Cortical sensorial processing of alpha rhythm in attention and hyperactivity deficit disorder

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Abstract

Attention-deficit/hyperactivity disorder (ADHD) is characterized by hyperactivity, impulsivity, and/or inattention. Changes in cortical processing, including impaired attention and concentration are widely seen in the literature. Furthermore, sensory processing disorders are frequent findings in this population. The electroencephalogram has been an instrument capable of providing real-time data on the cerebral cortex. Abnormalities in alpha band oscillations are found in individuals with ADHD. Although sensory alterations are reported in patients with ADHD, few studies correlate them with cortical activity and alpha rhythm. **Objective:** To compare the sensory processing of the alpha rhythm in individuals with ADHD and neurotypical individuals using electroencephalographic techniques. **Methods:** Comparative, analytical and cross-sectional study. Individuals of both sexes, aged

Recebido em: 09/17/2021 | Aprovado em: 02/02/2022

between five and 20 years, neurotypical and diagnosed with ADHD participated in the experiment. The alpha rhythm in visual, gustatory, auditory, olfactory and somesthetic cortical sensory processing was analyzed and compared between the groups. The Lilliefors normality test and the Mann-Whitney test were used. It was considered significant p ≤ 0.05. **Results:** The general mean age was 16.25 ± 4.61 years. There was a decrease in the alpha rhythm in light and gustatory visual cortical processing activities. However, there was an increase in the alpha rhythm in the activities of visual processing with image and auditory speech comprehension. **Conclusion:** The cortical sensory processing of the alpha rhythm is altered in individuals with ADHD for some of the activities performed. However, further studies are needed to expand and refine this analysis, in order to understand the neurophysiological mechanism involved in the cortical electrical sensory processing of individuals with ADHD.

Keywords

Attention deficit disorder with hyperactivity. Electroencephalography. Alpha rhythms. Sensory processing.

INTRODUCTION

Characterized by attention, concentration, and hyperactivity difficulties, the attention-deficit/hyperactivity disorder (ADHD) is a neurobiological disease of unknown etiology (TRIPP; WICKENS, 2009) that interferes with the affective, learning, and social relationships of those who have it (ASHERSON, 2012). There are cases with a prevalence of inattention and others with hyperactivity and impulsivity standing out. There are also cases associated with inattention and hyperactivity (PUENTE *et al*., 2002). Several studies have been conducted to discover which substrate in the neurological system is affected in individuals with ADHD (TRIPP; WICKENS, 2009; KONRAD; EICKHOFF, 2010). Researchers estimate that cortical electrical waveform alterations in prefrontal areas are associated with ADHD (ELLIS *et al*., 2017), compromising the performance of tasks requiring executive function skills, such as attention, concentration, planning, and working memory of these individuals (FAEDDA *et al*., 2019; SILVERSTEIN *et al*., 2018).

The genetic component appears to be related ADHD occurrence (DEMONTIS *et al*., 2019) and, worldwide, 5% to 8% of the children are affected by the disorder (ASHERSON, 2012). It is more frequent in boys than girls (SCHNEIDER; EISENBERG, 2006) and the cortical electrical changes found in girls are smaller in amplitude than in boys (CLARKE *et al*., 2003). In two-thirds of the cases, ADHD is persistent, remaining in adulthood, with an estimated prevalence of 2.5 to 4.5% (ASHERSON *et al*., 2016).

The electroencephalogram (EEG) is a neurophysiological measurement test that quantifies cortical electrical activity in real-time, making it possible to obtain records while the individual performs cortical processing activity, awake or sleepy, through electrodes on the scalp. Because of their versatility, low cost, and easy availability, EEG records are being studied as promising biomarkers for neuropsychiatric disorders, including in individuals with ADHD (MCVOY *et al*., 2019; LENARTOWICZ *et al*., 2014; ALDEMIR *et al*., 2018).

Delta, theta, alpha, beta, and gamma are the designations for the frequency variations of the EEG records found, floating between 0.5 and 70 Hz (ALDEMIR *et al*., 2018). The delta and theta bands are found during sleep, while the alpha rhythm is observed when the individual is awake, relaxed, with low mental activity, and it is possible to observe oscillations between 8 and 13 Hz in the electroencephalographic records. In turn, when there is an increase in blood supply in a region it may mean that there was increased cortical electrical processing in that area, as observed in the beta frequency range. Finally, the gamma rhythm has been attributed to the most intense cortical processing recorded in the human cerebral cortex, suggesting that the cortical area would be responsible for processing the activity performed (NIEDERMEYER, 1996).

Alpha-band oscillations have been designated as an important modulator of information processing in the brain, directing attention since the alpha activity is considered inversely proportional to the cortical activation increase. As it is known, ADHD makes it difficult for the patients to avoid distractions, control impulsivity, and self-regulate. Therefore, several pieces of evidence point to the alpha rhythm as a promising study target in this population (HUURNE *et al*., 2017; LENARTOWICZ *et al*., 2019).

Although authors have shown that ADHD individuals have a more distorted sensory processing than neurotypical people (LITTLE *et al*., 2017; KAMATH *et al*., 2020; GHANIZADEH, 2013; SMITH *et al*., 2020), few kinds of research correlate altered sensory processing with cortical electrical activity. The behavior of alpha-band oscillations in sensory cortical processing activities in individuals with ADHD is rarely studied. In this sense, the EEG is opportune to analyze the cortical sensory processing of individuals with ADHD in order to discover the sensory neurophysiology of the alpha rhythm of these patients.

METHODS

This is a comparative, analytical, cross-sectional, and experimental study, approved by the Research Ethics Committee of the Universidade Estadual de Ciências da Saude de Alagoas, under protocol number 2.383.568.

Following the study by Nazari *et al*. (2012), the sample was defined by convenience, and it was non-probabilistic by volunteering. Individuals of both genders were included, aged between five and 20 years, neurotypical and diagnosed with ADHD by a neuropediatrician and/or psychiatrist, following the *Diagnostic and Statistical Manual of Mental Disorders V* (DSM-V, 2013) criteria. Individuals with comorbidities were excluded, such as those with acquired brain damage and taking psychotropic drugs.

The independent variables were the alterations in sensory processing, and the dependent variables were the relative potency of the alpha rhythm.

After approval by the Research Ethics Committee, the participants were selected based on the eligibility criteria. At the time, the researchers presented the study proposal and procedures and, after a clear explanation of the steps, the participants were asked to sign the Informed Consent Form (ICF) to start data collection.

The participants were grouped into individuals with ADHD and neurotypical individuals, paired by sex and age. Everyone was submitted to an experimental session, always held in the morning shift.

It was used an EMSA EEG, model 64 nano, with 29 channels. In addition, the 10-20 international system was adopted, and after cleaning the scalp with gauze, an electrolytic paste was used to fix the electrodes. The brain electrical signals were sampled at 256 Hz and filtered for more in the range of 0.1 Hz.

For the experiment, the participants were asked to sit in a comfortable chair and close their eyes. The recording of the electroencephalographic began, following the protocol: one minute of basal recording in vigil, followed by 30 seconds of each sensory processing activity (visual [light and image], gustatory, auditory [noise and speech understanding], olfactory, and somesthetic).

Through two separate activities, visual sensory processing was analyzed. The first consisted of visual luminous stimulation. The stimulus was alternately applied to each eye with a yellow-light pen flashlight, occluding the contralateral eyeball with the researcher's hand. The second stimulus was visual with an image – the participant was asked to stare at a colorful image of animals in a children's book.

Next, gustatory sensory processing was evaluated. In this stage, two flexible shafts soaked in mint-flavored mouthwash were introduced into the participants' labial commissures.

The auditory sensory processing was evaluated using two stimuli: noise and speech compression. In the first moment, a rattle was used at an intensity of 64 dB. This was followed by a speech comprehension activity, in which four questions were asked and repeated twice each by the researcher ("What is your name?", "How old are you?", "Where do you live?" and "Do you study?"). The participant was instructed to understand the questions mentally.

Olfactory processing was analyzed from deep breathing in a solution of eucalyptus oil soaked in absorbent cotton. Finally, somesthetic processing was assessed by introducing the participant's hands into a recipient containing rice.

The analysis of the electroencephalographic records was performed by selecting three epochs (1.30s) of cortical electrical activity during each sensory processing activity performed. The Fourier transform was used to analyze the records, allowing the observation of the cortical alpha frequencies in each quadrant of the cerebral cortex. The electroencephalographic signals were amplified and digitalized, and the brain mapping information was analyzed. All the information obtained was archived on an external hard drive.

We compared the relative cortical frequency of alpha activity in each quadrant of participants of both groups. Lilliefors normality test and Mann-Whitney test were used. It was considered $p \leq 0.05$. Statistical analysis was performed using BioEstat 5.8.9 software (Mamirauá Institute, Tefé, Amazonas, Brazil).

RESULTS

Participants' characteristics

The study included 16 individuals, of whom eight (50%) were allocated to the ADHD group and eight (50%) to the control group, paired by sex. The overall mean age was 16.25 ± 4.61 years. In the ADHD group, the mean was 16.12 ± 5.16 years, and in the control group, it was 16.37 ± 4.34 years.

Alpha rhythm

In visual cortical processing activity with light stimulus, there was a significant decrease in alpha rhythm activity in the right posterior quadrant of the ADHD group individuals ($p \leq 0.05$). In contrast, in visual processing activity with image, alpha frequency activity was increased in the right anterior quadrant for the same group ($p \leq 0.05$).

During the gustatory stimulus activity, a significant decrease in alpha activity was observed in the left anterior quadrant in individuals with ADHD ($p \leq 0.05$), and in the language comprehension activity, in the experimental group, an increase in alpha rhythm activity was observed in the left anterior quadrant ($p \leq 0.05$). The sensory processing activities are displayed in Table 1.

Table 1 Mean, standard deviation, median, second, and third quartile of alpha rhythm power in the left anterior (LA), right anterior (RA), left posterior (LP), and right posterior (RP) quadrants, at the time of cortical processing activity

Visual processing				
Luminous stimulus				
	LA	**RA**	**LP**	**RP**
Control	9.93 ± 0.46 (9.75/9/10)	10.00 ± 0.35 (10/9.75/10)	9.50 ± 0.66 (9.5/9/9.25)	9.75 ± 0.35 (9.5/9/10)
ADHD	9.93 ± 0.52 (9.75/9/10)	9.87 ± 0.54 (9.75/9/10)	9.50 ± 0.79 (9.75/8.75/10)	9.12 ± 0.64* (9.5/8.75/9)
Image stimulus				
	LA	**RA**	**LP**	**RP**
Control	9.75 ± 9.43 (9.5/9/9.25)	9.56 ± 0.68 (9.5/9/10)	9.75 ± 0.79 (9.75/9/10)	10.25 ± 0.93 (10//10)
ADHD	10.25 ± 1.27 (10.25/9/10)	10.50 ± 0.93* (10.25/9.75/10.5)	9.37 ± 0.85 (9.5/8.75/10)	9.62 ± 0.73 (9.5/9/10)
Gustatory processing				
	LA	**RA**	**LP**	**RP**
Control	10.06 ± 0.39 (10/9.75/10)	9.87 ± 0.48 (9.5/9/10)	9.87 ± 0.48 (9.5/9/10)	9.87 ± 1.19 (9.5/9/10)
ADHD	9.00 ± 0.41* (9.5/9/9)	9.5 ± 0.39 (9.5/9/9)	9.5 ± 1.10 (9.5/8.75/9.25)	9.5 ± 0.78 (9.5/9/9)

(*continue*)

Table 1 Mean, standard deviation, median, second, and third quartile of alpha rhythm power in the left anterior (LA), right anterior (RA), left posterior (LP), and right posterior (RP) quadrants, at the time of cortical processing activity (*continuation*)

Auditory processing				
Noise stimulus				
	LA	**RA**	**LP**	**RP**
Control	9.00 ± 1.03 (8.75/8/10)	8.75 ± 0.90 (8.25/8/9)	9.43 ± 0.91 (9.5/8.75/10)	8.57 ± 0.94 (8/8/8.625)
ADHD	8.81 ± 0.74 (8.75/8/9)	9.12 ± 1.13 (9/8/9.25)	9.18 ± 1.22 (9/8/9.25)	8.87 ± 0.81 (8.5/8/9)
Speech comprehension stimulus				
	LA	**RA**	**LP**	**RP**
Control	9.25 ± 0.75 (9.5/8.75/9.25)	10.18 ± 0.34 (10.25/10/10)	9.93 ± 0.52 (10/9/10)	9.50 ± 0.68 (9.5/9/10)
ADHD	10.18 ± 0.86* (9.75/9/10.25)	9.81 ± 0.78 (10/9/10)	9.25 ± 0.91 (9.5/8/10)	9.25 ± 0.82 (9.5/8.75/9.25)
Olfactory processing				
	LA	**RA**	**LP**	**RP**
Control	9.87 ± 0.81 (10.25/9/10)	9.56 ± 0.68 (9.5/9/10)	9.93 ± 0.68 (10.25/9/10)	9.56 ± 0.94 (10/8.75/10)
ADHD	9.87 ± 1.21 (9.75/8.75/10.25)	9.81 ± 1.17 (9.75/8.75/10)	10.00 ± 0.96 (10.25/9/10)	9.75 ± 0.90 (9.75/9/10)
Somesthetic processing				
	LA	**RA**	**LP**	**RP**
Control	9.87 ± 0.41 (9.75/9/10)	9.93 ± 0.39 (10/9/10)	9.81 ± 0.34 (9.75/9/10)	9.56 ± 0.68 (9.5/9/10)
ADHD	9.75 ± 0.35 (9.5/9/10)	9.81 ± 0.65 (9.75/9/10)	9.50 ± 0.93 (9.75/9.75/10)	9.50 ± 0.82 (9.5/8.75/10)

Source: Elaborated by the authors.

Note: *$p \leq 0.05$.

DISCUSSION

The study was conducted with 16 participants, with a mean age of 16.25 ± 4.61 years. A decreased alpha rhythm was found in the visual luminous processing activities in the right posterior quadrant and, for the gustatory processing activities, in the left anterior quadrant. However, increased alpha rhythm was found in visual image processing activities in the right anterior quadrant and, for auditory speech comprehension, in the left anterior quadrant.

Ellis *et al*. (2017) suggested that asymmetry of alpha rhythm oscillation in the right and left frontal cortex is somewhat present in individuals with ADHD, indicating that altered alpha rhythm modulation in frontal areas is related to disinhibitory behavior. This finding corroborates those found in our experiment, in which changes of oscillations in frontal regions in three of the tested activities, such as decreased alpha activity in the left anterior quadrant in the gustatory cortical processing activity, increased alpha rhythm in the left anterior quadrant in the auditory speech comprehension activity. An increase in the right anterior quadrant in the visual image stimulus was found in individuals with ADHD, emphasizing the asymmetry of alpha rhythm between right and left anterior quadrants.

Huurne *et al*. (2017) investigated the cognitive activity of spatial attention and found that the power of the ipsilateral posterior alpha rhythm increases while decreasing the contralateral one to the attended visual hemifield, inhibiting or facilitating the flow of information, respectively. These results contribute to the high power of alpha over regions linked to autonomic information processing for ideal suppression of distraction. Our findings indicate that in the visual luminous processing activity, there was a decrease in alpha rhythm power in the right posterior quadrant in ADHD participants, demonstrating that alpha rhythm in the face of light stimulus oscillates in this group. In this way, the scientific community can be aware of the different modulations of alpha rhythm during cortical processing in individuals with ADHD, in activities that require the visual sensory system as an input pathway of information.

Among the activities of the protocol proposed in this study, the stimulation of looking at the color image and speech comprehension are the ones that demand a more elaborate level of attention. For Ellis *et al.* (2017), an increase in alpha rhythm would indicate a change in attention levels. This fact agrees with our electroencephalographic findings, when we observed increased alpha activity in the right anterior quadrant in imaging performance and, on the other hand, increased alpha rhythm in the left anterior quadrant in speech comprehension skills.

By looking into the literature, we notice that the visual and auditory sensory pathways are more studied than the olfactory, gustatory, and somesthetic ones.

Although Schecklmann *et al.* (2011) have used functional magnetic resonance in individuals with ADHD and found an alteration in the frontal and temporal regions during olfactory sensibility stimulation, Karsz *et al.* (2008) reported alterations in the prefrontal regions, and Lorenzen *et al.* (2016) found an increased size of the olfactory bulb, indicating that this might be related to higher olfactory sensibility in individuals with ADHD, our study did not find a significant difference in alpha rhythm during olfactory sensory processing activities when comparing individuals with ADHD and the control group using EEG. This fact may be justified by the analysis of olfactory processing being hampered by integration in the uncus, a deep cortical structure not correctly assessed from surface EEG, even though several types of research reinforce that individuals with ADHD present alterations in olfactory sensibility when using other investigation methods (SCHECKLMANN *et al.*, 2011; KARSZ *et al.*, 2008; LORENZEN *et al.*, 2016; WEILAND *et al.*, 2011).

Our findings showed a decreased alpha rhythm in the left anterior quadrant before gustatory stimulus in individuals with ADHD. No data were found in the literature about gustatory cortical sensory processing in individuals with ADHD, corroborating Ghanizadeh (2013), when he states that oral sensory processing in children with ADHD is a limited area of research. Despite this, Weiland *et al.* (2011) conducted an experiment in which they identified that increased sensibility to bitterness might be a specific feature in ADHD patients and suggested that assessment of gustatory function may be a biological biomarker for ADHD. Little *et al.* (2017) demonstrated that children with ADHD have altered oral sensory processing.

Our study has some limitations, such as the use of sensory stimuli that are not very expressive or in small quantities, which may not have allowed triggering the action potential to increase or reduce the electrical activities in the analyzed quadrants in some of the proposed activities (for instance, the somesthetic processing activity evaluated by introducing the participants' hands into a recipient containing rice). Another limiting point of this research was the small number of participants, which is explained by the difficulty in finding individuals with ADHD who allow, are allowed to or are able to participate in an activity like the one performed in this study.

Besides, the activities analyzed in this research did not follow a validated protocol, which may have influenced positively or negatively the results obtained. Not using a validated protocol is justified because some of the activities tested were not found, which caused a need for adaptation and elaboration by the researchers.

CONCLUSION

Although altered alpha rhythm is evident in some of the cortical sensory processing activities in individuals with ADHD, when compared to neurotypical, the authors suggest that further studies should be conducted with the use of more powerful stimuli, with an increased sample size, as well as with the use of validated protocols, which will allow consistent results with few methodological interferences. Thus, it will be possible to elucidate the pathophysiology of alpha rhythm sensory processing in this population, use it as a possible biomarker and direct effective treatments for individuals affected by this disorder.

Processamento sensorial cortical do ritmo alfa no transtorno do déficit de atenção e hiperatividade

Resumo

O transtorno do déficit de atenção e hiperatividade (TDAH) é caracterizado por hiperatividade, impulsividade e/ou desatenção. Alterações nos processamentos corticais, incluindo prejuízo em atenção e concentração, são amplamente vistas na literatura. Além disso, os distúrbios do processamento sensorial são achados frequentes nesta população. O eletroencefalograma tem sido um instrumento capaz de fornecer dados em tempo real sobre o córtex cerebral. Anormalidades nas oscilações da banda alfa são encontradas em indivíduos com TDAH. Apesar de as alterações sensoriais serem relatadas nos pacientes com TDAH, poucos estudos as correlacionam com atividade cortical e com o ritmo alfa. Objetivo: Comparar o processamento sensorial do ritmo alfa entre indivíduos com TDAH e neurotípicos por meio de técnicas eletroencefalográficas. Método: Estudo comparativo, analítico e transversal. Participaram do experimento indivíduos de ambos os sexos, com idade entre 5 e 20 anos, neurotípicos e diagnosticados com TDAH.

O ritmo alfa nos processamentos sensoriais corticais visual, gustativo, auditivo, olfativo e somestésico foi analisado e comparado entre os grupos. Utilizaram-se o teste de normalidade de Lilliefors e o teste de Mann-Whitney. Considerou-se significante p ≤ 0,05. Resultados: A média de idade geral foi de 16,25 ± 4,61 anos. Houve diminuição do ritmo alfa nas atividades de processamento cortical visual luminoso e gustativo. No entanto, houve um aumento do ritmo alfa nas atividades de processamento visual com imagem e auditivas de compreensão de fala. Conclusão: O processamento sensorial cortical do ritmo alfa é alterado em indivíduos com TDAH para algumas das atividades executadas. Contudo, novos estudos são necessários para ampliar e refinar esta análise, a fim de compreender o mecanismo neurofisiológico envolvido no processamento sensorial elétrico cortical dos indivíduos com TDAH.

Palavras-chave

Transtorno do déficit de atenção com hiperatividade. Eletroencefalografia. Ritmo alfa. Processamento sensorial.

Procesamiento sensorial cortical del ritmo alfa en el trastorno por déficit de atención e hiperactividad

Resumen

El trastorno por déficit de atención con hiperactividad (TDAH) se caracteriza por hiperactividad, impulsividad y/o falta de atención. Los cambios en el procesamiento cortical, incluido el deterioro de la atención y la concentración, se ven ampliamente en la literatura. Además, los trastornos del procesamiento sensorial son hallazgos frecuentes en esta población. El electroencefalograma ha sido un instrumento capaz de proporcionar datos en tiempo real sobre la corteza cerebral. Las anomalías en las oscilaciones de la banda alfa se encuentran en personas con TDAH. Aunque se reportan alteraciones sensoriales en pacientes con TDAH, pocos estudios las correlacionan con la actividad cortical y el ritmo alfa. Objetivo: Comparar el procesamiento sensorial del ritmo alfa en individuos con TDAH y neurotípicos mediante técnicas electroencefalográficas. Método: Estudio comparativo, analítico y transversal. En el experimento participaron individuos de ambos sexos, con edades comprendidas entre los cinco y los 20 años, neurotípicos y diagnosticados de TDAH. El ritmo alfa en el procesamiento sensorial cortical visual, gustativo, auditivo, olfativo y somestésico fue analizado y comparado entre los grupos. Se utilizaron la prueba de normalidad de Lilliefors y la prueba de Mann-Whitney. Se consideró significativo $p \leq 0,05$. Resultados: La edad media general fue de 16,25 ± 4,61 años. Hubo una disminución en el ritmo alfa en las actividades de procesamiento cortical visual luminoso y gustativo. Sin embargo, hubo un aumento del ritmo alfa en las actividades de procesamiento visual con imagen y comprensión auditiva del habla. Conclusión: El procesamiento sensorial cortical del ritmo alfa se altera en individuos con TDAH para algunas de las actividades realizadas. Sin embargo, se necesitan más estudios para expandir y refinar este análisis con el fin de comprender el mecanismo neurofisiológico involucrado en el procesamiento sensorial eléctrico cortical de las personas con TDAH.

Palabras claves

Trastorno por déficit de atención e hiperactividad. Electroencefalografía. Ritmo alfa. Procesamiento sensorial.

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