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Abnormalities in the absolute power of Delta and Alpha rhythms in the frontal lobe of patients suffering from psychosomatic disorders

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Summary

Aim. Psychosomatic disorders (somatic symptom disorder – SSD) constitute a heterogeneous group of medical conditions characterized by somatic symptoms without explained somatic causes. Due to the complexity of symptoms, they present a significant medical, social and economic challenge, and diagnosing and treating these disorders remains a substantial clinical challenge. The aim of the conducted research was an attempt to identify characteristic patterns in the surface-level brain bioelectrical activity of individuals experiencing psychosomatic disorders. The obtained results may contribute to understanding the pathomechanism of these disorders and developing objective methods for diagnosis and differentiation of functional dysfunctions.

Material and methods. The study involved a group of 49 individuals: 30 patients with somatic symptom disorder (SSD) and 19 individuals in the control group. Resting-state EEG signals were recorded from the subjects under two experimental conditions (eyes open, eyes closed). The recorded signals underwent quantitative EEG (QEEG) analysis followed by statistical analysis.

Results. EEG signal analysis revealed statistical differences between the studied groups in terms of absolute power in the Alpha band (8–12 Hz) in frontal areas (electrodes F3, Fz, F4) under eyes-open conditions, as well as in the Delta band (1–4 Hz) in the right frontal area (electrode F4) under eyes-closed conditions. Similar changes were not observed in the Beta (12–25 Hz) or High Beta (25–30 Hz) bands.

Conclusions. The detected abnormalities in the surface-level brain bioelectrical activity may indicate potential disturbances in the reception and interpretation of visceral sensations in patients with psychosomatic disorders. The lack of differences in higher frequencies could be helpful in the differential diagnosis between these disorders and other anxiety disorders where psychosomatic symptoms are observed. The obtained results could also be useful in planning protocols involving various neurotherapeutic methods.

Key words: psychosomatic disorders, quantitative EEG signal analysis, diagnostics

Introduction

Psychosomatic disorders (also known as somatic symptom disorder, SSD) are a concept encompassing a wide range of functional disorders or medical conditions without a clear and defined organic cause [1]. The World Health Organization (WHO) in 1964 defined psychosomatic disorders as conditions that manifest as disruptions in function or organic changes in individual organs or systems when psychological factors play a significant role in the onset, development, exacerbation, or withdrawal of the illness [2]. Individuals with SSD exhibit a variety of symptoms that affect both the psychological realm (sleep disturbances, fatigue) and the somatic realm (diarrhea, palpitations, pains in various body areas, and other complaints). From a clinical perspective, symptoms from both domains typically coexist and mutually reinforce each other [3]. Such correlations are observed, for instance, in fibromyalgia or irritable bowel syndrome. This represents a specific psychophysiological relationship characterized by dysfunctional processing and interpretation of interoceptive or proprioceptive sensations by higher, phylogenetically advanced cortical centers. As a result, an intensified focus on symptoms develops, accompanied by secondary anxiety [4]. Another example is chronic primary low back pain, which is one of the most common psychosomatic complaints in the population [5]. Although it is associated with musculoskeletal disorders, its origins are central. Research points to impaired functioning of the somatosensory cortex, heightened neural connections among subcortical structures (primarily within the thalamus), overly heightened or weakened stimulation of frontal and parietal brain regions, and abnormalities in the activation of the sympathetic nervous system [6].

Epidemiological studies from various years indicate that psychosomatic disorders may be the underlying cause of as much as one in five visits to primary healthcare facilities [7].

The duration of symptoms is also highly significant in the course of psychosomatic disorders. Research indicates that the longer the symptoms persist (assuming a chronic nature), the worse the prognosis becomes [8, 9]. Additionally, high correlations have been identified between the discomfort reported by patients and impaired daily functioning, experienced distress, and frequent utilization of healthcare and social services [10].

Until now, diagnostic classifications have categorized most psychosomatic disorders as somatoform disorders ("somatoforms"; for example, ICD-10: F45; DSM-5: 300.82) or medically unexplained symptoms (MUS) [11]. An important contribution from a clinical standpoint is the Italian proposal authored by Fava and colleagues [12] – the Diagnostic Criteria for Psychosomatic Research. This proposal offers diagnoses for several syndromes, with the primary criterion being "psychological factors influencing somatic conditions." It is worth noting that this classification is mainly based on qualitative research (structured interviews). Consequently, the diagnosis is primarily established based on the patient's self-reported experiences (narrative paradigm), and this may not be sufficient for establishing reliable and objective differential diagnoses (for instance, distinguishing illness anxiety disorder or generalized anxiety disorder, see [13]). Because of this, the development of reliable, objective differentiation protocols based on physiological parameters seems particularly important, especially for clinicians.

Modern knowledge in the field of anatomy and neurophysiology provides information about which structures and neural networks might potentially be involved in the emergence and development of psychosomatic symptoms. Research utilizing neuroimaging techniques such as functional magnetic resonance imaging (fMRI), positron emission tomography (PET), and electroencephalography (EEG) indicates that there is a correlation between various psychopathological symptoms and the activity of specific brain networks [14]. Such correlations appear to be of significant importance in understanding the mechanisms and neurophysiological origins of psychosomatic disorders. Among neuroimaging methods, quantitative electroencephalography (qEEG) might be of interest due to its relatively low cost and high temporal resolution. This technique involves a collection of various mathematical methods for analyzing brain's bioelectrical signals (EEG). Many of these methods, particularly source analysis of EEG signals and coherence analysis, serve as excellent tools for functional brain analysis – assessing the activity of selected neural networks and connecting information about their functioning with psychosomatic symptoms [15].

When analyzing the symptoms of psychosomatic disorders, it is important to note that a common accompanying symptom is pain. Research reveals that structures and networks involved in the experience of pain include the thalamus (intralaminar and posterior lateral nuclei), the magnocellular and parvocellular parts of the medullary reticular formation, the locus coeruleus, the periaqueductal gray matter, the amygdala, the insula, and the cingulate gyrus. Various regions of the prefrontal cortex, the anterior cingulate cortex, the cerebellum, and the amygdala also play a significant role [16]. The somatosensory cortex is also an important neural correlate of pain [17, 18]. Notably, the activation of these structures is relatively consistent and correlates with the subjectively perceived intensity of painful sensations. According to some researchers, these mentioned structures and areas collectively form what is called the "pain neuromatrix" [19]. Through mathematical analysis of the current distribution generated by different cortical regions, it is known that frontal and central electrodes, commonly used in EEG recordings, are the main sources of signals from structures within the pain neural network [20]. Detailed analysis of these signals using methods based on electroencephalography can thus provide reliable insights into the pain mechanisms in psychosomatic patients.

As previously mentioned, among individuals with psychosomatic disorders, in addition to pain, a widespread group of symptoms includes those related to autonomic arousal, such as heart palpitations, sweating, muscle tension, as well as gastrointestinal and urinary discomfort. The state of high nervous tension, stress, or autonomic arousal also has a cognitive component accompanying it. The stress response and autonomic arousal impact working memory capacity, verbal fluency, executive functions, and cognitive flexibility [21, 22]. The deficit in cognitive flexibility prevents individuals experiencing chronic stress from altering their perception of a problem for effective analysis and solution [23]. Issues with cognitive functions, emotional and physiological arousal are naturally reflected in the activity of specific brain structures and networks, as well as the bioelectrical brain activity of individuals with SSD. For instance, studies of individuals with fibromyalgia showed that during the processing of affective stimuli, these individuals exhibited higher absolute power in the 2-22 Hz frequency range compared to the control group [24]. Similarly, research involving individuals with chronic fatigue syndrome demonstrated a higher contribution of theta rhythm power in their EEG signal spectrum. As suggested by the authors, this might indicate a greater susceptibility to "mental fatigue" and attention concentration problems in psychosomatic patients [25, 26]. Furthermore, in a study comparing patients with SSD and those with Major Depressive Disorder (MDD) to a healthy control group, both clinical groups displayed a decrease in theta coherence in the temporal-parietal connection, which may have functional implications for attention processes and social interactions. In the same study, specifically in the SSD group, a decrease in theta coherence was also observed in the somatosensory band and frontal-temporal areas (associated with perception, emotions, and sensation) [27]. In this study, the surface analysis of brain bioelectrical activity served as the primary research tool. The main goal of the study was to verify the hypothesis that individuals experiencing long-term psychosomatic disorders exhibit different surface EEG activity compared to a control group. The results obtained are pilot and only preliminary. Detecting potential abnormalities can be crucial in understanding the pathological neurophysiological mechanisms underlying SSD. The developed findings may also point the way to further research on biomarkers in the group of these disorders, facilitate objective differential diagnosis of the described disorders, and be useful in designing neurotherapeutic protocols (for example, using methods such as EEG-biofeedback or transcranial current density stimulation, tCS).

Material and methods

In the research, a total of 49 participants took part. Individuals suffering from psychosomatic symptoms were recruited through advertisements placed on social media. All of the volunteers who expressed interest filled out a short online questionnaire, which allowed for a preliminary assessment of whether they met the inclusion criteria for the project. Meanwhile, detailed eligibility criteria have been developed based on the ICD-10 classification and the results of the latest scientific research. The control group consisted of volunteers (students and staff of Nicolaus Copernicus University in Toruń).

The inclusion criteria for participation in the research were: appropriate age (18-43 years), experiencing troublesome somatic symptoms without established organic causes, such as headaches, neck pain, back pain, muscle pain, dizziness, shortness of breath, abdominal bloating, stomach upset, tingling in the fingers, heart palpitations, chest pressure, blurred vision or spots in the eyes, ringing in the ears or head, and other discomforts, duration of symptoms lasting at least 6 months, absence of diagnosed serious neurological or psychiatric diseases (such as depression, schizophrenia, bipolar disorder), right-handedness, and no regular use of psychoactive substances.

Individuals who met the above criteria were invited to the first meeting, during which a detailed medical interview was conducted, and they also had a visit with a clinical psychologist. During these sessions, participants were informed about the study's purpose. They received information about the research measurement procedures, confidentiality guidelines, options for withdrawal from the study, and after being acquainted with the project details, they provided informed consent to participate in the study.

The visits to the doctor and psychologist were conducted in the form of face-to-face conversations, adhering to the criteria of a classic medical interview and individual psychological interview [28]. For the participants, previous medical test results were verified, and using the Polish version of SCID (Structured Clinical Interview for DSM Disorders), it was checked whether the participants met the criteria for psychosomatic disorders [29] and met the inclusion criteria for the study. The psychotraumatological aspect was also taken into account, in order to exclude those experiencing potential somatoform dissociations. Based on the medical and psychological interviews, it was revealed that among individuals reporting symptoms of psychosomatic disorders (PS), 30 people met the qualification criteria. The most common complaints reported by the participants were as follows: headaches (15 individuals), neck pain (13 individuals), back pain (13 individuals), heart palpitations (11 individuals), and chest tension (11 individuals).

The age of the psychosomatic group (PS) ranged from 19 to 43 years ($M = 24.4$; $SD = 5.58$). The age of individuals in the control group (CG) ranged from 18 to 32 years ($M = 23.4$; $SD = 3.89$).

Due to noticeable differences between the study groups in terms of gender (63.3% of the subjects were women) and the number of participants (30 patients in the experimental group, 19 subjects in the control group), a chi-square test was conducted to examine the significance of these differences. The test results indicated no statistical significance between the groups in these parameters. This suggests that the groups can be treated as equally sized and statistically do not differ in terms of the gender of the participants.

The main focus of the project was EEG recording, which was conducted on a different day from the interviews. The EEG signal was recorded using a 19-channel EEG device from Mitsar (St. Petersburg, Russia), and the electrode placement during the study adhered to the international 10-20 system [30]. The reference electrode was connected to the mastoids, and the ground electrode was located at the Fpz point. The electrode impedance during EEG signal recording was always below 5 kOhm. The signal was sampled at a frequency of 500 Hz and digitally filtered within the range of 0.3-50 Hz.

During the EEG recording, the participants sat in a comfortable chair. Before the recording began, they were instructed to try to relax, avoid body movement, and minimize muscle tension (especially in the facial, ocular, neck, and temporomandibular joint muscles). The study consisted of two 7-minute blocks. In the first block, participants were asked to maintain their gaze on a fixed point in front of them and let their thoughts drift freely in any direction – this was the eyes open condition (EO). The second block was identical, except participants were instructed to close their eyes – this was the eyes closed condition (EC). The order of the two recording blocks was randomly assigned to each participant.

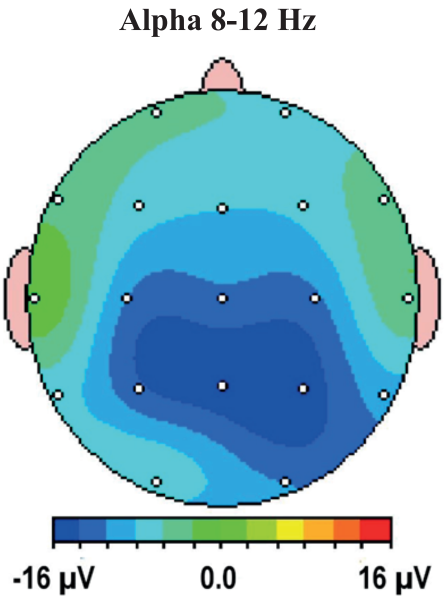
The recorded EEG signals underwent initial digital processing using Neuroguide version 2.9.4 (Applied Neuroscience, St. Petersburg, FL) and its implemented algorithms. The purpose of this processing was to remove artifacts that could disrupt the raw EEG signal. The artifact-free EEG signals were then subjected to quantitative analysis, referred to as quantitative electroencephalography (qEEG). The signal was Fourier-transformed, and the absolute power of the following frequency bands was calculated: delta (1-4 Hz), theta (4-8 Hz), alpha (8-12 Hz), beta (12-25 Hz), high beta (25-30 Hz), gamma (30-35 Hz), and high gamma (35-40 Hz). To analyze spatial changes in the EEG signal in selected regions, the power of individual frequency bands from specific electrodes was averaged, creating three regions of interest: frontal (electrodes: F3, Fz, F4), central (C3, Cz, C4), and parietal (P3, Pz, and P4). In addition, for more accurate diagnostics, significance analyses of absolute power differences for individual electrodes without averaging for regions were performed. Signals from electrodes located at the perimeter of the head were not analyzed due to numerous disturbances.

Statistical analyses were conducted using the IBM SPSS Statistics package, version 29.0. For the statistical description of electrophysiological indicators (absolute power of measured frequency bands), arithmetic means (*M*), standard deviations (*SD*), and tests for normality of distributions using the K-S (Kolmogorov-Smirnov) test were calculated. Additionally, sphericity of variance was assessed using Mauchly's test, and Bonferroni corrections were applied for multiple comparisons. All necessary statistical assumptions were met. The significance of differences in surface brain bioelectrical activity between the study groups was assessed using a multivariate analysis of variance (MANOVA) with repeated measures in two models: (1) group (2 levels) x condition (2 levels) x region (3 levels) and (2) group (2 levels) x condition (2 levels) x electrode (14 levels).

Results

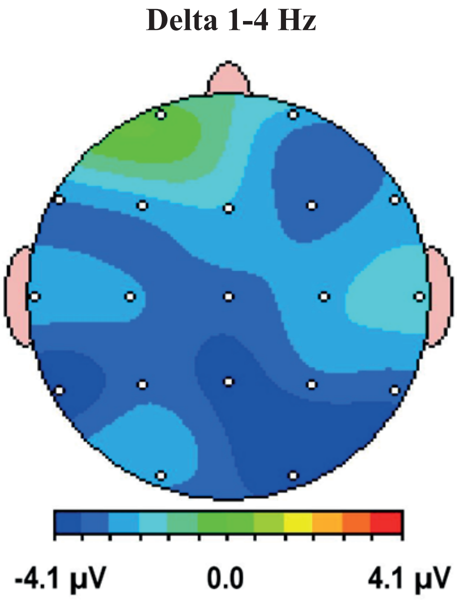
The analysis of the significance of MANOVA differences in model (1) showed significant intergroup differences in the alpha rhythm (8-12 Hz) in the frontal leads (F3, Fz, F4) for the EO condition: $F(4, 48) = 11.07$; $p = 0.05$ (Fig. 1). The mean power of the alpha band in the frontal region for the EO condition in the PS group was 14.327 uV^2; $SD = 8.093$, while in the CG group, it was 33.118 uV^2; $SD = 38.166$.

Furthermore, in the MANOVA (2) model, in signals recorded from the F4 electrode in the EC condition, the statistical analysis revealed significantly lower ($F(F4) = 1.464$, $p = 0.05$) mean absolute power of the delta band (1-4 Hz) in the PS group ($M = 12.485$ uV^2; $SD = 4.061$) compared to the same electrode and condition in the control group (CG) ($M = 15.408$; $SD = 8.243$) (Fig. 2).



The map was obtained by subtracting the average distribution (average map) of absolute alpha power from psychosomatic individuals (PS) from the average distribution of alpha power of the control group (CG).

Figure 1. **Two-dimensional (2D) differential map of spatial distribution of absolute power in the alpha band (8-12 Hz) for the eyes-open condition**



The map was obtained by subtracting the average distribution (average map) of absolute delta power from psychosomatic individuals (PS) from the average distribution of delta power of the control group (CG).

Figure 2. **Two-dimensional (2D) differential map of spatial distribution of absolute power in the delta band (1-4 Hz) for the eyes-closed condition**

The two tested MANOVA models showed no significant differences between studied groups in both conditions (EO, EC) for beta bands. No significant differences were observed for both the low-range (12-25 Hz) and high-range (25-30 Hz) beta bands. Lack of statistical differences between the experimental groups also extended to the theta and both gamma bands (for both analyzed MANOVA models).

Discussion

Psychosomatic disorders are a significant clinical challenge in both primary and specialized healthcare. Correct differential diagnosis and the selection of appropriate treatment methods can pose particular difficulties in this area. This study attempted to analyze differences in surface brain bioelectrical activity between individuals with psychosomatic disorders and healthy individuals. Utilizing electrophysiological methods to study patients with these conditions has the potential to objectify diagnosis, enhance diagnostic accuracy, and improve overall efficiency.

One of the challenges faced by modern psychiatry is distinguishing psychosomatic disorders from somatoform dissociation and cenesthetic (somatic) hallucinations. Previous scientific studies have shown that in the case of dissociative experiences, specific patterns of brain bioelectrical activity exist, characterized by decreased expression of theta (4-8 Hz) activity in the temporal areas [31]. This effect is particularly prominent in quantitative dissociative disorders like depersonalization and derealization. Conversely, in anxiety disorders such as generalized anxiety disorder, a different bioelectrical pattern is observed, featuring a significant increase in beta (12-23 Hz) amplitude and a decrease in alpha rhythm expression in frontal leads [32].

The conducted research has shown that patients diagnosed with psychosomatic symptomatology exhibit lower average values of absolute alpha band power in the frontal region during resting-state EEG recordings with eyes open. Additionally, a decreased absolute delta band power was observed specifically in the F4 lead (right frontal area) during the eyes closed condition.

The obtained results in the beta band range, in the context of the studies mentioned earlier, may suggest that patients suffering from psychosomatic disorders differ in this aspect from other anxiety disorders, including generalized anxiety disorder [32] and illness anxiety disorder [33]. It is important to note that the obtained results do not allow for a specific characterization of the patient group in terms of anticipatory threat and anxious external attention orientation. The lack of differences between the studied groups could be particularly helpful in the differential diagnosis among these three psychopathological conditions (especially in the case of hypochondriasis, where the object of fear is similar to psychosomatic symptoms). However, more data would be needed to confirm this proposition.

The existing scientific research suggests that the delta rhythm is functionally linked to focusing on sensations originating from the body. It has been shown that its amplitude increases, for example, during focusing on one's own breath [34]. The decrease in absolute power in the delta band in this study could potentially indicate that the studied patients experienced disruptions in concentrating on visceral sensations and might have had distortions in their perception and interpretation. Additionally, other studies have demonstrated that significantly higher delta power appears in the frontal brain regions often during tasks involving motor synchronization [35]. However, it is not clear whether this process is primarily related to interoception or if it involves other "more global" cognitive processes such as attention. It is also possible that it represents a specific interaction between both processes. The results require further exploration on a larger group of subjects and using different methods of measuring interoceptive processes, such as subjective self-report scales or electrophysiological biomarkers. It appears that heart rate-related evoked potentials (HEP [36, 37]) may be such an objective marker. An individual's predisposition to cognitive processes may also be an important factor [38] and an in-depth neuropsychological examination may help determine at what level abnormalities are present.

It is suggested that increased activity in the alpha band is found in individuals practicing traditional forms of meditation, where attention is directed inward towards the body [39]. Decreased absolute power in the alpha band could be potentially related to a disturbance or reduction in the ability to perceive and interpret signals from the body's interior. Additionally, the results might also be related to excessive anxiety caused by functional symptoms. Studies involving individuals experiencing anxiety and stress have shown decreased expression of oscillations within the alpha frequency range [40]. It is worth noting that this rhythm is not primarily associated with visual functions. Recent research has revealed its associations with higher cortical functions, including perception, working memory, and consciousness [41]. Therefore, abnormalities detected in the alpha band might indicate potential disruptions in various cognitive functions, such as processing and interpreting internal body signals. Furthermore, a significant decrease in alpha band absolute power could suggest potential difficulties for individuals with psychosomatic disorders in achieving mental states characteristic of relaxation [42].

The main limitation of the conducted study was the relatively small number of participants and a significant heterogeneity in the patient group in terms of symptoms. The symptoms were primarily focused around pain originating from various body regions (particularly the chest, head, and heart). An additional difficulty is the technical aspects of surface analysis of brain bioelectrical activity, which does not allow for accurate identification of structures characterized by abnormal activity and detailed visualization of changes between study groups.

Despite the increasing number of studies using advanced neuroimaging techniques, the exact functional significance of individual brain wave bands is still unknown. Despite methodological challenges, certain distinctive patterns of surface-level brain electrical activity were identified in psychosomatic patients, which could be useful in the differential diagnosis of the studied SDD disorders. In future studies, efforts are planned to increase the sample size of both experimental groups and standardize the reported symptoms among the enrolled patients. This should partially mitigate the issue of heterogeneity within the studied groups. Additionally, there are plans to conduct analyses of the intracranial sources of surface-recorded signals and perform coherence analyses to identify deeper-seated brain structures and networks dysfunctional in patients suffering from psychosomatic disorders. The obtained results may also aid in better understanding the origins of the disease and establishing objective diagnostic criteria.

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