Reduced electrocortical responses to pleasant pictures in depression: A brief report on time-domain and time-frequency delta analyses

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Abstract

Background. The late positive potential (LPP) to pleasant content is an electrocortical indicator of blunted emotional reactivity in depression. A reduced time-frequency delta power has never been investigated in clinical samples. The present study aimed at analyzing time-frequency delta in depression and at investigating whether the combination of time-domain and time-frequency data would explain additional variance in the depression status.

Methods. The study was a secondary analysis of data collected during a passive viewing task of pleasant and neutral pictures in a community-based sample of 75 participants with a current depressive disorder and 42 controls. A time-frequency analysis on event-related changes within delta frequency band was conducted.

Results. Cluster-based statistics revealed a centro-parietal increase in delta power to pleasant relative to neutral pictures in the control group but not within the depression group. Moreover, a fronto-centro-parietal reduction in delta power to pleasant pictures emerged in depression relative to controls. Both a smaller LPP and delta power to pleasant pictures were independently related to depression status. The model explained a greater amount of variance (Nagelkerke R^2 = .11) compared to the logistic regression where the LPP_{res} was entered as independent predictor of group status (Nagelkerke R^2 = .07).

Conclusions. These data suggest that delta power might be a promising electrocortical correlate of the hypoactivation of the approach-related motivational system in depression. Additionally, a blunted delta and LPP might reflect unique processes related to depression. A combination of these measures can be leveraged together to enhance clinical utility.

Keywords: Depression; Time-frequency; delta power; event-related potentials; LPP; emotion

Introduction

The hypoactivation of the approach-related motivational system in depression (Admon & Pizzagalli, 2015) has been extensively documented by event-related potentials (ERPs) studies, that reported a blunted late positive potential (LPP) to pleasant pictures in current depression (Klawohn et al., 2021; Weinberg et al., 2016; for a review see Hajck Proudfit et al., 2015).

Additional insight into emotional reactivity can be provided using time-frequency decomposition of electroencephalography (EEG) data (e.g., Bernat, Nelson, & Baskin-Sommers, 2015; Herrmann et al., 2014). Time-frequency approach allows disentangling multiple overlapping spectral components that are embedded in the time-domain data (Foti et al., 2015). Conceptualizing EEG data as a multidimensional time-frequency signal has advantages over ERP analyses (Cohen, 2014). For example, task-related information, such as non-phase locked (i.e., induced) dynamics, can be lost during ERP averaging but are observable with time-frequency analysis, which adopts a trial-by-trial approach (Cohen, 2014; Herrmann et al., 2014).

Delta oscillations (< 3 Hz) are associated with the motivational processing of salient stimuli (Bernat et al., 2015; Foti et al., 2015; Güntekin & Başar, 2016; Nelson et al., 2018; Knyazev, Slobodskoj-Plusnin, & Bocharov, 2009; Knyazev, 2012; Williams et al., 2021; Zhang et al., 2013). Considering that delta power might add additional information to time-domain measures in the study of emotional reactivity in depression, it stands to reason that both time-domain and time-frequency might be leveraged together to better understand depression.

Recently, a smaller centro-parietal delta power to pleasant images in individuals with dysphoria was reported (Dell'Acqua et al., 2022). Time-frequency delta activity to emotional pictures, however, has not been examined in individuals with a clinical diagnosis of depressive disorder. Also, whether delta power represents a unique indicator of depression status, independent of the time-domain LPP, remains unexplored.

In the current study, emotional reactivity to pleasant vs. neutral images through the analysis of time-frequency changes during an emotional passive viewing task of pleasant and neutral pictures in individuals with and without clinical depression was examined. The depression group was expected to show a blunted delta activity in response to pleasant pictures relative to healthy controls. A second goal of this work was to examine whether utilizing a combination of LPP and delta activity would explain additional variance in depression status. In addition, the association of both LPP and delta power with self-report measures of interest (i.e., depressive symptom severity and anhedonia) was investigated.

Method and Materials

Participants

The present study is a secondary analysis of EEG data collected during a passive viewing paradigm (Klawohn et al., 2021). The present study included 117 (92 F) participants between 18 and 60 years of age. The depressed (DEP) group included 75 (58 F, 17 M) participants that met diagnostic criteria for a current depressive disorder (current MDD and/or persistent depressive disorder, PDD), and scored equal to or greater than 13 on the Beck Depression Inventory-II (BDI-II; Beck, Steer, & Brown, 1996). The healthy control group (HC) included 42 (34 F, 8 M) participants that never met the diagnostic criteria for a mood disorder, did not currently meet criteria for any psychiatric disorder, and scored less than a 13 on the BDI-II. Exclusion criteria included the presence of a lifetime diagnosis of a bipolar or psychotic disorder or any neurological disorders, a current substance use disorder.

The sample included both right- and left-handed participants, as assessed with the Edinburgh handedness inventory (Oldfield, 1971). The two groups did not differ in terms of handedness ($p = 0.232$). Participants were compensated for their participation ($20 per hour). All procedures were approved by the local ethics committee.

Measures

Clinical interviews

The presence of current and past mood disorders was determined using the Structured Clinical Interview for DSM-5 (SCID-5-Research Version; First et al., 2015). Other past and present psychopathology was evaluated using the Mini-International Neuropsychiatric Interview (M.I.N.I.; Sheehan et al., 1998), updated for DSM-5 (version 7.0.2) (Sheehan et al., 1997).

Self-report symptoms

Depressive symptoms in the past two weeks were assessed using the Beck Depression Inventory-II (BDI-II; Beck, Steer, & Brown, 1996). Higher scores indicate greater depressive symptoms. Internal consistency resulted high for the 21 items of the BDI-II (Cronbach's $\alpha = .96$).

Participants also completed the anhedonia facet subscale of the Personality Inventory for DSM-5 (PID-5; Krueger et al., 2012). Higher scores indicate greater anhedonia. Internal consistency resulted high for the items of the PID-5 anhedonia subscale (Cronbach's $\alpha = .95$).

Electroencephalogram recording

The electroencephalogram (EEG) was recorded using a 32-channel system (ActiCHamp, Brain Products GmbH) referenced online to Cz with a sampling rate of 1000 Hz using a bandpass recording filter of 0.01–100 Hz. Both vertical and horizontal electrooculograms (EOGs) were recorded using a bipolar montage to monitor eye movements and eye-blinks.

EEG task

The picture viewing task comprised 60 color pictures selected from the International Affective Picture System (IAPS; Lang, Bradley, Cuthbert, 2008); 30 pleasant images (e.g., erotic and affiliative images) and 30 neutral images (e.g., objects, humans with neutral facial expression; specific IAPS picture numbers and normative ratings are listed in the supplementary material).

All pictures were presented for 1500 ms, spanning approximately 15 by 20 degrees of visual angle, in random order across three blocks of 20 trials. Each picture was preceded by a fixation cross with a random duration of 500–900 ms. Participants were required keep their gaze on the center of the screen. Picture presentation was followed by a variable intertrial interval of 500-900 ms, during which a white fixation cross was presented.

EEG Data Processing

Time domain

Offline time-domain EEG data processing was conducted using Brain Vision Analyzer (Brain Products, Gilching, Germany). Data was referenced to the average mastoid electrodes and filtered from 0.01 to 30 Hz. Epochs from 200 ms before until 1200 ms after picture onset were extracted and corrected for eye movement artifacts (Gratton, Cole, & Donchin, 1983). Segments containing voltage steps >50 mV between sample points, a voltage difference of 175mV within a 400 ms interval, or a maximum voltage difference of <0.5mV within 100 ms intervals were automatically rejected and additional artifacts were identified and removed based on visual inspection. Baseline correction was applied using the 200 ms pre-stimulus interval. Stimulus-locked averages were calculated separately for pleasant and neutral images, and the LPP was quantified at a parietal electrode-pool (Pz, Cz, CP1 and CP2) as the mean amplitude from 400 to 1000 ms after picture onset.

Time-Frequency domain

The processing pipeline for the time-frequency domain was similar to the one conducted for the time domain. Here, the extracted time windows were wider to allow for the discarding of edge effects, and the artifact rejection procedure was somewhat more conservative. EEG data processing was conducted in Brainstorm (Tadel et al., 2011). The signal was filtered offline with a band-pass filter of 0.3-30 Hz to minimize slow drifts that could have adverse effects on time-frequency decomposition. Also, independent component analysis (ICA) was used to correct for blink artifacts. The data were segmented into epochs from 500 ms before until 1500 ms after picture onset.

Time-frequency analysis was conducted using Morlet wavelet transformation on individual trials for each 1-Hz frequency bin between 1 and 30 Hz, using a mother wavelet at 1 Hz with 3-s time resolution (as calculated by the full width at half maximum, FWHM). Time-frequency decompositions were then averaged for each participant and emotional condition, and the event-related spectral perturbation (ERSP) was computed as the change in power expressed in decibels (dB) relative to the baseline (−300 to −100 ms) in each frequency bin at each time point. Then, data were grand averaged across each group for each emotional condition.

With respect to time-frequency data, a cluster-based permutation approach was run on the event-related delta (1–3 Hz), as implemented by the FieldTrip toolbox (Oostenveld et al., 2011). With this approach, the theoretical underlying distribution of test statistics under the null hypothesis is generated by the data itself, by iteratively shuffling the condition labels over trials or over subjects and recomputing the statistics. If the test statistic associated with the non-shuffled data falls within the distribution of the null-hypothesis test statistic values, the null hypothesis cannot be rejected and this would indicate that the observed data could have been randomly generated (Cohen, 2014; Luck, 2014). With cluster-based correction, at each iteration of the null-hypothesis distribution generation, the outcome is units of clusters instead of single pixels (i.e., electrodes) (Cohen, 2014). In the present study, the differences within emotional conditions or between groups were shuffled pseudo-randomly 2000 times. To obtain a 'null' distribution of effect sizes, the maximal cluster-level statistics (i.e., the sum of values across contiguously significant electrodes and time points at the threshold level) were extracted for each shuffle. For each significant cluster in the (non-shuffled) data, the cluster-corrected *p*-value was computed as the statistics of the proportion of clusters in the null distribution that exceeded the one obtained for the cluster in question. Clusters with a $p_{corr} < .05$ were considered statistically significant. This approach provides solid control over type I error rate arising from multiple comparisons across electrodes and time points (Maris & Oostenveld, 2007). Cluster-based repeated measures ANOVAs were conducted to test within-group differences in event-related power changes between emotional categories (i.e., pleasant versus neutral). Two-tailed independent samples *t*-tests were conducted to test between-group (i.e., DEP versus HC) differences within each emotional category.

Further statistical analyses were conducted using a two-tailed $\alpha = .05$. Delta power was extracted according to the significant time window and location (i.e., sensors) that emerged from the cluster-based between-group differences for pleasant pictures. Residualized difference measures for the LPP and delta power were determined by saving the unstandardized residuals in linear regressions predicting LPP to pleasant images from LPP to neutral images (i.e., LPP_{resid}) and predicting delta power to pleasant images from delta power to neutral images (i.e., $Delta_{resid}$), respectively. The Shapiro-Wilk test was conducted to ensure that data was normally distributed. Then, within each group, Pearson correlations were performed. Finally, a logistic regression was conducted to examine whether the $Delta_{resid}$ and LPP_{resid} explained unique or shared variance in depression diagnostic status, and to determine the amount of variance that was explained by using the two measures as simultaneous predictors of depression status.

Results

Characteristics of the sample

Table 1 illustrates demographic and clinical characteristics of the sample (DEP, HC). In the DEP group, several individuals met diagnostic criteria for one or more comorbid psychiatric diagnoses, in particular: panic disorder (n = 13), agoraphobia (n = 8), social anxiety disorder (n = 12), obsessive compulsive disorder (n = 5), post-traumatic stress disorder (n = 4), generalized anxiety disorder (n = 19), specific phobia (n = 4), eating disorder (n = 7), somatic symptoms disorder (n = 3) and illness anxiety (n = 2). Moreover, in the DEP group, 39 individuals (52 %) were currently taking psychotropic medication (antidepressants, n = 33; anxiolytics, n = 13; stimulants, n = 5; anticonvulsants, n = 5).

Cluster-based analysis on Delta power

Differences among emotional categories in event-related delta power. The cluster-based analysis on event-related delta power showed a significant positive centro-parietal cluster (electrodes = CP1, PZ, P3, CP2) in the HC group (cluster F-valuemax = 9908.62, p_{corr} = .036, time window -0.010 to 0.594 s; Cohen's d = 0.44), with significantly larger delta power to pleasant relative to neutral pictures (Figure 1, panel a and b). A marginally significant cluster emerged in event-related delta power by emotional category within the DEP group, (electrodes = PZ, P4, CP2; cluster F-valuemax =4810.42, p_{corr} = .052, time window 0.784 to 1.228 s; Cohen's d = 0.06), showing a decrease of delta power to pleasant relative to neutral in a late time window (Figure 1, panel c and d).

Differences between groups in event-related delta power for each emotional category. Cluster-based independent samples t-tests on event-related delta power revealed a significant positive cluster for the difference between the two groups for pleasant pictures (electrodes = FZ, FCZ, FC1, C3, CP5, CP1, PZ, P3, P7, O1, P4, CP2; cluster t-valuemax = 9879.36; p_{corr} = .030, time window = -0.010 to 0.860 s; Cohen's d = 0.42), with reduced delta power to pleasant pictures in the DEP compared to HC group (Figure 2, panel a, b and c). There were no group differences in delta power to neutral pictures.

Correlations

The Shapiro-Wilk test revealed that the EEG measures were normally distributed (LPP_{res}, p = .30; $Delta_{res}$, p = .80). The LPP_{resid} and $Delta_{resid}$ were uncorrelated across the whole sample (r (115) = .07, p = .437) and within each group separately (DEP: r (73) = -.03, p = 0.801; HC: r (39) = .13; p = .419), suggesting that these two measures are distinct measures of positive emotional reactivity. Within the DEP group, the correlation between LPP_{resid} and self-report anhedonia approached significance (r (73) = -.212, p = .067), whereas there was no correlation between other variables (all ps >.229). In the HC group, there were no correlations among study variables (all ps >.316). Correlation among study variables within the DEP group are shown in the Supplementary Material.

Logistic regression

Results of the logistic regression are shown in Table 2. The multiple logistic regression showed that both smaller LPP_{resid} and smaller $Delta_{resid}$ were independently related to increased likelihood of being diagnosed with a depressive disorder[1]. The model explained a greater amount of variance (Nagelkerke R^2 =0.11) compared to the logistic regression where the LPP_{res} was entered as independent predictor of group status (Nagelkerke R^2 =0.07).

[1] Considering that, due to the different EEG data processing method required in the time-frequency analysis, the current sample was slightly different from the one included in the previous work (Klawohn et al., 2021), a logistic regression with the LPP_{resid} entered as an independent predictor of group status was run. The results confirmed a significant model wherein LPP_{resid} predicted depression status (Nagelkerke R^2 =0.07, $\chi2$ = 5.97; Odds ratio =0.88, p = .018).

Discussion

The current study sought to examine emotional reactivity to pleasant pictures in adults with a current depressive disorder by examining time-frequency changes within the delta frequency band in response to pleasant and neutral pictures (Lang et al., 2008). Consistent with the hypotheses, individuals with depression were characterized by reduced delta power to pleasant pictures, but to neutral, relative to healthy controls.

With respect to the time-frequency analysis, increased event-related delta power to pleasant relative to neutral images emerged in both groups, indicating that affective modulation of pleasant images occurred. As expected, the depression group showed reduced event-related delta power to pleasant images relative to the control group. This is consistent with a recent report conducted on a sample of individuals with dysphoria (Dell'Acqua et al., 2022). Overall, these findings provide support the view of depression as characterized by an hypoactivation of the approach-related motivational system in the brain.

Moreover, the combination of delta power and LPP to pleasant pictures increased the explained variance in the likelihood of suffering from depression relative to the sole employment of either time-domain or frequency-based measures. This study was the first attempt to simultaneously examine both EEG measures in clinical depression and it suggests that leveraging time-frequency delta in conjunction with time-domain measures might be particularly useful in better elucidating the pathophysiology of depression. The time domain and spectral representations were not correlated, suggesting that frequency-based representation provide unique information that is not apparent with time-domain analysis. Considering that these electrocortical measures were uniquely related to depression status they might reflect distinct processes relevant to depression. In line with the fact that the LPP and delta power are separate predictors of depression status, these two measures were uncorrelated, suggesting that they could represent distinct aspects of positive emotional reactivity.

Considering the extensive literature indicating that LPP to pleasant stimuli is a reliable indicator of depression status (for a review see, Hajcak Proudfit et al., 2015), the present study suggests that the analysis of time-frequency delta could be a complementary measure in the prediction of depression. The analysis of both LPP and delta can reveal two interrelated processes, namely reduced motivated attention to positively valenced content and reduced approach-related motivation, respectively.

The present study has some limitations worth noting. First, most of the participants included in the study were female and Caucasian. Future investigations should replicate these findings in more diverse samples. Also, although some evidence suggests that these findings would generalize to unpleasant pictures (e.g., Foti et al., 2010; Weinberg et al., 2016), unpleasant pictures were not included in the task, and thus it is unclear if depression is exclusively characterized by a dysfunction in approach-motivation or by a general emotional disengagement (i.e., emotion context insensitivity; Bylsma, 2021).

In conclusion, the current study provided converging evidence across multiple approaches that a blunted emotional reactivity to pleasant pictures is an indicator of depression. Considering that both LPP and time-frequency delta power can be obtained from the same task, our findings suggest that a combination of EEG measures can be leveraged together from the same paradigm to enhance clinical utility.

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Disclosures

All authors report no financial interests or potential conflicts of interest.

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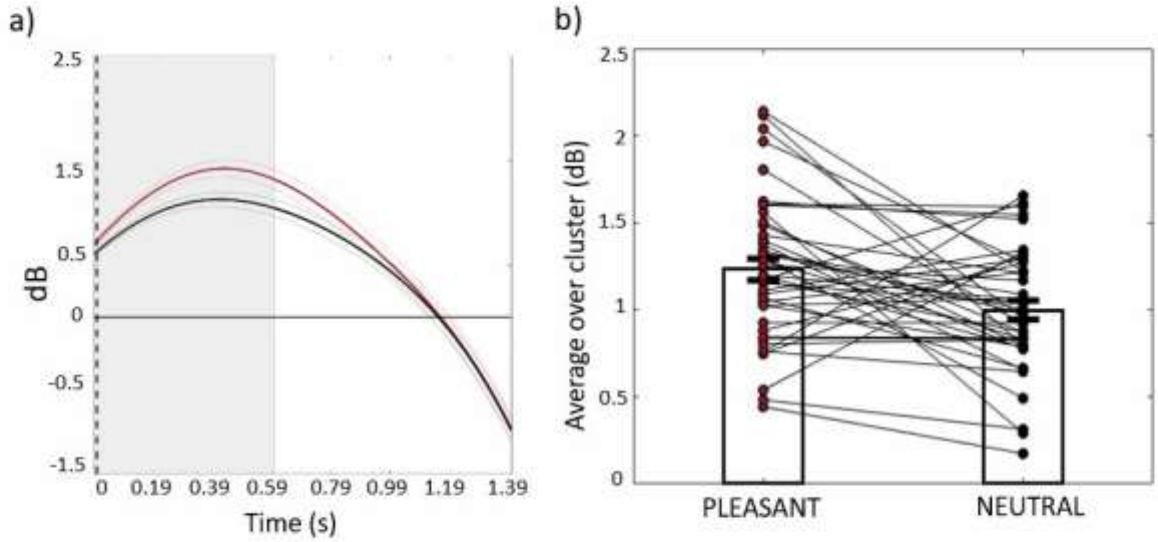

Figure 1. (Panel a) Time course of grand-average event-related delta power of control individuals averaged over the significant electrodes for pleasant (red line) and neutral (black line) conditions. Shaded areas represent ± standard error of the mean (SEM) and the gray box represents the end of the significant time window (0.594 s). (Panel b) Mean event-related delta power of each participant (in the control group) averaged over the significant electrodes and time points for pleasant and neutral conditions. Each circle represents one participant (Panel c) Time course of grand-average event-related delta power of individuals with depression averaged over the marginally significant electrodes for pleasant (red line) and neutral (black line) conditions. Shaded areas represent ± standard error of the mean (SEM) and the gray box represents the significant time window. (Panel d) Mean event-related delta power of each participant (in the depression group) averaged over the significant electrodes and time points for pleasant and neutral conditions. Each circle represents one participant.

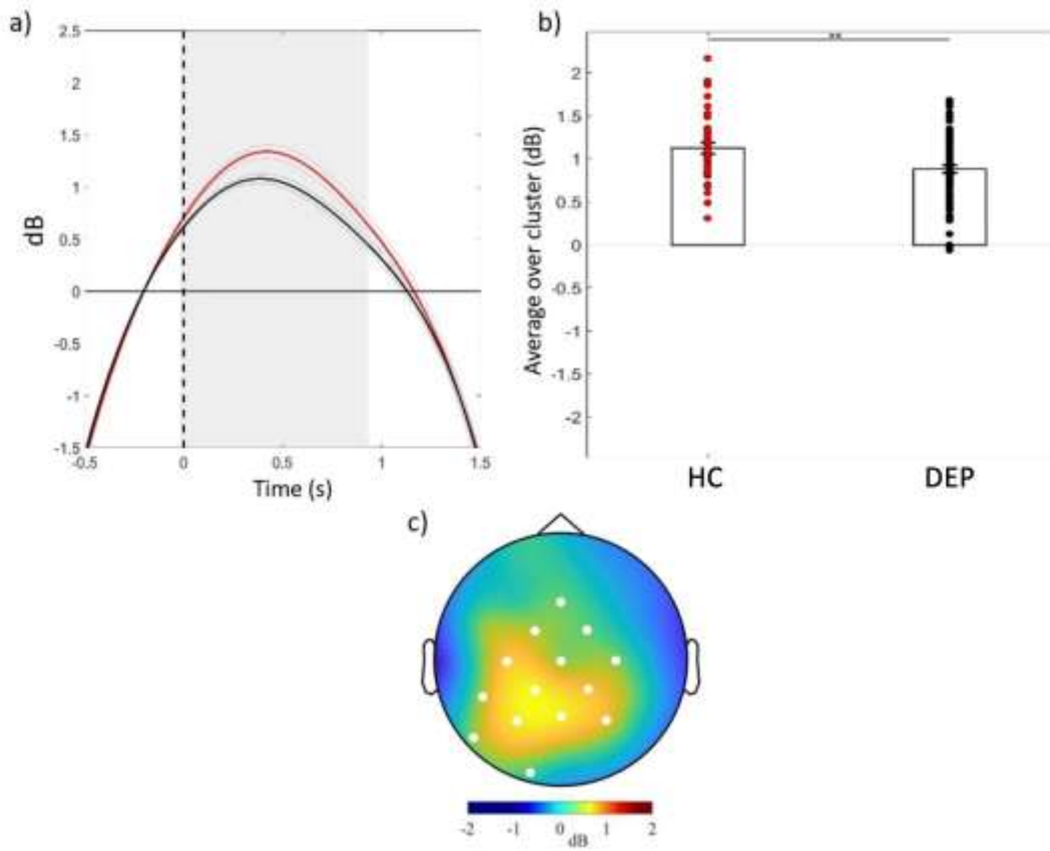

Figure 2. (Panel a) Time course of grand-average event-related delta power averaged over the significant electrodes for the pleasant condition in the depression (DEP) group (black line) and the control (HC) group (red line). Shaded areas represent ± standard error of the mean (SEM); the gray box represents the significant time window. (Panel b) Mean event-related delta power of each participant in the DEP group and the HC group averaged over the significant electrodes and time points for the pleasant condition. Each circle represents one participant. (Panel c) Topography of the mean difference between groups in event-related delta power (dB; DEP group minus HC group) averaged over the significant time points (-0.010 to 0.860 s time window) for the pleasant condition. $**p < .01$.

Table 1. Demographic, clinical variables, and EEG data for group with a current depressive disorder (DEP) and the healthy control group (HC).

	HC group (*n* = 42)	DEP group (*n* = 75)	*p*
Age	37.0 (14.2)	39.70 (11.9)	.280
Sex (% female)	77.33	80.95	.847
Ethnicity (% Caucasian)	92.86	92.00	.571
Education	16.50 (1.60)	16.00 (15.00)	.229
BDI	2.21 (3.06)	29.40 (9.32)	< .001
PID 5-Anhedonia	2.48 (3.40)	13.80 (5.58)	< .001
LPP pleasant (μV)	6.06 (4.19)	4.02 (4.31)	.020
LPP neutral (μV)	-2.62 (3.54)	-3.05 (3.48)	.520
Delta pleasant (dB)	0.99 (0.37)	0.84 (0.33)	.030
Delta neutral (dB)	0.89 (0.25)	0.85 (0.38)	.610

BDI-II, Beck Depression Inventory-II; LPP, late positive potential; μV, microvolts; dB, decibels.
Note: Means are displayed, standard deviations are in parentheses.

Table 2. Results of the logistic regression analysis predicting diagnostic status (DEP, HC) from LPP and Delta power.

Measure	Prediction of diagnostic status (DEP, HC)				
	R^2	$\chi 2$	OR	95% CI_{OR}	*p*
Model on combined LPP and delta power	0.11	10.1			
LPP_{resid}			0.89	0.80 – 0.98	.023
$Delta_{resid}$			0.29	0.08 – 0.99	.050

Note. Logistic regression was used to predict the dichotomous dependent variable diagnosis of depression (0 = absent, 1 = present); The Nagelkerke R^2 and $\chi 2$ statistics are reported for the logistic regression models. CI = confidence intervals; OR = odds ratio.