ORIGINAL ARTICLE
TRAUMA
http://dx.doi.org/10.1590/S1808-185120222204276734

MODULATION OF BRAIN WAVES IN SPINAL CORD INJURY PATIENTS WITH PAIN: CROSS-SECTIONAL ANALYSIS

MODULAÇÃO DE ONDAS CEREBRAIS EM PACIENTES COM LESÃO MEDULAR E DOR: UMA ANÁLISE TRANSVERSAL

MODULACIÓN DE ONDAS CEREBRALES EN PACIENTES CON LESIÓN DE MÉDULA ESPINAL Y DOLOR: UN ANÁLISIS TRANSVERSAL

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ABSTRACT

Objective: This study aimed to describe the encephalographic electrical rhythm pattern of the Alpha wave in patients with traumatic spinal cord injury in the thoracic spine. Methodology: This is a cross-sectional observational study conducted from January to March 2022. A total of 20 patients with traumatic spinal cord injury were included in the study and divided into two groups, with pain symptoms and without pain symptoms. Both groups were submitted for evaluation for population characterization, identification of the presence of pain and the possible presence of signs and symptoms of central sensitization and quantitative electroencephalographic examination. Results: Comparing them, it was possible to observe a reduction of 38.7% (2.69μV; 95%CI 1.28 to 4.09) in the Alpha 2 wave (10-12 Hz) in the group with pain symptoms. This alteration was identified in the parietal lobe, mainly in PZ. Conclusion: We observed a selective reduction of Alpha 2 waves, mainly in the parietal region (PZ), in spinal cord injury patients with pain compared to spinal cord injury patients without pain. ***Level of Evidence III; Diagnostic Studies.***

Keywords: Brain Waves; Electroencephalography; Spinal Cord Injuries.

RESUMO

Objetivo: O objetivo deste estudo foi descrever o padrão do ritmo eletroencefalográfico da onda Alfa em pacientes com lesão medular traumática na coluna torácica. Metodologia: Trata-se de um estudo observacional transversal, realizado no período de janeiro a março de 2022. No total 20 pacientes com lesão medular traumática foram incluídos no estudo e divididos em dois grupos, com sintomas de dor e sem sintomas de dor. Ambos os grupos foram submetidos a avaliação para caracterização populacional, identificação de presença de dor e possível presença de sinais e sintomas de sensibilização central e ao exame Eletroencefalográfico quantitativo. Resultados: Ao compará-los foi possível constatar uma redução de 38,7% (2.69μV; 95%IC 1,28 to 4.09) da onda Alfa 2 (10-12 Hz) do grupo com sintomas de dor. Essa alteração foi identificada no lobo parietal, principalmente em PZ. Conclusão: Observamos uma redução seletiva de ondas Alfa 2, principalmente na região parietal (PZ), em pacientes com lesão medular com dor em relação aos pacientes lesão medular sem dor. ***Nível de Evidência III; Estudo diagnóstico.***

Descritores: *Ondas Encefálicas; Eletroencefalografia; Traumatismos da Medula Espinal.*

RESUMEN

Objetivo: El objetivo de este estudio fue describir el patrón del ritmo electroencefalográfico de la onda Alfa en pacientes con lesión medular traumática en la columna torácica. Metodología: Se trata de un estudio observacional transversal realizado entre enero y marzo de 2022. En total, se incluyeron 20 pacientes con lesión medular traumática en el estudio, divididos en dos grupos, uno con síntomas de dolor y otro sin síntomas de dolor. Ambos grupos fueron sometidos a evaluación para caracterización poblacional, identificación de presencia de dolor y posible presencia de signos y síntomas de sensibilización central, así como al examen electroencefalográfico cuantitativo. Resultados: Al compararlos, se pudo constatar una reducción del 38,7% (2,69 μV; IC del 95%: 1,28 a 4,09) en la onda Alfa 2 (10-12 Hz) del grupo con síntomas de dolor. Esta alteración se identificó en el lóbulo parietal, principalmente en PZ. Conclusión: Observamos una reducción selectiva de las ondas Alfa 2, principalmente en la región parietal (PZ), en pacientes con lesión medular y dolor en comparación con pacientes con lesión medular sin dolor. ***Nivel de Evidencia III; Estudios de diagnósticos.***

Descriptores: *Ondas Encefálicas; Electroencefalografía; Traumatismos de la Médula Espinal.*

Study conducted by the Dell Research, Development, and Innovation Center at Aldeota, Fortaleza, CE, Brazil.
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Received on 07/19/2023 accepted on 10/19/2023
Reviewed by: Murilo Daher

INTRODUCTION

Spinal cord injury (SCI) is an injury to the spinal canal structures (spinal cord, medullary cone, and cauda equina), which can cause motor, sensory, autonomic, and/or psycho-affective changes. Worldwide, the incidence of SCI is estimated to be between 768,473 and 790,695 cases yearly.[1] In Brazil, the prevalence of SCI is higher in the Northeast region (49%), with a higher percentage in males (83.5%) compared to females (16.5%) and with the most prevalent age being between 16 and 30 years (56.7%), the leading causes being firearm injuries (28.4%), motorcycle accidents (24.6%) and car accidents (19.1%).[2]

The diagnosis of SCI occurs through imaging tests associated with the clinical diagnosis. Guided by the International Standards for Neurological Classification of Spinal Cord Injury (ISNCSCI), defined in the American Spinal Injury Association (ASIA) Impairment Scale,[3,4] it is possible to classify the patient according to the type of lesion (complete or incomplete) and to determine the neurological level through the evaluation of sensorimotor deficiencies.

The main clinical manifestations found are limb paralysis or paresis, changes in muscle tone,[5] changes in superficial and deep reflexes, sensitivity, loss of sphincter control,[6] sexual dysfunction,[7] autonomic alterations, and the presence of pain.[8-10] This last manifestation may have functional, psychological, socioeconomic implications and may be a disabling factor that is sometimes more relevant than the motor loss itself.[11,12] According to the International Association for Study of Pain (IASP), pain is defined as "an unpleasant sensory and emotional experience associated, or similar to that associated, with actual or potential tissue injury".[13]

The prevalence of pain is reported between 11% and 94% of patients with SCI, and it can be classified into neuropathic, musculoskeletal, and visceral. When the pain is located above the compromised medullary region, the possibility of its origin being musculoskeletal is interpreted.[14] Musculoskeletal pain (MSD) originates from trauma or inflammation in bone, joint, or muscle tissues, mechanical instability, muscle spasm, or secondary to excessive use,[15] which in these cases are justified by the excessive use of intact body segments, and/or by staying in a wheelchair for a long time, as well as postural changes resulting from muscle imbalances caused by plegic or paretic muscles.

Several clinical instruments, such as the Nordic questionnaire,[16] can be used to assess pain. Still, most scales and/or questionnaires are based on the patient's subjective perception of pain, which can be influenced by factors such as cognitive status, mood, sleep, environment, etc. Such factors can interfere with pain regulation and perception, making a complementary assessment necessary, such as biomarkers, which allow the objective characterization of pain, thus favoring the determination of the best management.[17]

The use of potential electroencephalographic (EEG) biomarkers, already described in the literature with an accuracy of 87-90%, identified patterns of pain in the population with SCI, in addition to having significant implications for the assessment of pain in its neurophysiological characteristics and in terms of their response to treatments.[18]

It is a non-invasive test that analyzes the brain's electrical activities generated mainly by neuronal postsynaptic potentials, recorded through electrodes positioned on the scalp.[19] EEG signals can be differentiated into oscillations of different frequencies, with the delta band varying between 0.1 and 4 Hz, theta 4 and 8Hz, alpha 8 and 13Hz, beta 13 and 30Hz and gamma above 30Hz. Brain rhythms may change according to the behavioral state, level of attention, sleep, wakefulness, and some pathological conditions.[20]

Although there is no clear consensus to determine which rhythmic band has the most reliable correlation with different levels of pain induction, compared to other frequency domains, alpha-band oscillations (8–13 Hz) are the most commonly explored.[21,22] However, the literature does not mention which part of the alpha band in oscillation is related to musculoskeletal pain. Such specificity can better direct interventions through brainwave modulation. Therefore, this study aimed to describe the electroencephalographic rhythmic pattern of alpha waves in patients with traumatic spinal cord injury in the thoracic spine.

METHODOLOGY

This is a cross-sectional observational study based on a strategy of secondary analysis of quantitative data. This study follows the recommendations of the STROBE guideline (Strengthening the reporting of observational studies in epidemiology), which can be accessed at: https://www.strobe-statement.org/checklists/.

The study was conducted at the Dell Research, Development, and Innovation Center at Av. Santos Dumont, CEP 60.150-151 – Aldeota, Fortaleza – CE, from January to March 2022, upon approval by the Ethics Committee of the State University of Ceará (protocol number CAAE 51751021.4.0000.5534) and opinion nº 5.136.501. The volunteers signed the Informed Consent Form to participate in the study.

The profile of the participants consisted of twenty individuals diagnosed with traumatic spinal cord injury, paraplegic, with a thoracic spinal cord injury level (T1-T12), conveniently recruited via telephone, clinics, universities in the state of Ceará, and social and sports projects. The patients were adults over 18, of different genders, with a height between 1.50 cm and 1.83 cm and weight between 40 kg and 90 kg, with up to 10 years of injury. Healthy, without associated vascular diseases (for example, coagulation disorders and decompensated diabetes), and with blood pressure classified as normotension (120/80 mmHg or even ≤139/89 mmHg).[23]

As exclusion criteria, we considered individuals with blood pressure values ≥140/90 mmHg, classified as having hypertension,[23] vascular alterations (history of pulmonary or venous thromboembolism, aneurysm rupture less than one year ago), and/or cognitive disorders (Alzheimer's and/or Parkinson's in an advanced stage) that would decisively limit their responses to the applied questionnaires, as well as a panic syndrome, anxiety or depression crises during the evaluation, or individuals with relevant speech impairments that make it impossible to communicate/ full comprehension during qEEG tests.

The participants were divided into two groups, the Control Group (n=11), composed of paraplegics but without reports of MSD, and the Pain Group (n=9), composed of people with paraplegia and reports of MSD, in a convenience sample.

Sociodemographic Questionnaire

To characterize the sample, age, sex, weight (kg), height (m), and physical activity were collected. Individuals were asked about their neurological classification of spinal cord injury and whether the injury is complete or incomplete considering the ASIA scale through the assessment of sensorimotor deficiencies carried out by the physician.[4,5] Subsequently, the body mass index (BMI) was calculated considering weight (kg) and height (m) using the formula weight/ height 2 and classified with the parameters of BMI <18.5kg/m2 (low weight); BMI >18.5 to 24.9kg/m2 (eutrophic); BMI ≥25 to 29.9kg/m2 (overweight); and BMI >30.0kg/m2 (obesity).[24] The practice of physical activity was answered with yes or no, which activity was practiced, and the weekly frequency.

QNSO (Nordic Musculoskeletal Symptoms Questionnaire)

Developed to standardize the measurement of musculoskeletal symptoms and thus facilitate the comparison of results between studies, the QNSO is an instrument that consists of multiple or binary choices regarding the occurrence of symptoms in different anatomical regions. The patient must report symptoms during the 12 months and seven days before the interview and report the occupation of absence from routine activities in the last year. The questionnaire was translated and validated for the Brazilian version.[25] For this study, the data used were only the responses classified in the item "In the last seven days have you had problems with?", which showed relevance for the lumbar regions and lower limbs for the population addressed.

Brazilian Portuguese Inventory Awareness Center - CSI-BP

Conceived as an easy-to-administer trigger for patients at high risk of centenary sensitization or to assess related symptoms, the

CSI is a self-report questionnaire translated and validated in several countries, including for the Brazilian population, with reliability and satisfactory psychometric evaluations.[26] To start this study, only Part A of the questionnaire was applied, consisting of 25 speech items to consider the daily presence of symptoms or on most days in the last three months.

QEEG (Quantitative Electroencephalography)

Data acquisition strategy

The examination was performed with the participant sitting in his wheelchair, wearing a cap made of Neoprene material, with 950 silver electrodes attached, imposed on specific areas according to the international system 10 -20[20] and to conduct electrical brain signals from the leather scalp for the electrodes, a carbopol gel (2%) was used. (Figure 1)

The qEEG device used to record the brain mapping was an iCelera (r) amplifier model iBlue 52 (512 and 12-bit sampling rate), and the iCelera software was used for data collection. The qEEG configurations selected for data collection were 20 channels of average mounting, grounding, and network in standard mode, with a passband filter from 0.5 Hz to 50 Hz. Subsequently, the data were processed and exported by the iCelera® software in files in the European Data Format (EDF) model. All analyses of the qEEG were performed with the evaluated eyes open (OA), mimicking the condition of an individual awake in a usual way. Conditions with eyes closed (simulating sleep) or performing specific tasks (such as reading) were not evaluated.

Data analysis - qEEG

After collecting data in the iCelera software, a visual inspection was performed on all data using the beta version of the Biolucida ® software (BioNeuro & Lucida). The Laplacian assembly was used, in which the electrodes now have the same polarity at all points concerning the electrode taken as reference, providing data with less interference.[27] In addition, the ICA independent component analysis algorithm (MaxICA) was implemented, and with that, the removal of recorded artifacts, such as involuntary muscle contractions, eye movements, among others, was performed.

Subsequently, a new visual inspection was also made for the necessary manual cutting of artifacts, which persisted in the signal. The data were standardized around 500 seconds, and a bandpass filter of 1.5 - 50hz was used. Next, the software extracted data tables of qEEG, dominant frequency, and mean frequency in each of the 20 recorded electrodes. The analyzed brain wave frequencies were: Alpha 1 (8-10 Hz), Alpha 2 (10-12mHz), and Global Alpha Wave (8-12 Hz).

When selecting the EDF file with pre-processing, the data were inserted into the BRAINSTORM®[28] system to perform group calculations (generating one piece of data for each group) and thus generate the Phase-Amplitude Coupling file (Phase -Amplitude Coupling – PAC)[29] of the group and the file sLORETA (Standardized Loreta)[30] of each group. Using these data, comparisons were made between information from volunteers with SCI with and without pain using the BRAINSTORM ®[28] system.

Statistical analysis

Data were described as mean and standard deviation or as absolute frequency and percentage, according to the type of data to be presented. Before comparing the groups, a Shapiro-Wilk normality test was performed. Alpha 1 waves (8-10 Hz) did not show normal distribution, while Alpha 2 waves (10-12 Hz) and global Alpha (8-12 Hz) showed normal data distribution. This fact allowed for defining the comparative tests between the groups. Student's t analysis (normal distribution) or Mann-Whitney t analysis (no normal distribution) were performed using the GraphPad statistical software Prism 9.0 for MAC OS X, $p<0.05$.

RESULT

Twenty SCI volunteers were included in a formal interview and participated in the qEEG evaluation. The pain-free group represented 55% of the sample and 45% of the pain group. About 85% were male; the mean age was 33.85 (± 7.49) years. The practice of physical activity was also used to characterize the sample, 90.9% of the group without pain performed regular physical activity, with a mean BMI of 23.6 kg/m2, and in the pain group, 55.55% performed regular physical activity, with a BMI on average 22.2 kg/m^2.

Regarding the affected neurological level, the volunteers are classified using the American Spinal Injury Association (ASIA) commitment scale, performed in medical centers, the highest representation was demonstrated in the lower thoracic region between T9-T12 (63.63%), in the group without pain and in the group with pain, there was equal distribution unintentional between the upper

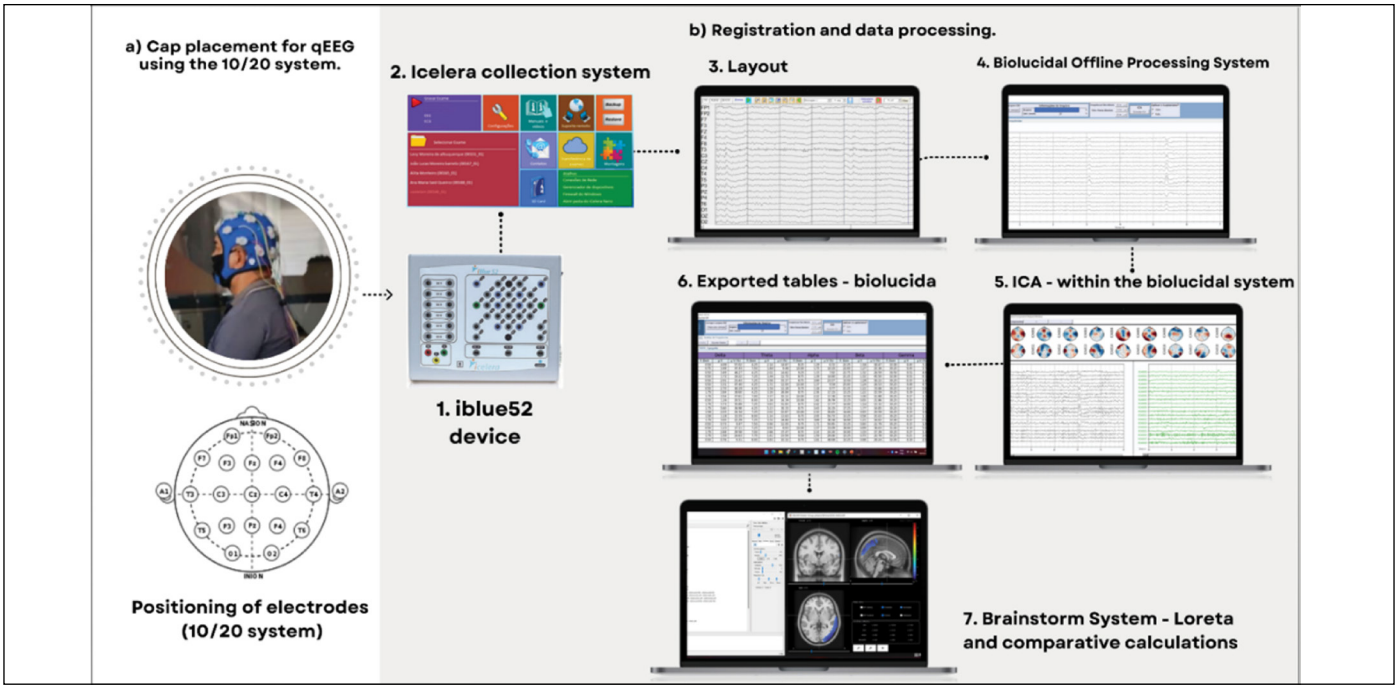

Figure 1. Flowchart for capturing data from the qEEG exam.

chest (T1-T4), middle chest (T5-T8) and lower chest (T9-T12) regions with a prevalence of 33.33% each. Injuries classified as incomplete prevailed (55.55%) in the pain group, and in the group without pain, injuries classified as complete prevailed (66.67%). All volunteers had less than 10 years of injury. There was no statistical difference when analyzing the data on signs and symptoms of central sensitization (CSI - PA). (Table 1)

By analyzing the mean of all 20 brain points, when comparing the two groups, it is possible to observe a 38.7% reduction in the Alpha 2 wave in the group with pain symptoms, suggesting compensation for the Alpha 1 wave in other brain areas, such as shown in the red area of Figure 2 C(II), making the global alpha wave result in no statistically significant difference. (Table 2)

In Figure 2(C), it is possible to observe that in the difference between the groups, there was an increase in the occipital region of the Alpha 1 wave C(I). In contrast, the Alpha 2 and global Alpha waves present a reduction in the parietal lobe region. The graphs at the bottom of Figure 2 A and 2 B are representative of the behavior of the Alpha band in each group. The orange columns highlight the behavior of the Alpha 1 subband and the blue columns the behavior of the Alpha 2 subband.

From the topographic point of view represented by Figure 3, when comparing the groups, there is a reduction in Alpha 2 and global Alpha waves in the parietal region and diffuse in the occipital region, more specifically in the PZ point, which seems to be a common perspective of reduction.

Table 1. Characterization of the sample (N=20).

	Painless (N = 11)	**Pain (N = 9)**
Gender (M/F)	10/1	7/2
Age (years)	34 (7.5)	33.7 (7.9)
Height (m)	1.72 (0.06)	1.67 (0.09)
Weight (kg)	70.7 (12.5)	62.6 (13.8)
BMI (kg/m2)	23.6 (3.3)	22.2 (3.8)
Physical activity	10 (90.90%)	5 (55.55%)
Spinal cord injury		
complete	6 (66.67%)	4 (44.44%)
incomplete	5 (45.45%)	5 (55.55%)
Higher level of spinal cord injury		
High chest (T1-T4)	3 (27.27%)	3 (33.33%)
Middle chest (T5-T8)	1 (9.09%)	3 (33.33%)
Low chest (T9-T12)	7 (63.63%)	3 (33.33%)
Pain (n)		
Low back	-	4 (44%)
Hip	-	7 (77.77%)
Knee	-	2 (22.22%)
Ankle	-	3 (33.33%)
*CSI - BP	22.36 (17.7)	20 (10.7)

*CSI - BP (Central Awareness Inventory - Brazilian Population).

DISCUSSION

The study aimed to compare alpha wave brain electrical activity patterns among volunteers with SCI who reported pain in the lumbar region and/or lower limbs and without pain employing quantitative electroencephalography. Our findings allowed us to observe a reduction in the amplitude of the Alpha 2 wave (10-12Hz) in the pain group in the parietal region of the brain. This region's functions are processing of perceptions and somatosensory information, such as temperature, touch, pressure, and pain.[31] Conversely, Alpha 1 and global Alpha waves did not differ between groups.

The reduction in alpha wave amplitude is already well evidenced in the literature on pain,[32-34,] including in the post-SCI population.[18] The Alpha wave is related to cognitive processing, emotional control, and integrative brain functions, in addition to having a specific role in the regulation of sensorimotor processes.[35,36] When found in reduced activity, the Alpha wave is associated with sleep dysfunction (insomnia),[37] anxiety, and stress.[38] The activity of this wave is physiologically related to the inhibitory impulse of the activation of the neurotransmitter GABA

Table 2. Comparison of different alpha brain waves across the brain in patients with spinal cord injury with and without pain below the thoracic region (N=20).

	Painless (N = 11)	**Ache (N = 9)**	**mean difference (CI 95%)**
Alpha 1 (8-10Hz)	4.59 μV (1.83)	4.95 μV (1.66)	0.2 (-1.36 to 0.44)
Alpha 2 (10-12Hz)	6.92 μV (2.83)	4.24 μV (1.29)	2.69 (1.28 to 4.09) *
Global Alpha (8-12Hz)	5.65 μV (2.13)	4.51 μV (1.44)	1.14 (-2.30 to 0.03)

*$p < 0.05$.

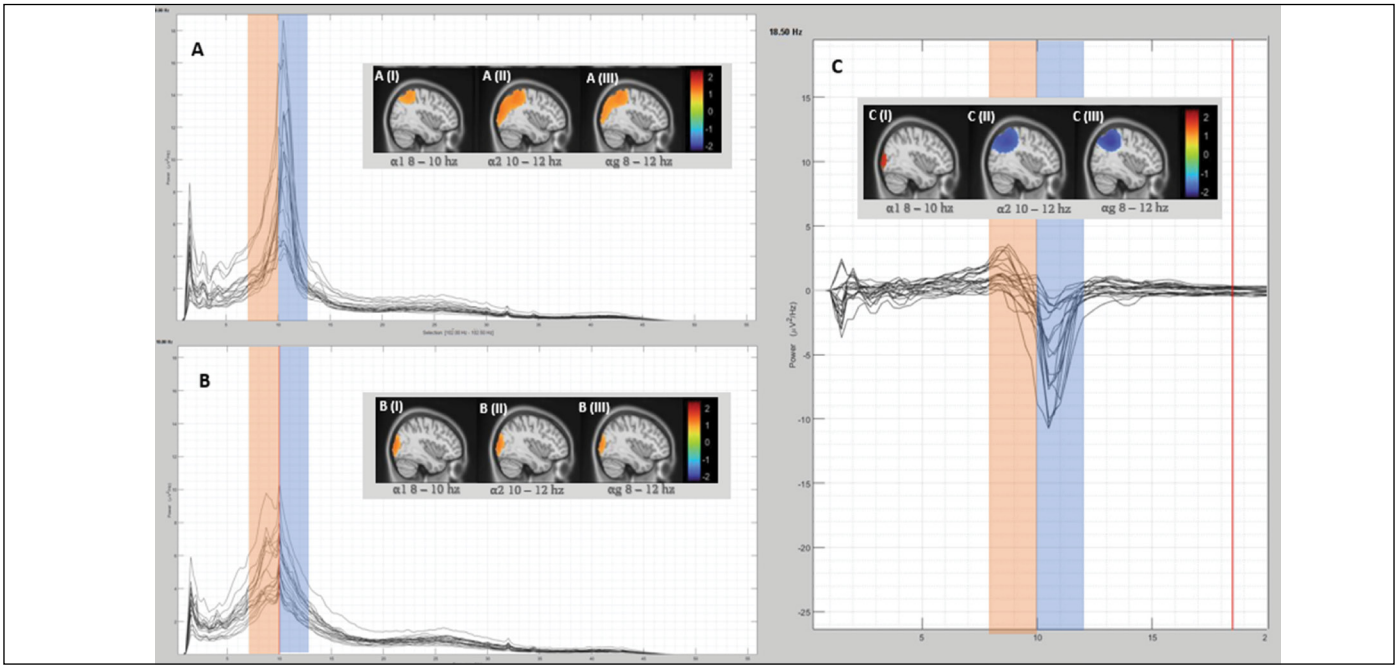

Figure 2. (A) group without pain, wave A(I) α1, wave A(II) α2, global α wave A(III); (B) pain group, wave B(I) α1, wave B(II) α2, global α wave B(III); (C) Difference group, C(I) wave α1, C(II) wave α2, global α wave C(III). Graphics: orange column - wave Alpha 1; column in blue - wave Alpha 2.

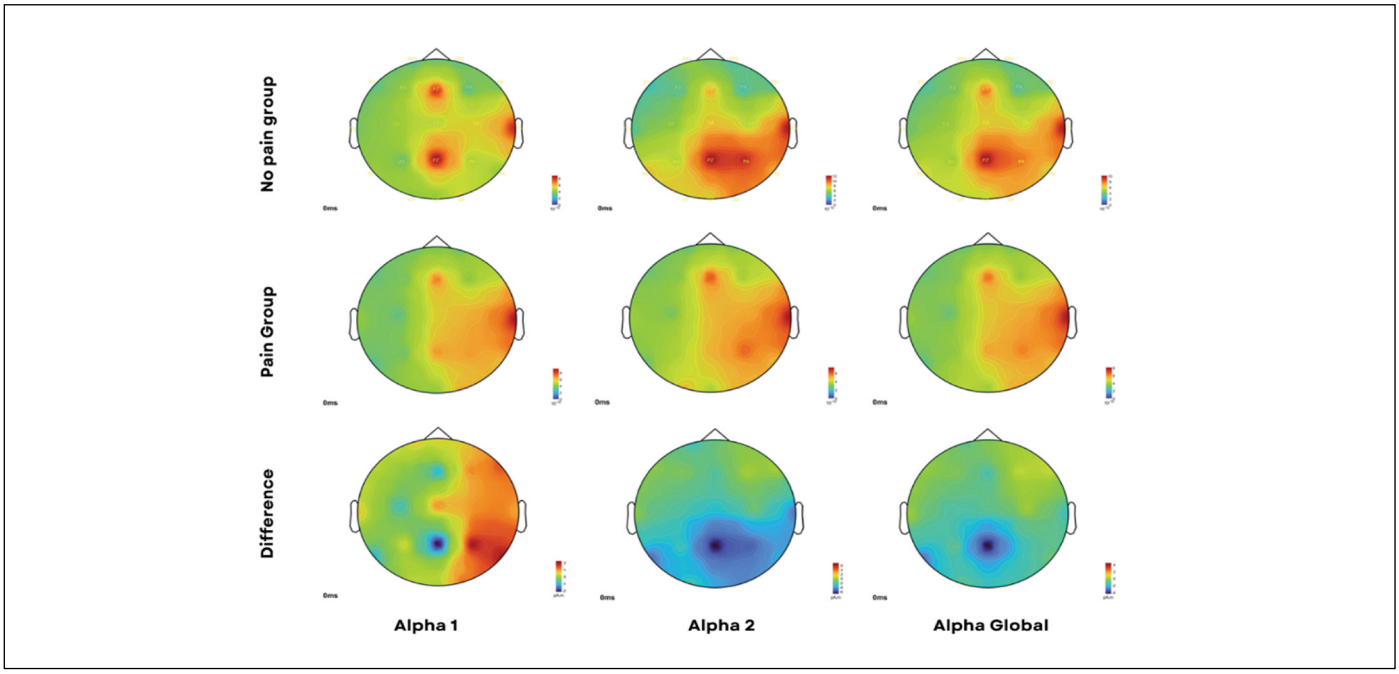

Figure 3. Computerized electroencephalographic topography.

(Gamma-Aminobutyric Acid) synapses, which regulate neuronal excitability from the thalamic projections to the cortex.[39]

The reduction of Alpha 2 found in our study in patients with SCI with pain has already been described in the literature in healthy individuals submitted to pain induction about the anticipatory phenomena of painful processes.[18] In individuals with fibromyalgia, it was also possible to observe a reduction in the Alpha 2 power range at rest, suggesting that chronic pain in these patients modulates this frequency range over time.[40] It is known that the population diagnosed with fibromyalgia is characterized by the presence of signs and symptoms of central sensitization, dysfunction of the neurocircuits that involve the perception, transmission, and processing of afferent nociceptive stimuli, with a prevalent manifestation of pain in the locomotor system,[41] however, this sensitization Central was not observed in individuals with SCI, with or without pain, analyzed in this study.

Regarding the population with SCI and chronic pain, there is also suppression of the global Alpha band, differing from the group without pain.[42] Thus, we believe that in paraplegics with reports of musculoskeletal pain, there is a selective inhibition in the production of Alpha 2 waves, mainly in the parietal region, as well as a diffuse parieto-occipital reduction of these same waves when we observe the EEG topography of this group.

Implications for doctors

Considering these results, possible options for therapeutic procedures for patients with a diagnosis of spinal cord injury and reported musculoskeletal pain could be suggested, such as yoga,[43] biofeedback,[44] neurofeedback,[45] transcranial direct current stimulation,[46] among other therapeutic interventions that may interfere with the capacity of modulating Alpha waves and that aim to reduce the symptoms of the intensity of the painful pattern.

Study limitations

The restricted sample size characterizes this study's main limitation, given the group's specificities and the failure to perform tests with painful stimuli during the evaluation of qEEG data, which could open new perspectives for patients with SCI.

CONCLUSION

A selective reduction of Alpha 2 waves, mainly in the parietal region (PZ), was observed in SCI patients with pain compared to SCI patients without pain.

The authors declare that there is financial support for the development of this study by Dell Computers, and it was developed at Dell LEAD - Centro de Pesquisa, Desenvolvimento e Inovação Dell, within the scope of the project entitled "Technologies for job accessibility in the Brazilian Electronic Industry".

CONTRIBUTIONS OF THE AUTHORS: All authors made individual and significant contributions to the development of this article. TSA worked on conceptualization, writing, original draft revision, and editing. YCAM contributed to data curation and writing of the original draft. LPO also helped with data curation and writing of the original draft. GHH was responsible for formal analysis, methodology, validation, visualization, and proofreading and editing. FCMBO was in charge of acquiring financing, project management, resources, and supervision. PCNF assisted with data curation, formal analysis, funding acquisition, and methodology. Lastly, FFUSJ contributed to data curation, formal analysis, funding acquisition, methodology, project management, validation, and review and editing of the writing.

REFERENCES

1. Kumar R, Lim J, Mekary R, Rattani A, Dewan MC, Sharif SY, et al. Traumatic spinal injury: global epidemiology and world volume. World Neurosurg. 2018;113:e345-63.
2. Barbetta D, Smanioto T, Poletto M, Ferreira R, Lopes A, Casaro FM, et al. Epidemiological profile of spinal cord injury in the Sarah Network of Rehabilitation Hospitals – a Brazilian population sample. Spinal Cord Ser Cases. 2018;4:32.
3. Kirshblum S, Snider B, Rupp R, Read MS; International Standards Committee of ASIA and ISCoS. Updates of the International Standards for Neurologic Classification of Spinal Cord Injur: 2015 and 2019. Phys Med Rehabil Clin N Am. 2020;31(3):319-30.
4. Shabani S, Meyer BP, Budde MD, Wang MC. Diagnostic Imaging in Spinal Cord Injury. Neurosurg Clin N Am. 2021;32(3):323-31.
5. Santos PL do A, Gaspar RC, Padula N, Almeida DM, Voos MC. Translation and cross-cultural adaptation into Brazilian Portuguese of the Modified Tardieu Scale for assessing muscle tone in patients with spinal cord injury. Arq Neuropsiquiatr. 2021;79(7):590-7.
6. Hu HZ, Granger N, Jeffery ND. Pathophysiology, Clinical Importance, and Management of

Neurogenic Lower Urinary Tract Dysfunction Due to Suprasacral Spinal Cord Injury. J Vet Intern Med. 2016;30(5):1575-88.
7. Stoffel JT, Van Der AA F, Wittmann D, Yande S, Elliot S. Fertility and sexuality in patients with spinal cord injury. World J Urol. 2018;36(10):1577-85.
8. Hagen EM, Rekand T. Management of neuropathic pain associated with spinal cord injury. Pain Ther. 2015;4(1):51-65.
9. Tong C, Zhengyao Z, Mei L, Dongpo S, Qian H, Fengqun M. Pregabalin and gabapentin in patients with spinal cord injury-related neuropathic pain: a network meta-analysis. Pain Ther. 2021;10(2):1497-509.
10. de Miguel M, Kraychete DC. Pain in Patients with Spinal Cord Injury: A Review. Rev Bras Anestesiol. 2009;59(3):350-7.
11. Heutink M, Post MWM, Bongers-Janssen HMH, Dijkstra CA, Snoek GJ, Spijkerman DCM, et al. The CONECSI study: results of a randomized controlled clinical trial of a multidisciplinary cognitive-behavioral program to manage chronic neuropathic pain after spinal cord injury. Pain. 2012;153(1):120-8.
12. Ministério da Saúde. Diretrizes de Atenção à Pessoa com Lesão Medular. 2nd ed. Brasília: Ministério da Saúde; 2015.
13. Raja SN, Carr DB, Cohen M, Finnerup NB, Flor H, Gibson S, et al. The revised International Association for the Study of Pain definition of pain: concepts, challenges and commitments. Pain. 2020;161(9):1976-82.
14. Rodrigues AV, Vidal WAS, Lemes JA, Gongora CS, Neves TC, Santos SMS, et al. Study on the characteristics of pain in patients with spinal cord injury. Acta Fisiatr. 2012;19(3):171-7.
15. Sociedade Brasileira para o Estudo da Dor – SBED. Ano Mundial Contra Dor Musculoesquelética. 2009:1-2. Available at: https://sbed.org.br/wp-content/uploads/2019/02/51.pdf.
16. De Barros ENC, Alexandre NMC. Cross-cultural adaptation of the Nordic musculoskeletal questionnaire. Int Nurs Rev. 2003;50(2):101-8.
17. Teixeira M, Mancini C, Wicht CA, Maestretti G, Kuntzer T, Cazzoli D, et al. Beta electroencephalographic oscillation is a potential GABAergic biomarker of chronic peripheral neuropathic pain. Front Neurosci. 2021;15:594536.
18. Simis M, Pacheco-Barrios K, Uygur-Kucukseymen E, Castelo-Branco L, Battistella LR, Fregni F. Specific Electroencephalographic Signatures for Pain and Descending Pain Inhibitory System in Spinal Cord Injury. Pain Med. 2021;23(5):955-64.
19. Gomes M da M. Bases fisiológicas do eletroencefalograma. Rev Bras Neurol. 2015;51(1):12-7.
20. Montenegro MA, Cendes F, Guerreiro MM, Guerreiro CAM. EEG in clinical practice. 3rd ed. Rio de Janeiro: Thieme Revinter Publications; 2018. 424p.
21. Mayaud L, Wu H, Bathelemy Q, Favennec P, Delpierre Y, Congedo M, et al. Alpha phase synchronization EEG training for patients with multidrug resistant chronic low back pain: an open pilot study. Eur Spine J. 2019;28(11):2487-501.
22. Feng Li, Li H, Cui H, Xie X, Xu S, Hu Y. Low Back Pain Assessment Based on Alpha Oscillation Changes in Spontaneous Electroencephalogram (EEG). Neural Plast. 2021;2021:8537437. doi:10.1155/2021/8537437.
23. Malachias MVB, Souza WKSB, Plavnik FL, Rodrigues CIS, Brandão AA, Neves MFT, et al. 7th Brazilian Guideline on Arterial Hypertension. Arq Bras Cardiol. 2016;107(3 Suppl 3):1-103.
24. World Health Organization. Physical status: use and interpretation of anthropometry. Geneva: WHO; 1995. p. 854.
25. Pinheiro FA, Tróccoli BT, Carvalho CV. [Validity of the Nordic Musculoskeletal Questionnaire as morbidity measurement tool]. Rev Saude Publica. 2002;36(3):307-12.
26. Caumo W, Antunes LC, Elkfury JL, Herbstrith EG, Busanello Sipmann R, Souza A, et al. The Central Sensitization Inventory validated and adapted for a Brazilian population: psychometric properties and their relationship to brain- derived neurotrophic factor. J Pain Res. 2017;10:2109-22.
27. Kayser J, Tenke CE. Issues and considerations for using the scalp surface Laplacian in EEG/ERP research: a tutorial review. Int J Psychophysiol. 2015;97(3):189-209.
28. Tadel F, Baillet S, Mosher JC, Pantazis D, Leahy RM. Brainstorm: a user-friendly application for MEG/EEG analysis. Comput Intell Neurosci. 2011:2011:879716.
29. Samiee S, Donoghue T, Tadel F, Baillet S. Phase -Amplitude Coupling [accessed on Feb 05, 2022]. Available at: https://neuroimage.usc.edu/brainstorm/Tutorials/TutPac.
30. Pascual-Marqui RD. Low-resolution standardized cerebral electromagnetic magnetic tomography (sLORETA): Technical details. Methods Find Exp Clin Pharmacol. 2002;24(Suppl D):5-12.
31. Klingner CM, Witte OW. Somatosensory deficits. Handb Clin Neurol. 2018;151:185-206.
32. Aguiar DP, do Nascimento PCF, Moreira AG, Alves GCV de M, Hotta GH, Santos-Júnior FFU. People with amputation and musculoskeletal pain show reduced electrical activity of Alpha brain waves: cross-sectional study. BrJP. 2022;5(3):226-32.
33. Pinheiro ES dos S, de Queirós FC, Montoya P, Santos CL, do Nascimento MA, Ito CH, et al. Electroencephalographic Patterns in Chronic Pain: A Systematic Review of the Literature. PLoS One. 2016;11(2):0149085.
34. Camfferman D, Moseley GL, Gertz K, MW Pettet, MP Jensen. Waking EEG Cortical Markers of Chronic Pain and Sleepiness. Pain Med. 2017;18(10):1921-31.
35. Babiloni C, Percio CD, Arendt-Nielsen L, Soricelli A, Romani GL, Rossini PM, et al. Alpha EEG cortical rhythms reflect task-specific somatosensory and motor interactions in humans. Clinical Neurophysiol. 2014;125(10):1936-45.
36. Melo MH, Martins NL, Oldenburg MV, Takase E. Influência do ritmo Alfa (8-12Hz) no tempo de reação em uma tarefa de controle inibitório. Rev Lat Neurop. 2017;9(2):33-43.
37. Schwabedal JT, Riedl M, Penzel T, Wessel N. Alpha-wave frequency characteristics in health and insomnia during sleep. J Sleep Res. 2016;25(3):278-86.
38. Clancy KJ, Andrzejewski JA, Simon J, Ding M, Schmidt NB, Li W. Post-traumatic stress disorder is associated with α dysrhythmia in the visual cortex and default mode network. eNeuro. 2020;7(4):ENEURO.0053-20.2020.
39. Camfferman D, Moseley GL, Gertz K, Pettet MW, Jensen MP, Waking EEG. Cortical Markers of Chronic Pain and Sleepiness. Pain Med. 2017;18(10):1921-31.
40. Villafaina S, Collado-Mateo D, Fuentes-García JP, Cano-Plasencia R, Gusi N. Impact of fibromyalgia on alpha-2 EEG power spectrum at rest: a descriptive correlational study. BioMed Res Int. 2019;2019:7851047.
41. Siracusa R, Paola RD, Cuzzocrea S, Impellizzeri D. Fibromyalgia: Pathogenesis, Mechanisms, Diagnosis and Treatment Options Update. Int J Mol Sci. 2021;22(8):3891.
42. Jensen M, Sherlin L, Gertz K, Braden AL, Kupper AE, Gianas A, et al. EEG brain activity correlates with chronic pain in people with spinal cord injury: clinical implications. Spinal Cord. 2013;51(1):55-8.
43. Malhotra V, Hulke SM, Bharshankar R, Chouhan S, Ravi N, Patrick KP. Effect of slow, deep breathing on brain waves in regular yoga practitioners. Mymensingh Med J. 2021;30(4):1163-7.
44. Hallman DM, Olsson EMG, von Schèele B, Melin L, Lyskov E. Effects of heart rate variability biofeedback in subjects with chronic stress-related neck pain: a pilot study. Appl Psychophysiol Biofeedback. 2011;36(2):71-80.
45. Jensen MP, Gertz KJ, Jupper AE, Braden AL, Howe JD, Hakimian S, et al. Steps towards developing an EEG biofeedback treatment for chronic pain. Appl Psychophysiol Biofeedback. 2013;38(2):101-8.
46. De Melo GA, de Oliveira EA, Andrade SMM dos S, Fernández-Calvo B, Torro N. Comparison of two tDCS protocols on pain and alpha-2 EEG oscillations in women with fibromyalgia pain. Sci Rep. 2020;10:18955.