, IMG = Imagery, *SD* = Standard Deviation.

Table 2. Left intrahemispheric coherence values

Bands	RET	*SD*	IMG	*SD*	*t*	*p*
Fronto-temporal derivations (F3-T3)						
Delta	0.883	0.06	0.867	0.051	0.260	.79738
Theta	0.876	0.058	0.875	0.055	0.017	.98627
Alpha1	0.841	0.055	0.824	0.061	0.325	.74831
Alpha2	0.817	0.056	0.823	0.057	-0.091	.92844
Beta1	0.849	0.060	0.846	0.057	0.043	.96614
Beta2	0.813	0.063	0.818	0.055	-0.082	.93512
Gamma	0.755	0.06	0.758	0.051	-0.048	.96249
Fronto-parietal derivations (F3-P3)						
Delta	0.494	0.031	0.514	0.034	-0.527	.60333
Theta	0.586	0.033	0.562	0.039	0.495	.6255
Alpha1	0.513	0.031	0.503	0.034	0.276	.78486
Alpha2	0.453	0.039	0.458	0.035	-0.140	.89013
Beta1	0.526	0.038	0.554	0.043	-0.577	.5699
Beta2	0.527	0.040	0.559	0.044	-0.713	.48348
Gamma	0.552	0.036	0.572	0.046	-0.399	.69355
Fronto-occipital derivations (F3-O1)						
Delta	0.316	0.028	0.376	0.029	-2.136	.04407 *
Theta	0.352	0.030	0.412	0.035	-1.793	.08676
Alpha1	0.330	0.024	0.386	0.031	-1.767	.09117
Alpha2	0.312	0.027	0.363	0.032	-1.858	.07653
Beta1	0.347	0.029	0.418	0.041	-2.095	.04788 *
Beta2	0.365	0.036	0.433	0.048	-2.051	.05237
Gamma	0.395	0.032	0.462	0.047	-1.610	.12157
Temporo-parietal derivations (T3-P3)						
Delta	0.609	0.056	0.615	0.055	-0.174	.86361
Theta	0.688	0.052	0.646	0.055	1.284	.21247
Alpha1	0.627	0.044	0.627	0.049	0.013	.98963
Alpha2	0.601	0.048	0.603	0.047	-0.068	.94655
Beta1	0.659	0.045	0.663	0.049	-0.096	.92406
Beta2	0.664	0.052	0.676	0.047	-0.360	.72226
Gamma	0.644	0.051	0.665	0.048	-0.648	.52375
Temporo-occipital derivations (T3-O1)						
Delta	0.361	0.035	0.416	0.042	-1.740	.09583
Theta	0.377	0.041	0.430	0.045	-2.326	.02965*

Alpha1	0.363	0.041	0.397	0.039	-1.033	.31293
Alpha2	0.347	0.035	0.384	0.041	-1.251	.22393
Beta1	0.376	0.038	0.414	0.042	-1.248	.22528
Beta2	0.416	0.044	0.442	0.044	-0.863	.39765
Gamma	0.429	0.044	0.464	0.046	-1.058	.30172
Parieto-occipital derivations (P3-O1)						
Delta	1.073	0.065	1.152	0.066	-1.771	.09034
Theta	1.045	0.067	1.115	0.065	-1.700	.10319
Alpha1	1.042	0.063	1.099	0.059	-1.468	.15616
Alpha2	0.988	0.068	1.023	0.064	-0.698	.4925
Beta1	1.031	0.068	1.055	0.074	-0.554	.58514
Beta2	1.059	0.071	1.096	0.072	-0.895	.38067
Gamma	1.059	0.068	1.088	0.073	-0.665	.51321

Note. Left intrahemispheric coherence mean values for each condition for the seven frequencies bands with their standard deviation, statistical comparation from Student *t* test with 22 degrees of freedom and his correspondent *t* in each pair of electrodes. RET = Retention, IMG = Imagery, *SD* = Standard Deviation. RET = Retention, IMG = Imagery, *SD* = Standard Deviation

*$p < .05$.

Table 3. Right Intrahemispheric Coherence values

Bands	RET	*SD*	IMG	*SD*	*t*	*p*
Fronto-temporal derivations (F4-T4)						
Delta	0.864	0.043	0.809	0.040	1.366	.18578
Theta	0.873	0.040	0.829	0.041	1.169	.25491
Alpha1	0.807	0.039	0.785	0.040	0.678	.50456
Alpha2	0.816	0.037	0.799	0.045	0.585	.5643
Beta1	0.778	0.035	0.777	0.034	0.013	.98991
Beta2	0.764	0.037	0.770	0.039	-0.226	.82305
Gamma	0.739	0.040	0.717	0.042	0.740	.46718
Fronto-parietal derivations (F4-P4)						
Delta	0.474	0.030	0.555	0.031	-2.989	.00676*
Theta	0.518	0.035	0.592	0.032	-2.478	.02134*
Alpha1	0.425	0.027	0.496	0.040	-1.772	.09021
Alpha2	0.397	0.026	0.482	0.036	-2.724	.01240*
Beta1	0.442	0.033	0.540	0.040	-2.889	.00852*
Beta2	0.499	0.038	0.600	0.044	-2.842	.00948*
Gamma	0.583	0.042	0.671	0.038	-2.503	.02025*

Fronto-occipital derivations (F4-O2)						
Delta	0.332	0.021	0.388	0.033	-1.665	.11014
Theta	0.328	0.022	0.394	0.040	-1.856	.07692
Alpha1	0.310	0.016	0.389	0.040	-2.122	.04537*
Alpha2	0.311	0.023	0.375	0.039	-1.525	.14151
Beta1	0.305	0.019	0.385	0.043	-2.490	.02082*
Beta2	0.341	0.027	0.438	0.055	-2.354	.02792*
Gamma	0.404	0.037	0.482	0.051	-2.169	.04117*
Temporo-parietal derivations (T4-P4)						
Delta	0.451	0.031	0.506	0.039	-1.394	.17717
Theta	0.516	0.037	0.535	0.038	-0.525	.60513
Alpha1	0.500	0.039	0.516	0.035	-0.394	.69709
Alpha2	0.442	0.034	0.497	0.034	-1.388	.17900
Beta1	0.479	0.037	0.529	0.033	-1.454	.16013
Beta2	0.515	0.036	0.552	0.038	-0.963	.34603
Gamma	0.529	0.040	0.548	0.038	-0.549	.58875
Temporo-occipital derivations (T4-O2)						
Delta	0.344	0.023	0.378	0.033	-0.800	.43247
Theta	0.332	0.024	0.357	0.034	-0.738	.46844
Alpha1	0.327	0.019	0.364	0.032	-1.163	.25718
Alpha2	0.319	0.019	0.384	0.035	-1.956	.06328
Beta1	0.312	0.020	0.364	0.032	-1.574	.12984
Beta2	0.332	0.025	0.385	0.038	-1.388	.17907
Gamma	0.355	0.031	0.386	0.037	-0.831	.41511
Parieto-occipital derivations (P4-O2)						
Delta	1.003	0.053	1.088	0.073	-1.941	.06516
Theta	1.003	0.055	1.055	0.079	-1.150	.26265
Alpha1	1.012	0.060	1.016	0.071	-0.098	.92279
Alpha2	0.964	0.062	0.965	0.074	-0.027	.97868
Beta1	0.985	0.057	0.976	0.075	0.226	.82311
Beta2	1.000	0.059	1.016	0.077	-0.366	.71812
Gamma	1.009	0.061	1.015	0.076	-0.159	.87551

Note. Right intrahemispheric coherence mean values for each condition for the seven frequencies bands with their standard deviation, statistical comparation from Student *t* test with 22 degrees of freedom and his correspondent *t* in each pair of electrodes. RET = Retention, IMG = Imagery, *SD* = Standard Deviation

*$p < .05$.

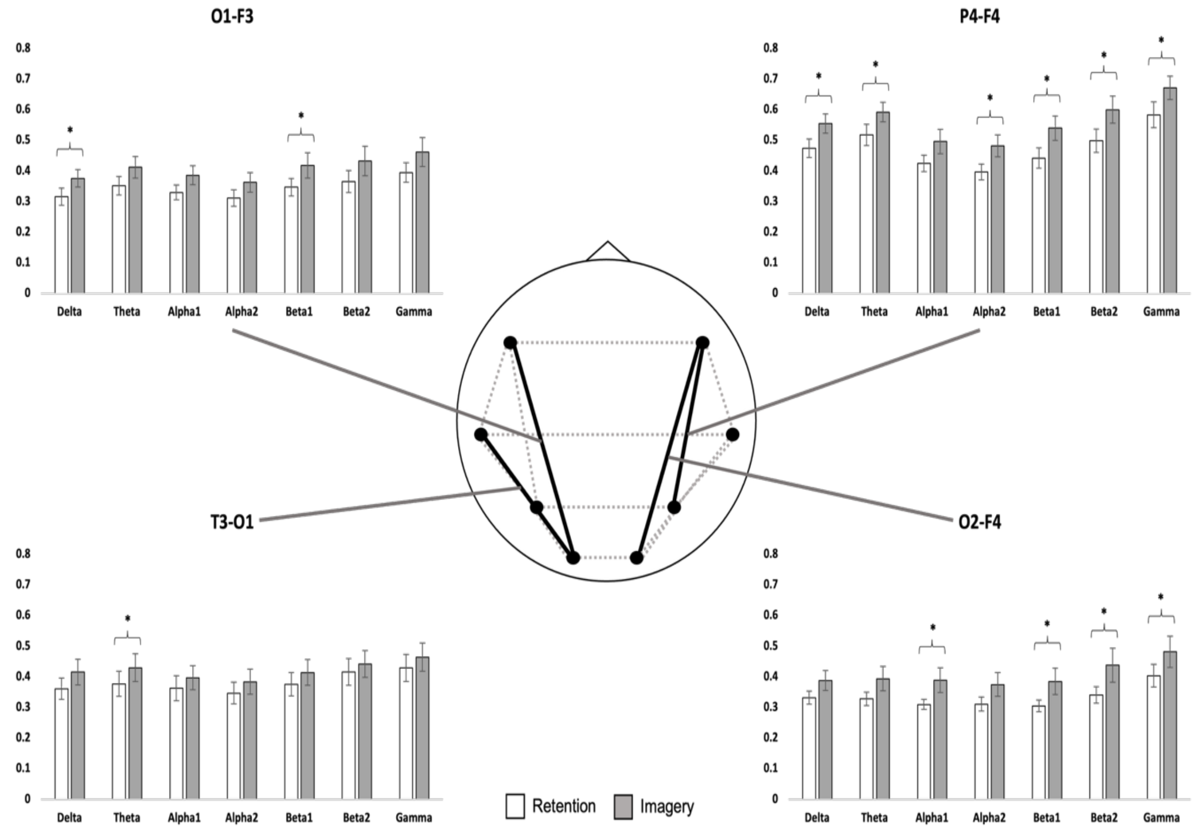
The left intrahemispheric EEG coherence showed significant differences for the F3-O1 and T3-O1 derivations. In the case of F3-O1, the coherence values for the Delta band were increased in Imagery phase compared with the Retention phase, as well as Beta1 coherence values. For T3-O1, derivations coherence values show a similar pattern to those previous derivations, with an increased coherence values during the Imagery phase compared with Retention phase.

In the case of right intrahemispheric EEG coherence significant differences were observed for the F4-P4 and F4-O2 derivations. F4-P4 coherence showed significant differences for almost all bands with exception of Alpha1, characterized by an increased coherence values during the Imagery condition compared with Retention condition. F4-O2 coherence showed significant differences just for Alfa1, Beta1, Beta2 and Gamma bands, with increased coherence values for Imagery condition compared to Retention condition. Results are synthetized in Figure 2. Post hoc power analysis showed a statistical power value > .99 for all comparisons.

Discussion

A comparison of the measures of EEG signals in terms of coherence was made. It is hypothesized that mental imagery elicitation in young men will have a pattern of increased synchronization in fast bands (Beta1, Beta2 and Gamma) among occipital and frontal regions, which was confirmed by the results finding a greater synchronization during the Imagery with regard to the Retention phase in left

Figure 2. Coherence means values of comparisons for both conditions in the pair of electrodes with statistical significance



Note. In graphs x axis shows the seven frequency bands analyzed and y axis shows coherence expressed in *z*. $*p < .05$.

fronto-occipital regions in delta and beta1 bands; in temporo-occipital regions in the theta band; in delta, theta, alpha1, alpha2, beta1, beta2 and gamma bands in right front-parietal regions; finally, in right front-occipital regions in alpha1, beta1, beta2 and gamma. Although the hypothesis did not include hemispheric lateralization, a characteristic pattern was found and is described below.

Coherence levels related to left hemisphere participation on temporo-occipital regions could be linked to the semantic characteristics involved in generating new images, provided that occipito-temporal connections are recognized as the ventral pathway or the "what" in visual recognition (Otegui et al., 2013). Other studies describe that visual processing is a response inside the left ventral pathway, where the posterior regions specifically assess visual shapes, while anterior regions assess the lexical and semantic characteristics (Moore & Price, 1999; Simons et al., 2003; Price & Mechelli, 2005; Vinckier et al., 2007; Levy et al., 2008).

Contrary to the hypothesis, slow bands coherence differences were observed, mainly on the theta band between the temporal and occipital derivations could suggest the participation of stimuli previously stored in memory, as explained by Klimesch et al. (2001). Since it is possible to identify the brain regions activated when subjects report conscious experiences, specifically, in object detection and previous event recovery. In other words, subjects can usually recognize and create conscious experiences after visualizing an image. Also, the activation in the theta band has been related to prolonged attention and information retention, as happens in working memory, in addition to information retrieval and episodic codification (Klimesch, 1999; Klimesch et al., 2010). Studies like the one of Guderian et al. (2009) indicate that the activity of the theta band increases when objects are observed when they have been watched before. This may relate to the subject's familiarity with the visual stimuli, as could be the case with the geometric figures presented in our study.

Furthermore, we can find that the temporal lobes participate in information segmentation to make sense of the images and to identify objects in space (Gallegos-Duarte, 2016). This is due to the importance of the second visual pathway, named the pathway of "where". This could be related to the presented stimuli on the screen, since subjects were supposed to integrate the construct of the presented images and in this sense, they could follow the instruction "imagine a new figure" to integrate the elements of the presented stimuli.

In the case of the left fronto-occipital coherence, it was found that the frontal activation is stratified for perceptual tasks, principally in an attention state towards a visual stimulus during prolonged time (Culham et al, 1998). Although little is known about the ventral pathway, associated with attention and visual process, a greater lateralization in the left hemisphere is described in right-handed people (González & Hornauer-Hughes, 2014). This claim matches results in this study, considering that the sample was made with right-handed subjects, and perhaps the activation mainly in this pathway, maybe due to the characteristics of the task and the attentional resources needed to execute it.

The coherence pattern observed in the right hemisphere matches prior claims herein regarding hemispheric lateralization in graphic content management in comparison to verbal content; since it is considered that the right hemisphere is associated mainly with visual and symbols representation and in general all the creative process (Cueva, 2016). Pérez-Rubín (2001) mentioned that creativity is highly lateralized in the right hemisphere, having a greater participation in low frequency waves as alpha and theta, where the latter is activated in the creative dream and active imagination, while alpha is present during relaxation, deep meditation, and alertness responsiveness. Otherwise has been recognized the relevant of alpha activity during creativity process (Lustenberger et al., 2015). Also, a dynamic interaction among default and control networks has been proposed in creative process, with the contribution of possible ideas by the default network, and the evaluation of the effectiveness of those ideas by the control network (Beaty et al., 2016).

Villena-González (2016) described that the process of attentional control involved in internal attention is probably present during imagery. This author proposes that alpha oscillations have a direct relationship with cortical visual processing, proving that attention is oriented internally, and it has been identified as a reduction in the brain capacity to external stimuli processing. Pursuant to this claim, it is considered that both supramodal processing and specific sensory mode could be pertain in paying attention to inner thoughts; therefore, thoughts are more associated with image processing, more likely related to visual than verbal mode.

However, there is a primary visual pathway, located in the occipital cortex in the 17 Brodmann area. Likewise, the visual association areas are in Brodmann areas 18 and 19; this track is represented in the left hemisphere and viceversa (Molina et al., 1984). Furthermore, Otegui et al. (2013) identified the superior longitudinal fasciculus, which contains occipito-temporal fibers, a system that connects Brodmann area 37 in the temporal lobe with areas 17, 18 and 19, which build the visual ventral pathway, explained herein above. D'Andrea et al. (2019) propose that alpha rhythm in the parietal lobe modulates the relation between frontal and visual cortex supported by the superior longitudinal fascicule activity.

While the superior longitudinal fascicle contains occipito-frontal fibers, this system connects Brodmann areas 17, 18 and 19 with the parietal lobe, through the dorsal flow and temporal lobe through the ventral flow. This dorsal pathway is responsible for volunteer visual exploration and focused attention on an object of interest (Otegui et al., 2013). Thus, the coherence results in front-occipital in fast bands could be related to the active manipulation of visual information coming from the occipital region, through the occipito-frontal fascicle.

Lutzenberger et al. (1995) explain that humans and animals experience an increase in the gamma band in cortical areas when they see moving objects. Tallon-Baudry et al. (1996) found a correlation between the activity increase about gamma band in stimuli such as illusory figures or rotating faces images. It has also been identified that increased activity of this band is interpreted as an ascendant activation of the cortical networks that generate a subjective perception as a possible neural correlate of consciousness, at the same time, descendant processes are identified in the internal activation, during the representation of an object in a visual search task (Engel et al., 2001; Tallon-Baudry et al., 1997).

In a study during the conservation task of abstract drawings, Sarnthein et al. (1998) identified the participation of the right prefrontal cortex, showing the importance of episodic memory recovery. In this study, it was possible to correlate the gamma band with sensorial processing and an increase in attention. Locally driven synchronization, such as sensory processing, could give rise to a gamma band range, in the support of the working memory with lower frequencies. In other words, it is possible that gamma oscillations occur simultaneously with longer-range theta waves, which could allow fast oscillations, nesting in slow ones, providing a temporary structure to assemble neurons involved in working memory retention (Sarnthein et al., 1998).

Another study by Sauseng et al. (2005), on executive function and working memory, where participants were asked to make associations on abstract images, short-range connectivity in alpha and gamma waves was found. Gamma band coherence was shown as a local activity, which could suggest that alpha band activity might play an important role in long-range connectivity in specific cognitive demands, such as memory, and it could be interpreted as increased cortical inhibition, while the theta band is related to the encoding process. In this sense, it is proposed that coherence could be influenced by phase coupling between brain regions due to power changes, which could indicate a precise adjustment of a neural network to the demands of central executive functions in working memory.

On the other hand, Fries (2005) explains how numerous neuronal groups can interact with each other, in a flexible manner, through temporally aligned communication windows. The author proposes communication through coherence, which relies on the fact that activated neuronal groups have the intrinsic property of oscillating, and these oscillations constitute a rhythmic modulation in neuronal excitability; therefore, they can affect the probability of peak output as well as the sensitivity to synaptic input. Thus, the peaks of rhythmic excitability constitute a rhythmically recurring temporally aligned communication windows, and only coherently oscillating neuronal groups can communicate effectively, because their temporally aligned communication windows for input and output are open at the same time. This study reports that there is experimental evidence that the coherence between neuronal groups favors their communication and that the oscillations maintaining could be associated with the representation of the neural substrate of our cognitive flexibility.

Regarding connectivity between distant regions, it has been observed that there is interhemispheric synchronization during the resolution of mathematical problems. It has also been observed that there are transitions from one hemisphere to another in slow and fast bands, mentioning that the last ones are activated in parietal regions. In addition, it has been recognized the gamma band in cognitive tasks and with high levels of abstraction is linked as a band that allows communication between regions (Molina et al., 2021), so they could be associated with the information communication process which enables to analyze and send a response.

Regarding the front-parietal coherence, slow bands such as delta and theta were associated with an activation of frontal networks, updating the representations within memory, while parietal networks were activated to enable store long-term semantic knowledge of objects and that this knowledge increases during maintenance or retention period (Tóth et al., 2012), and even in the absence of a stimulus. In their study, the delta band was associated with the synchronization of the frontal region, indicating the maintenance of active memory functioning, while theta rhythm increased in visual tasks. This was related to the maintenance of memory and better performance on memory tasks.

Klimesch (1999) distinguishes the memory processes, such as working memory, long-term memory, and short-term memory, and explains that the cognitive process of memory depends on the resources that allow the activation of pathways from the bottom up, when recognizing an everyday or familiar object, where a sensory code is established, which allows semantic information into the long-term memory. This way the object is identified, creating in turn a code in the short-term memory. The author also considers that this route is not only identified visually, but also in a more complex cognitive way, such as speech and thought processes, since an interaction occurs between long-term memory and working memory.

Solís & Lopez-Hernandez (2009) proposed that working memory is made up by two systems: the first refers to attention control, which coordinates and supervises the activity of the articulatory and phonological system, since these allow the manipulation of the information that comes from language, while the second focuses on a type of "visual-spatial agenda" which is responsible for mental images. Among the areas that stand out as essential for memory activation are the primary sensory areas, prefrontal lobe, dorso-medial nucleus, thalamus, and neostriatum. Other authors found structures concentrated in the medial temporal lobe, and the hippocampal area (Squire et al., 1993; Markowitsch & Pritzel, 1985; Klimesch, 1999).

The frequency band that has been linked to working memory and mental effort is the theta band. Its activity has been observed mainly in the hippocampus and is considered essential for learning and memory acquisition and suggests that theta wave regulates the timing of information transmission. In this sense a large-scale functional network that involves frontal delta oscillations and his regulation via top-down control over posterior alpha oscillations plays a relevant role during the priority of visual working memory representation (de Vries et al., 2018).

In addition, studies have reported that frontal theta activity increases due to the difficulty of the task and memory demands. And they recognize a higher power of this band during memory encoding and retrieval. Furthermore, it is suggested that theta band is not related to manipulation, but rather to the mental effort to cope with a task (Klimesch, 1999; Gevins, 1997; Sarnthein et al., 1998). Therefore, it could be suggested that an increase in fronto-parietal coherence in the delta and theta bands could be linked to the participation of working memory in the process of manipulation and generation of new figures, which implies the maintenance of the stimulus figure in the mind. While in the fast bands, the greater coherence observed could be associated with the active participation of the superior longitudinal fasciculus during the transmission process of the manipulation of graphic information.

The presented data contributes to understand mental imagery through a coherence-based approach, trough this we found a right hemispheric lateralized processing involved posterior-anterior vias which can be using the synchronization towards slow bands to maintain the attention process and fast bands supporting the working memory behind mental imagery manipulation. The EEG coherence technique gives information about how the posterior and anterior areas communicate. In addition, this experimental task allows to evaluate the difference between retention and mental imagery production.

The study limitations are, in first instance, the dropout of a part of the initial sample, reducing the number of recordings to the final statistics. Besides, the drawings that the participants made after the imagery phase wasn´t considered in the analysis.

Future investigations could consider a correlation of electroencephalographic activity during the phase of imagery with the characteristics of the drawings, which could give more information about brain activity and the graphic content during imagery. Balbuena (2014) explains that graphic representation is a communication form that expresses formal elements of design, reinforcing the communications strategy and these types of expression. Some aspects can be evaluated in the mental representations and in the visual representations, that are important to define the meaning and classifications of the graphic structures.

Another future consideration, to generalize the results, is to expand the sample and considerer not only young men, but also women.

In accordance to the obtained results, it can identified a differentiated pattern of coherence for the retention and imagery states providing evidence of the particularities in functional electrical connectivity, which could imply the process of internal image manipulation, characterized by a predominant synchronous participation between the occipital and parietal regions with the prefrontal regions of the right hemisphere, associated with maintenance, manipulation and creation of new graphic elements processes.

Characterization of cognitive processes through EEG data brings an approximation to understand the neural and functional substrates of subjective activity like imagery and can provide objective data for artificial cognitive systems with applications in machine learning and artificial intelligence.

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