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The multimodal emotion perception in codependent individuals

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Abstract: The emotional disturbances of individuals with codependency are often ignored. This study aimed to investigate the emotional perception of codependent individuals in four modalities – visual, auditory, tactile and olfactory. An EEG study was performed and presented pleasant and unpleasant stimuli selected by a panel of experts for each modality. Participants (fifteen codependent individuals and fifteen healthy volunteers) were instructed to assess the emotional impact and pleasantness of stimuli. The method of EEG spaces was used to visualize how close perceived stimuli were according to EEG data. The results showed ambivalence of emotional response to emotional stimuli with social component and lack of recognition of emotional tone detected in EEG and behavioral levels. The empathy feeling in codependent individuals was detected for fewer emotional stimuli. The group differences were associated with evolutionary newer modalities (auditory and visual). The lack of emotional perception in codependent subjects was determined by social factors and was detected in visual and auditory modalities, which were more involved in social interactions than olfactory and tactile modalities.

Keywords: codependent individuals; EEG indexes; emotional perception; modality; method of EEG spaces; FFT value

1.0 INTRODUCTION

Codependency as a psychological problem has been known for a long time. However, the neurophysiological basis of emotional dysregulation in codependent individuals remained underinvestigated. According to previous studies, codependency was characterized by belonging to a dysfunctional, one-sided relationship where one person relies on the other to meet nearly all their emotional and self-esteem needs (Fischer & Spann, 1991). The codependent individual could be characterized by the dependence of the subject's self-esteem on the ability to control both self and others, the necessity to satisfy the needs of others, down to denying their own and anxiety due to problems in relationships with relatives suffering from psychopathic, addictive, emotional or behavioral disorders (Gierymski & Williams, 1986; Kim, 2015).

The described emotional and behavioral problems of codependent persons could also influence other cognitive functions, including emotional perception, which could be observed in the different modalities in varying degrees found in previous clinical studies. Deficits in both facial emotion and affective prosody recognition could be detected in most psychiatric disorders. In particular, patients with schizophrenia showed decreased accuracy of emotional voice recognition, as well as impaired perception of facial expression (Kim, 2015) (Lawrence et al., 2004). The deficit of voice prosodic perception and lack of recognition of emotionally charging visual stimuli was also found in individuals with autistic spectrum disorder (Kaiser et al., 2016; Oakley, 2013) and patients with depression (Yang et al., 2013). Alcohol-dependent patients showed olfactory deficits associated with difficulties recognizing odor familiarity and edibility (Rupp et al., 2004).

The impairment of emotional perception depended on the specificity of mental illness, the actual needs of the subject, his emotional state, preferences or previous experience (Carr & Buchanan, 1997; Cermak, 1986; Morgan, 1991; Prest et al., 1998). In particular, patients with schizophrenia could easily emit emotions of fear and anger but showed significant differences in differentiating emotions of happiness or sorrow (Nevidimova et al., 2018; Reyomw et al., 2010; Rozhnova et al., 2020). Patients with addiction disorders demonstrated olfactory attractiveness manifested in assessing unpleasant odors as pleasant (gasoline, acetone, etc.) (Nevidimova et al., 2015). Aversive responses to some odors were also found in patients with obsessive-compulsive disorder. Other findings indicated that patients with depression had difficulties with odor identification and the predominance of negative assessments for neutral and pleasant olfactory stimuli as well as an extremely negative response to unpleasant stimuli. Patients with mania, on the contrary, overestimated the pleasantness of odors (Croy & Hummel, 2017).

Hypo and hypersensitivity to some modalities could also be one of the trendiest in which emotional perception could be impaired (Croy et al., 2014). For example, people with addiction disorders demonstrated a need for auditory, visual or vestibular stimulation, which led to risk-related behavior. Individuals with autistic spectrum disorder, on the contrary, showed high sensitivity to tactile stimuli when soft touch induced a sense of severe discomfort (Kaiser et al., 2016). The emotional perception of codependents remained still understudied. There are very few studies investigating the impairment of emotional perception in codependent individuals, and most of them demonstrated that during the processing of emotional stimuli in codependent subjects was often accompanied by variable coping strategies, including denial, confrontation, avoidance and positive reappraisal (Chang, 2018; Coleman, 1987; Politica, 2020). In particular, codependent persons tend to idealize some memories while denying other events or facts, resulting in selective emotional perception (Nikolaev & Chuprova, 2013; Kaplan, 2022). Other codependency experts suggested that codependents could have altered sensitivity to emotional stimuli and could be less empathetic when perceiving others' emotions (Ansara, 1995; Lancer, 2015).

This study hypothesized that the emotional disturbances of codependent individuals, particularly the altered emotional perception, obey certain laws that underlie the development of this mental disease. The aims of this study were: (1) to compare the ability to perceive emotional stimuli in four modalities between codependent individuals and control subjects; (2) to identify the relation between the ability to perceive emotion and its social context; and (3) to investigate the EEG changes corresponded to the altered emotional perception. By doing so, we can learn the neurophysiological mechanisms underlying the particular processes of emotional perception in which codependent individuals may have particular difficulty and which could have important implications for developing novel psychological interventions. So, the research specificity of emotional perception in codependent persons could help to identify the origin of their behavioural and emotional problems and could be further used for rehabilitation and psychotherapeutic work.

2.0 MATERIALS AND METHODS

2.1 Participants

Fifteen healthy right-handed subjects (7 male, 8 female, 28.4 ± 3.7 years old; 12.1 ± 7.7 scores by Friel Codependency Assessment Inventory (Fischer 1991) and 15 codependent individuals (6 male, 9 female, 29.7 ± 4.1 years old; 49.8 ± 9.1) participated in our study.

Exclusion criteria included: menstrual cycle phase, use of oral contraceptives, previous neurological or psychiatric history, pregnancy, and treatment with antidepressants and anxiolytics. All participants signed the informed consent for the research document indicating a willingness to participate. The work was approved by the Institute of Higher Nervous Activity and Neurophysiology ethics committee of the Russian Academy of Sciences (protocol № 2 24/05/2017).

Participants were asked to evaluate their emotional state (self-assessment) using scales of arousal, empathy, anxiety, aggression, fatigue, and irritation (0-5). The results of the self-assessment are depicted in **Figure 1**. Participants did not differ based on their self-assessments.

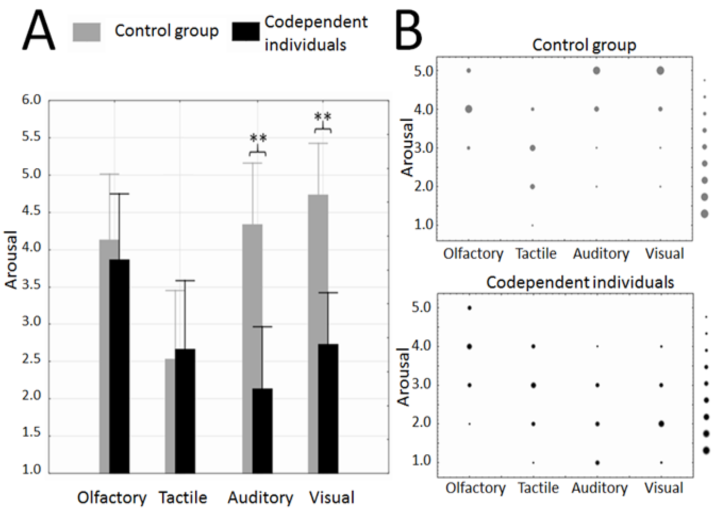

Figure 1. (A) Subjective rate of arousal of unpleasant stimuli (the individual values were averaged over unpleasant stimuli inside each modality) presented in four modalities in control group subjects and codependent individuals. **(B)** scatterplots (with frequencies) of individual value points of subjective arousal for the following stimuli: Acetone (olfactory), hard brush (tactile), Scream (auditory) , and Snakes (visual).

2.2 Stimuli

The experiment consisted of 4 series corresponding to 4 modalities. Stimuli were selected during the pilot study with healthy adult volunteers (n=89), who were instructed to assess stimuli by scales of pleasantness (-5 – 5) and arousal (0-5). As a result of the pilot study of more than a hundred stimuli, the most pleasant and unpleasant stimuli of similar pleasantness and arousal were selected. The selected pleasant stimuli did not differ between the four modalities' pleasantness and arousal. The unpleasant stimuli also did not differ by their arousal; however, as for the pleasantness, the same unpleasant tactile stimuli cannot be applied as odors, images or sounds due to the ethical protocol. At the same time, the differences between the pleasantness of unpleasant tactile stimuli and unpleasant stimuli of other modalities were not significant ($p>0.11$).

The number of stimuli varied depending on modality: 14 pictures from The International Affective Picture System (IAPS) (6 pleasant, 8 unpleasant), 14 sounds (6 pleasant, 8 unpleasant), 10 tactile stimuli (3 pleasant, 3 unpleasant), 14 odors (6 pleasant, 8 unpleasant). The stimulation was randomized, odors and tactile stimuli had a duration of about 20-30 sec and were repeated 4 times, auditory and visual stimuli had a duration of 8 seconds and were repeated 20 times. The stimuli were presented using Presentation Software (Neurobehavioral Systems, USA).

2.3 Assessment of stimuli

Participants assessed the stimuli by the scales of pleasantness, arousal, and feelings of empathy toward the stimuli during EEG recording. The pleasantness, arousal and empathy were assessed by scales from 0 (most unpleasant) to 5 (most pleasant) - the gradient was marked on the keyboard. The clinical psychologist (experienced in working with codependent persons) prepared the experimental procedures and managed trustworthy and comfortable communication during the study.

2.4 EEG registration

During the EEG recording, the participants were instructed to remain calm and to listen to the presented sounds (via earphones), watch the visual stimuli (presented on the monitor), smell the odors, and perceive tactile stimuli to avoid falling asleep. The auditory olfactory and tactile stimuli were presented while the subject's eyes were closed to avoid visual interference. EEG was recorded using Neurotravel-24D (ATES Medica, Italy), with 32-channel Electro-Cap (USA). The amplifier bandpass filter was nominally set to 1.6-30 Hz.

For EEG preprocessing, continuous EEG fragments corresponding to the stimulation and each subject's resting state were cleaned from eye movements and muscle artifacts by an ICA-based algorithm in the EEGLAB plugin for MatLab 7.11.0. Movement artifacts were cut out through manual data inspection. The continuous resting-state EEG of each subject was filtered with a bandpass filter of 0.5–30 Hz.

2.5 Data processing

EEG intervals corresponding to a specific stimulus (about 200-250 sec) were concatenated. Eyes movement artifacts were cleaned out using EOG data by EEGLab. Small intervals affected by muscle activity were excluded (cut) manually using visual inspection. All the following processing was performed using the EEGLab plugin for MatLab (Mathwork Inc.). The "EEG spaces" calculations were implemented in C# programming language by the lab's engineer.

2.5.1 EEG spaces

The method of EEG spaces previously adapted to clinical data was used and allowed to visualize how close/distant the perceived stimuli were according to EEG data. The technique consists of the following steps:

1. The EEG fragment corresponding to each emotional stimulus sound was divided into small non-overlapping epochs of 8 seconds.
2. FFT (absolute value) was calculated for the epochs in the 2-20 Hz band for electrodes (F3, F4, F7, F8, FC5, FC6, T3, T4, T5, T6, CP5, CP6, P3, P4, C3, C4, O1, O2 international 10–20 system)
3. The distance between each pair of emotional stimuli was calculated: for each frequency bin, two samples of FFT values (of the epochs of these fragments) were compared using Mann-Whitney U-test ($p < 0.05$). The distance was equal to the percentage of differing frequency bins.
4. Emotional stimuli were placed onto a plane using a multidimensional scaling method, namely Sammon projection. EEG spaces for visual and auditory modalities were depicted using color **(Figure 2)**. So, the distances between the stimuli types in the plane were as similar as possible to the distances calculated from FFT values. This similarity was always good enough to claim the projection is legit.
5. The resulting pictures (obtained for each subject) were standardized and then averaged.
6. After standardization, individual pictures were averaged over groups. So, these EEG spaces showed relational distances between emotional sounds based on how much the corresponding EEG data differ in terms of rhythm magnitudes.

2.5.2 Power spectral density (PSD)

Fast Fourier transform (FFT) was used to analyze PSD. The EEG spectrum was estimated for every 178 ± 22.3 s intervals. The resulting spectra were integrated over intervals of unit width in the range of interest (2–3 Hz, 3–4 Hz, … 19–20 Hz). The PSD values were log-transformed for further analyses.

2.5.3 Peak alpha frequency

Alpha peak frequency identification was conducted by exploring source-level power spectra at scalp electrodes using a fast Fourier transform (FFT). It was identified as the center of gravity frequency within the 8–13 Hz band. The center of gravity frequency refers to the "weighted sum of spectral estimates divided by alpha power": $\Sigma(a(f)\times f)(\Sigma a(f))$. If no peak was present, it was not counted.

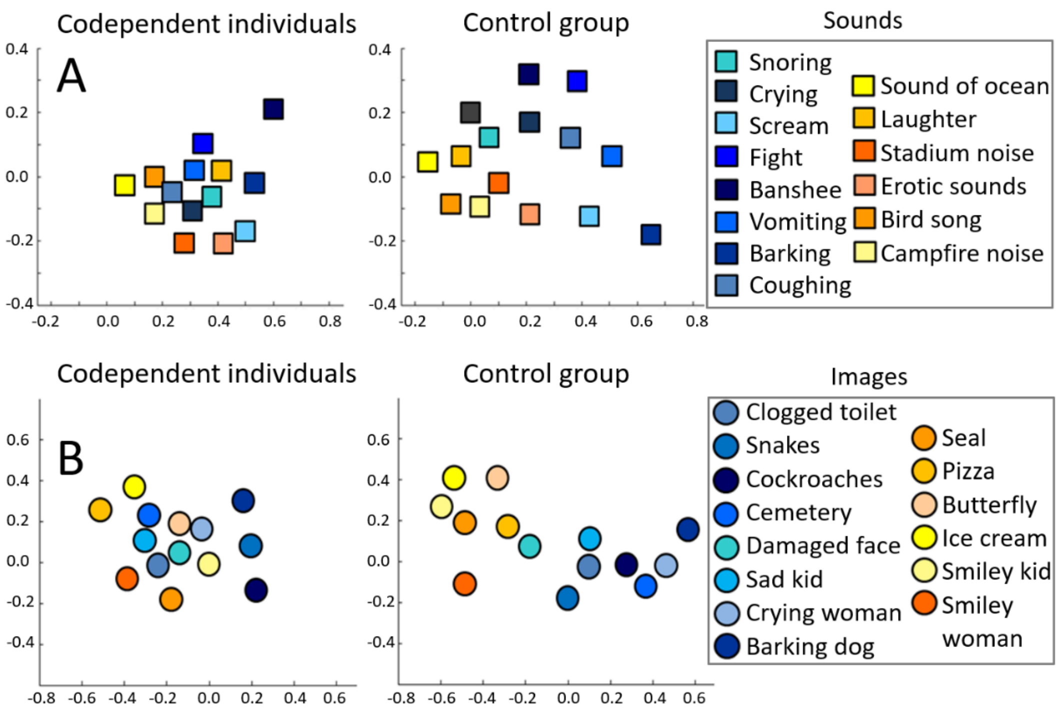

Figure 2. The EEG spaces visualized how close perceived stimuli were according to EEG data (cold colors – unpleasant stimuli, warm- pleasant stimuli). A – Auditory modality; B – visual modality.

2.5.4 Higuchi fractal dimension (FD)

HFD was evaluated using the Higuchi algorithm. The examined signal bandpass-filtered in the range of interest (1.6 - 30 Hz) was calculated with a Butterworth filter of order 12 with an IIR filter (Matlab, MathWorks).

2.5.5 Ratio of envelope's mean frequency standard deviation to its mean (StDE)

The following method was applied to evaluate the (de-) synchronization dynamics of the rhythms. First, the envelope of the EEG signal for the whole frequency range (1.6 - 30 Hz) was calculated using the Hilbert transform. Second, the (in-) stability of the envelope's amplitude was assessed by calculating its average frequency using FFT. Finally, the ratio of its standard deviation to its mean (wideband – RAT) was calculated.

2.6 Statistical analysis

One-way and Factorial ANOVA with Bonferroni correction was used to determine modality and group effects on EEG metrics. To calculate differences between pleasant and unpleasant stimuli, we used averaged values of EEG parameters (for all pleasant and all unpleasant stimuli) separately in each modality. Significant R values were used for further analysis ($p < 0.05$). The Mann-Whitney U test was used to calculate group differences in stimuli assessment.

A cluster-based permutation test calculated the correlation between EEG indices and emotional assessments. A possible association of the EEG metrics with the ratings of subjective assessments of emotional stimuli was analyzed using Spearman correlation analysis and was corrected for multiple comparisons using clustering methods (Matlab toolbox for BCI) with 500 permutations at each node (the Bonferroni corrected p-value of 0.05). The permutation test was performed to compensate for the multiple statistical estimations of the correlations in different EEG channels. Correlation for each EEG channel was computed with Spearman correlation across subjects. Only significant ($p < 0.05$) correlation values were used for further analysis.

3.0 RESULTS

This section provides a concise and precise description of the experimental results, their interpretation, and the experimental conclusions that can be drawn.

3.1 Emotional assessment of pleasantness

The codependent subjects were abnormally resistant to some unpleasant stimuli and estimated them as neutral. Subjects of the control group unambiguously distinguished pleasant and unpleasant stimuli in all modalities. The participants with codependency assessed some of the stimuli as being neither pleasant, nor unpleasant. The average values (mean±sd) are presented in **Tables 1, 2 and 3**.

Table 1. Descriptive statistics of stimuli assessment by scale Pleasantness (0 -5) and group differences between codependent subjects and control group in olfactory and tactile modalities.

	Control group	Codependent individuals	Mann-Whitney U test (p-value)
Olfactory stimuli			
Alcohol	0.6 ± 1.0	1.0± 1.8	0.25
Isopropyl alcohol	0.2 ± 0.3	0.2± 0.4	0.58
Vinegar	0.4 ± 0.5	0.5± 0.8	0.47
Vishnevsky ointment	0.5 ± 0.8	1.5± 1.8	0.09
Acetone	0.9 ± 0.8	0.3± 0.5	0.23
Garlic	1.2 ± 1.3	2.0 ± 1.3	0.09
Rotten fish	0.7 ± 0.9	1.7± 1.8	0.08
Diluent	0.4 ± 0.4	0.2± 0.3	0.48
Rose	4.3 ± 1.2	4.7 ± 1.2	0.38
Vanilla	4.4 ± 1.2	4.8 ± 1.3	0.42
Coffee	4.2 ± 1.5	3.1 ± 1.7	0.14
Grass	4.1 ± 1.4	3.5 ± 2.0	0.24
Salami	4.1 ± 1.7	3.1 ± 1.7	0.09
Cinnamon	4.3 ± 1.2	4.8 ± 1.0	0.38
Tactile stimuli			
Niddles	1.0 ± 0.5	0.8± 0.4	0.58
Hard brush	1.0 ± 0.5	0.8± 0.4	0.58
Ice	0.8 ± 0.8	0.9± 1.7	0.10
Warm massage bag	4.3 ± 1.0	3.9 ± 1.6	0.41
Wide soft brush	4.3 ± 1.8	4.4 ± 2.0	0.61
Paintbrush	4.6 ± 1.2	3.2 ± 1.6	0.11

Thus, subjective assessment results by scale Pleasantness demonstrated that Codependent individuals under-evaluated the unpleasantness of some images and sounds compared to the control group and assessed these unpleasant stimuli as neutral or even pleasant. At the same time, Codependent individuals under-evaluated the same way the pleasantness of some pleasant stimuli. For example, group differences during the assessment of the image of the sad kid: the control group participants assessed this picture as being significantly more unpleasant than codependent individuals **(Table 2)**, and the latter groups also significantly under-evaluated pleasantness of almost all pleasant stimuli in visual and auditory modalities (butterfly, seal, smiley kid, smiley woman) [F(13, 364)=8.5977, p<0.0001].

Further, Codependent individuals under-evaluated the unpleasantness of a few unpleasant stimuli compared to the control group (in particular, the unpleasantness of images with damaged faces). The rates of pleasantness for stimuli presented in olfactory and tactile modalities did not differ between groups **(Table 1)**.

3.2 Emotional assessment of arousal

The arousal level in codependent individuals was significantly lower compared to controls during the perception of some emotional stimuli in auditory and visual modalities. In particular, the images of a clogged toilet (z=2.8, p=0.004), damaged face (z=3.1, p=0.001), seal (z=3.0, p=0.001) and smiley kid (z=3.1, p=0.001), the sound of vomiting (z=3.4, p=0.0005) and snoring (z=2.7, p=0.006), stadium noise (z=2.8, p=0.004) and erotic sounds (z=3.3, p=0.0008) had higher arousal rates in subjects of the control group compared to codependent individuals.

In the more ancient olfactory and tactile modalities, significant group differences were found for only pleasant stimuli. Codependent individuals had lower arousal rates than controls during the perception of cinnamon and vanilla odors (z=2.6, p=0.006; z=2.3, p=0.01), and perception of soft brush stroking, simulating the CT-afferents (z=2.4, p=0.009). The repeated measures ANOVA showed that taking into account only unpleasant stimuli, the subjective level of arousal in codependent subjects compared to controls was significantly lower only for visual and auditory modalities. It did not differ for olfactory and tactile modalities [F(1, 28)=12.189, p=0.0016]**(Figure 1)**.

3.3 Assessment of feelings of empathy toward the stimuli

The significant group differences between the empathy rate of stimuli were detected only in visual and auditory modalities and were found for images of damaged faces, smiley kids and smiley women and of sounds of vomiting, screaming, coughing, fighting, stadium noise, erotic sounds, campfire noise, and laughter. The empathy scores for these stimuli were significantly higher in the control group than in the codependent individuals. At the same time, few stimuli induced higher empathy in codependent participants compared to the control group. In particular, during the perception of a clogged toilet and cemetery images, Codependent individuals reported higher empathy feelings than the control group **(Tables 2 and 3)**.

Table 2. Descriptive statistics of stimuli assessment by scale Pleasantness (0 -5) and stimuli impact by scale Empathy and group differences between codependent subjects and control group for auditory modality. P-values were calculated for the Mann-Whitney U test.

Visual stimuli	Pleasantness			Empathy		
	Control group	Codependent individuals	P value	Control group	Codependent individuals	P value
Clogged toilet	0.9 ± 0.3	0.2 ± 0.2	0.09	2.0 ± 1.0	2.9 ± 0.7	0.05*
Snakes	1.2 ± 0.8	0.8 ± 0.5	0.29	1.3 ± 1.2	1.2 ± 1.5	0.61
Cockroaches	1.1 ± 0.5	0.7± 0.4	0.26	1.1 ± 1.3	1.3 ± 1.0	0.53
Cemetery	1.0 ± 0.9	0.6 ± 0.7	0.31	2.1 ± 1.0	3.4 ± 0.6	0.005*
Damaged face	0.8 ± 0.7	2.0 ± 1.0	0.009*	4.8 ± 0.9	3.3 ± 0.5	0.04*
Sad kid	1.4 ± 1.7	2.8 ± 1.5	0.01*	4.1 ± 1.7	3.9 ± 1.5	0.54
Crying woman	1.5 ± 0.9	2.6 ± 1.1	0.02*	4.5 ± 0.9	4.6 ± 1.1	0.62
Barking dog	0.9 ± 1.1	2.2 ± 0.9	0.03*	0.9 ± 1.3	1.2 ± 1.4	0,31
Ice cream	4.3 ± 0.8	4.8 ± 0.5	0.48	0.2 ± 1.1	0.6 ± 1.5	0.44
Pizza	4.1 ± 1.1	4.7 ± 0.9	0.25	0.5 ± 1.2	0.7 ± 0.9	0.56
Butterfly	4.6 ± 0.9	3.1 ± 1.7	0.03*	1.3 ± 0.9	1.0 ± 1.5	0.49
Seal	4.5 ± 1.1	2.8 ± 1.9	0.008*	1.4 ± 1.0	1.3 ± 1.8	0.69
Smiley kid	4.2 ± 0.7	3.2 ± 1.5	0.01*	4.0 ± 0.9	3.0 ± 1.4	0.05*
Smiley woman	4.1 ± 0.8	2.7 ± 2.2	0.03*	3.5 ± 0.9	2.2 ± 1.7	0.03*

Note: * Significant differences are noted.

Table 3. Descriptive statistics of stimuli assessment by scale Pleasantness (0 -5) and stimuli impact by scale Empathy and group differences between codependent subjects and control group for auditory modalitiy. P-values were calculated for the Mann-Whitney U test.

Auditory stimuli	Pleasantness			Empathy		
	Control group	Codependent individuals	P value	Control group	Codependent individuals	P value
Crying	0.8 ± 0.9	2.2 ± 1.3	0.04*	4.3 ± 0.9	4.5 ± 0.3	0.64
Fight	1.1 ± 1.3	2.4 ± 1.5	0.04*	4.0 ± 1.3	2.7 ± 0.6	0.04*
Vomiting	0.5 ± 0.8	2.5± 1.8	0.009*	4.6 ± 0.9	3.2± 1.2	0.009*
Banshee	1.1± 0.9	0.4± 0.8	0.17	1.1± 0.9	1.2 ± 0.9	0.61
Barking	0.6 ± 0.9	2.4 ± 1.3	0.009*	1.6 ± 0.9	1.4 ± 1.3	0.58
Snoring	1.7 ± 1.3	1.6 ± 1.5	0.48	2.1 ± 1.4	2.7 ± 0.9	0.13
Scream	0.3 ± 0.9	2.2 ± 1.5	0.007*	4.8 ± 0.9	3.5 ± 1.5	0.008*
Coughing	0.8 ± 1.0	2.5 ± 1.1	0.01*	4.1 ± 1.1	2.9 ± 1.0	0.007*
Bird song	4.3 ± 1.2	4.8 ± 0.7	0.42	2.0 ± 1.0	1.8 ± 1.5	0.58
Stadium noise	4.1 ± 1.7	2.3 ± 1.8	0.05*	3.1 ± 1.5	2.3 ± 1.9	0.007*
Sound of the ocean	4.2 ± 0.9	4.1 ± 1.7	0.54	2.4 ± 0.8	2.1 ± 1.5	0.39
Erotic sounds	4.1 ± 1.7	2.9 ± 2.0	0.04*	3.9 ± 1.6	1.1 ± 1.6	0.002*
Campfire noise	4.3 ± 0.9	4.2 ± 1.5	0.51	3.8 ± 0.9	2.5 ± 1.7	0.019*
Laughter	4.2 ± 1.3	2.4 ± 2.1	0.03*	4.0 ± 1.3	2.8 ± 2.2	0.006*

Note: * Significant differences are noted.

3.4 Group differences of subjective rates between pleasant and unpleasant stimuli

For pleasant and unpleasant stimuli, their subjective rates of pleasantness, arousal, and empathy were averaged separately for each modality between groups of subjects. The difference between subjective pleasantness of pleasant and unpleasant stimuli was significantly higher in subjects of CG compared to CI in visual [F(1, 28)=19.337, p=0.0009] and auditory [F(1, 28)=15.974, p=0.0011] modalities. The difference in arousal rates between pleasant and unpleasant stimuli was significantly higher in CI compared to CG and was found for all modalities [F(1, 28)=15.014, p=0.0012]. The difference between the empathy level of pleasant and unpleasant stimuli did not differ between groups.

3.5 EEG indexes

The EEG responses showed similarity to behavioral findings results. EEG indexes between pleasant and unpleasant stimuli were analyzed, and there was significantly higher in the control group. Factorial ANOVA showed that independent of modality, the EEG indexes between pleasant and unpleasant stimuli were higher in the control group [main effect: F(1, 298)=11.184, p=0.003]. At the same time, evolutionary newer modalities – visual and auditory showed separately higher group differences [main effect: F(1, 188)=26.719, p<0.0001], whereas EEG indexes of olfactory and tactile modalities did not show significant differences.

The spaces of EEG indexes with emotional assessments of visual and auditory stimuli are depicted in **Figure 2**. Thus, codependent individuals assessed some pleasant (erotic sounds, stadium noise, campfire noise, laughter) and unpleasant (fight, vomiting, scream, coughing) auditory stimuli as being relatively neutral than pleasant or unpleasant. The visual EEG spaces and assessments showed the same trend **(Figure 2, Table 1)**.

3.6 Differences of PSD between pleasant and unpleasant stimuli

The PSD during resting states did not differ between groups. The group differences between PSD during the presentation of stimuli and rest did not pass the Bonferroni correction.

In tactile and olfactory modalities, there was group independent differences between pleasant and unpleasant stimuli. The delta-rhythm PSD was significantly higher for the pleasant stimuli than the unpleasant ones in both groups of subjects [F(1, 28)=14.0212, p=0.0034]. At the same time, we compared the PSD during the presentation of pleasant and unpleasant stimuli in visual and auditory modalities and revealed significant group differences. In particular, the subjects of the control group demonstrated higher beta-rhythm (14-20 Hz) and alpha-rhythm (8-11 Hz) PSD during perception of pleasant sounds compared to unpleasant in the left TPO area. However, CI did not show significant differences between stimuli [F(3, 84)=19.531, p<0.0001]. In the visual modality, similar group differences were revealed between pleasant and unpleasant stimuli in codependent subjects. The subjects of the control group demonstrated higher beta-rhythm (14-20 Hz), alpha1-rhythm (8-10 Hz) and theta2-rhythm (6-10 Hz) PSD during perception of pleasant images compared to unpleasant in the left parietal areas and absence of significant differences between stimuli in CI [F(3, 84)=16,97, p<0.0001] **(Figure 3)**.

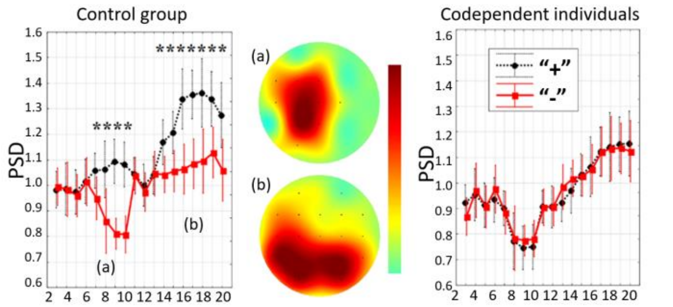

Figure 3. Visual modality. «+» - pleasant stimulus (butterfly) «-» - unpleasant stimulus (barking dog). (a) – Significant differences in 6-10 Hz band, (b) – significant differences in 14-20 Hz band.

3.7 Differences of FD and StDE between pleasant and unpleasant stimuli

FD increased during stimulation compared to the resting state. Despite the differences that did not pass the Bonferroni correction, the increase of FD compared to the background for pleasant stimuli was significantly higher in CG compared to CI [main group effect for all modalities F(1, 28)=11,0212, p=0.0064].

The FD during perception of pleasant stimuli compared to unpleasant was significantly higher (and StDE was significantly lower) in both groups of subjects and for all modalities [main effect F(1, 298)=15,292, p=0.0006] in left temporal and frontal areas. Group differences in FD and StDE differences between pleasant and unpleasant stimuli were detected only in visual and auditory modalities. The differences between FD [F(1, 28)=13.486, p=0.004] and StD [F(1, 28)=18.764, p=0.0005] between pleasant and unpleasant sounds and pictures were significantly higher in the control group compared to CI.

3.8 Differences of PAF between pleasant and unpleasant stimuli

The PAF during perception of pleasant stimuli compared to unpleasant was significantly lower in both groups of subjects and for all modalities [main effect, F(1, 28)=10.0212, p=0.00972]. Group differences were detected only in visual modality: the difference between PAF for pleasant and unpleasant stimuli was significantly higher in CG compared to CI [F(1, 28)=15.307, p=0.0008) **(Figure 4)**.

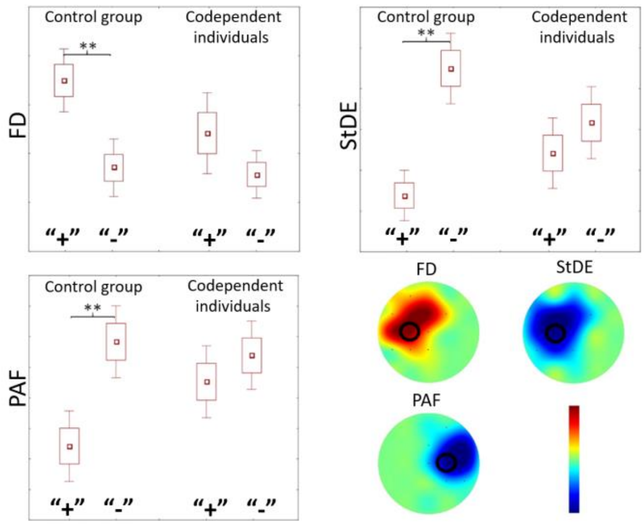

Figure 4. The values (mean ± St.D) of non-linear features for pleasant and unpleasant images (scores were averaged inside each modality) in codependent individuals and subjects of control group. The black circle means the electrode used for visualization.

3.9 Correlation analysis between emotional assessment and EEG response

Considering the inconsistency of over- and underestimation of some emotional stimuli by CI, we performed a correlation analysis between EEG metrics and subjective rates separately for each stimulus. Also, we conducted correlation analysis for pleasant and unpleasant stimuli averaged separately for each modality, however, did not receive significant results.

We found that the increased FD during listening to some stimuli compared to background correlated with empathy. In particular, the higher the empathy rates for vomiting (r=0.59, p=0.0009), coughing (r=0.57, p=0.0015), and screaming (r=0.62, p=0.0006), the higher empathy feelings for these sounds were reported.

Using correlation analysis, we also revealed a positive correlation between the reported pleasantness of some sounds and pictures and alpha-rhythm PSD (8-10 Hz). The significant correlations were found for sounds of stadium noise ($r=0.62$, $p=0.0005$) and laughing ($r=0.61$, $p=0.0007$) and images of smiley kid ($r=0.59$, $p=0.0009$) and cemetery ($r=0.64$, $p=0.0002$).

4.0 DISCUSSION

Our results showed that codependent individuals showed a simultaneously lower response to some emotional stimuli and higher reactivity to other unpleasant stimuli. In particular, codependent individuals showed a lack of recognition of stimuli emotional tone and estimated some stimuli (for example, crying, vomiting, damaged face, etc.) as neither pleasant nor unpleasant. At the same time, these individuals demonstrated inverse and ambivalent feelings associated with these stimuli and reported significantly higher irritation and anxiety impacts than the control group. The ambivalent feelings were previously associated with the emotional state of codependent women who demonstrated controversial feelings to variable stimuli associated with their alcoholic husbands (Asher, 2018). Confirming these findings, our results also revealed that most of the stimuli rated as neutral (vomiting, laughter, stadium noise) by codependent subjects were associated with social interactions (Gierymski & Williams, 1986).

Another characteristic feature of our participants with codependency was hyperreactivity to some negative stimuli. For example, the sound of crying was assessed by codependent individuals who reported significantly higher irritation and anxiety feelings than subjects of the control group. The data confirmed previous findings that codependent individuals were more sensitive to specific environmental influences. Moreover, codependent individuals could demonstrate excessive emotional reactivity or suppressed emotions in similar at first glance circumstances (Gotham & Sher, 1996).

The obtained results were supported by the EEG data demonstrating similar psychological assessment trends. In particular, EEG indexes between pleasant and unpleasant stimuli were significantly higher in the control group, indicating that these individuals distinguished stimuli according to their emotional tone at the level of EEG patterns. At the same time, the described group differences were revealed only on evolutionarily newer and more socially related modalities – visual and auditory. The olfactory and tactile modalities were less susceptible to the described group differences, which confirmed the absence of the primary deficit of emotional perception in codependent individuals and supported its family and relationship origin (Rupp et al., 2004; Prest et al., 1998).

The last result which should be discussed was associated with empathy feelings of codependent subjects. In particular, we found that less emotional stimuli induced empathy feelings in codependent participants, at the same time, the stimuli which induced empathy response were characterized by overreacted empathy. This result was consistent with previous findings showed that the codependent individual tended to demonstrate pathological altruism characterized by unhealthy, ineffective empathy focused on others to the detriment of one's own needs (Oakley, 2013).

5.0 CONCLUSIONS

Our findings demonstrated the ambivalence of emotional response to emotional stimuli with the most pronounced social component in codependent individuals that could be detected using the EEG spaces (EEG indexes) method of psychological assessment. Participants with codependency also demonstrated difficulties when attempting to distinguish the pleasantness of emotional stimuli. The empathy of codependent individuals was reduced and detected for fewer emotional stimuli, which included only unpleasant images and sounds. All detected group differences were associated with newer evolutionary modalities, whereas the differences in olfactory and tactile modalities were less significant.

Abbreviations: EEG: electroencephalogram; FFT: fast Fourier transform; Hz: Hertz; PSD: the particle-size distribution; HFD: Higuchi fractal dimension; FFT - Fast Fourier transform; PAF - Peak alpha frequency; FD - fractal dimension; CG – control group; CI – codependent individual; PSD – power spectral density; StDE - the ratio of envelope's mean frequency standard deviation to its mean

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References

Ansara, W. (1995). *The relationship between codependency, alcoholism, and the family of origin*. Eastern Illinois University.

Asher, R. M. (2018). Women with alcoholic husbands: Ambivalence and the trap of codependency. University of North Carolina Press.

Carr, A., & Buchanan, D. P. (1997). A theological analysis of codependency theories. *Journal of Pastoral Care, 51*(3), 303-314. https://doi.org/10.1177/002234099705100306

Cermak, T. L. (1986). Diagnostic criteria for codependency. *Journal of Psychoactive Drugs, 18*(1), 15-20. https://doi.org/10.1080/02791072.1986.10524475

Chang, S. H. (2018). Testing a model of codependency for college students in Taiwan based on Bowen's concept of differentiation. *International Journal of Psychology, 53*(2), 107-116. https://doi.org/10.1002/ijop.12271

Coleman, E. (1987). Marital and relationship problems among chemically dependent and codependent relationships. *Journal of Chemical Dependency Treatment, 1(*1), 39-60. https://doi.org/10.1300/J034v01n01_04

Croy, I., & Hummel, T. (2017,). Olfaction as a marker for depression. *Journal of Neurology, 264*(4), 631-638. https://doi.org/10.1007/s00415-016-8227-8

Croy, I., Symmank, A., Schellong, J., Hummel, C., Gerber, J., Joraschky, P., & Hummel, T. (2014). Olfaction as a marker for depression in humans. *Journal of Affective Disorders, 160*, 80-86. https://doi.org/10.1016/j.jad.2013.12.026

Fischer, J. L., & Spann, L. (1991). Measuring codependency. *Alcoholism Treatment Quarterly, 8*(1), 87-100. https://doi.org/https://doi.org/10.1300/J020V08N01_06

Friel, J., & Friel, L. (1988). Adult children secrets of dysfunctional families: The secrets of dysfunctional families. Health Communications, Inc.

Gierymski, T., & Williams, T. (1986). Codependency. *Journal of Psychoactive Drugs, 18*(1), 7-13. https://doi.org/10.1080/02791072.1986.10524474

Gotham, H. J., & Sher, K. J. (1996). Do codependent traits involve more than basic dimensions of personality and psychopathology? *Journal of Studies on Alcohol, 57*(1), 34-39. https://doi.org/10.15288/jsa.1996.57.34

Kaiser, M. D., Yang, D. Y., Voos, A. C., Bennett, R. H., Gordon, I., Pretzsch, C., Beam, D., Keifer, C., Eilbott, J., McGlone, F., & Pelphrey, K. A. (2016). Brain mechanisms for processing affective (and nonaffective) touch are atypical in autism. *Cerebral Cortex, 26*(6), 2705-2714. https://doi.org/10.1093/cercor/bhv125

Kaplan, V. (2023). Mental health states of housewives: an evaluation in terms of self-perception and codependency. *International Journal of Mental Health and Addiction, 21*, 666–683. https://doi.org/10.1007/s11469-022-00910-1

Kim, H.S. (2015). The relationship of codependency and mental health in social worker. *Journal of the Korea Academia-Industrial Cooperation Society*, *16*(5), 3162–3171. https://doi.org/10.5762/KAIS.2015.16.5.3162

Lancer, D. (2015). Codependency for dummies. John Wiley & Sons.

Lawrence, N. S., Williams, A. M., Surguladze, S., Giampietro, V., Brammer, M. J., Andrew, C., Frangou, S., Ecker, C., & Phillips, M. L. (2004). Subcortical and ventral prefrontal cortical neural responses to facial expressions distinguish patients with bipolar disorder and major depression. *Biological Psychiatry, 55*(6), 578-587. https://doi.org/10.1016/j.biopsych.2003.11.017

Morgan, J. P., Jr. (1991). What is codependency?. *Journal of Clinical Psychology, 47*(5), 720-729. https://doi.org/10.1002/1097-4679(199109)47:5<720::aid-jclp2270470515>3.0.co;2-5

Nevidimova, T. I., Batukhtina, E. I., Savochkina, D. N., Vetlugina, T. P., Nikitina, V. B., & Bokhan, N. A. (2015). Association between pathological olfaction, immunological abnormalities and predisposition to substance use. *Zhurnal nevrologii i psikhiatrii imeni S.S. Korsakova, 115*(11), 80-84. https://doi.org/10.17116/jnevro201511511180-84

Nevidimova, T. I., Savochkina, D. N., Masterova, E. I., & Bokhan, N. A. (2018). Results and prospects of research of interaction between sensory and immune systems in addictive disorders. *Siberian Bulletin of Psychiatry and Addiction, 2*(99), 56-63. https://doi.org/10.26617/1810-3111-2018-2(99)-56-63

Nikolaev, E. L., & Chuprova, O. V. (2013). Psychological characteristics of personality temporal perspective in "dependent-codependent" system. *Bulletin of the Chuvash University, 2*, 102-105.

Oakley, B. A. (2013). Concepts and implications of altruism bias and pathological altruism. *Proceedings of the National Academy of Sciences of the United States of America, 110*(Suppl 2), 10408-10415. https://doi.org/10.1073/pnas.1302547110

Politica, O. I. (2020). Profile of a codependent personality in an addictive relationship. *International Research Journal, 5-3*(95), 207-210. https://doi.org/10.23670/IRJ.2020.95.5.122

Prest, L. A., Benson, M. J., & Protinsky, H. O. (1998). Family of origin and current relationship influences on codependency. *Family Process, 37*(4), 513-528. https://doi.org/10.1111/j.1545-5300.1998.00513.x

Reyome, N. D., Ward, K. S., & Witkiewitz, K. (2010). Psychosocial variables as mediators of the relationship between childhood history of emotional maltreatment, codependency, and self-silencing. *Journal of Aggression, Maltreatment & Trauma, 19*(2), 159-179. https://doi.org/10.1080/10926770903539375

Rozhnova, T. M., Kostyuk, S. V., & Malygin, V. L. (2020). The phenomenon of codependency: psychological and medical genetic aspects. *Neurology, Neuropsychiatry, Psychosomatics, 12*(5), 53-59.

https://doi.org/10.14412/2074-2711-2020-5-53-59
Rupp, C. I., Fleischhacker, W. W., Hausmann, A., Mair, D., Hinterhuber, H., & Kurz, M. (2004). Olfactory functioning in patients with alcohol dependence: impairments in odor judgements. *Alcohol and alcoholism, 39*(6), 514-519. https://doi.org/10.1093/alcalc/agh100
Yang, Y., Fairbairn, C., & Cohn, J. F. (2013). Detecting depression severity from vocal prosody. *IEEE Transactions on Affective Computing, 4*(2), 142-150. https://doi.org/10.1109/T-AFFC.2012.38