Article

Deciding on optical illusions: Reduced alpha power in Body Dysmorphic Disorder

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Abstract: *Background:* Body dysmorphic disorder (BDD) is a psychiatric disorder characterized by excessive preoccupation with imagined defects in appearance. Optical illusions induce illusory effects that distort the presented stimulus thus leading to ambiguous percepts. Using electroencephalography (EEG), we investigated whether BDD is related to differentiated perception during illusory percepts. *Methods:* 18 BDD patients and 18 controls were presented with 39 optical illusions together with a statement testing whether or not they perceived the illusion. After a delay period, they were prompted to answer whether the statement is right/wrong and their degree of confidence for their answer. We investigated differences of BDD on task performance and self-reported confidence and analysed the brain oscillations during decision-making using nonparametric cluster statistics. *Results:* Behaviorally, the BDD group exhibited reduced confidence when responding incorrectly, potentially attributed to higher levels of doubt. Electrophysiologically, the BDD group showed significantly reduced alpha power at mid-central scalp areas, suggesting impaired allocation of attention. Interestingly, the lower the alpha power of the identified cluster, the higher the BDD severity, as assessed by BDD psychometrics. *Conclusions:* Results evidenced that alpha power during illusory processing might serve as a quantitative EEG biomarker of BDD, potentially associated with reduced inhibition of task-irrelevant areas.

Keywords: body dysmorphic disorder; EEG; optical illusions; alpha oscillations

1. Introduction

Body dysmorphic disorder (BDD) is an often-severe psychiatric disorder, recently classified within the Obsessive-Compulsive and Related Disorders (OCD) [1]. BDD is characterized by excessive preoccupation with imagined defects in appearance that are not at all or slightly observable to others (DSM-5) [2]. Constant preoccupation is associated with many time-consuming rituals, such as mirror gazing or constant checking [1]. Optical illusions are context-induced subjective distortions of visual features, such as the length, size, shape, or direction of elements within a visual context [3–5]. Notably, it is widely suggested that optical illusions induce illusory effects that distort the presented stimulus thus leading to ambiguous percepts [5,6].

The overarching question of our study is whether BDD is related to differentiated perception of optical illusions and brain activation while making judgements on the illusions. Do BDD patients succumb to illusory effects more than healthy people do? Are BDD

patients less confident when making judgements on optical illusions? What are the neural correlates of the decision-making process, and, finally, are those related to BDD severity? We investigated these questions by presenting BDD patients and healthy controls with optical illusions and asking them to make subjective judgements, while electroencephalogram (EEG) was recorded.

A promising way to investigate the neurophysiological signatures of BDD patients would be to consider their observed cognitive deficits. Previous studies have shown that BDD patients exhibit executive dysfunction, as evidenced from impairments in memory and attention in the digit span, story memory recall, and Stroop interference tasks [7]. BDD, as well as OCD patients, show significantly poorer memory and attention compared to healthy controls, as assessed by the Repeatable Battery for the Assessment of Neuropsychological Status (RBANS) [8]. During processing of inverted faces on a screen, BDD show reduced inversion effect compared to healthy controls, attributed to greater focus on detail (over-attention) and reduced holistic processing [9]. Furthermore, OCD is characterized by high levels of doubt, uncertainty and repetitiveness [10,11]. For instance, in checking situations, OCD sufferers are doubtful of whether or not they performed the ritual and need to repeat it over and over again [12].

Previous research investigating the neural signatures of BDD in various tasks has interpreted the results mainly on the basis of the attentional impairments that this patient group exhibits [13–17]. It is known that OCD patients, including BDD, are constantly preoccupied with a certain action/feature and are not able to suppress their obsessive thoughts [1]. In this context, alpha oscillations fine-tune sensory processing by actively inhibiting task-irrelevant networks [18,19]. Thus, decreased alpha power during cognitive tasks in BDD and OCD has been associated with their inability of cognitive inhibition [15]. More specifically, previous studies reported reduced task-related alpha power in OCD patients compared to healthy controls [14,16]. Min and colleagues (2011) [14] used a color and shape discrimination task, while Simpson and colleagues (2000) [16] exposed subjects to OCD symptom provoking stimuli. Furthermore, in two recent studies, our group found reduced alpha power at left temporo-parietal areas [13] in response to prepulse inhibition in BDD patients compared to healthy controls, attributed to impaired resource allocation.

Following up from the above, the present study aims to investigate the neural correlates of BDD by analyzing brain oscillations during decision-making on optical illusion judgements. We examined this by presenting BDD and healthy controls with optical illusions, while recording their EEG. After a delay period has passed, they were prompted to make a judgement on the illusion, showing whether they succumbed or not to the illusory effect. They were also asked to report the degree of confidence for their answer. Participants completed questionnaires assessing BDD symptomatology. On the behavioural level, we investigated whether BDD influenced performance on the task and self-reported confidence, whereas, from the electrophysiological perspective, we analyzed the brain oscillatory activity during the decision-making period. Finally, we examined the relationship between BDD severity and the identified neural signatures.

Based on the aforementioned studies on cognitive deficits in BDD [9], we expect that BDD patients will not show impaired performance in identifying the illusory effects, as the current evidence suggests over-attention and non-holistic processing in BDD patients only for their own face processing. It is also expected that BDD patients will report higher uncertainty about their answers, in line with enhanced feelings of doubt that characterize this disorder [20]. We further hypothesize that BDD patients will show reduced alpha oscillatory activity during decision-making, potentially attributed to impaired inhibition of task-irrelevant thoughts. Finally, we will explore what brain signatures are related to BDD degree of symptomatology.

2. Materials and Methods

2.1. Participants

Thirty-six adult volunteers took part in this study. Eighteen patients comprised the body dysmorphic (BDD) group (9 females, mean ± SD age of 36.7 ± 8.3 years; 9 males, mean ± SD age of 27.1 ± 6.0 years). Eighteen healthy controls (CTL) were matched for age and sex (10 females, mean ± SD age of 28.8 ± 4.9 years; 8 males, mean ± SD age of 30.0 ± 5.7 years). The absence of significant group differences in age was confirmed by an independent-samples t test ($t(34) = -1.081, p = .287$). Participants underwent clinical interviews by two psychiatrists. BDD was diagnosed according to DSM-5 criteria. The YBOCS-BDD Questionnaire and the Dysmorphic Concern Questionnaire confirmed the diagnosis. All participants had no history of neurological or psychiatric disorders, and normal or corrected vision.

The study was conducted in the psychophysiology laboratory of the University Mental Health, Neurosciences and Precision Medicine Research Institute "Costas Stefanis" (U.M.H.R.I.), in collaboration with the First Department of Psychiatry, Medical School, Eginition Hospital, National and Kapodistrian University of Athens. All participants were informed about the experimental procedure and provided written consent prior to their participation. The study was approved by the local ethics committee of the First Department of Psychiatry, Medical School, Eginition Hospital, National and Kapodistrian University of Athens.

2.2. Experimental design and procedure

We used a set of 39 optical illusions composed by Papageorgiou and colleagues (2020) [6] (see Fig. 1A for examples). Those comprised two-dimensional images (28 black and white, 11 coloured) of 23 well-known optical illusions plus their variations. The length of the images ranged from 8 to 33 cm, while the height of the images ranged from 5.5 to 14.5 cm. The optical illusions were accompanied with written statements referring to a feature of the respective image. More specifically, there were 19 right (e.g., illusion 3 in Fig. 1A: Line C is an extension of line A.) and 20 wrong statements (e.g., illusion 2 in Fig. 1A: The diagonal lines are not parallel.).

A.

B.
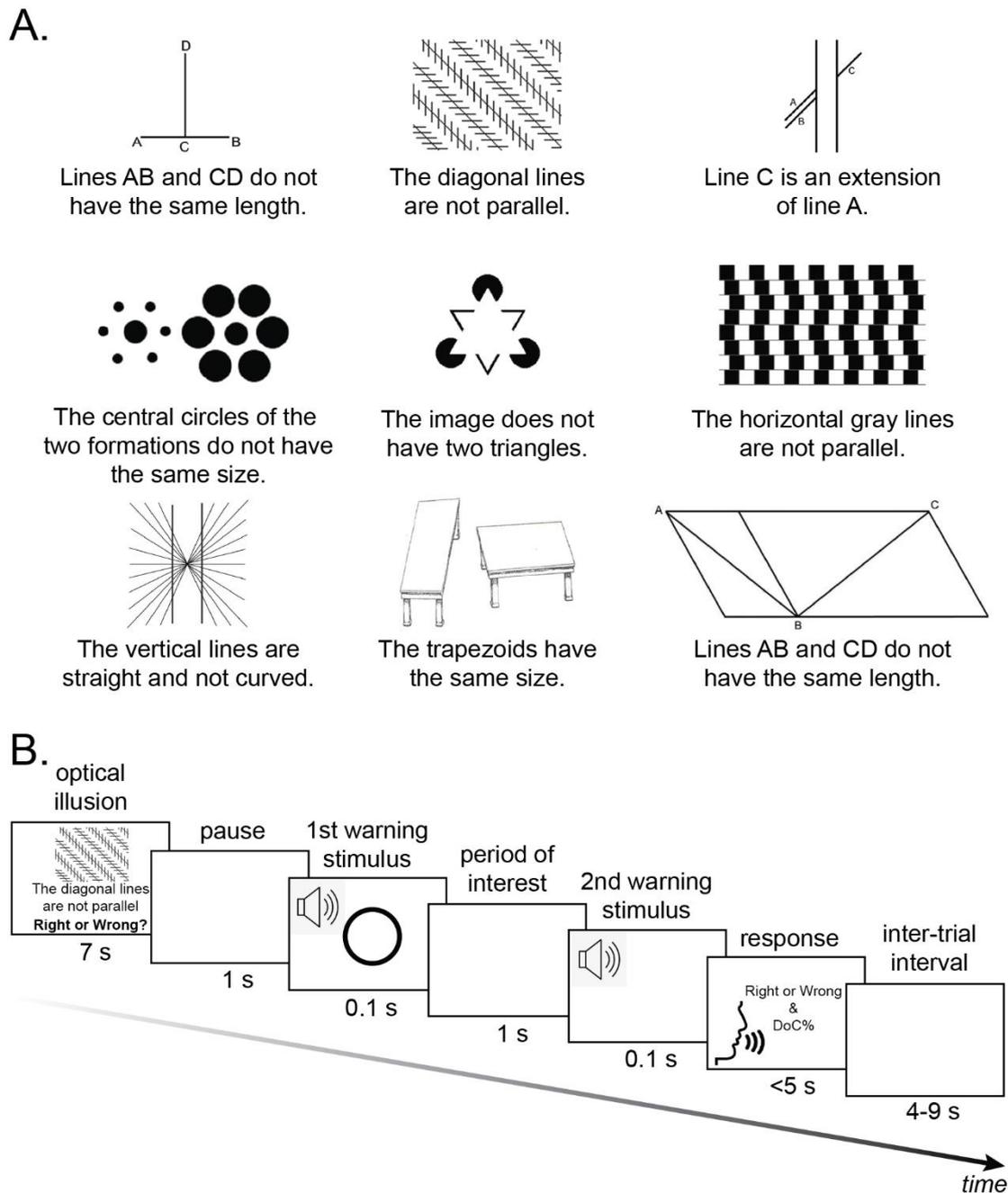
Figure 1. A. Examples of the experimental stimuli composed by Papageorgiou and colleagues (2020) [6]. The illusions depicted are the following: vertical-horizontal, Zöllner, Poggendorff, Ebbinghaus, Kanizsa's triangle, café wall, Hering, Shepard tables, and Sander. The images have been obtained by the authors from Wikipedia; **B.** Illustration of the trial structure. First, an optical illusion is presented on screen for 7 secs, together with a statement and the question *Right or Wrong?* below the stimulus. A blank screen is then presented for 1 sec, followed by a 0.1-sec warning stimulus tone. Participants are given 1 sec to think of their response. A second warning stimulus tone is then presented for 0.1 sec. Afterwards, participants verbalize two responses: 1. Whether the statement is right or wrong, and 2. What is their degree of confidence (DoC) for their answer. There is an inter-trial interval jittered from 4 to 9 secs.

Participants were seated in a Faraday cage to minimize interference caused by external electromagnetic fields during the EEG recording. They were asked to look straight and keep their eyes open throughout the session. Participants were instructed that they would be presented with 39 optical illusions together with a written statement, and would be prompted to answer two questions: 1. Whether the statement is right or wrong, and 2. What is their degree of confidence for their answer on a scale from 0 (not at all certain) to

100 (absolutely certain). In each trial, the optical illusion was presented on screen for 7 secs (see Fig. 1B for the trial structure). A statement referring to the illusion was presented below the stimulus, as well as the question Right or Wrong?. A blank screen was then presented for 1 sec, followed by a 0.1-sec warning stimulus tone (500 Hz, 65 dB). Then, participants were given 1 sec to think of their response. A second warning stimulus tone was then presented for 0.1 sec prompting participants to respond. Participants' verbal responses were recorded by an experimenter seated outside the testing room. There was an inter-trial interval jittered from 4 to 9 secs.

2.3. EEG recording and preprocessing

The EEG signals were recorded from 30 Ag/AgCl electrodes mounted on an elastic cap according to the International 10-20 System: Fp1, F3, P3, O1, F7, T3, T5, AFz, Fz, FCz, CP3, FC3, TP7, Fpz, FT7, Oz, FT8, Fp2, F4, C4, P4, O2, F8, T4, T6, Cz, Pz, CPz, CP4, FC4. The sampling frequency was 1 kHz. Electrode impedance was kept constantly below 5kΩ. EEG activity was referenced online to the average of the left and right ear lobes, while the ground electrode was placed on the left mastoid.

The continuous EEG data were high-pass filtered at 1 Hz to remove DC offsets and baseline drifts. The data were then low-pass filtered at 45 Hz. Using the "clean_rawdata" function, an EEGLAB [21] plug-in for bad channel detection, along with visual inspection of the detected bad channels, electrodes showing abnormal time-course were excluded and interpolated. EEG signals were then re-referenced to the whole-scalp common average. Subsequently, Independent Component Analysis (ICA) was performed to correct eye-blinks and saccades. To semi-automatize the process of hand-labeling artifactual components, rejection was performed by visual inspection along with simultaneous consideration of the SASICA tool [22]. In controversial cases, we consulted the MARA tool suggestions [23]. The SASICA guidelines were parameterized as: "Autocorrelation" (Threshold r = auto; Lag = 20ms), "Focal components" (Threshold z = auto), "Correlation with EOG" (enabled for VEOG and HEOG with threshold r = 0.2), "ADJUST" [24] and "FASTER" [25] methods (enabled for blink channels). Finally, continuous data were epoched from -0.5 to 1.0 sec around the first warning stimulus tone.

2.4. Psychometric ratings

The Y-BOCS and the DCQ questionnaires were used in order to investigate potential correlations between BDD symptomatology and EEG measures.

- *Yale-Brown Obsessive-Compulsive Scale (Y-BOCS) for BDD:* This psychometric questionnaire evaluates the severity of BDD symptoms [26]. We used a 12-item version translated, adapted and validated in Greek [27]. Items 1-5 assess obsessional preoccupation with the perceived defect in appearance, while items 6-10 assess compulsive behaviours. Item 11 measures the degree of insight, and item 12 avoidance. It is rated on a 0 (not at all) to 4 (every day) Likert scale. Scores for all items are summed up to create the total score.
- *Dysmorphic Concern Questionnaire (DCQ):* This questionnaire is a 7-item self-report measure that assesses cognitive and behavioural symptoms of physical overconcern without seeking to establish a "diagnosis" of BDD [28]. Respondents rate their concern on their physical appearance on a 4-point scale, ranging from 0 (not at all) to 3 (much more than most people).

Independent samples t tests were used to confirm the differences in psychometrics between control vs. BDD (DCQ: $t(34) = -10.9, p < .001$; Y-BOCS: $t(34) = -13.8, p < .001$). The descriptive statistics for control vs. BDD psychometrics, respectively, are 5.9 ± 0.8 vs. 18.9 ± 0.8 (in DCQ) and 3.7 ± 0.6 vs. 29.8 ± 1.7 (in Y-BOCS).

2.5. Data Analysis

2.5.1. Behavioral Analysis

Correctness: First, we assessed participants' ability to get away from the illusory effect of the images by evaluating their responses in the first question (*Right or Wrong?*).

Specifically, a response was considered correct if the subject did not succumb to the illusory effect, while it was considered incorrect if the subject succumbed to the illusion. For each participant, correctness was calculated as the number of their correct responses divided by the total number of trials (39). To investigate whether BDD influenced the perception of illusions, we performed an independent samples t-test between percentage correct of the CTL vs. the BDD group.

Degree of Confidence (DoC): To examine whether correctness influenced the level of confidence in the two groups, a 2 (*correctness: correct vs. incorrect*) × 2 (*group: CTL vs. BDD*) mixed ANOVA was performed on their DoC averaged over the respective trials.

2.5.2. EEG Analysis

Time-frequency representation (TFR): To analyse oscillatory brain activity during the period of interest (decision-making), we conducted a time-frequency analysis from -0.3 to 0.8 sec time-locked to the onset of the first warning tone. The EEG signals were convolved with complex Morlet wavelets using 50 linearly separated frequencies (from 1 to 40 Hz) and a variable number of wavelet cycles (from 3 to 12). Single-subject TFRs (power values, P) were dB-normalized (P_{dB}) based on the pre-stimulus period from -0.3 to -0.1 sec by applying the following formula (for each time-frequency point (t, f)):

$$P_{dB}(t,f) = 10 \cdot \log_{10} \frac{P(t,f)}{\frac{1}{200}\sum_{i\in[-0.3,-0.1]} P(i,f)} \tag{1}$$

The power of each frequency band was then calculated by averaging the power values within delta (1-4 Hz), theta (4-8 Hz), alpha (8-12.5 Hz), beta (12.5-30 Hz), and gamma (30-40 Hz) bands. Electrode- and band-specific time-courses (power values relative to pre-stimulus baseline) were calculated for each participant.

Nonparametric cluster permutation test: We used a nonparametric cluster permutation procedure to compare the alpha oscillatory power during the period of interest in CTL vs. BDD groups. All time points were considered from 0 to 0.8 sec around the period of interest. First, all the possible uncorrected t values (resulting from independent-samples t tests) were computed for each electrode and time-point, and absolute t values smaller than 2 were discarded. Then, clusters of spatiotemporally neighbouring t scores were formed. The clustering process for any pair of the remaining t scores was based on three criteria, according to whether same-sign t values are neighboured in space and time. Specifically, any pair (i, j) of t values belongs to the same cluster if and only if:
1) i and j belongs to neighbouring electrodes
2) i and j belongs to successive time-points
3) i and j have the same sign.

Subsequently, empirical distribution curves of the group differences were estimated using 5000 random permutations by shuffling the subject labels (CTL vs. BDD). In each randomly permuted instance, we calculated the sum of t values within each cluster. Then, the maximum (absolute value) cluster score was considered as the cluster t-statistic. All randomizations were done for a rejection of the null hypothesis and a control of false alarm rate at $p = .05$ (two-tailed). Clusters formed by the actual labels with t value exceeding the t critical values acquired from the permutation analysis were finally identified. As a control analysis, the same statistical procedure was conducted also for the other bands (delta, theta, beta and gamma).

### 2.5.3. Relationship between EEG measures and BDD severity

We examined potential relationships between the EEG clusters identified from the nonparametric cluster permutation procedure and BDD severity. For this purpose, we computed the Pearson's product-moment correlation coefficients between the identified cluster and the psychometric indices of BDD severity, as assessed by the DCQ and Y-BOCS ratings, separately.

3. Results

3.1. Behavioral results

Correctness: Independent-samples t tests showed no significant differences in correctness between the two groups ($p = .722$). Specifically, the average percentage of correct responses for the CTL group was 55.0 ± 12.2%, whereas for the BDD group correctness was at 53.6 ± 11.6% (Fig. 2A).

Degree of Confidence (DoC): A 2 *(correctness: correct vs. incorrect)* x 2 *(group: CTL vs. BDD)* mixed ANOVA revealed that participants were more confident on their answers when they responded correctly ($M = 89.437, SE = 1.587$) compared to when they responded incorrectly ($M = 85.934, SE = 1.726$) (main effect of *correctness* ($F(1,34) = 5.501, p = .025, \eta_p^2 = .139$). Results also showed a significant *correctness×group* interaction ($F(1,34) = 6.026, p = .019, \eta_p^2 = .151$). To investigate the interaction further, planned contrasts were conducted. Interestingly, the BDD group exhibited significantly lower DoC when responding incorrectly compared to when responding correctly ($t(17) = 2.727, p = .014$), whereas the CTL group showed no significant difference in DoC between conditions ($p = .910$). Finally, the BDD group showed significantly lower DoC than the CTL group for incorrect answers ($t(34) = 2.537, p = .016$), but that was not the case for correct answers ($p = .657$) (Fig. 2B).
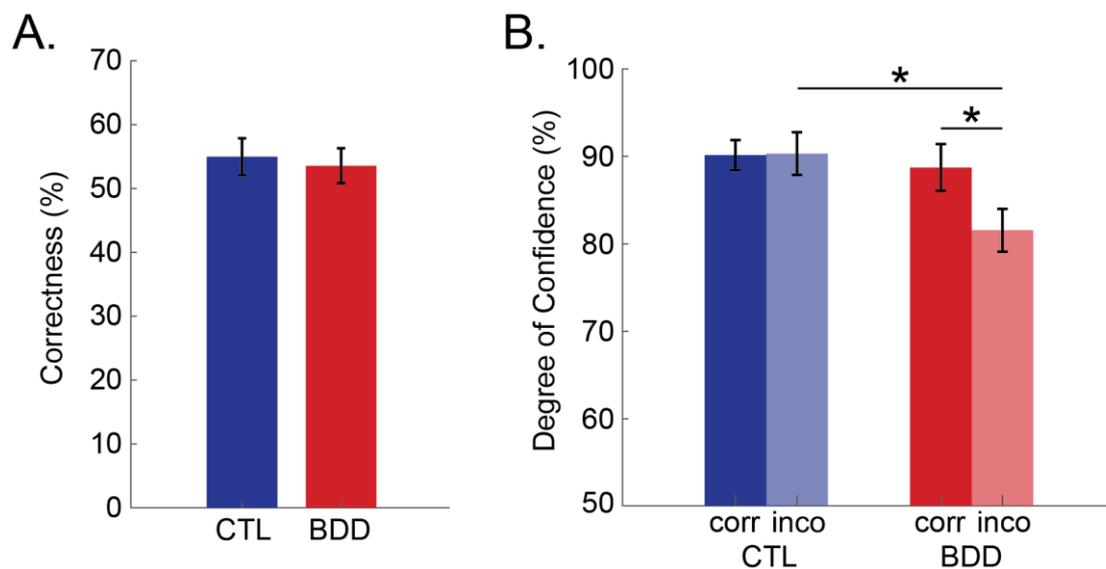
Figure 2. Behavioural performance on the optical illusion task. **A.** Percentage of correct responses (i.e. identifying the illusory effect) separately for the control (CTL; blue) and the body dysmorphic group (BDD; red); **B.** Degree of confidence separately for CTL and BDD when responding correctly (opaque) and when responding incorrectly (transparent). Error bars represent ±1 SEM. * p < .050.

3.2. EEG results

The cluster permutation procedure revealed a significant spatiotemporal cluster in the alpha band, showing greater power in the CTL than the BDD group ($t = 56.8 \times 10^3$) (Fig. 3C). Specifically, electrodes AFz, Fz, F4, FCz, Cz, CPz, Pz, and P3 exhibited higher alpha power in CTL compared to BDD subjects (Fig. 3B). The topographical maps of the t values in the alpha band in successive 100-ms time windows are presented in Fig. 3A. Control analysis revealed no significant clusters in the delta, theta, beta or gamma bands.
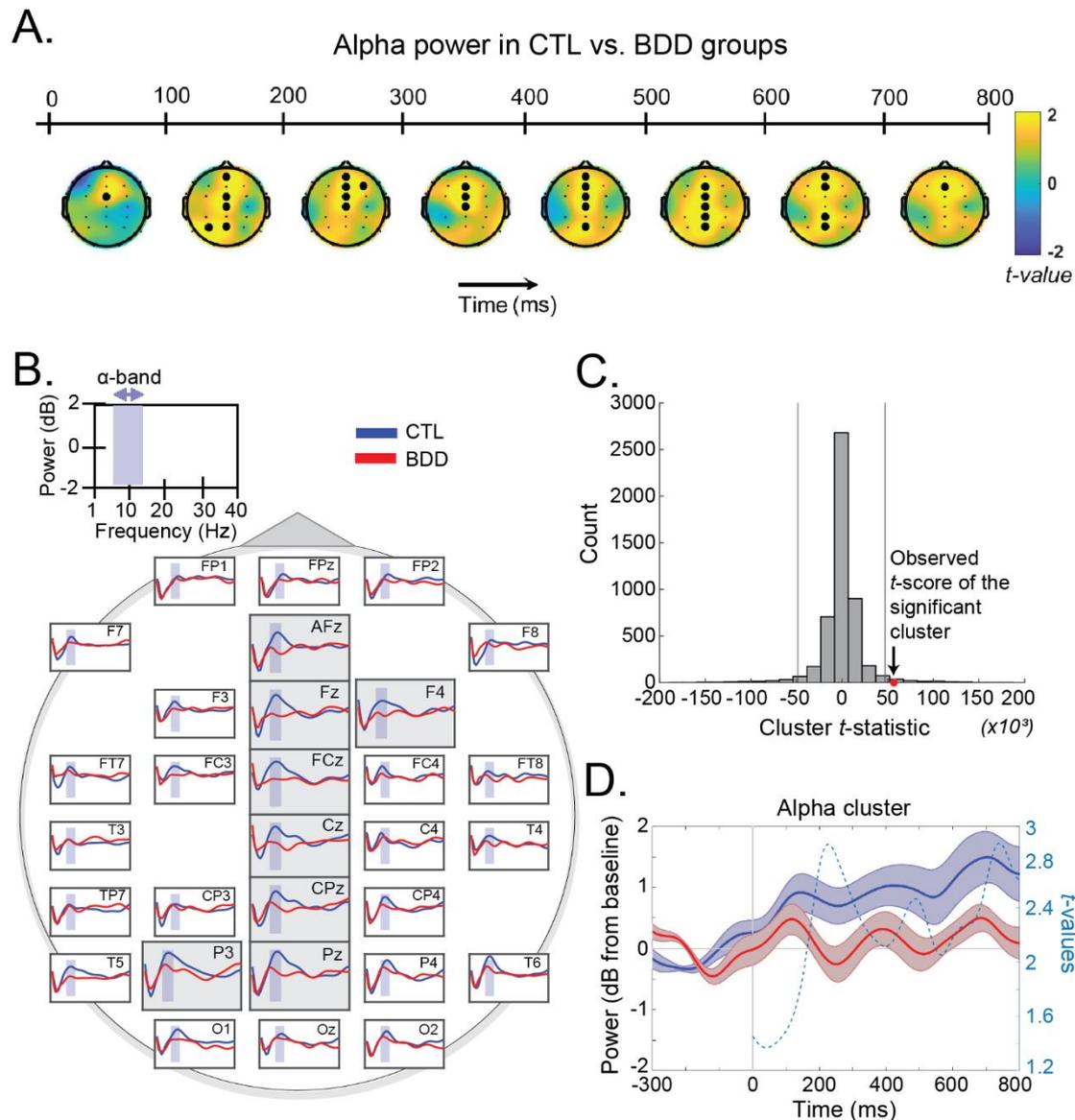
Figure 3. A. Topographical maps of the t-values between the control (CTL) vs. the body dysmorphic patients (BDD) group in the alpha frequency band from 1-800 ms (in steps of 100 ms). The significant cluster consists of electrodes AFz, FCz, F3, Fz, FCz, Cz, CPz, Pz and P3. In each time window, electrodes that are significant for at least 70% of the time are highlighted in bold; **B.** Scalp array of the group-specific (blue: CTL; red: BDD) grand-average spectrum. Purple-shaded range corresponds to the alpha frequency band (8-12.5 Hz); **C.** Difference distribution (CTL vs. BDD) for the cluster t_max-statistic in the alpha band. The red marker corresponds to the t-statistic of the significant spatiotemporal cluster; **D.** Grand-average waveforms of the alpha activity for CTL (blue) and BDD (red) groups over the significant cluster (averaged across the electrodes of the cluster). Shaded areas correspond to ±1 SEM. The dashed line indicates the time-course of the t-values (right y-axis).

3.3. Relationship between EEG measures and BDD severity

Significant outcomes resulting from the prior behavioural and electrophysiological analyses were further assessed for potential correlational relationships. Firstly, the alpha power of the significant cluster (averaged across the electrodes) was calculated for each participant and for possible correlation with psychometric ratings. Correlation was assessed via Pearson's product-moment coefficients. Results showed that the alpha cluster was positively correlated both with the Y-BOCS ($r = -.347$, $p = .038$) and the DCQ scores ($r = -.349$, $p = .037$) (Fig. 4).
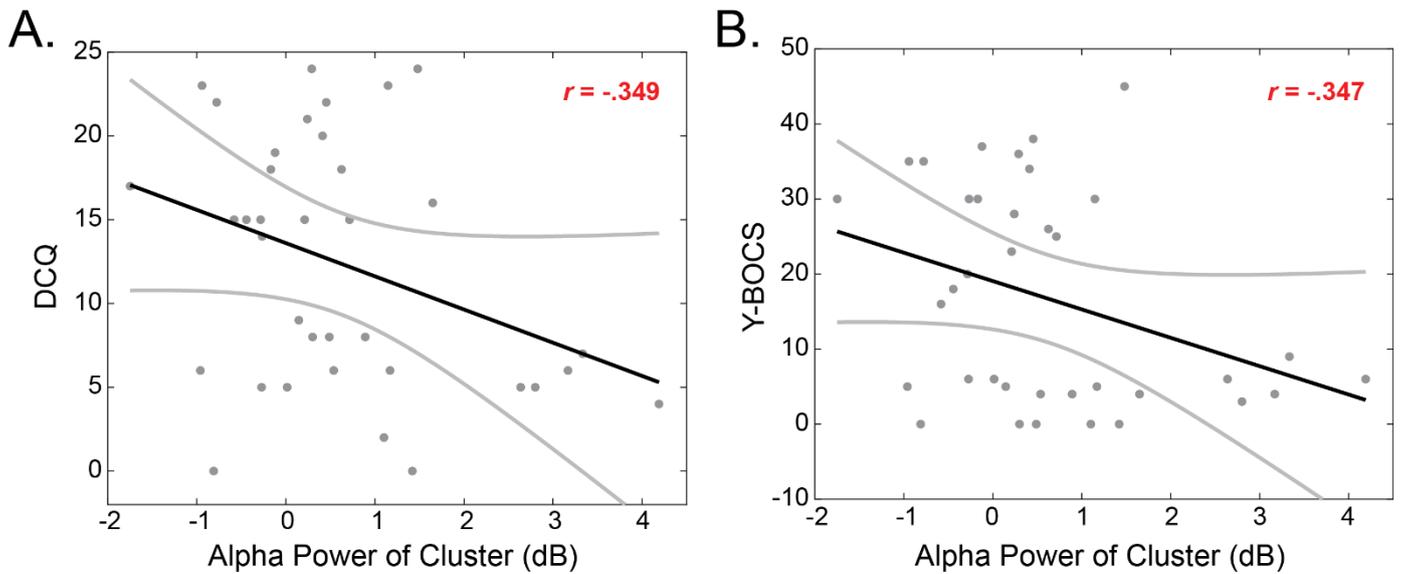
Figure 4. Relationship (Pearson's coefficients) between the alpha power of the midline cluster of electrodes and BDD questionnaires. **A.** Correlation between alpha power and the DCQ questionnaire; **B.** Correlation between alpha power and the Y-BOCS questionnaire. Gray lines illustrate 95% confidence interval.

4. Discussion

In this study, we investigated the neural correlates of BDD patients relative to healthy controls during decision-making on judgements of optical illusions. In brief, results showed no differences in performance accuracy between BDD and CTL groups, i.e. groups were equally correct in identifying illusions. Interestingly, the BDD group exhibited lower confidence than the CTL group when responding incorrectly. Time-frequency analysis showed that BDD patients exhibit reduced alpha power, primarily at midline areas. Finally, the lower the alpha power of the identified cluster, the higher the BDD severity.

The first hypothesis, that the BDD group would not show poorer performance in identifying illusory features than the CTL group, was supported. There were no significant differences between BDD and CTL groups in the percentage of correct responses. There could be a few explanations for this finding. First, it is possible that BDD patients show impaired performance when making judgements on their own appearance, while their performance is unaffected when judging external, non-threatening stimuli. For instance, during processing of inverted faces on a screen, BDD show reduced inversion effect compared to healthy controls, attributed to greater focus on detail (over-attention) and reduced holistic processing [9]. Second, it could be that the task was very easy and might not have provided sufficient challenge to distinguish performance between groups. However, the behavioural results do not suggest a ceiling effect, which speaks against this possibility.

Our second hypothesis with regards to the BDD group exhibiting lower confidence was supported. Specifically, the BDD group was less confident of their responses than the CTL group, but only when they were incorrect. This is in line with the observation that OCD is characterized by high levels of doubt and uncertainty [20,29], potentially reflecting an inability to remember or monitor previous actions [30]. Tolin and colleagues (2001) [12] measured memory accuracy and confidence in OCD in a memory recall task of objects. Interestingly, OCD patients reported lower confidence in their memories when repeatedly exposed to threat-related objects [12]. However, there was no difference in memory accuracy between OCD patients and controls. Results suggested that lower confidence in OCD is not due to memory deficits. Rather, the authors proposed that it might reflect the increased doubt observed in OCD patients when the same ritual is performed over and over again [12].

On the neural level, BDD patients showed reduced alpha power at midline scalp areas during decision-making compared to healthy controls. Alpha oscillations are principally associated with the regulation of attentional processes [31]. In particular, alpha oscillations have been shown to facilitate resource allocation to task-relevant brain areas, by inhibiting task-irrelevant areas [18]. This is achieved in a top-down manner by guiding attention, suppressing distracting input, and facilitating the processing of task-relevant stimuli [18]. Aligned with this, reduced alpha band activity has been related to difficulties in inhibiting task-irrelevant distractors [32]. For instance, Haegens and colleagues (2011) [33] found that lateralization of alpha power positively influenced the subjects' behavioural performance on a spatial discrimination task, i.e. both accuracy and reaction times improved with the degree of alpha lateralization. Further, Pogarell and colleagues (2006) [34] found reduced alpha power during wakeful-resting condition in OCD patients compared to healthy controls. In the context of illusory perception, alpha oscillations have been proved to play a critical role, mainly reflecting the degree of excitability [35]. Specifically, increased excitability is associated with low alpha power. BDD patients have impaired attentional processes, potentially associated with a hyperactivity of the functional circuits involved in the selective attention [36,37]. Therefore, our findings may indicate an over-attention of BDD during illusory perception.

Interestingly, we found that alpha power was negatively correlated with BDD severity. Previous neurophysiological research has identified neural indices of perceptual distortions in BDD [38,39]. For example, Scholz and colleagues (2017) [40] found reduced N170 amplitude in BDD patients during visual processing of faces and houses. Frontostriatal hyperactivity has been mainly associated with obsessive thoughts and compulsive behaviours, as evidenced in an fMRI study [39]. Furthermore, the brain anatomical characteristics of BDD patients revealed correlations between BDD symptom severity and volumes of the left inferior frontal gyrus and right amygdala, potentially contributing to the involvement of these regions in pathological face processing [41]. Our study might add to the previous findings by proposing alpha oscillations as a novel biomarker of illness phenotype to be used in clinical practice.

This research is not without limitations. First, it might be that different neural processes take place when participants succumb to the illusory effect vs. when they do not succumb to the effect. However, the low number of trials did not allow to compare brain activity for correct vs. incorrect responses. Second, due to the low signal-to-noise ratio of the EEG data, it was not possible to further investigate the neural signatures of confidence in the single-trial level. Finally, non-invasive brain stimulation experiments might be useful to provide causal evidence for the role of alpha oscillations during optical illusion processing, by directly stimulating participants at that frequency band.

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Institutional Review Board Statement: The study was conducted in accordance with the Declaration of Helsinki, and approved by the local ethics committee of the First Department of Psychiatry, National and Kapodistrian University of Athens, Medical School, Athens, Greece (protocol code 349 and date of approval 29/8/2013).

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

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