International Journal of Psychophysiology 207 (2025) 112466

Contents lists available at ScienceDirect

International Journal of Psychophysiology

journal homepage: www.elsevier.com/locate/ijpsycho

Full Length Article

Reduced resting and task-related alpha activity in mine workers: Implications for occupational health and neurodegenerative risk

Samet Çelik [a], Ebru Yıldırım [b], Bahar Güntekin [c,d,*]

[a] Department of Psychology, Bartin University, Bartin, Turkey
[b] Department of Physiotherapy and Rehabilitation, Faculty of Health Sciences, Istanbul Gedik University, Istanbul, Turkey
[c] Neuroscience Research Center, Research Institute for Health Sciences and Technologies (SABITA), Istanbul Medipol University, Istanbul, Turkey
[d] Department of Biophysics, School of Medicine, Istanbul Medipol University, Istanbul, Turkey

ARTICLE INFO

Keywords:
Cognitive impairment
Underground miners
EEG
Worker health
Event-related oscillations
Alpha
Unsafe behavior

ABSTRACT

Underground mine workers face many risk factors at work sites that are known to affect the neural system. Observational studies report that these risk factors precede neuromuscular and neurodegenerative disorders, especially in old-age miners. Neurodegenerative disorders have electrophysiological, anatomical, and functional changes long before symptoms are seen in older adults. Therefore, this study investigated whether risks faced by miners at young ages were reflected in electrophysiological signals. Twenty-one underground miners and twenty-two above-ground workers matched with them in terms of age, education, and working duration were included in this study. Participants were recorded with a 20-channel EEG during the resting-state (eyes open and closed; EO-EC) and the perception of the International Affective Picture System Paradigm (IAPS). Time-frequency analyses were performed for alpha frequency. Rs-EEG results showed a statistically significant difference in alpha power between the EO and EC states in the control group. However, there was no statistical difference in alpha power between these two conditions in the miners. Additionally, we noted a more pronounced decrease in alpha responses in the posterior region during EC in the miners. The group's main effects were statistically significant in event-related alpha responses during emotional responses. Accordingly, event-related alpha responses of the miner group were lower than the control group in terms of both power spectrum and phase-locking. Underground mine workers are cognitively and emotionally affected by risks in the work environment. Electrophysiological changes seen in young underground workers may be a harbinger of neurodegenerative disorders in miners' old age. Our research findings may lead to the development of occupational neuroscience, social policies, and worker health, which are necessary to improve working conditions for mineworkers.

1. Introduction

Alpha frequency bands, typically oscillating between 8 and 13 Hz, are a hallmark of the brain's resting state. Because of its importance, researchers have long focused on alpha frequency's role and modulation in the resting state in healthy individuals and those with cognitive impairment (Herring et al., 2015; McMackin et al., 2019).

The alpha rhythm during EC conditions is higher than during EO conditions in healthy individuals. This phenomenon is the first and most typical finding in the EEG literature (Berger, 1933; Chae et al., 2020). Moreover, when alpha changes are examined, it is seen that the alpha difference between the two conditions decreases/disappears in people suffering from neurodegenerative and mental disorders (Rossini et al., 2007; Başar and Güntekin, 2012; Helvaci - Yilmaz et al., 2020; Babiloni et al., 2022). Based on this, biomarkers and current treatment approaches focus on changes in alpha frequency in EO-EC conditions (Bazanova and Vernon, 2014).

Researchers focus on alpha rhythm during "relaxed waking" and event-related alpha responses that occur during tasks such as attention, working memory, and inhibition (Jensen, 2023). ERP (event-related potential) and ERO (event-related oscillation) studies suggest that the alpha responses are prolonged during different cognitive stimuli (Öniz and Başar, 2009), and the power of the alpha responses increases as the working memory load increases (Jensen et al., 2002; Klimesch et al., 1999). In parallel, a decrease in event-related alpha responses in terms of both power spectrum (Güntekin et al., 2022) and phase locking

* Corresponding author at: Istanbul Medipol University, Istanbul, Turkey.
E-mail addresses: psk.sametcelik@gmail.com (S. Çelik), ebru.yildirim@gedik.edu.tr (E. Yıldırım), bguntekin@medipol.edu.tr (B. Güntekin).

https://doi.org/10.1016/j.ijpsycho.2024.112466
Received 18 May 2024; Received in revised form 19 November 2024; Accepted 19 November 2024
Available online 20 November 2024

(Yıldırım et al., 2024) has been reported in clinical groups characterized by cognitive impairment during cognitive tasks.

The event-related alpha oscillations' functionality is not limited to cognitive processes and short-term memories (Başar and Güntekin, 2012). Besides its role during resting state activity and cognitive stimuli, alpha oscillations are related to emotional processes. Many researchers have investigated event-related alpha oscillations during emotional stimuli. However, there is no consensus on its neural role during the processing of emotional stimuli. Early research focused on frontal asymmetry and the desynchronization of alpha responses in response to emotional stimuli (event-related desynchronization/ERD) (Onoda et al., 2007). Some researchers tested the ERD and inhibition during emotional processes in later publications. These studies didn't confirm the inhibition theory (Klimesch et al., 1999; Klimesch et al., 2007), and their findings corresponded more closely to Başar's alertness hypothesis (Başar, 1998, 1999). The later publications showed that event-related alpha responses in healthy individuals were higher during emotional facial expressions, emotional photos, and videos in the temporoparietal regions (Aktürk et al., 2021). This increase is especially evident for negative emotions rather than positive ones in the late time window reflecting top-down inhibitory control processes (Güntekin and Basar, 2007; Schubring and Schupp, 2021). There is an increase in right hemisphere alpha responses in the control group compared to the left hemisphere, but Alzheimer's disease subjects lack this asymmetry, and their right hemisphere alpha responses are lower than the alpha responses of healthy controls (Güntekin et al., 2019).

Mine workers are exposed to various stressors for long periods, including psychological stressors (e.g., fatigue and high physical effort) and environmental factors (e.g., lack of light, toxic gases, and noise). While long-term exposure to each of these stressors is known to be sufficient to produce adverse effects on an individual's neural dynamics and cognitive functions, mine workers are exposed to all of these risk factors collectively. Research on the impact of stress on neural oscillations is limited. However, one common hypothesis points to an inverse relationship between the power of alpha oscillations and cortical activation during high-stress situations (Vanhollebeke et al., 2023; Vanhollebeke et al., 2022; Allen et al., 2004; Jensen and Mazaheri, 2010; Mathewson et al., 2011). In particular, it has been reported that exposure to high stressors causes a decrease in the power of cortical alpha oscillation while leading to higher arousal and vigilance and activation of the hypothalamic-pituitary-adrenal (HPA) axis (Campbell and Ehlert, 2012; Kudielka et al., 2004). Furthermore, our recent study revealed that the event-related alpha responses of miners during the visual oddball paradigm were reduced in terms of both power spectrum and phase locking. Moreover, a negative relationship was found between the alpha power spectrum and the working duration in the underground; It was not found in the group working above ground (Çelik et al., 2024).

In the past two decades, many studies have reported that miners are at risk for mental disorders such as depression and anxiety (Carlisle and Parker, 2014; Joaquim et al., 2018), sleep disorders (Uehli et al., 2014), and alcohol and substance use (James et al., 2021; Tynan et al., 2017). Moreover, social scientists have reported that miners engage in more risky behaviors (e.g., unprotected sexual intercourse, alcohol, and substance use) and experience much more domestic violence and interpersonal problems than the general population (Sharma, 2009; van Tuan, 2010). In addition, in a study (2021) in which Zeng and colleagues retrospectively examined physician billing and hospital discharge records over 17 years, miners were shown to be at risk for neuromuscular and neurodegenerative disorders (Zeng et al., 2021). The potential mechanisms underlying the neurological disorders seen in older underground workers are not yet known. However, since it is known that the pathophysiology of many neurodegenerative disorders appears much earlier than the symptoms, we assumed that if miners are at risk for neurodegenerative diseases in old age, electrophysiological changes begin at earlier ages. So in this study, we aimed to investigate possible changes in the electrophysiological signals of young and middle-aged miners who continue to work underground.

Finally, as summarized above, observations such as the fact that miners are known to have problems in family and social relations and that substance and alcohol use are higher suggest that miners may have impaired emotional processing and regulation skills. Research conducted with healthy individuals has demonstrated a notable augmentation in event-related alpha responses when engaging with emotional stimuli (Onoda et al., 2007; Güntekin and Basar, 2007; Cushing et al., 2018). Furthermore, it has been observed that clinical samples characterized by deficits in emotional processing exhibit concomitant deficits in event-related alpha responses (Güntekin et al., 2019; Segrave et al., 2012). In our study, there were two main reasons for choosing alpha oscillations. First, it is well known that alpha power decreases in clinical populations with cognitive impairment, both at rest and in event-related responses. Therefore, our basic assumption is that if cognitive impairment occurs in individuals working underground, this situation will be reflected in alpha oscillations. The second reason is that recent studies have shown that long-term stressors cause a decrease in cortical alpha oscillations (Allen et al., 2004; Jensen and Mazaheri, 2010; Mathewson et al., 2011). One widely accepted approach is that during the stress phase, the power of alpha oscillations in the brain decreases, and as a result, stress increases arousal and vigilance (Vanhollebeke et al., 2023; Vanhollebeke et al., 2022). Based on this, we assumed that alpha oscillations would decrease in miners exposed to long-term stressors. In particular, the widespread distribution of alpha rhythm among both cortico-cortical and thalamocortical loops has shifted attention to alpha oscillation (Lozano-Soldevilla, 2018) regarding possible neural changes that may be seen in miners.

2. Materials and methods

2.1. Participants

Twenty-one miners working underground and twenty-two control groups working above ground participated in this research. Both groups are equivalent to each other in terms of age, education level, and working duration. Descriptive statistics are presented in Table 1.

The inclusion criteria for the present study were having worked underground for at least five years, being at least a primary school graduate, and working the day shift during the month of data collection. The exclusion criteria were: having had a severe head injury or work accident, having a first-degree relative diagnosed with schizophrenia or bipolar disorder, being diagnosed with any psychiatric or neurological disease, using drugs that affect cognitive functions (such as stimulants, antidepressants, and anxiolytics) in the past year, high alcohol intake in the last month, and using substances in the past six months.

The sample size was calculated by using G*Power (3.1.9.7 version). The effect size was 0.25, and the type I error margin was considered 0.05. The power was considered at 0.80 based on repeated measures ANOVA test. When calculating the effect size, Görsev et al.'s study was

Table. 1
The comparison of socio-demographic characteristics of the samples.

Variables	Miners Group ($N = 21$)	Control Group ($N = 22$)	Z/t	P
Age*	37.00 ± 5.06	36.00 ± 4.93	0.685	0.497
Education level (years)**	12.00 (8.00–16.00)	12.00 (8.00–16.00)	−0.050	0.961
Working duration (years)*	11.24 ± 4.73	11.95 ± 5.51	−0.445	0.659

* The age variable is distributed normally, and an independent *t*-test statistic was performed to compare the age differences. The mean ± standard deviation is reported.

** Normally undistributed data. Mann-Whitney *U* test was applied to this data, and median (min-max) values were given.

taken into account due to the similarity of the methodology. The number of participants was determined to be twenty people for each group. This sample size is similar to previous EEG studies (Aktürk et al., 2020; Yıldırım et al., 2020; Kasten et al., 2016). All participants who completed the study were given a gift card worth 400 TL at the end of the experiment. Before starting the study, ethical approval was obtained from the Istanbul Medipol University Non-Interventional Clinical Research Ethics Committee (Approval number: E-10840098-772-02-897).

2.2. EEG recording

EEG was recorded from Fp1, Fp2, F3, F4, Fz, F7, F8, C3, C4, Cz, T7, T8, P3, P4, Pz, P7, P8, O1, O2, and Oz electrodes and electrodes placements based on the international 10–20 system. The EEG was amplified by Enobio32 (NeuroElectrics, Spain) with band limits of 0 to 125 Hz and digitized online with a sampling rate of 500 Hz. Enobio32 has an active and wet electrode system, which saves the researcher time, especially for impedance reduction and preparation before EEG recording. The participants sat in a dimly lit room during EEG recordings. The right earlobe was taken as the reference electrode. The impedance was kept below 10kohm during all recordings.

2.3. Procedure and task

The electrophysiological activity of all participants at rest with eyes open and eyes closed was recorded for 6 min each. During the resting state EEG recording, a 6-min eyes-open condition EEG recording was first performed; when the time was up, the participant was instructed to close their eyes without a break. A black screen was presented to participants throughout the EEG recording without fixation cross.

After the resting state EEG recording was completed, EEG was recorded during an emotional paradigm. In this paradigm, the stimuli consisted of images from the International Affective Pictures System (IAPS) presented to the participants (Lang et al., 1999). Twenty-nine images, divided into three subtypes, were selected from the IAPS stimulus set. These pictures are as follows, by subtype: Unpleasant pictures: 2353.2; 6350; 2205; 6540; 3400; 1930; 1052; 1274; 1932; 1114. Pleasant pictures: 2050; 2332; 2340; 2080; 1460; 1500; 1610; 1722; 1710. Neutral pictures: 2190; 2210; 2214; 2480; 2495; 7020; 7030; 7041; 7080; 7150. The unpleasant, pleasant, and neutral pictures were randomly presented on the screen for 1 s. The interval between stimuli was determined as 3–7 s. Each picture was presented three times in total. During the EEG recording, participants were not asked to give any response. There was no break during the resting state EEG and IAPS recordings. After the EEG recording was finished, the participants were asked by the researcher to score the whole set of stimuli regarding the degree of valence (negativity/positivity) and arousal (calm/excited) using a Self-Assessment Manikin (SAM) scale. Participants scored the valence values of visual stimuli from 1 to 4 points as negative (1 point = the highest negative score), from 6 to 9 points as positive (9 point = the highest positive score), and five as neutral (Bradley and Lang, 1994). For arousal values, they were asked to score 1 point, the lowest arousal, and 9 points, the highest arousal. Stimulus presentations were made via *E-prime*.

2.4. EEG analysis

2.4.1. Resting state EEG analysis

Resting state EEG data analyses were performed using Brain Vision Analyzer 2.2 Software (Brainproducts, Munich, Germany). The EEG data were analyzed separately for open and closed eyes conditions. Raw EEG data were preprocessed. In the preprocessing stage, raw EEG data were filtered in the 0.1 Hz and 60 Hz range with IIR (Infinite Impulse Response filters). Then, ICA (Independent Component Analysis) was performed by using the Infomax algorithm to remove eye movement-related artifacts. EEG data were segmented into 1-s epochs. Manual artifact rejection was performed off-line. There were no distinct drifts in our resting-state EEG data. Any observed drifts were removed from the EEG signal and not included in the data analysis.

The power spectrum analysis was applied to preprocessed EEG data. In the power spectrum analysis, the Fast Fourier Transform (FFT) was applied to each epoch using the Hanning window (length of 10 %). The FFT was performed with maximum resolution (0.9 Hz). Later, all epochs which were applied FFT were averaged. The maximal peak value was measured in the 8–13 Hz alpha frequency band for each electrode and each participant. These maximal alpha peak values were used for the statistical analysis.

2.4.2. Time-frequency analyses

Event-related time-frequency analyses were performed using Brain Vision Analyzer Software (Brainproducts, Munich, Germany). Preprocessing steps similar to the resting state were applied for the event-related oscillation analysis. Digital filtering between 0.1 Hz and 60 Hz was applied. Then, independent component analysis was performed by using the Infomax algorithm for artifacts. Afterward, the artifact-free continuous EEG data were segmented to epochs from −1000 to 1000 ms relative to stimulus onset. Artifact rejection was performed manually.

The time-frequency analyses were performed separately for unpleasant, pleasant, and neutral stimuli. In both event-related power spectrum and event-related phase-locking analyses, continuous wavelet transform (Gabor normalization, complex Morlet wavelet) was applied to preprocessed data for the alpha frequency band (8-13 Hz; 3 cycle). All epochs were averaged. The baseline correction was also made (−500; −300 ms) for the event-related power spectrum analysis. Afterward, grand averages were analyzed for each group. We have observed that there was a decrease in alpha power and phase-locking in miners in the grand averages. Accordingly, we have decided on the time window for the analyses by considering the alpha responses of the miner group in the grand averages. The alpha power and phase-locking values were calculated for a 50–200 ms time window according to the grand averages.

2.5. Statistical analysis

Jamovi software (2.3.24 version) was used for the statistical analyses. The resting state EEG statistical analyses were performed with repeated measures of analysis of variance (ANOVA). In the ANOVA design, the Group effect (miners and control group) was identified as the between-subject effect. The Condition effect (eyes open and eyes closed condition), location effect (Frontal: F3-F4, Central: C3-C4, Temporal: T7-T8, Parietal-1: P3-P4, Parietal-2: P7-P8, Occipital: O1-O2), and Hemisphere effect (left and right) were identified as within-subject effects. In event-related oscillation analysis, stimulus type was added as three factors (Neutral, positive, negative). Greenhouse–Geisser corrected *p*-values were reported in the statistical results. Post hoc comparisons were performed using the Bonferroni correction. The significance level was determined as $p < 0.05$.

3. Results

3.1. Results of the resting state EEG analysis

The miners had lower alpha power than the controls. However, this difference was insignificant ($F(df = 1,42) = 1.41$; $p = 0.2411$; $\eta^2p = 0.033$). The Condition*Group interaction was statistically significant ($F(df = 1,42) = 7.759$; $p = 0.008$; $\eta^2p = 0.156$). Post-hoc comparisons showed that controls had higher alpha power in the eyes-closed condition than the eyes-open condition ($t(42.0) = 5.326$, $p < 0.001$). However, there was no difference in miners ($t(42.0) = 1.237$, $p > 0.05$). Fig. 1 shows Topographical plots of the alpha power during the resting-state EEG. In Fig. 1, the left column represents the alpha power of the

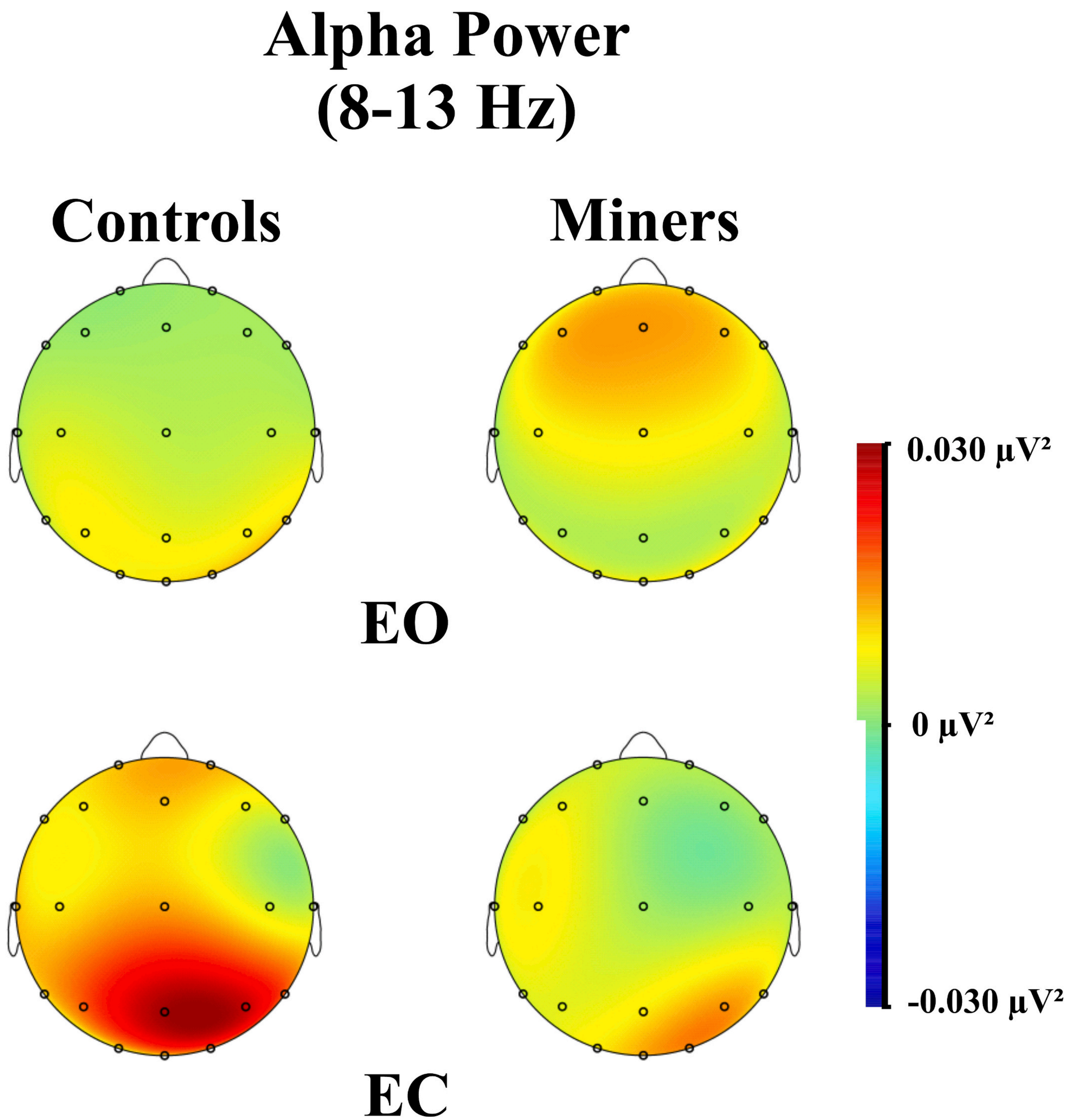

Fig. 1. Topographical plots of the alpha power during the resting-state EEG. EO: eyes open condition; EC: eyes closed condition.

control group, whereas the right column represents the alpha power of the miner group. The upper part of the figure represents alpha power during the eyes open condition while the lower part represents alpha power during the eyes closed condition. The alpha power increases from blue color to red color in the color scale. As seen in Fig. 1, controls had increased alpha power during the eyes-closed condition compared to the open condition. However, there was no difference in miners. In particular, miners had reduced alpha power compared to controls during the eyes closed condition.

The Condition*Location*Group interaction was statistically significant (F(df = 2.67,112.13) = 3.340; $p = 0.026$; $\eta^2p = 0.074$). Post-hoc analyses showed that controls had higher alpha power in the eyes-closed condition than the eyes-open condition in the parietal-1 ($t(42.0) = 4.989$, $p = 0.003$) and parietal-2 ($t(42.0) = 4.821$, $p = 0.005$) locations. Furthermore, this interaction was marginally significant for the occipital locations ($t(42.0) = 4.043$, $p = 0.061$). The controls had higher alpha power in the eyes-closed condition than the eyes-open condition in the occipital locations. However, there was no difference specific to eyes open/closed condition in miners ($p > 0.05$) in the posterior locations. Fig. 2 shows the statistical results of the Condition*Location*Group interaction of the ANOVA design for the resting alpha power spectrum analysis. In Fig. 2, the vertical axis represents

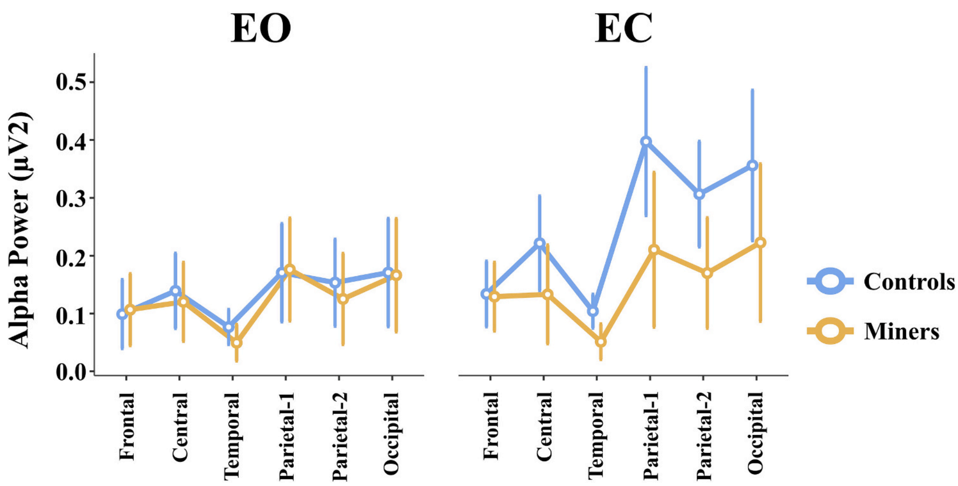

Fig. 2. The statistical results of the Condition*Location*Group interaction for the resting alpha power spectrum analysis.

resting alpha power, while the horizontal axis represents locations. The blue line represents the alpha power of the control group, whereas the orange line represents the alpha power of the miner group. The left column represents alpha power during the eyes open condition while the right column represents alpha power during the eyes closed condition. Fig. 2 shows miners had decreased alpha power compared to controls during the eyes closed conditions. This reduction was more pronounced in posterior locations.

Fig. 3 shows the grand average of the alpha power during the resting-state EEG over the parietal and occipital electrodes for the controls and miners. The black line represents alpha power in the eyes open condition and the red line represents alpha power in the eyes closed condition. Fig. 3 shows miners had decreased eyes-closed alpha power in the posterior locations compared to controls.

3.2. Results of the time-frequency analysis during IAPS paradigm

The power spectrum of the responses occurring in the alpha frequency band was compared. As a result of the analysis, it was found that the main group effect in the alpha power spectrum was statistically significant ($F(df = 1,36) = 9.16$, $p = 0.005$; np2 = 0.203). Accordingly, underground miners' alpha response to emotional stimuli is lower than the control group, regardless of the stimulus type (Fig. 4). Fig. 5 shows the grand average of the alpha power spectrum during the perception of the unpleasant stimuli. The alpha power increases from the blue color to the red color. The red areas represent higher alpha power values whereas the blue areas represent lower alpha power values. Fig. 5 shows that miners had decreased alpha power compared to controls.

Secondly, stimulus responses were compared in terms of phase-locking values. According to the results of the statistical analysis, the main group effect was found to be statistically significant, $F(df = 1,36) = 8.95$, $p = 0.005$; np2 = 0.199). Accordingly, the alpha phase locking responses of the miners are lower than the control group, regardless of the stimulus type (Fig. 6).

3.3. Behavioral results in IAPS scores

It was compared whether there was a difference in the valence and

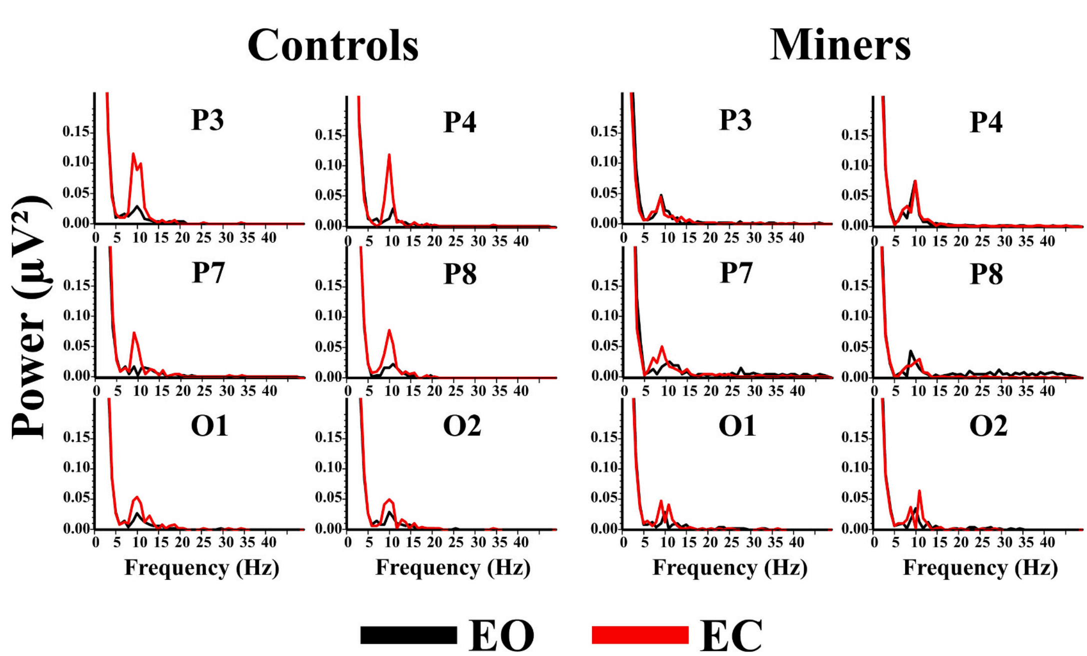

Fig. 3. The grand average of the alpha power during the resting-state EEG over the parietal and occipital electrodes. EO: eyes open condition; EC: eyes closed condition.

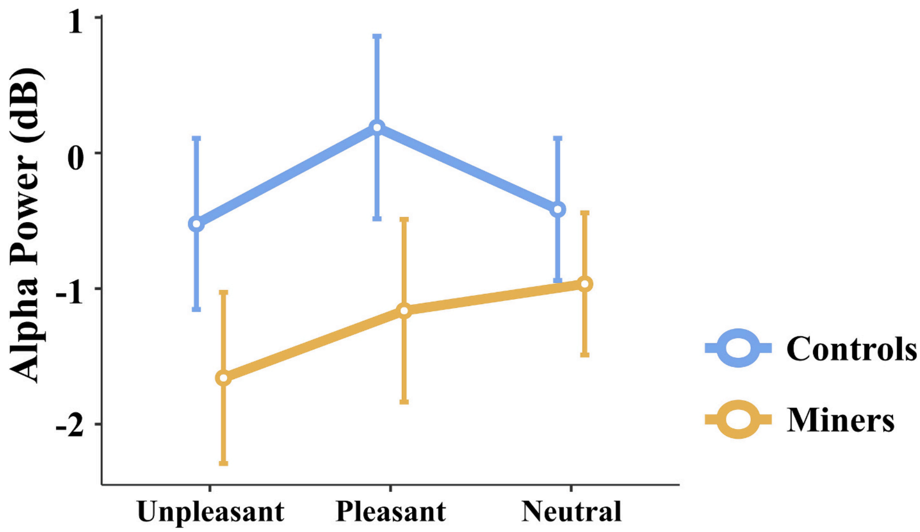

Fig. 4. Means and confidence intervals of event-related alpha responses according to stimulus types.

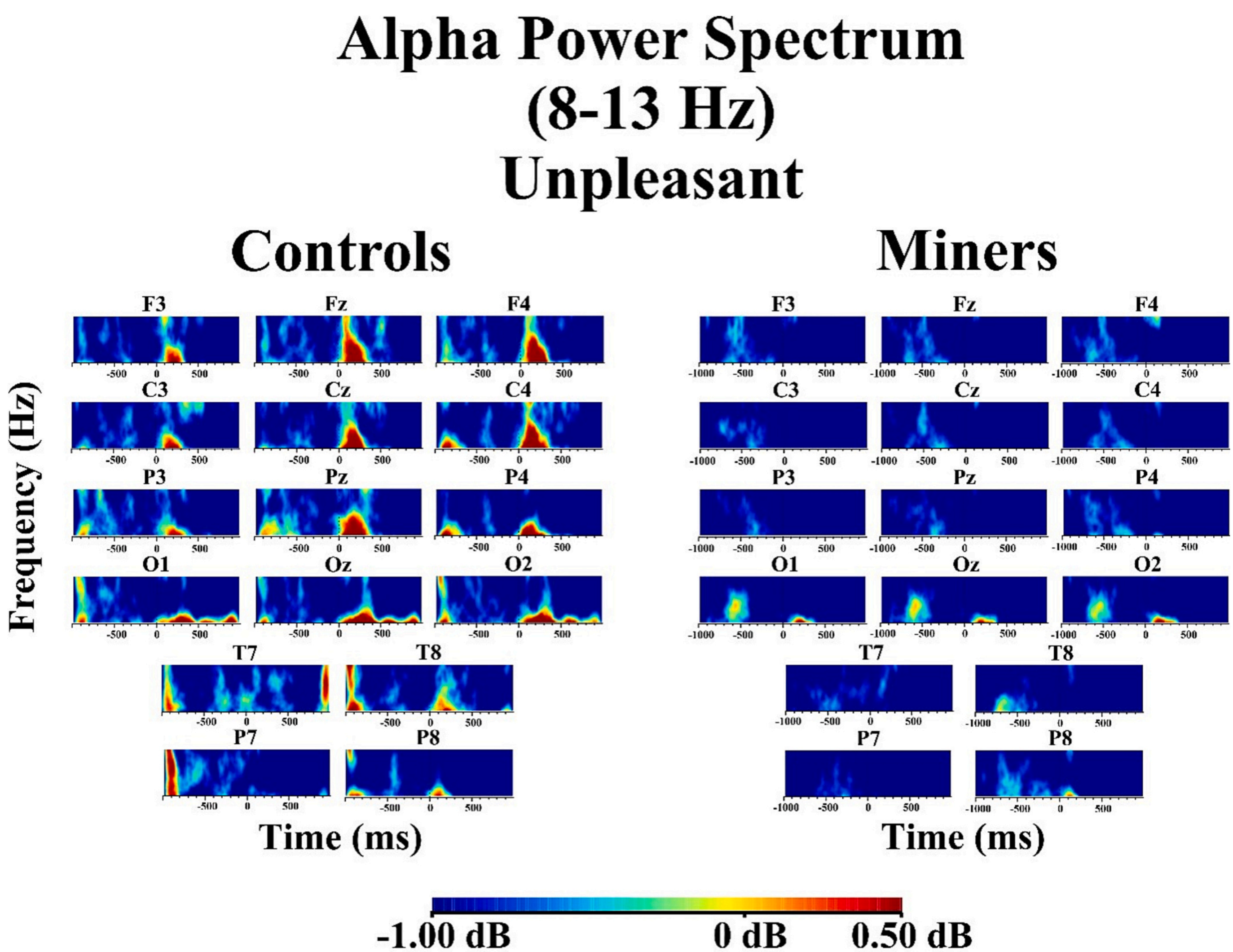

Fig. 5. The grand average of the alpha power spectrum during the perception of the unpleasant stimuli.

arousal scores the participants gave to the emotional stimulus. Whether valance scores differed between groups and stimulus types was examined. According to the one-way PERMANOVA score, a statistically marginally significant difference was found regarding group*stimulus type interaction ($p = 0.057$). Then, the Mann-Whitney *U* test compared each stimulus type between groups. Accordingly, a statistical difference

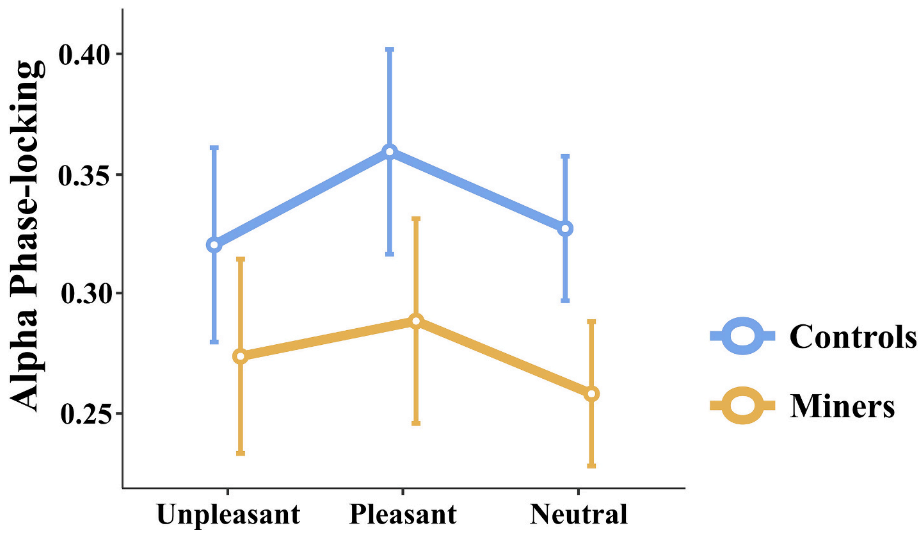

Fig. 6. Means and confidence intervals of event-related alpha phase-locking responses according to stimulus types.

was found between the two groups for negative stimuli (Z = −2.296; p = 0.022; effect size = 0.44). Accordingly, the control group's average valance score given to negative images (2.47 ± 0.70) is lower than the control group (3.23 ± 1.60). When the mean scores of positive stimuli were compared, no statistically significant difference was found (p = 0.098). Similarly, no significant difference was found in neutral stimuli (p = 0.598).

Then, arousal score averages were compared for each stimulus type. When compared, no significant difference was found in the arousal scores of the two groups (p = 0.208). When the stimulus types were compared between groups using the Mann-Whitney U test, a significant difference was found in the scores given to negative stimuli (Z = −2.266, p = 0.023). No statistically significant difference was detected for positive and neutral stimuli (p = 0.549, p = 0.158, respectively).

4. Discussion

The current investigation sought to determine potential impairments within the alpha rhythms of miners. This examination was approached from two distinct perspectives. The study compared the power spectrum values of the alpha rhythm during both eyes open and eyes closed conditions within the resting-state EEG activity to a control group. It explored changes in the alpha frequency band during emotional stimuli using the event-related oscillations (ERO) method. The assessment of alpha rhythm within the ERO framework encompassed an evaluation of the power spectrum and phase-locking characteristics.

As a result of the analysis, no statistical difference was observed in the power of the alpha responses of the miners with eyes closed and eyes open. However, a significant difference was found in the control group. Moreover, the Condition*Location*Group interaction was also found to be statistically significant. Accordingly, the alpha responses of the miners were lower, especially in the parietal and occipital regions. In parallel with the resting state EEG results, the main group effect was significant in both event-related power spectrum and phase locking in miners. Accordingly, regardless of the type of stimulus, miners almost do not have an alpha response to emotional stimuli.

The increase in alpha rhythm during the transition from eyes open (EO) to eyes closed (EC) in healthy individuals is one of the first and most typical findings in the EEG literature (Babiloni et al., 2022; Başar and Güntekin, 2012). Even the apparent alpha difference observed between the two conditions is suggested to be used as a biomarker since it varies in different clinical samples (Başar and Güntekin, 2012; Başar and Güntekin, 2012). Similarly, a decrease in alpha rhythm from EC to EO, and the subjects with cognitive impairment had lower reductions compared to healthy controls, which is indicated as a neural marker for cognitive impairment (Babiloni et al., 2022). These changes in alpha power are more evident in the posterior regions (Babiloni et al., 2004; Grunwald et al., 2001; Moretti et al., 2004). This could be attributed to alterations in the neural synchronization mechanisms that regulate vigilance within the posterior cortical systems of individuals with cognitive impairment (Babiloni et al., 2022). From this point of view, the fact that no difference was observed in the alpha power response in EO and EC conditions in miners supports our hypothesis that miners suffer cognitive impairment. Furthermore, it can be speculated that there were alterations in the neural synchronization mechanisms regulating the vigilance of the miners.

Alpha oscillations that occur during emotional stimuli are unable to respond to emotional stimuli, regardless of the type of stimulus. Surprisingly, miners had lower mean scores than the control group, even during neutral expressions as well as images with high arousal ratings. Moreover, when Fig. 1 is examined, the alpha responses of the miners regarding the event do not even differ in locations. As it is known, processing emotional stimuli requires complex bottom-up and top-down processes (Balconi and Mazza, 2009). When visual input begins to be processed, it includes steps such as recognizing emotion, making decisions about behavior, and determining appropriate behavior. Moreover, all these processes include attention and memory (Campagnoli et al., 2019; Jensen et al., 2002). The decrease in miners' alpha responses to the event suggests that the overall emotional network, not location-specific, was disrupted. In terms of time-frequency analysis, alpha responses disappeared in power and phase-locked.

Studies conducted with healthy individuals report that event-related alpha responses are higher during negative than positive stimuli (Güntekin and Basar, 2007). Moreover, the right temporoparietal alpha activity is more prominent than the left hemisphere (Aktürk et al., 2021). In terms of clinical groups, it has been shown that alpha power and phase locking are low in Alzheimer's patients, especially in the right hemisphere (Güntekin et al., 2019). Accumulated evidence in social and affective neuroscience has consistently pointed to the significant role of the alpha rhythm in supporting various aspects of social functioning, such as empathy, theory of mind, and so on (Decety, 2011). It is known that oxytocin increases alpha oscillations, especially in the mirror neuron system, whose role in emotional processing is well known (Perry et al., 2010). Furthermore, alpha activity has been demonstrated to play a role in perceiving and processing the pain of others—a fundamental precursor of empathy (Decety, 2011).

Our event-related alpha oscillation findings also parallel the valence and arousal scores that participants gave the images. According to behavioral findings, the valance scores given to negative stimuli by underground workers are higher than those of the control group, especially for negative stimuli. In other words, underground mine workers reported that they did not perceive negative stimuli as "negative" as much as the control group. This may be related to miners' difficulty perceiving and recognizing emotional stimuli. Moreover, the arousal score averages for negative stimuli also support this finding. The control group's arousal scores for emotional stimuli are higher than those of underground workers. EEG and behavioral findings show miners have difficulty recognizing and processing emotions and producing appropriate emotional responses. This situation may be related to domestic violence, deterioration in interpersonal relationships, stimulant use, and other addictions, especially among miners.

5. Conclusion

Working underground involves many risk factors. To what extent these risk factors contribute to the cognitive impairment observed in miners is unknown. Methodologically, structural and environmental factors make it challenging to investigate the causes of this situation. In the conceptual background of this study, all risk factors that miners are exposed to are grouped under the heading of "stressor". However, some of these may have a greater effect on neural oscillations than others. For example, the findings of this study focus on alpha oscillation, and light has long been known to modulate alpha oscillations and cognition. So, one of the important risk factors is that miners work in a dark environment for years, which suggests that it affects the nervous system, especially the visual network (Ergenoglu et al., 2004; Stecher et al., 2017). Considerable research has been dedicated to investigating the influence of light upon electroencephalogram (EEG) oscillatory patterns, concurrently recognizing the modulatory impact of light on cognitive processes (Vandewalle et al., 2009). Among the various EEG oscillations, the alpha rhythm is particularly amenable to studying electrophysiological responses influenced by insufficient light. Accordingly, this scholarly article focuses on resting-state and event-related alpha responses in light of this context. One piece of evidence to support our findings comes from people with congenital blindness. The miners showed an EEG pattern similar to the EEG findings of individuals with congenital blindness (Kriegseis et al., 2006). Other evidence comes from human and animal studies (see review; Vandewalle et al., 2009). However, in addition to the light factor, mining sites involve many risks. Among these risk factors, chronic stress, harsh working conditions, and individual differences (vulnerability, psychological resilience, etc.) may contribute to the change in miners' electrophysiological responses. In particular, the effects of chronic stress on cognition and emotion are known systematically in vivo and in vitro. Therefore, it is assumed that risk factors at underground work sites cumulatively affect the role of the neural network. Therefore, the findings of this research are also crucial in terms of human-environment interaction. The effects of working conditions on the human nervous system are examined by subdisciplines such as human factors/neuroergonomics. In this respect, it is necessary to thoroughly understand the ergonomic conditions in work areas and make arrangements to minimize their negative effects.

Another critical point of the research is from the perspective of the social sciences. This research reveals the importance of working conditions in terms of employee health. In this respect, showing that miners are especially at risk for neurodegenerative disorders and presenting objective methods to show that this deterioration begins at a very young age will lead to the development of social policies and legal regulations. In addition, electrophysiological changes at an early age may make miners more susceptible to mental disorders. Therefore, while future studies investigate the etiology of mental disorders seen in miners, we recommend that they also focus on impairments in neural systems.

Finally, this research has some limitations. First, as mentioned before, mental disorders are very common in mine workers. For our findings to come from a more homogeneous group, those with psychiatric illnesses were excluded from the study. During the interviews, many volunteers who wanted to participate in the research (for this research, this number was close to 50) were excluded because they did not meet the criteria. Additionally, behavioral problems were very common in the volunteers (such as anger control problems, domestic violence, involvement in criminal matters, alcohol, and substance use), and miners with these characteristics were not included in the study. However, as a third group, data can be collected from people with behavioral problems, and their EEG characteristics can be examined. Secondly, this study included people of relatively young age and high education level. Worse electrophysiological responses are likely to be found if data are collected from older individuals, especially those who have retired from mining companies. Because even in healthy aging, changes in electrophysiological signals are known. Brain dynamics of miners of similar age but different working durations can be compared to examine the effect of working duration on underground miners in future studies. Again, a high level of education may be a protective variable for the cognitive performance of mine workers. Lastly, it is thought that the cause of behavioral problems, which indicate that there may be an increase in impulsivity and a decrease in behavioral inhibition in miners, is caused by biological and cognitive changes in the nervous system and brain rather than sociological and environmental factors. However, large-scale controlled studies showing causality are required to confirm this hypothesis.

CRediT authorship contribution statement

Samet Çelik: Writing – review & editing, Writing – original draft, Visualization, Validation, Software, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Ebru Yıldırım:** Writing – review & editing, Writing – original draft, Visualization, Validation, Software, Methodology, Investigation, Funding acquisition, Formal analysis. **Bahar Güntekin:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Funding acquisition, Formal analysis.

Consent

Written informed consent was obtained from all participants before starting the study.

Ethical approval

Ethical approval was obtained from the Istanbul Medipol University Non-Interventional Clinical Research Ethics Committee (Approval number: E-10840098-772-02-897).

Funding

The segment of this research pertaining to the emotional stimulus paradigm received support from the Scientific and Technological Research Council of Türkiye (TÜBİTAK) under project number 122K561.

Declaration of competing interest

We have no known conflict of interest to disclose.

Data availability

Data will be made available on request.

References

Aktürk, T., İşoğlu-Alkaç, Ü., Hanoğlu, L., Güntekin, B., 2020. Age related differences in the recognition of facial expression: Evidence from EEG event-related brain oscillations. International Journal of Psychophysiology ,147, 244–256. https://doi.org/10.1016/j.ijpsycho.2019.11.013.

Aktürk, T., de Graaf, T.A., Abra, Y., Şahoğlu-Göktaş, S., Özkan, D., Kula, A., Güntekin, B., 2021. Event-related EEG oscillatory responses elicited by dynamic facial expression. Biomed. Eng. Online 20 (1), 1–17. https://doi.org/10.1186/s12938-021-00882-8.

Allen, J.J., Coan, J.A., Nazarian, M., 2004. Issues and assumptions on the road from raw signals to metrics of frontal EEG asymmetry in emotion. Biol. Psychol. 67 (1–2), 183–218. https://doi.org/10.1016/j.biopsycho.2004.03.007.

Babiloni, C., Binetti, G., Cassetta, E., Cerboneschi, D., Dal Forno, G., Del Percio, C., Ferreri, F., Ferri, R., Lanuzza, B., Miniussi, C., Moretti, D.V., Nobili, F., Pascual-Marqui, R.D., Rodriguez, G., Romani, G.L., Salinari, S., Tecchio, F., Vitali, P., Zanetti, O., Rossini, P.M., 2004. Mapping distributed sources of cortical rhythms in mild Alzheimer's disease. A multicentric EEG study. NeuroImage 22 (1), 57–67. https://doi.org/10.1016/j.neuroimage.2003.09.028.

Babiloni, C., Lorenzo, I., Lizio, R., Lopez, S., Tucci, F., Ferri, R., Soricelli, A., Nobili, F., Arnaldi, D., Famà, F., Buttinelli, C., Giubilei, F., Cipollini, V., Onofrj, M., Stocchi, F., Vacca, L., Fuhr, P., Gschwandtner, U., Ransmayr, G., Aarsland, D., Noce, G., 2022. Reactivity of posterior cortical electroencephalographic alpha rhythms during eyes opening in cognitively intact older adults and patients with dementia due to Alzheimer's and Lewy body diseases. Neurobiol. Aging 115, 88–108. https://doi.org/10.1016/j.neurobiolaging.2022.04.001.

Balconi, M., Mazza, G., 2009. Brain oscillations and BIS/BAS (behavioral inhibition/activation system) effects on processing masked emotional cues. ERS/ERD and coherence measures of alpha band. Int. J. Psychophysiol. 74 (2), 158–165. https://doi.org/10.1016/j.ijpsycho.2009.08.006.

Başar, E., 1998. Brain Oscillations I: Principles and Approaches. Springer-Verlag, Heidelberg.

Başar, E., 1999. Brain Function and Oscillations: II. Neurophysiology and Cognitive Processes, Springer-Verlag, Heidelberg, Integrative brain function.

Başar, E., Güntekin, B., 2012. A short review of alpha activity in cognitive processes and in cognitive impairment. Int. J. Psychophysiol. 86 (1), 25–38. https://doi.org/10.1016/j.ijpsycho.2012.07.001.

Bazanova, O.M., Vernon, D., 2014. Interpreting EEG alpha activity. Neurosci. Biobehav. Rev. 44, 94–110. https://doi.org/10.1016/j.neubiorev.2013.05.007.

Berger, H., 1933. Über das Elektrenkephalogramm des Menschen - Sechste Mitteilung. Arch. Psychiatr. Nervenkr. 99 (1), 555–574. https://doi.org/10.1007/BF01814320.

Bradley, M.M., Lang, P.J., 1994. Measuring emotion: the self-assessment manikin and the semantic differential. J. Behav. Ther. Exp. Psychiatry 25 (1), 49–59. https://doi.org/10.1016/0005-7916(94)90063-9.

Campagnoli, R.R., Wieser, M.J., Gruss, L.F., Boylan, M.R., McTeague, L.M., Keil, A., 2019. How the visual brain detects emotional changes in facial expressions: evidence from driven and intrinsic brain oscillations. Cortex 111, 35–50. https://doi.org/10.1016/j.cortex.2018.10.006.

Campbell, J., Ehlert, U., 2012. Acute psychosocial stress: does the emotional stress response correspond with physiological responses? Psychoneuroendocrinology 37 (8), 1111–1134. https://doi.org/10.1016/j.psyneuen.2011.12.010.

Carlisle, K.N., Parker, A.W., 2014. Psychological distress and pain reporting in Australian coal miners. Saf. Health Work 5 (4), 203–209. https://doi.org/10.1016/j.shaw.2014.07.005.

Çelik, S., Yıldırım, E., Güntekin, B., 2024. Electrophysiological and cognitive changes in hard coal miners associated with working underground. Clinical EEG and Neuroscience 55 (5), 561–571. https://doi.org/10.1177/15500594241237912.

Chae, S., Park, J., Byun, M.S., Yi, D., Lee, J.H., Byeon, G.H., Suk, H.W., Choi, H., Park, J. E., Lee, D.Y., 2020. Decreased alpha reactivity from eyes-closed to eyes-open in non-demented older adults with Alzheimer's disease: a combined EEG and [18F] florbetaben PET study. J. Alzheimers Dis. 77 (4), 1681–1692. https://doi.org/10.3233/JAD-200442.

Cushing, C.A., Im, H.Y., Adams Jr., R.B., Ward, N., Albohn, D.N., Steiner, T.G., Kveraga, K., 2018. Neurodynamics and connectivity during facial fear perception: the role of threat exposure and signal congruity. Sci. Rep. 8 (1), 2776. https://doi.org/10.1038/s41598-018-20509-8.

Decety, J., 2011. The neuroevolution of empathy. Ann. N. Y. Acad. Sci. 1231 (1), 35–45. https://doi.org/10.1111/j.1749-6632.2011.06027.x.

Ergenoglu, T., Demiralp, T., Bayraktaroglu, Z., Ergen, M., Beydagi, H., Uresin, Y., 2004. Alpha rhythm of the EEG modulates visual detection performance in humans. Cogn. Brain Res. 20 (3), 376–383. https://doi.org/10.1016/j.cogbrainres.2004.03.009.

Grunwald, M., Busse, F., Hensel, A., Kruggel, F., Riedel-Heller, S., Wolf, H., Arendt, T., Gertz, H.J., 2001. Correlation between cortical θ activity and hippocampal volumes in health, mild cognitive impairment, and mild dementia. J. Clin. Neurophysiol. 18 (2), 178–184. https://doi.org/10.1097/00004691-200103000-00010.

Güntekin, B., Aktürk, T., Arakaki, X., Bonanni, L., Del Percio, C., Edelmayer, R., Farina, F., Ferri, R., Hanoğlu, L., Kumar, S., Lizio, R., Lopez, S., Murphy, B., Noce, G., Randall, F., Sack, A.T., Stocchi, F., Yener, G., Yıldırım, E., Babiloni, C., 2022. Are there consistent abnormalities in event-related EEG oscillations in patients with Alzheimer's disease compared to other diseases belonging to dementia? Psychophysiology 59 (5). https://doi.org/10.1111/psyp.13934.

Güntekin, B., Basar, E., 2007. Emotional face expressions are differentiated with brain oscillations. Int. J. Psychophysiol. 64 (1), 91–100. https://doi.org/10.1016/j.ijpsycho.2006.07.003.

Güntekin, B., Hanoğlu, L., Aktürk, T., Fide, E., Emek-Savaş, D.D., Ruşen, E., Yıldırım, E., Yener, G.G., 2019. Impairment in recognition of emotional facial expressions in Alzheimer's disease is represented by EEG theta and alpha responses. Psychophysiology 56 (11). https://doi.org/10.1111/psyp.13434.

Helvaci - Yilmaz, N., Çalisoglu, P., Güntekin, B., Hanoglu, L., 2020. Correlation between alpha activity and neuropsychometric tests in Parkinson's disease. Neuroscience Letters 738, 135346. https://doi.org/10.1016/j.neulet.2020.135346.

Herring, J.D., Thut, G., Jensen, O., Bergmann, T.O., 2015. Attention modulates TMS-locked alpha oscillations in the visual cortex. J. Neurosci. 35 (43), 14435–14447. https://doi.org/10.1523/JNEUROSCI.1833-15.2015.

James, C.L., Tynan, R.J., Bezzina, A.T., Rahman, M.M., Kelly, B.J., 2021. Alcohol consumption in the Australian mining industry: the role of workplace, social, and individual factors. Workplace Health and Safety 69 (9), 423–434. https://doi.org/10.1177/21650799211005768.

Jensen, O., 2023. Gating by alpha band inhibition revised: a case for a secondary control mechanism. BioRxiv 1–15.

Jensen, O., Gelfand, J., Kounios, J., Lisman, J.E., 2002. Oscillations in the alpha band (9-12 Hz) increase with memory load during retention in a short-term memory task. Cereb. Cortex 12 (8), 877–882. https://doi.org/10.1093/cercor/12.8.877.

Jensen, O., Mazaheri, A., 2010. Shaping functional architecture by oscillatory alpha activity: gating by inhibition. Front. Hum. Neurosci. 4, 186. https://doi.org/10.3389/fnhum.2010.00186.

Joaquim, A.C., Lopes, M., Stangherlin, L., Castro, K., Ceretta, L.B., Longen, W.C., Ferraz, F., Perry, I.D.S., 2018. Mental health in underground coal miners. Arch. Environ. Occup. Health 73 (6), 334–343. https://doi.org/10.1080/19338244.2017.1411329.

Kasten, F.H., Dowsett, J., Herrmann, C.S., 2016. Sustained aftereffect of α-tACS lasts up to 70 min after stimulation. Frontiers in Human Neuroscience 10. https://doi.org/10.3389/fnhum.2016.00245. Article 245.

Klimesch, W., Doppelmayr, M., Schwaiger, J., Auinger, P., Winkler, T., 1999. "paradoxical" alpha synchronization in a memory task. Cogn. Brain Res. 7 (4), 493–501. https://doi.org/10.1016/S0926-6410(98)00056-1.

Klimesch, W., Sauseng, P., Hanslmayr, S., 2007. EEG alpha oscillations: the inhibition–timing hypothesis. Brain Res. Rev. 53 (1), 63–88.

Kriegseis, A., Hennighausen, E., Rösler, F., Röder, B., 2006. Reduced EEG alpha activity over parieto-occipital brain areas in congenitally blind adults. Clin. Neurophysiol. 117 (7), 1560–1573. https://doi.org/10.1016/j.clinph.2006.03.030.

Kudielka, B.M., Schommer, N.C., Hellhammer, D.H., Kirschbaum, C., 2004. Acute HPA axis responses, heart rate, and mood changes to psychosocial stress (TSST) in humans at different times of day. Psychoneuroendocrinology 29 (8), 983–992. https://doi.org/10.1016/j.psyneuen.2003.08.009.

Lang, P.J., Bradley, M.M., Cuthbert, B.N., 1999. International Affective Picture System (IAPS): Instruction Manual and Affective Ratings. *The Center for Research in Psychophysiology*. University of Florida.

Lozano-Soldevilla, D., 2018. On the physiological modulation and potential mechanisms underlying parieto-occipital alpha oscillations. Frontiers in Computational Neuroscience 12, 23. https://doi.org/10.3389/fncom.2018.00023.

Mathewson, K.E., Lleras, A., Beck, D.M., Fabiani, M., Ro, T., Gratton, G., 2011. Pulsed out of awareness: EEG alpha oscillations represent a pulsed-inhibition of ongoing cortical processing. Front. Psychol. 2, 99. https://doi.org/10.3389/fpsyg.2011.00099.

McMackin, R., Bede, P., Pender, N., Hardiman, O., Nasseroleslami, B., 2019. Neurophysiological markers of network dysfunction in neurodegenerative diseases. NeuroImage: Clinical 22 (February), 101706. https://doi.org/10.1016/j.nicl.2019.101706.

Moretti, D.V., Babiloni, C., Binetti, G., Cassetta, E., Dal Forno, G., Ferreric, F., Ferri, R., Lanuzza, B., Miniussi, C., Nobili, F., Rodriguez, G., Salinari, S., Rossini, P.M., 2004. Individual analysis of EEG frequency and band power in mild Alzheimer's disease. Clin. Neurophysiol. 115 (2), 299–308. https://doi.org/10.1016/S1388-2457(03)00345-6.

Öniz, A., Başar, E., 2009. Prolongation of alpha oscillations in auditory oddball paradigm. Int. J. Psychophysiol. 71 (3), 235–241. https://doi.org/10.1016/j.ijpsycho.2008.10.003.

Onoda, K., Okamoto, Y., Shishida, K., Hashizume, A., Ueda, K., Yamashita, H., & Yamawaki, S. (2007). Anticipation of affective images and event-related desynchronization (ERD) of alpha activity: an MEG study. Brain Res., 1151(1), 134–141. doi:https://doi.org/10.1016/j.brainres.2007.03.026.

Perry, A., Bentin, S., Shalev, I., Israel, S., Uzefovsky, F., Bar-On, D., Ebstein, R.P., 2010. Intranasal oxytocin modulates EEG mu/alpha and beta rhythms during perception of biological motion. Psychoneuroendocrinology 35 (10), 1446–1453. https://doi.org/10.1016/j.psyneuen.2010.04.011.

Rossini, P.M., Rossi, S., Babiloni, C., Polich, J., 2007. Clinical neurophysiology of aging brain: from normal aging to neurodegeneration. Progress in Neurobiology 83 (6), 375–400. https://doi.org/10.1016/j.pneurobio.2007.07.010.

Schubring, D., Schupp, H.T., 2021. Emotion and brain oscillations: high arousal is associated with decreases in alpha-and lower beta-band power. Cereb. Cortex 31 (3), 1597–1608.

Segrave, R.A., Thomson, R.H., Cooper, N.R., Croft, R.J., Sheppard, D.M., Fitzgerald, P.B., 2012. Emotive interference during cognitive processing in major depression: an investigation of lower alpha 1 activity. J. Affect. Disord. 141 (2–3), 185–193. https://doi.org/10.1016/j.jad.2012.03.004.

Sharma, S. (2009). An exploration into the wellbeing of the families living in the "suburbs in the bush." in Aust. N. Z. J. Public Health (Vol. 33, Issue 3, pp. 262–269). doi: https://doi.org/10.1111/j.1753-6405.2009.00386.x.

Stecher, H.I., Pollok, T.M., Strüber, D., Sobotka, F., Herrmann, C.S., 2017. Ten minutes of α-tACS and ambient illumination independently modulate eeg α-power. Front. Hum. Neurosci. 11 (May), 1–10. https://doi.org/10.3389/fnhum.2017.00257.

Tynan, R.J., Considine, R., Wiggers, J., Lewin, T.J., James, C., Inder, K., Kay-Lambkin, F., Baker, A.L., Skehan, J., Perkins, D., Kelly, B.J., 2017. Alcohol consumption in the Australian coal mining industry. Occup. Environ. Med. 74 (4), 259–267. https://doi.org/10.1136/oemed-2016-103602.

Uehli, K., Mehta, A. J., Miedinger, D., Hug, K., Schindler, C., Holsboer-Trachsler, E., Leuppi, J. D., & Künzli, N. (2014). Sleep problems and work injuries: a systematic review and meta-analysis. In *sleep medicine reviews* (Vol. 18, issue 1, pp. 61–73). doi: https://doi.org/10.1016/j.smrv.2013.01.004.

van Tuan, T., 2010. Meanings of sex, concepts of risk and sexual practices among migrant coal miners in Quang Ninh. Vietnam. Culture, Health and Sexuality 12 (Suppl. 1), 31–40. https://doi.org/10.1080/13691051003731296.

Vandewalle, G., Maquet, P., Dijk, D.J., 2009. Light as a modulator of cognitive brain function. Trends Cogn. Sci. 13 (10), 429–438. https://doi.org/10.1016/j.tics.2009.07.004.

Vanhollebeke, G., De Smet, S., De Raedt, R., Baeken, C., van Mierlo, P., Vanderhasselt, M. A., 2022. The neural correlates of psychosocial stress: a systematic review and meta-analysis of spectral analysis EEG studies. Neurobiology of stress 18, 100452. https://doi.org/10.1016/j.ynstr.2022.100452.

Vanhollebeke, G., Kappen, M., De Raedt, R., Baeken, C., van Mierlo, P., Vanderhasselt, M. A., 2023. Effects of acute psychosocial stress on source level EEG power and functional connectivity measures. Sci. Rep. 13 (1), 8807. https://doi.org/10.1038/s41598-023-35808-y.

Yıldırım, E., Güntekin, B., Hanoğlu, L., Algun, C., 2020. EEG alpha activity increased in response to transcutaneous electrical nervous stimulation in young healthy subjects but not in the healthy elderly. PeerJ 8, e8330. https://doi.org/10.7717/peerj.8330.

Yıldırım, E., Aktürk, T., Hanoğlu, L., Yener, G., Babiloni, C., Güntekin, B., 2024. Lower oddball event-related EEG delta and theta responses in patients with dementia due to Parkinson's and Lewy body than Alzheimer's disease. Neurobiol. Aging 137, 78–93.

Zeng, X., Debono, N.L., Harris, A.M., Arrandale, V.H., Demers, P.A., 2021. Neurodegenerative diseases among miners in Ontario, Canada, using a linked cohort. Occup. Environ. Med. 78 (6), 385–392. https://doi.org/10.1136/oemed-2020-106958.