SPORMETRE
The Journal of Physical Education and Sport Sciences
Beden Eğitimi ve Spor Bilimleri Dergisi

DOI: 10.33689/spormetre.1477527
Research article

Geliş Tarihi (Received): 02.05.2024 Kabul Tarihi (Accepted): 27.01.2025 Online Yayın Tarihi (Published): 30.03.2025

COMPARISON OF ALPHA FREQUENCY BAND POWER IN ACTIVE AMATEUR BOXERS AND SEDENTARY INDIVIDUALS USING EEG TECHNOLOGY

Muhammed Sıddık Çemç[1*], Onur Erdem Korkmaz[2]
[1]Boğaziçi University, Department of Physical Education and Sports, Istanbul, Türkiye
[2]Atatürk University, Department of Electrical and Electronics Engineering, Erzurum, Türkiye

Abstract: Chronic traumatic brain injury has been a major concern in combat sports, particularly boxing, due to the reoccurring impacts to the head that might result in lasting neurological effects. This research was conducted to address the lack of sufficient research on the resting-state alpha frequency band power in active amateur boxers, which may provide insights into early signs of brain injury. Participants included 7 male amateur boxers whose average age was 19.57 ± 2.63 and who had been actively boxing for 7.57 ± 3.55 years, and 9 healthy males whose average age was 19.88 ± 0.92 and who had not participated in any combat sports. EEG recordings were obtained according to the international 10-20 system for 3 minutes with eyes open and 3 minutes with eyes closed. The raw EEG data were inspected and cleaned to remove artifacts. Finite Impulse Response (FIR) and Infinite Impulse Response (IIR) filters were applied to eliminate unwanted frequencies during frequency analysis. Fast Fourier Transform (FFT) was utilized to convert EEG signals from the time domain to the frequency domain and to calculate alpha band power (μV^2). The data obtained were analyzed using the Analyzer2 software. Mann-Whitney U test was utilized to measure the dissimilarities between the two groups. When examining the alpha frequency band power values of participants at rest with eyes open and eyes closed, there were not any statistically significant dissimilarities in the frontopolar region (Fp1, Fp2), frontal region (F3, F4), central region (C3, Cz, C4), parietal region (P3, Pz, P4), and occipital region (O1, Oz, O2) in terms of microvolts squared (μV^2) of the groups. However, boxers had partially lower alpha frequency band power values in all analyzed channels. This finding may be related to the specific sport practiced. Although no significant dissimilarities were noted in alpha frequency band power values between the two groups, the lower values observed in boxers across all channels may be linked to the repetitive head impacts inherent in the sport. This finding highlights the importance of further research to explore the neurophysiological effects of boxing and the potential role of protective measures in minimizing health risks.
Keywords: Boxing, electrophysiology, traumatic brain injury

EEG TEKNOLOJİSİ KULLANILARAK AKTİF AMATÖR BOKSÖRLERİN ALFA FREKANSI BANT GÜCÜNÜN SEDANTER BİREYLERLE KARŞILAŞTIRILMASI

Öz: Kronik travmatik beyin hasarı, özellikle boks gibi dövüş sporlarında, baş bölgesine alınan tekrarlayan darbelerin uzun vadeli nörolojik etkiler yaratabilmesi nedeniyle önemli bir endişe kaynağı olmuştur. Bu çalışma, aktif amatör boksörlerde dinlenik durumdaki alfa frekansı bant gücüne ilişkin araştırma eksikliğini gidermek ve beyin hasarının erken belirtilerine ışık tutmak amacıyla icra edilmiştir. Katılımcılar en az lise düzeyinde eğitim almış sağ el tercihli; 19.57 ± 2.63 yaş ortalaması olan 7.57 ± 3.55 yıldır aktif boks yapan 7 erkek amatör boksör ve 19.88 ± 0.92 yaş ortalamasına sahip herhangi bir dövüş sporu yapmamış 9 sağlıklı erkekten oluşmaktadır. Araştırma kapsamında EEG kaydı uluslararası 10-20 sistemine uygun, 3 dk göz açık ve 3 dk göz kapalı olacak şekilde alınmıştır. Ham veriler, artefaktları gidermek amacıyla incelenmiş ve temizlenmiştir. Frekans analizlerinde, istenmeyen frekansların elimine edilmesi için Finite Impulse Response (FIR) ve Infinite Impulse Response (IIR) filtreleri kullanılmıştır. EEG sinyallerinin zaman alanından frekans alanına dönüştürülmesi ve alfa bant güçlerinin (μV^2) hesaplanması için Hızlı Fourier Dönüşümü (FFT) yöntemi uygulanmıştır. Elde edilen veriler, Analyzer2 yazılımı kullanılarak analiz edilmiştir. Verilerin gruplar arasındaki farkını değerlendirmek için Mann-Whitney U testi uygulanmıştır. Katılımcıların dinlenik durumda göz açık ve göz kapalı alfa frekansı bant gücü değerleri incelendiğinde her iki grup arasında frontopolar bölgede Fp1, Fp2; frontal bölgede F3, F4; santral bölgede C3, Cz, C4; parietal bölgede P3, Pz, P4; oksipital bölgede O1, Oz, O2 kanallarında mikrovolt kare (μV^2) cinsinden istatistiksel olarak anlamlı bir fark gözlenmemiştir. Fakat boksörlerin analiz edilen tüm kanallarda kısmen daha düşük alfa frekansı bant gücü değerine sahip olduğu tespit edilmiştir. Bu durumun icra edilen spor branşı ile ilişkili olabileceği fikri doğmaktadır. İki grup arasında alfa frekansı bant gücü değerlerinde anlamlı bir fark bulunmamasına rağmen, boksörlerde tüm kanallarda gözlemlenen daha düşük değerler, bu sporun doğasında bulunan tekrarlayan kafa darbeleri ile ilişkili olabilir. Bu bulgu, boksun nörofizyolojik etkilerini ve koruyucu önlemlerin sağlık risklerini azaltmadaki potansiyel rolünü araştırmak için daha fazla çalışmanın önemini vurgulamaktadır.
Anahtar Kelimeler: Boks, elektrofizyoloji, travmatik beyin hasarı

[*]*Corresponding Author: Muhammed Sıddık Çemç, Instructor PhD, E-mail: mscemc@gmail.com*

INTRODUCTION

Since the 1920s, reoccurring brain trauma connected with boxing has been considered a helping element for the progressive neurological decline, at first referred to as 'dementia pugilistica' and more lately known as chronic traumatic encephalopathy (CTE) (Mckee et al., 2009). CTE is a neurodegenerative condition created by reoccurring head blows, which gradually deteriorates over time. Its hallmark symptoms include difficulties with memory, cognitive dysfunction, alterations in behavior, and a decline in motor abilities. Furthermore, it is often associated with depression, aggressive tendencies, and the eventual onset of dementia (Montenigro et al., 2015) Boxing is recognized as one of the sports with the highest risk of sustaining injuries (Siewe et al., 2015).

Since 1732 until November 2007, a total of 1465 deaths worldwide have been recorded due to boxing. Around 70% of these deaths have been among professional boxers. While the count of deaths has substantially dropped since 1960, there is still an average of 77 deaths every ten years (Svinth, 2007). Most of these deaths occur due to the progression of cognitive impairments or undiagnosed conditions or as a result of Severe concussions and injuries sustained during matches. Ample evidence indicates that these concussions themselves may end up with neural impairments (Stojsih et al., 2010). Boxing is a harmful sport with the possibility to produce life-altering, deathly, and adverse outcomes (Donnelly et al., 2023). Additionally, recent literature reports that dementia is significantly more common among professional boxers compared to amateur boxers, with an estimated occurrence rate of approximately 20% (Da Broi et al., 2023).

According to Roberts' retrospective, randomized study on chronic traumatic brain injury among former boxers in the United Kingdom, approximately 17% of boxers exhibited symptoms consistent with "Dementia Pugilistica," which is widely thought to stem from years of repeated concussive and subconcussive head injuries (Roberts, 1969). There is also evidence indicating that symptoms of chronic traumatic brain injury may worsen and become more pronounced as a boxer nears the end of their career or after retirement. (Roberts, 1969; Stiller & Weinberger, 1985). These symptoms commonly include a mix of cognitive and motor function impairments, along with alterations in state of emotions and behavior (Förstl et al., 2010; Jordan et al., 2000). Associated motor impairments frequently appear as dysarthria, parkinsonism, and signs of asymmetric involvement of the pyramidal system (e.g., spasticity) (Stiller et al., 2014).

Dementia pugilistica, or "punch-drunk" syndrome, is a type of obtained cognitive damage observed in approximately one-fifth of elite boxing athletes (Latin: pugilator, meaning boxer) (Johns, 2014). Acute neurological injuries encompass a wide range of conditions, including mild concussions, cerebral hemorrhages, axonal damage in the cerebral white matter, and even death. A significant proportion of the findings related to acute and chronic concussions in sports competitions are observed in boxing and kickboxing matches. It has been reported that many boxers experience memory problems not only during the immediate post-match period but also in their daily lives. Some clinical manifestations of motor, cognitive, and/or behavioral disorders have been reported to emerge after athletes retire from their boxing careers, with neurological and neuropathological findings becoming more pronounced in retired boxers over the age of fifty (Memmedov, 2014). Therefore, researchers have focused on investigating the brain's electrical activity to catch encephalopathy in its initial periods. Electroencephalography (EEG) offers the unique capability of assessing brain function in real-time by capturing the brain's electrical signals (Mizuguchi et al., 2021).

Sports physiologists are researching various ways to prevent potential accidents in specific sports, and providing sufficient protection against such risks is crucial. This calls for the application of objective instrumental methods in the pertinent field of research. It's also essential to be aware that early identification of various adverse changes in brain electrical activity after head trauma or concussion could facilitate the introduction of appropriate and effective treatments, specifically incorporating EEG biofeedback (neurofeedback) techniques (Ziółkowski et al., 2015).

EEG (Electroencephalography) is a strategy for documenting the electrical potential variations of the brain (Holmes et al., 2006). EEG involves the amplification of voltage changes occurring in time between electrodes put on the scalp, which represent the electrical potential oscillations that occur in the brain (Fisch, 1991). EEG is a non-invasive method with high temporal resolution that directly monitors the spontaneous electrical activity of the cerebral cortex, making it suitable for use in various settings with some modifications (Gökmen et al., 2009).

Alpha frequency band activity, particularly observed during resting states, is considered a critical neurophysiological marker of brain health. Research indicates that reductions in alpha power are related to cognitive decline (Lejko et al., 2020) and that disruptions in alpha oscillations are often linked to traumatic brain injuries (Angelakis et al., 2004). These alterations may indicate impaired cognitive functioning and reduced neural efficiency, especially in individuals exposed to repeated head impacts. Furthermore, alpha peak frequency has been associated with processing speed and cognitive performance, highlighting its potential as a diagnostic tool for the early detection of neurological disorders (Rathee et al., 2020).

CTBI is a vital matter in combat sports, particularly in boxing, due to the repetitive head impacts athletes endure during training and competitions. The alpha frequency band, which reflects the brain's resting-state activity, has been widely studied as a potential indicator of neurological and cognitive impairments (Gonzalez-Escamilla et al., 2016; Michels et al., 2017; Musaeus et al., 2019). On the other hand, a notable void exists in the previous research regarding comparisons of alpha frequency band power between athletes involved in combat sports and non-athletic individuals. This research targets to resolve this void by evaluating prolonged consequences of recurrent head impacts in boxing on brain activity. The literature indicates a small number of research that comprehensively explore the manifestations of such impacts on brain activity. In this context, measuring alpha frequency band power emerges as a critical marker for resting-state brain activity and holds promise for the early detection of neurological impairments. The results of this research could help the design of more impactful and safer protective strategies for boxers. Additionally, EEG techniques may support advancements in therapeutic methods, providing opportunities to monitor brain activity and facilitate early interventions to safeguard athletes' health. Guided by these insights, this research focuses on analyzing the resting-state alpha frequency band power of active amateur boxers and comparing the results with healthy individuals to draw implications related to chronic traumatic brain injury.

METHODS

Participants

All measurements within the scope of this research were conducted at the Neuropsychology Laboratory of Atatürk University. The participants of this study were selected using a convenience sampling method. A descriptive design was utilized in this research as it facilitates the examination and understanding of specific characteristics—such as neurophysiological differences—within a given sample without manipulating variables. This approach was chosen to explore and compare alpha frequency band power in amateur boxers and healthy individuals, providing a foundational basis for the following research."

The research was implemented with right-handed participants who had a minimum of a high school diploma. The experimental group comprised seven male boxers, aged 19.57 ± 2.63 years on average, who had been actively training in local amateur boxing clubs in Erzurum for 7.57 ± 3.55 years. These athletes, actively training in local amateur boxing clubs in Erzurum, had an average training experience of 7.57 ± 3.55 years. They participated in boxing training sessions lasting approximately 90 minutes, three days per week. The control group included 9 healthy male participants, with a mean age of 19.88 ± 0.92 years, selected from the university student population to ensure compatibility in age and education level.

Participants were informed about the measurement device. It was ensured that the participants were healthy during the study, meaning they had no chronic or acute illnesses. Participants were screened for neurological health conditions before inclusion in this study. No participants stated using medications known to affect brain activity or having a history of diagnosed neurological disorders. Ensuring participants were free from such confounding factors was essential for accurately isolating the potential effects of repetitive head impacts on alpha frequency band power. Boxers with at least five years of active training background and no reported acute neurological conditions were involved in the study. These criteria were chosen to ensure that participants had sufficient exposure to repetitive head impacts inherent in boxing, which is relevant for studying potential neurophysiological alterations. For the control group, participants who had no combat sports or activities involving repetitive head impacts in their past were included to provide a baseline comparison. However, since this research aims to explore potential neurophysiological alterations regarding chronic traumatic brain injury (CTBI), participants in the boxer group were not precluded based on prior exposure to repetitive head impacts. Instead, this study focused on assessing alpha frequency band power through EEG to detect possible neurophysiological signs linked to CTBI, as boxers inherently have a higher risk of head trauma due to their sports discipline.

The measurements were taken in a 21°C and 15 decibels setting at ideal humidity levels and isolated from electromagnetic fields. Environmental conditions were consistently controlled. Measurements were performed on all participants in the same environment, ensuring they were in comfortable clothing and without the presence of hunger or fatigue. The time allotted for the measurements was sufficient and equally set for everyone. The data collection process was completed over 1 day and in 1 session for each participant. Additionally, considering the biological clock, participants were ensured to attend the measurements at noon.

Measures

Edinburgh Inventory Hand Preference Survey

Oldfield's (1971) survey was applied to identify the hand preferences of the attendants. They replied to the inquiries in the survey based on their hand choices. The given answers were assessed based on the Geschwind score.

EEG Measurements

The EEG signals were recorded using the ActiChamp device (Brain Product). The EEG data were recorded from 13 channels, including Fp1, Fp2, F3, F4, C3, Cz, C4, P3, Pz, P4, O1, Oz, and O2. These channels were selected based on the international 10-20 system, which ensures standardized electrode placement for comprehensive brain activity analysis. During the recording process, all electrode impedance values remained below 5 KΩ throughout the data acquisition process. The 'Fz' channel was designated as the reference electrode. The sampling frequency was set at 250 Hz.

Resting-state EEG is considered a gold standard for measuring baseline neural activity. The resting-state paradigm was chosen because it minimizes external stimuli and provides a stable condition for observing intrinsic brain dynamics. This is especially critical for evaluating the alpha frequency band, which is sensitive to changes associated with head trauma and neurological conditions. It minimizes external stimuli and allows for the observation of intrinsic brain dynamics, particularly the alpha frequency band, which is highly sensitive to neurological alterations (Fisch, 1991; Zhang et al., 2021). The resting-state paradigm is especially relevant in this study, as it provides a stable condition for comparing groups without the confounding effects of task performance.

This study employed both 'Eyes Open' and 'Eyes Closed' conditions to evaluate resting-state alpha frequency band activity under varying sensory stimulation. The 'Eyes Closed' condition is widely recognized for eliciting dominant alpha wave activity due to reduced visual input and minimal external stimuli, thereby reflecting a true resting state of the brain (Klimesch, 1999). Conversely, the 'Eyes Open' condition provides a contrast by introducing visual stimuli, which typically suppress alpha activity, allowing for a comparative assessment of the brain's ability to regulate sensory inputs and maintain cortical balance. This dual-paradigm approach enables a comprehensive analysis of resting-state alpha activity and its potential alterations in individuals exposed to repetitive head impacts.

Measurements were conducted with participants seated comfortably in a chair, approximately 1.5 meters away from a 28-inch LCD monitor placed at eye level. Before initiating measurements, participants were provided with the necessary information. The EEG cap was applied to participants' scalps with the assistance of conductive gel. During the EEG measurement session, participants were instructed via an LCD monitor to alternate between "Eyes Open" and "Eyes Closed" conditions. EEG recordings were obtained for 3 minutes with eyes open and an equal duration of 3 minutes while their eyes are closed.

After the measurement, an average was calculated for each participant, and the power of the alpha (8-13 Hz) frequency band was measured and checked. The measurements were completed by analyzing the values obtained from electrode placements in the regions indicated above.

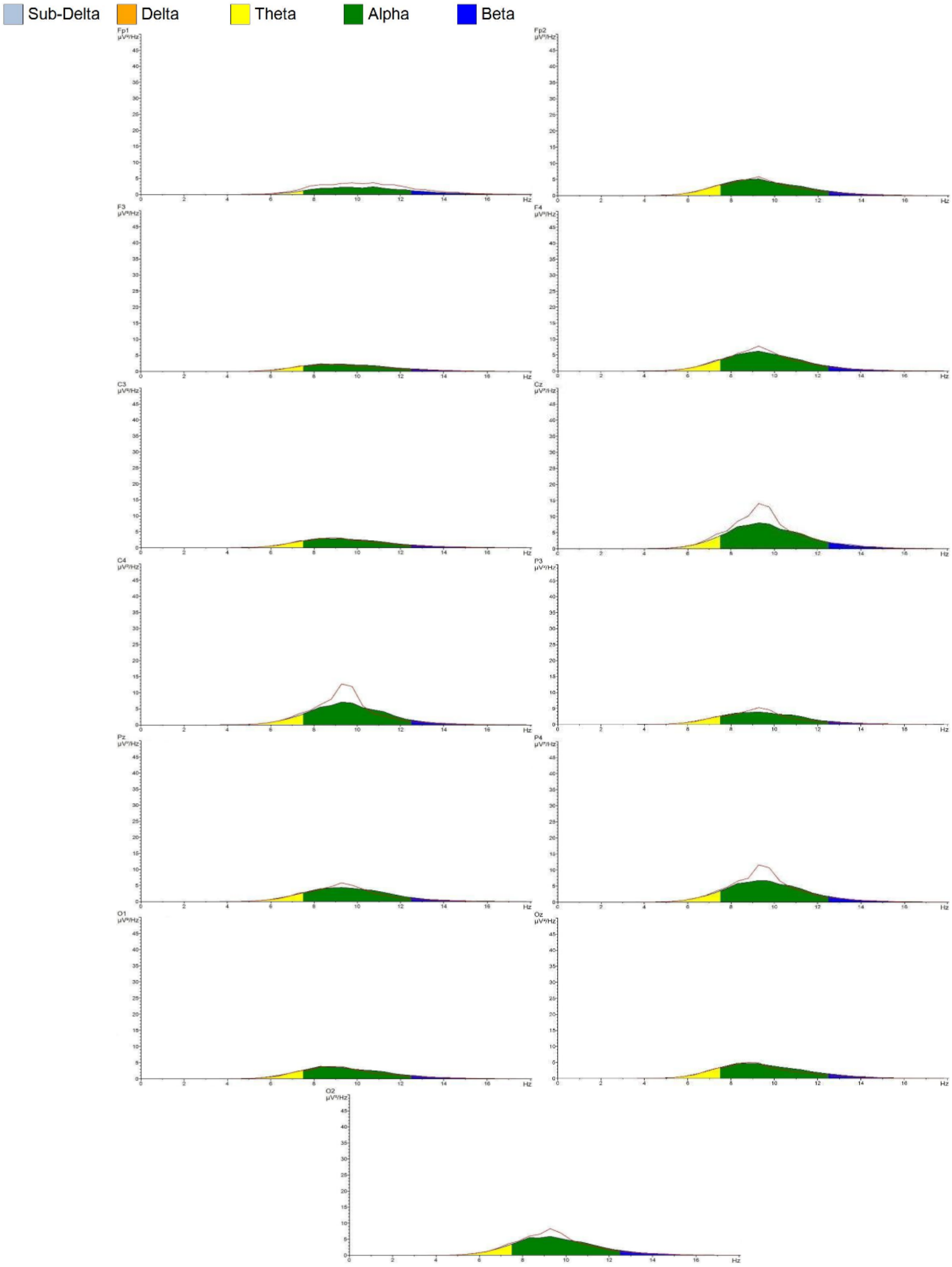
The raw EEG data were inspected and cleaned to remove artifacts. Finite Impulse Response (FIR) and Infinite Impulse Response (IIR) filters were applied to eliminate unwanted frequencies during frequency analysis. Fast Fourier Transform (FFT) was utilized to convert EEG signals from the time domain to the frequency domain and to calculate alpha band power. The processed data were analyzed in μV^2 units using the Analyzer2 software.

Statistical Analysis

The alpha frequency band power values were assessed using the JASP 0.19 program, an open-source statistical software designed for user-friendly and robust data analysis. To measure the dissimilarities among participants in the alpha frequency band power, the Mann-Whitney U test was applied because the data did not follow a normal distribution as assessed by the Shapiro-Wilk test. The significance level for the analyses was set as p<0.05.

RESULTS

Figure 1 Comparison of resting and eyes-open alpha frequency band power values between boxers and the control group (Red lines represent the control group)



When examining the above graphs, it is evident that the control group's alpha frequency band power values during the eyes-open condition are somewhat higher compared to those of the boxers.

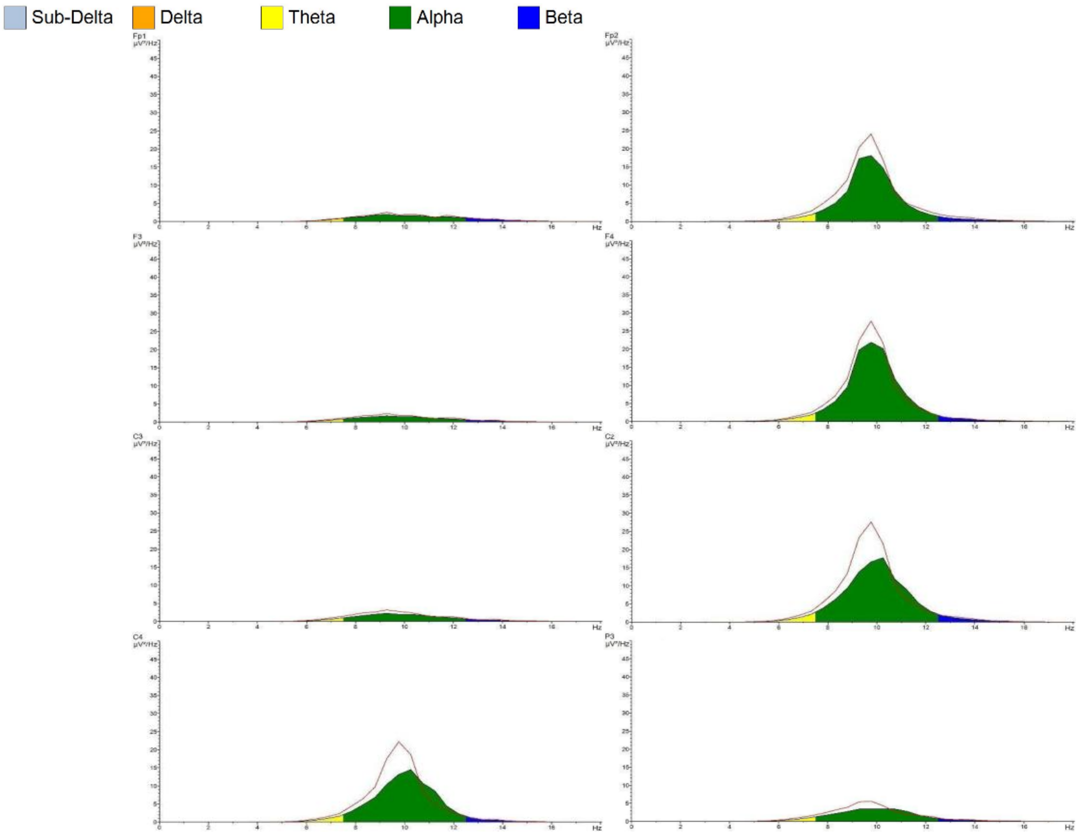
Table 1 Statistical comparison of the participants' intergroup resting, eyes-open alpha frequency band power values

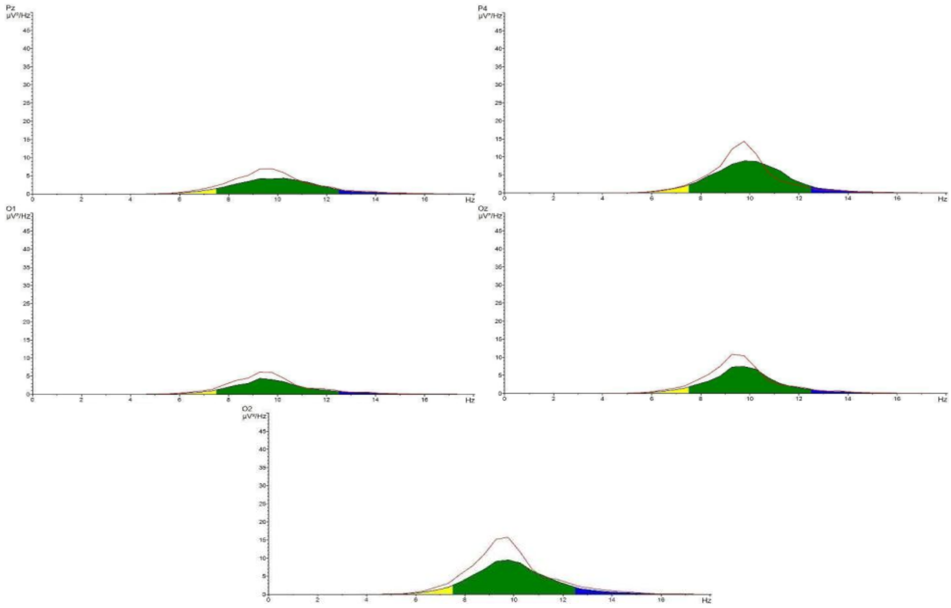
Electrode Placements		Boxer	Control	w	p
Region	**Channel**	**Mean ± SD**	**Mean ± SD**		
Frontopolar	**Fp1**	0.913±0.232	3.470±2.193	24.000	0.470
	Fp2	3.881±0.593	7.290±2.429	26.000	0.596
Frontal	**F3**	2.084±0.343	2.761±0.992	33.000	0.918
	F4	5.877±1.992	9.460±3.164	28.000	0.758
Central	**C3**	2.523±0.422	3.948±1.460	35.000	0.758
	Cz	5.684±1.897	13.797±5.799	21.000	0.299
	C4	4.977±1.807	10.076±3.280	19.000	0.210
Parietal	**P3**	3.379±0.566	5.207±1.668	32.000	1.000
	Pz	4.134±1.148	5.611±1.924	29.000	0.832
	P4	4.501±1.459	10.974±4.084	22.000	0.351
Occipital	**O1**	2.881±0.516	5.318±2.218	32.000	1.000
	Oz	3.574±0.662	5.918±1.995	30.000	0.918
	O2	4.896±1.284	6.266±1.617	31.000	1.000

$p<0.05$

The table shows that no statistically significant dissimilarities were observed in alpha frequency band power values obtained from participants during the eyes-open condition at rest between the groups. However, the control group presented slightly higher alpha frequency band power values in comparison to the boxers.

Figure 2 Comparison of resting and eyes-closed alpha frequency band power values between boxers and the control group (Red lines represent the control group)





Upon examination of the figures above, it can be observed that the control group's alpha frequency band power values during eyes closed condition are somewhat higher compared to those of the boxers.

Table 2 Statistical comparison of the participants' intergroup resting, eyes-closed alpha frequency band power values

Electrode Placements		Boxer	Control	w	p
Region	**Channel**	**Mean ± SD**	**Mean ± SD**		
Frontopolar	**Fp1**	1.074±0.199	1.908±1.173	37.500	0.560
	Fp2	15.519±6.346	37.278±13.877	26.000	0.606
Frontal	**F3**	1.457±0.358	1.433±0.193	30.000	0.918
	F4	14.723±4.782	34.408±10.900	21.000	0.299
Central	**C3**	1.601±0.289	1.902±0.305	24.000	0.470
	Cz	8.941±4.656	32.007±10.453	17.000	0.142
	C4	8.137±4.081	22.242±8.920	24.000	0.470
Parietal	**P3**	2.803±0.872	4.368±0.999	21.000	0.289
	Pz	4.334±1.832	5.136±1.412	27.000	0.681
	P4	8.681±4.778	14.607±4.658	19.000	0.210
Occipital	**O1**	2.544±0.771	7.342±3.051	21.000	0.299
	Oz	4.981±1.852	12.832±4.589	26.000	0.606
	O2	5.367±2.085	15.188±4.287	20.000	0.252

$p<0.05$

The table shows that there were no statistically significant differences in alpha frequency band power values obtained from participants during the eyes-closed condition at rest between the groups. However, the control group exhibited slightly higher alpha frequency band power values compared to the boxers.

DISCUSSION AND CONCLUSION

This study sets out to explore the alpha frequency band power of active amateur boxers at rest and evaluate the obtained data in terms of chronic traumatic brain injury by comparing it with healthy individuals. When analyzing the alpha frequency band power values of participants in a resting state with both eyes open and eyes closed, no significant changes were tracked between both groups on microvolts squared (μV^2) in the frontopolar regions Fp1, Fp2; frontal regions F3, F4; central regions C3, Cz, C4; parietal regions P3, Pz, P4; and occipital regions O1, Oz, O2 channels. However, it was found that boxers had slightly lower alpha frequency band power values.

Temmes and Huhmar (1952) observed that brain lesions in boxers manifested as a progressive process even after retiring from the sport, characterized by a decrease in alpha waves. Busse and Silverman (1952) noted more severe electroencephalographic disturbances in boxers who had been knocked out. Johnson (1969) identified abnormalities in EEG recordings of retired boxers with traumatic encephalopathy. A study conducted in 1981 (Electroencephalographic Changes in Boxers, 1982) reported a higher rate of abnormal EEGs in boxers compared to healthy participants, with an increase in abnormal EEG rates correlated with the number of matches and knockout experiences. Thompson et al. (2005) found a reduction in EEG power across all bandwidths in individuals who had experienced mild traumatic brain injury, accompanied by postural instability. Brooks et al. (2018) observed significant differences in Brain Function Index scores between athletes with head trauma and healthy participants within three days after the injury. However, these significant changes in the Brain Function Index were no longer present 45 days after the injury. This return of the Brain Function Index to levels similar to the control group suggested that the recovery process had occurred in athletes with head trauma.

Angelakis et al. (2004) state that people who have traumatic brain injury exhibited lower alpha peak frequency (APF) values during eyes-open resting states compared to healthy individuals. Rathee et al. (2020) demonstrated that people with higher APF outperformed those with lower APF in reading comprehension tasks. Jann et al. (2010) observed that participants with more APF showed lower neural activation in response to stimuli, suggesting greater efficiency in task execution. Zhang et al. (2021) identified higher APF values and superior performance in multiple object-tracking tasks among elite athletes compared to other groups.

The outcomes of this research present no statistically significant dissimilarities in resting alpha frequency band power values between active amateur boxers and healthy individuals. However, boxers generally exhibit lower alpha frequency band power values. This observation may reflect the potential effects of repeated head impacts inherent in boxing, as well as short-term recovery processes occurring in the nervous systems of boxers. In the literature, it has been reported that brain function indices in athletes show significant differences in the initial days following head trauma but may return to normal levels within 45 days (Brooks et al., 2018). Such recovery processes are thought to depend on individual differences, the severity of trauma, and the total amount of head impacts sustained. Additionally, some studies in the literature have suggested that metrics such as alpha peak frequency may demonstrate longer-term and cumulative changes (Angelakis et al., 2004; Temmes and Huhmar, 1952). To obtain a better comprehension of the mechanisms causing these outcomes, future research should adopt a longitudinal approach with larger sample sizes to yield more definitive results.

To protect the neurological health of athletes in high-impact sports like boxing, it is essential to encourage the use of protective equipment, minimize head impacts during training and competitions, and perform regular neurological assessments. Non-invasive tools such as EEG can also be invaluable for detecting early brain changes, allowing for timely preventive actions to safeguard athletes' well-being. While the difference in sample sizes is a limitation of this study, largely due to the challenge of finding eligible and willing participants in the boxer group, the research offers valuable initial insights into the neurophysiological effects of boxing. Future studies should aim to obtain a deeper comprehension of neurophysiological differences in boxers in the long run and to enhance safety protocols in combat sports.

Ethical Approval

Before commencing measurements, the present study received ethical clearance from the Ethics Committee of Atatürk University Faculty of Sport Sciences (Number: E-70400699-000-2300375265, Dated: 23.11.2023).

REFERENCES

Angelakis, E., Lubar, J.F., Stathopoulou, S., & Kounios, J. (2004). Peak alpha frequency: an electroencephalographic measure of cognitive preparedness. *Clin Neurophysiol.* 115:887–97. https://doi.org/10.1016/j.clinph.2003.11.034

Brooks, M. A., Bazarian, J. J., Prichep, L. S., Dastidar, S. G., Talavage, T. M., & Barr, W. (2018). The Use of an Electrophysiological Brain Function Index in the Evaluation of Concussed Athletes. *The Journal of head trauma rehabilitation*, 33(1), 1–6. https://doi.org/10.1097/HTR.0000000000000328

Busse, E.W., & Silverman, A.J. (1952). Electroencephalographic changes in professional boxers. *Journal of the American Medical Association*, 149(17), 1522–1525. https://doi.org/10.1001/jama.1952.02930340006003

Da Broi, M., Al Awadhi, A., Voruz, P., Nouri, A., & Schaller, K. (2023). The spectrum of acute and chronic consequences of neurotrauma in professional and amateur boxing - A call to action is advocated to better understand and prevent this phenomenon. *Brain & spine*, 4, 102743. https://doi.org/10.1016/j.bas.2023.102743

Donnelly, R. R., Ugbolue, U. C., Gao, Y., Gu, Y., Dutheil, F., & Baker, J. S. (2023). A Systematic Review and Meta-Analysis Investigating Head Trauma in Boxing. *Clinical journal of sport medicine: official journal of the Canadian Academy of Sport Medicine*, 33(6), 658–674. https://doi.org/10.1097/JSM.0000000000001195

Electroencephalographic Changes in Boxers. (1982 Volume 19 No. 1 p.287-294). *Korea Univercity Medical Journal.* http://en.medric.or.kr/Main.aspx?menu=01&d=KMBASE&m=VIEW&i=0352519820190010287

Fisch, B. J. (1991). *Spehlmann's EEG Primer. 2nd Revised and Enlarged Edition.* Published by Saint Louis, Missouri, USA. ELSEVIER.

Förstl, H., Haass, C., Hemmer, B., Meyer, B., & Halle, M. (2010). Boxing-acute complications and late sequelae: from concussion to dementia. *DtschArzteblInt,* 107:835–9. https://doi.org/10.3238/arztebl.2010.0835

Gonzalez-Escamilla, G., Atienza, M., Garcia-Solis, D., & Cantero, J. L. (2016). Cerebral and blood correlates of reduced functional connectivity in mild cognitive impairment. *Brain structure & function*, 221(1), 631–645. https://doi.org/10.1007/s00429-014-0930-6

Gökmen, N., Öniz, A., Erdoğan, U., Akkan, T., Özkurt, A., & Özgören, M. (2009). Spinal cerrahi operasyonlarında EEG monitörlemesini etkileyen işitsel ve elektromanyetik gürültünün irdelenmesi. *Journal of Neurological Sciences* [Turkish], 26:(4) 21: 472- 483.

Holmes, P., Collins, D., & Calmels, C. (2006). Electroencephalographic functional equivalence during observation of action. *Journal of Sport Science,* 605-616. https://doi.org/10.1080/02640410500244507

Jann, K., Koenig, T., Dierks, T., Boesch, C., & Federspiel, A. (2010). Association of individual resting state EEG alpha frequency and cerebral blood flow. *Neuroimage.* 51:365–72. https://doi.org/10.1016/j.neuroimage.2010.02.024

Johns, P. (2014). *Chapter 12 - Dementia*. Clinical Neuroscience, Pages 145-162. https://doi.org/10.1016/B978-0-443-10321-6.00012-6

Johnson J. (1969). The EEG in the traumatic encephalopathy of boxers. *Psychiatria clinica*, 2(4), 204–211. https://doi.org/10.1159/000278571

Johnson, J. (1969). Organic psychosyndrome due to boxing. *Br J Psychiatry*. 115:43-45. https://doi.org/10.1192/bjp.115.518.45

Jordan, B. D., Bennet, A., Gandy, S., Alan, R., Ravdin, R. D., & Norman, R. (2000). Chronic traumatic brain injury associated with boxing. *Seminars in Neurology Journal*, 20:179- https://doi.org/10.1055/s-2000-9826

Klimesch, W. (1999). *EEG alpfa and theta oscillations reflect cognitive and memory performance: A review and analysis.* Brain Res.-Brain Res. Rev, 29, Nos. 2/3, 169-195. https://doi.org/10.1016/s0165-0173(98)00056-3

Lejko, N., Larabi, D. I., Herrmann, C. S., Aleman, A., & Ćurčić-Blake, B. (2020). Alpha Power and Functional Connectivity in Cognitive Decline: A Systematic Review and Meta-Analysis. *Journal of Alzheimer's disease: JAD*, 78(3), 1047–1088. https://doi.org/10.3233/JAD-200962

McKee, A. C., Cantu, R. C., Nowinski, C. J., Hedley-Whyte, E. T., Gavett, B. E., Budson, A. E., Santini, V. E., Lee, H. S., Kubilus, C. A., & Stern, R. A. (2009). Chronic traumatic encephalopathy in athletes: progressive tauopathy after repetitive head injury. *Journal of neuropathology and experimental neurology*, 68(7), 709–735. https://doi.org/10.1097/NEN.0b013e3181a9d503

Memmedov, H. (2014). *Boks ve kick boks spor müsabakalarının travmatik beyin hasarı oluşturma riskinin laboratuar açısından değerlendirilmesi*. Atatürk Üniversitesi, Sağlık Bilimleri Enstitüsü, Tıbbi Biyokimya Anabilim Dalı, Yüksek Lisans Tezi.

Michels, L., Muthuraman, M., Anwar, A. R., Kollias, S., Leh, S. E., Riese, F., Unschuld, P. G., Siniatchkin, M., Gietl, A. F., & Hock, C. (2017). Changes of Functional and Directed Resting-State Connectivity Are Associated with Neuronal Oscillations, ApoE Genotype and Amyloid Deposition in Mild Cognitive Impairment. *Frontiers in aging neuroscience*, 9, 304. https://doi.org/10.3389/fnagi.2017.00304

Mizuguchi, M., Ichiyama, T., Imataka, G., Okumura, A., Goto, T., Sakuma, H., Takanashi, J. I., Murayama, K., Yamagata, T., Yamanouchi, H., Fukuda, T., & Maegaki, Y. (2021). Guidelines for the diagnosis and treatment of acute encephalopathy in childhood. *Brain & development*, 43(1), 2–31. https://doi.org/10.1016/j.braindev.2020.08.001

Montenigro, P. H., Corp, D. T., Stein, T. D., Cantu, R. C., & Stern, R. A. (2015). Chronic traumatic encephalopathy: historical origins and current perspective. *Annual review of clinical psychology*, 11, 309–330. https://doi.org/10.1146/annurev-clinpsy-032814-112814

Musaeus, C. S., Engedal, K., Høgh, P., Jelic, V., Mørup, M., Naik, M., Oeksengaard, A. R., Snaedal, J., Wahlund, L. O., Waldemar, G., & Andersen, B. B. (2019). Oscillatory connectivity as a diagnostic marker of dementia due to Alzheimer's disease. *Clinical neurophysiology: official journal of the International Federation of Clinical Neurophysiology*, 130(10), 1889–1899. https://doi.org/10.1016/j.clinph.2019.07.016

Oldfield, R. C. (1971). The Assessment and analysis of handedness: The Edinburgh Inventory. *Neuropsychologia*, 17-35. https://doi.org/10.1016/0028-3932(71)90067-4

Rathee, S., Bhatia, D., Punia, V., & Singh, R. (2020). Peak Alpha Frequency in Relation to Cognitive Performance. *J Neurosci Rural Pract.* 11:416–9. https://doi.org/10.1055/s-0040-1712585

Roberts, A. H. (1969). *Brain damage in boxers: a study of the prevalence of traumatic encephalopathy among ex-professional boxers.* Pitman Medical & Scientific Publishing Co, Ltd.

Siewe, J., Rudat, J., Zarghooni, K., Sobottke, R., Eysel, P., Herren, C., Knöll, P., Illgner, U., & Michael, J. (2015). Injuries in competitive boxing. A prospective study. *International journal of sports medicine*, 36(3), 249–253. https://doi.org/10.1055/s-0034-1387764

Stiller, J. W., & Weinberger, D. R. (1985). Boxing and chronic brain damage. *Psychiatr Clin North Am*, 8:339–56.

Stiller, J. W., Yu, S. S., Brenner, L. A., Langenberg, P., Scrofani, P., Pannella, P., Hsu, E. B., Postolache, T. T. (2014). Sparring and neurological function in professional boxers. *Front Public Health,* 21;2:69. https://doi.org/10.3389/fpubh.2014.00069

Stojsih, S., Boitano, M., Wilhelm, M., & Bir, C. (2010). A prospective study of punch biomechanics and cognitive function for amateur boxers. *Br J Sports Med,* 44(10), 725-730. http://dx.doi.org/10.1136/bjsm.2008.052845

Svinth, J. R. (2007). Death under the Spotlight: The Manuel Velazquez Boxing Fatality Collection. *Journal of Combative Sport.* http://ejmas.com/jcs/jcsart_svinth_a_0700.htm

Temmes, Y., & Huhmar, E. (1952). Electroencephalographic changes in boxers. *Acta psychiatrica et neurologica Scandinavica,* 27(1-2), 175–180. https://doi.org/10.1111/j.1600-0447.1952.tb04650.x

Thompson, J., Sebastianelli, W., & Slobounov, S. (2005). EEG and postural correlates of mild traumatic brain injury in athletes. *Neuroscience letters,* 377(3), 158–163. https://doi.org/10.1016/j.neulet.2004.11.090

Zhang, Y., Lu, Y., Wang, D., Zhou, C., & Xu, C. (2021). Relationship between individual alpha peak frequency and attentional performance in a multiple object tracking task among ice hockey players. *PLOS ONE* 16(5): e0251443. https://doi.org/10.1371/journal.pone.0251443

Ziółkowski, A., Gorkovenko, A., Pasek, M., Włodarczyk, P., Zarańska, B., Dornowski, M., & Graczyk, M. (2015). EEG Correlates of Attention Concentration in Successful Amateur Boxers. *Neurophysiology,* 46(5), 422–427. https://doi.org/10.1007/s11062-015-9468-3