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Research Paper

The Effect of Brainwave Synchronization Using Binaural Beats on Improving Working Memory and Reducing the Severity of Symptoms in Women With Obsessive-compulsive Disorder

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ABSTRACT

Introduction: Binaural beats are one of the new methods of brainwave synchronization. However, there is little knowledge about its clinical applications. The positive effect of this method on executive functions, such as attention and working memory, in the γ band has been mainly confirmed in healthy individuals. Still, its effectiveness on disorders such as obsessive-compulsive disorder (OCD), with a prominent cognitive profile, has not been established. Therefore, the present study was conducted to examine the effect of binaural beats on working memory and the severity of OCD symptoms in the γ band in the affected women.

Methods: Twenty-nine OCD women aged 25-40 years referring to psychological clinics in Tehran City, Iran, were selected by convenience sampling. After completing the symptom checklist 90 (SCL90) and the Yale-Brown severity scale (SS), the participants were given the Wechsler memory scale (WMS) digit repetition subtests. Then, they were randomly assigned to the experimental (n=15) and control (n=14) groups. The audio file of the binaural beats in the γ band was provided to the experimental group. The participants in the control group listened to the normal (no-wave) audio file. Both groups listened to the audio files for two weeks, three times a week, for 30 minutes each time. The Yale-Brown SS and digit repetition in post-test and one-month follow-up periods were obtained from both groups.

Results: According to the results, the severity of OCD symptoms was significantly reduced in the post-test and follow-up stages by the γ binaural beats ($P<0.05$). Also, the working memory function was improved, although it was not statistically significant ($P>0.05$).

Conclusion: The results of this study show that binaural beats can be used as a complementary treatment to reduce the severity of OCD symptoms. Also, it seems that the patients' working memory is strengthened with this method.

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Highlights

- Binaural beats in the γ band reduce the severity of obsessive-compulsive disorder symptoms (in both dimensions of obsession and compulsion).

- Binaural beats in the γ band can be considered a potential amplifier to improve working memory function in obsessive-compulsive disorder patients.

Plain Language Summary

So far, treatment methods for obsessive-compulsive disorder (OCD) have been pharmacotherapy and cognitive-behavioral therapy (CBT). Besides short-term positive effects, pharmacotherapy has possible complications, such as drug dependence, recurrence of symptoms after discontinuation, side effects specific to each drug, potential drug interactions, external control of the patient for treatment, and no recovery to the patient's abilities and efforts. Psychotherapy is also effective, provided the sessions continue weekly, permanently, and sometimes over several years. The disadvantages of this method are that it is time-consuming, has high costs, causes the psychological resistance of the patient to accept therapeutic strategies, and relies on the therapist's expertise and experience to achieve desired treatment outcomes. It is better to know that according to research, both treatments are ineffective in about 40%-60% of cases. For this reason, new therapies have turned to modulate brainwaves in this disorder. We know that the memory of OCD patients does not work well, which is why they keep checking to see if they have done something. We hypothesized that if we could induce γ waves in the brain by beats, we could generate the highest level of attention, accuracy, and alertness and thus improve memory. The results were amazing. The severity of OCD symptoms is reduced by this method. Patients' memory was also strengthened. Although more research is needed in this regard, we can suggest binaural beats as a minimal complementary treatment, along with other therapies for individuals with OCD. Binaural beats are safe, accessible, complication-free, easy to use, and can be applied anywhere and time. Also, binaural beats enhance the effect of other treatments and pave the way for recovery.

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1. Introduction

Obsessive-compulsive disorder (OCD) is an inherited neuropsychiatric disorder characterized by disturbing and distressing thoughts constructed in the individual's mind, repetitive and compulsive behaviors, or mental rituals. Over the past three decades, systematic research has shown that this disorder is associated with cortico-striatal-thalamo-cortical dysfunction, mainly in the orbitofrontal cortex, dorsolateral prefrontal cortex (DLPFC), and caudate nucleus. This integrated circuit seems to be related to cognitive executive functions, which are higher-level mental processes and modulate sensory, motor, cognitive, emotional, and memory capabilities (Yücel et al., 2007; Cavedini et al., 2006; Bechara, 2001). Among neurocognitive deficits, working memory function in OCD has been studied in several studies (Olley et al., 2007). Many cognitive neuroscientific studies have supported the role of the fronto-parietal network, including DLPFC, anterior cingulate cortex, and parietal cortex, as the neural network involved in working memory (Chai et al., 2018).

A review of the available literature suggests that working memory deficits may underlie OCD patients' difficulty controlling their thoughts and actions. Some researchers believe that the need for control in this disorder stems from cognitive control deficits (also known as executive dysfunction) (Oberauer, 2009; Engle & Kane, 2004). While keeping task-related information in mind, working memory prevents them from interfering (Engle & Kane, 2004; Kane & Engle, 2002). Accordingly, obsessions can cause trouble in working memory (Grisham & Williams, 2013; Brewin & Smart, 2005; Tolin et al., 2002). It is assumed that working memory deficits play a role in compulsive checking and cause problems monitoring and controlling measures (Harkin, et al., 2011; Harkin & Kessler, 2011a, Harkin & Kessler, 2011b, 2009). The above hypotheses are consistent with neuroimaging studies, which have found evidence of memory deficits in OCD (de Vries et al., 2013), and animal models have also confirmed the relationship between working memory and OCD (Shahar et al., 2017).

The first-line treatments for OCD are pharmacotherapy, cognitive-behavioral therapy (CBT), or cognitive reconstruction (Baldwin et al., 2014). CBT is ineffective in 20% of cases, and selective serotonin reuptake inhibitors (SSRIs) in 40% of cases (Ferrão et al., 2006). However, other studies show a higher percentage of ineffectiveness, about 40%-60% for both treatments (Beşiroğlu, 2016). So, about one-third of cases do not achieve the desired clinical response (Fineberg & Gale, 2005).

Although many studies have been performed on the effectiveness of the mentioned methods, according to Moritz et al. (2005), if a deficit in rational-abstract thinking and forgetfulness in OCD is evident, psychological interventions will face problems. In addition, if there is a deficit in executive functions, mental inflexibility can affect the patient's ability to transfer the skills learned in therapy sessions to daily life (Moritz et al., 2005). In this case, the neurocognitive disorder can increase functional deficits (for example, in work and social relationships), which in turn can exacerbate psychopathology. Therefore, if neurocognitive deficits are present in a disorder such as OCD or its subset, specialized treatment programs are needed to address such deficits specifically (FitzGerald et al., 2011).

New therapeutic strategies that have focused on the neuromodulation of OCD cognitive functions over the past few decades have their complications (Bais et al., 2014). These topical therapies are associated with altered circuit function, and their effects may work over long distances (McCracken & Grace, 2007). The important point is that since the processing sites of emotions and behaviors are not likely to be at discrete centers and rely on the interaction between multiple neural circuits, neuromodulation approaches must be continually refined to further influence specific areas spatially distributed throughout the brain. Closed-loop systems that create stimulation only when necessary (Morrell, 2011) are non-invasive stimulation techniques with greater electrical transmissibility in the brain or a combination of neuromodulation strategies needed to create the optimal benefit in regulating circuits and relieving symptoms (Lapidus et al., 2014).

The latter approach to non-invasive brain stimulation suggests that rhythmic magnetic or electrical stimulation can synchronize neural oscillations in a specific frequency band, such as γ waves. As an alternative to electrical stimulation, rhythmic sensory stimulation can synchronize neural oscillations. In particular, binaural beats have been suggested as a beneficial, stimulating sound because they involve the complex interaction of brain processes and play a critical role in increasing neural synchronization (Colzato et al., 2017). This method delivers two different frequencies to each ear via headphones (150 Hz to the left ear and 100 Hz to the right ear). The brain processes the difference between the two frequencies as a new frequency. This way, the previous frequency is converted to the new frequency, and the brain is somehow "taken over". At this stage, the individual enters the desired mental state (one of the five types of brainwaves), and the waves' synchronization is performed (Wahbeh et al., 2007).

Low-frequency binaural beats are correlated with mental relaxation, and high-frequency beats are associated with alertness and focused attention (Turow & Lane, 2011; Vernon, 2009). Thus, high-frequency beats can facilitate attention control, a finding consistent with the effect of high-frequency neurofeedback waves on the frontal cortex and, therefore, improved attention efficiency (Keizer et al., 2010). In other words, the role of high frequencies in creating alertness and focused attention (Turow & Lane, 2011; Vernon, 2009) reminds the hypothesis that a high frequency will lead to continuity and robustness of cognitive control, whereas recent findings have shown the opposite (Keizer et al., 2016; Reedijk et al., 2015). Therefore, considering the principal role of cognitive control in executive functions such as working memory (Chen et al., 2019), it seems that induction of γ frequency by the binaural beats method can improve the mentioned executive function. The effectiveness of this method in γ band on working memory (Khattak, 2021; Jirakittayakorn & Wongsawat, 2017) has been confirmed in healthy individuals, but its clinical application in mental disorders has not been investigated, except in Parkinson disease and attention deficit hyperactivity disorder (McMurray, 2004). Also, according to recent findings, the binaural beats in the γ band increase flexibility in cognitive control (Keizer et al., 2016; Reedijk et al., 2015). Therefore, this method may reduce the severity of OCD symptoms. On the other hand, research conducted so far has often assessed the short-term effects of binaural beats and the duration of stimulation presentation (Colzato, 2017), the length of the experiment period, and the specific frequency that alters cortical activities (Al-Shargie et al., 2019) are among the research proposals and gaps in this field. Also, differences in the effectiveness of binaural beats in various age and sex groups (Calzato, 2017) indicate the need to control such variables too.

Based on what has been said, the questions studied in the present study are as follows:

1) Does brainwave synchronization in the γ band using the binaural beats method lead to improved working memory function in patients with OCD?

2) Does this method reduce the severity of OCD symptoms?

2. Materials and Methods

Study participants

In the present study, the clinical sample was selected through judgmental sampling from the women referring to the two governmental centers (consulting centers of Tehran and Al-Zahra universities) in the city of Tehran, whose OCD development had been confirmed by a psychiatrist. The participants were selected by referral method. Women were chosen for the study because of their higher auditory sensitivity and greater susceptibility to noise exposure at high frequencies (McFadden, 2009).

After obtaining written informed consent to continue voluntary participation, the participants completed the Yale-Brown severity scale (SS) and the symptom checklist 90 (SCL90). They were included in the study if they obtained scores above 10 on the Yale-Brown SS and lacked OCD comorbidity with other psychological disorders screened and identified by the SCL90. Finally, according to the inclusion and exclusion criteria, 35 women were selected. This sample size was estimated based on the minimum sample size in experimental studies (n=30) (Quinn et al., 2002) and the following formula.

Equation 1 is the formula for calculating the sample size in conditions in which the study variable(s) is small:

$$1.\quad n=\frac{(Z_{1-\alpha/2}+Z_{1-\beta})^2(S_1^2+S_2^2)}{(\mu_1-\mu_2)^2}$$

, Where S_1 is the standard deviation of the studied variable in the first group (case, exposed, or intervention), S_2 is the standard deviation of the studied variable in the second group (control, unexposed, or comparison), μ_1 is the mean of the studied variable in the first group, and μ_2 is the mean of the studied variable in the second group.

Then, the participants were randomly assigned to the experimental and control groups. In the following, 2 people were excluded from the research in the pre-test stage, 2 during the intervention, and 2 in the follow-up stage. Thus, the final sample size consisted of 29 people. The selection flowchart is shown in Figure 1.

The experimental interventions and writing and compiling of the present study were conducted in Tehran City, Iran, from August 2021 to May 2022.

Demographic characteristics

Table 1 lists the Mean±SD of OCD and working memory variables at the beginning of the study for the total sample and separately for the two groups. Based on the results reported in this Table and concerning P>0.05 for OCD (P=0.629) and working memory (P=0.982) variables, we can ensure the homogeneity of the mentioned variables between the two groups.

Table 2 presents the frequency distribution of age, education, marital status, and occupation variables. Based on the information presented in this Table, most participants in this study were single, aged under 30, had a university education, or were university students. Also, based on the obtained significance values, the intervention and control groups were similar in terms of age, education, marital status, and occupation variables (P<0.05).

The inclusion criteria comprised female gender, aged 25-40 years, with informed consent, with OCD development without comorbidity with other psychiatric disorders, no use of psychiatric drugs one month before entering the study, and no use of other psychological and pharmacological treatments for OCD during research. The exclusion criteria included having neurological and infectious disorders (which cause OCD symptoms in the individual), taking psychiatric medications while conducting the research, having other psychiatric disorders, or substance dependence that is identified based on the individual's report or diagnosis by a psychiatrist or clinical psychologist, undergoing psychological treatment or pharmacotherapy while conducting the research, and having any disease of hearing loss or deafness. The reason for choosing the mentioned age range is the relationship of decline in cognitive and physical functions with age.

At the beginning of the research, during the implementation phase, and after diagnosing patients with OCD, the researcher introduced herself and the research plan in a brief session and explained the research objectives and the possible advantages and disadvantages, such as headache and fatigue. Patients freely declared whether they wished to participate in the study. If satisfied, the volunteers completed a written ethical commitment

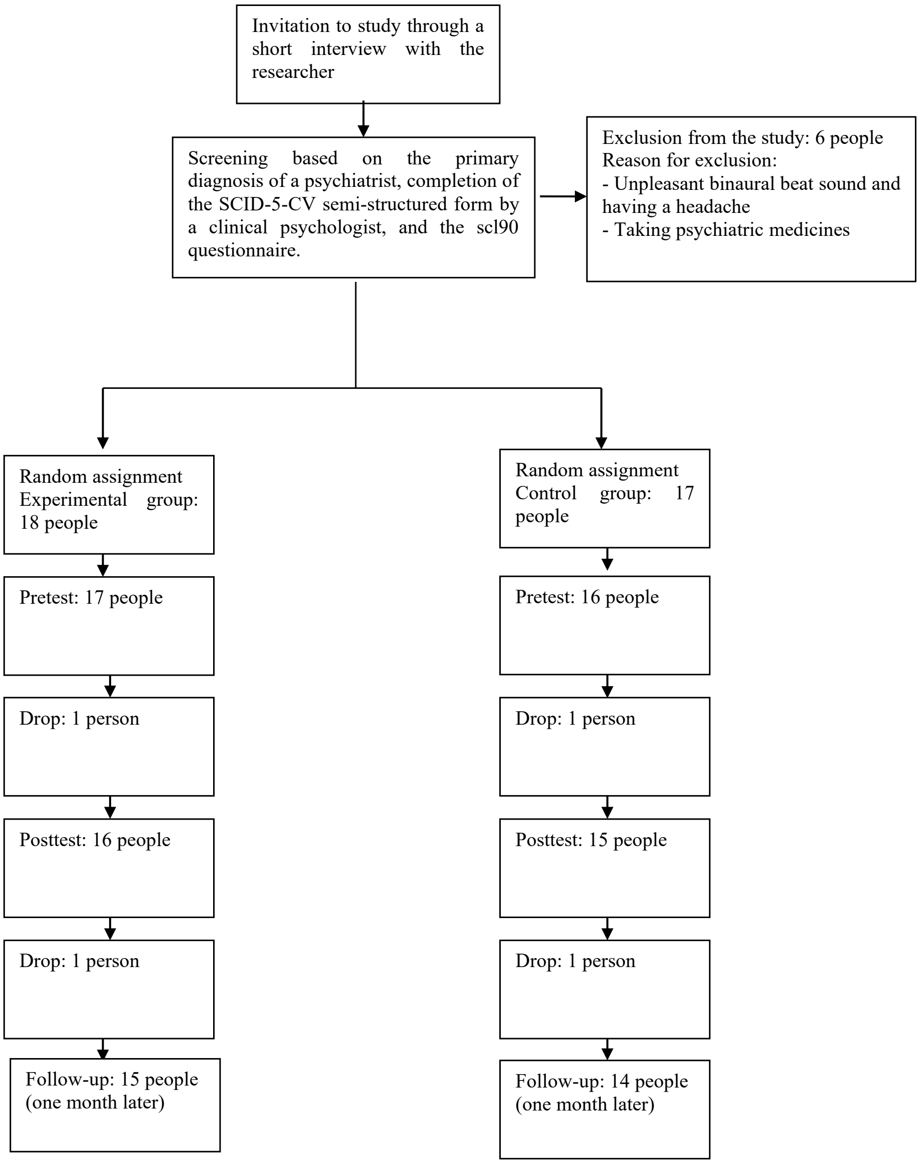

Figure 1. CONSORT flow diagram to illustrate the progress of patients through the trial

form and committed not to use other treatments during the month and a half of the study implementation. Patients were free to leave the study whenever they wished. The researcher answered the participants' questions or ambiguities and assured them that their names would not be mentioned in any part of the research and that their details would remain confidential.

Then, the participants were randomly assigned to the experimental and control groups, and the Wechsler memory scale (WMS) digit repetition subtest, the Yale-Brown SS, and the SCL90 were taken from them. After analyzing the results and selecting the samples, the audio file of the binaural beats in the γ band was provided to the experimental group, and the other audio file without the brainwaves was given to the control group. Audio files were sent to the participants' telegrams. All participants were asked to listen to their files for 15 days, three times a week, for 30 minutes at home or work, using hands-free. To ensure the intervention implementation by the participants, the researcher called each participant based on the schedule announced by the participant after each listening time and made sure that she had listened to the audio file. At the end of the 15 days, the WMS digit repetition subtest and the Yale-Brown SS were taken from both groups. One month after the end of the intervention, the participants were followed up, and the two tests were retaken.

At the end of the intervention, the test time was adjusted according to the participants' suitable conditions and the hours they announced. Also, given the coronavirus disease (COVID-19) condition and compliance with health protocols, we used unattended facilities such as telephones or applications that can be installed on mobile phones as much as possible to perform various experiment stages. The researcher agreed to exclude 6 participants without any insistence or implicit emphasis on continuing the research.

Study measures

The Yale-Brown obsessive-compulsive scale

The Yale-Brown obsessive-compulsive scale (Y-BOCS) (Goodman et al., 1989) is a semi-structured interview scale to assess the severity of obsessions and compulsions, regardless of the number and content of current obsessions and compulsions. The Y-BOCS has two parts: The symptom checklist (SC) and the severity scale (SS). Fifteen SC items are scored on a 5-point Likert scale on a self-report basis. In the SS, each obsession or compulsion is evaluated in five dimensions: Confusion level, frequency, interference, resistance, and symptom control. The Y-BOCS yields three scores: The severity of obsessions, the severity of compulsions, and a total score that includes all items. Today, the Y-BOCS has become a tool for screening patients with OCD and is used in many studies. Between assessors and test-retesting, the scale reliability of the Y-BOCS has been reported to be appropriate for assessing OCD symptom change, not in other anxiety disorders as well as depressive disorders (Woody et al., 1995; Rajezi Esfahani et al., 2011). In Rajezi Esfahani et al.'s (2011) study, the internal stability of SC and SS parts was obtained at 0.97 and 0.95, respectively. The validity scores of the halving method for SC and SS were 0.93 and 0.89, respectively, and the test re-test reliability was obtained at 0.99. Given the study's objective, which was to examine the degree of changes in the cognitive dimension of OCD, i.e. obsession, only the SS was used in the present study.

The symptom checklist 90

This questionnaire included 90 questions to evaluate psychological symptoms and was designed initially to show the psychological aspects of physical and mental patients. Its original form was introduced by Derogatis et al. (1977), revised based on clinical experiences and psychometric analyses, and eventually converted to its current form (Dergutis et al., 1976). The answers are scored on a 4-point Likert scale that shows the degree of discomfort from (none) to (severe). Ninety questions of this questionnaire evaluate 9 dimensions: Physical complaints, obsession-compulsion, sensitivity in interpersonal relationships, depression, anxiety, aggression, morbid fear, paranoid ideation, and psychosis. In addition to the 9 dimensions mentioned, the SCL90 questionnaire evaluates three general indicators of mental distress, each showing the individual's psychological depth and weakness in terms of pathology with a score. These three indicators are the global severity index, the positive symptom distress index, and the positive symptoms total. Dergutis and Savitz (1999) obtained the internal consistency coefficients of the SCL90 from 0.77 to 0.90. The validation was obtained as 0.68 to 0.90 by test re-test within one week. Tomioka et al. (2008) evaluated SCL90 validity and reliability through confirmatory factor analysis for all 9 dimensions and showed that the goodness-of-fit index corresponds to all 9 factors that are considered the first signs of the test (Akhavan Abiri & Shairi, 2020). SCL90 validation was estimated by calculating the Cronbach α between 0.76 and 0.86 by the internal consistency method and the correlation coefficient between 0.81 and 0.90 by the re-test method (Akhavan Abiri & Shairi, 2020). In the present study, this test was used to screen for other psychological disorders. Participants whose discomfort index score was higher than 3 in each dimension were excluded from the study.

The Wechsler memory scale

This test was developed by Wechsler (1945) and consists of 7 subscales: General and personal information, orientation, mental control, logic memory, digit repetition, visual review, and learning associations (Tabatabai et al., 2014). Reliability of the WMS test was obtained at 0.75 by the test re-test method in a group of normal individuals and 0.89 in a group of individuals with psychiatric-neurological disorders (Ryan et al., 2006). In Tabatabai et al.'s (2014) study, the Cronbach α coefficient of the WMS total score was calculated to be 0.87, and the Cronbach α coefficients of the subscales of short-term memory (0.71), working memory (0.79), and long-term memory (0.75) were calculated. Abilities that the numerical memory subscale measures include short-term memory, attention, auditory short-term memory, working memory, and focus (Karami, 2011).

Study intervention

Binaural beats

In this study, the binaural beats sound that contained 300 and 340 Hz frequencies were presented to both ears of the participants, and thus, the perceived tone was 40 Hz in the γ range. To prevent participants' mental fatigue, the background sound of the sea waves was added to the main audio frequency. Audacity produced the audio frequency and audition Adobe software (Dadashi et al., 2018), and the subjects listened to it using hands-free. The duration of each intervention was 30 minutes, 3 times a week for 15 days. The persistence of the effects of the intervention was re-evaluated after a 1-month follow-up period.

3. Results

A single-sample Kolmogorov-Smirnov test was first used to evaluate the normality of the distribution of scores. Then, the homogeneity of the two groups was evaluated for the dependent variable by the t-test. Considering P>0.05 for OCD (P=0.629) and working memory (P=0.982) variables, it can be concluded that all variables in the pre-test stage have a normal distribution, and there is no difference between the participants of the two groups in terms of the dependent variable. Also, there was no missing value due to answering all the questionnaire questions (Tables 1 and 2).

In our study, we used the GEE (generalized estimating equations) technique in SPSS software, version 22, to investigate the effect of binaural beats on the severity of OCD symptoms and working memory between three time points of pre-test, post-test, and follow-up measurements, and also due to the low sample size. This method is an analysis method suitable for analyzing longitudinal data. Some advantages of this method over other methods include not being sensitive to the assumption of observations' normality and the ability to analyze incomplete data. The interpretation of the GEE model results is the same as that of a regression model. The results show that at the end of the intervention, a 3.47-unit decrease in the severity of OCD symptoms in the experimental group was significant (P=0.030). However, this decrease in the control group was not statistically significant despite a 2.16-unit decrease (P=0.101). Further results showed that, in general, the variability of the intervention group from the control group was statistically significant (P=0.007). Also, in the follow-up phase, a 3.57-unit decrease in the severity of OCD symptoms in the

Table 1. The study variables according to the two groups at the baseline

Variables	Mean±SD Control (n=14)	Mean±SD Experimental (n=15)	Mean±SD Total (n=29)	P
OCD	16.23±5.56	15.33±5.18	15.75±5.27	0.629
Working memory	4.43±0.76	4.40±1.12	4.41±0.95	0.982

OCD: Obsessive-compulsive disorder.

Table 2. The frequency distribution of age, education, marriage, and occupation among two groups

Variables	Level	No. (%) Control (n=14)	No. (%) Experimental (n=15)	No. (%) Total (n=29)	P
Age (y)	≤30	10(71.4)	9(60.0)	19(65.52)	0.772
	31-35	3(21.4)	5(33.3)	8(27.59)	
	36>	1(7.1)	1(6.7)	2(6.90)	
Education	Non-university	1(7.1)	1(6.7)	2(6.90)	0.999
	University	13(92.9)	14(93.3)	27(93.10)	
Marital status	Single	13(92.9)	10(66.7)	23(79.31)	0.169
	Married	1(7.1)	5(33.3)	6(20.69)	
Occupation	Student	6(42.9)	9(60.0)	15(51.72)	0.466
	Other	8(57.1)	6(40.0)	14(48.28)	

Table 3. The result of GEE regression for OCD variable between two groups

Stage	Group	β	SE	η^2	Observed Power	P	
						Within	Between
Post-pre	Control	-2.16	1.31	0.041	0.169	0.101	0.007
	Experimental	-3.47	1.59	0.08	0.326	0.03	
Follow-pre	Control	-3.37	1.55	0.075	0.278	0.03	0.044
	Experimental	-3.57	1.37	0.105	0.406	0.009	

OCD: Obsessive-compulsive disorder; GEE: Generalized estimating equations.

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Table 4. The result of GEE regression for working memory variable between two groups

Stage	Group	β	SE	η^2	Observed Power	P	
						Within	Between
Post-Pre	Control	0.357	0.313	0.043	0.181	0.25	0.263
	Experimental	0.40	0.245	0.034	0.160	0.104	
Follow-Pre	Control	0.286	0.326	0.021	0.112	0.381	0.556
	Experimental	0.333	0.293	0.021	0.117	0.255	

GEE: Generalized estimating equations.

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experimental group patients was statistically significant (P=0.009). In the control group, a 3.37-unit decrease in the severity of OCD symptoms was statistically significant (P=0.03). Further results indicate that, in general, the variability of the intervention group from the control group was statistically significant (P=0.044) (Table 3).

The numerical eta coefficient is between 0 and 1, and its higher values indicate a greater influence of the studied variable on the dependent variable. According to the values obtained for eta squares at the end of the intervention, it can be concluded that the severity of OCD symptoms in the experimental group was affected by the binaural beats at 0.08 and improved. Also, in the follow-up period, the impact rate of experimental operation on the dependent variable was 0.1 (Table 3).

In addition, data analysis showed that at the end of the intervention, a 0.40-unit increase in working memory function in the experimental group was not significant (P=0.1). However, the improvement of working memory function in the control group, despite a 0.35-unit increase, was not statistically significant (P=0.25). Further results showed that, in general, the variability of the intervention group from the control group was not statistically significant (P=0.26). Also, in the follow-up stage, a 0.33-unit increase in working memory function in the experimental group was not statistically significant (P=0.25). Thus, in the control group, a 0.28-unit increase in working memory function was not significant (P=0.38). Further results indicate that, in general, the variability of the intervention group from the control group was not statistically significant (P=0.55). The values obtained for eta squares at the end of the intervention show that the impact rate of binaural beats on working memory was 0.03. Also, in the follow-up period, the rate of changes in working memory due to binaural beats was 0.02 (Table 4).

4. Discussion

The present study aimed to evaluate the effectiveness of binaural beats in the γ band in improving working memory function and reducing the severity of symptoms in women with OCD. The results showed that the induction of γ frequency in the 40 Hz range led to a significant reduction in the severity of OCD symptoms and improved working memory function in patients; however, such an improvement was not statistically significant.

The finding that binaural beats reduce the severity of OCD symptoms is consistent with Hommel et al.'s (2016) study, in which they examined whether binaural beats at high frequencies would affect the formation of cognitive control. They hypothesized that the binaural beats in the γ range would make the cognitive control style more flexible. Hommel et al. (2016) found that cognitive control style can be systematically directed by inducing specific internal states. The high-frequency binaural beats lead the control style toward greater flexibility. Also, different styles are reinforced by changing the power of internal competition and top-down bias.

In this regard, Reedijk et al. (2015) in their study presented participants with high-frequency binaural beats (γ range), low-frequency binaural beats (α range), or a continuous 340 Hz sound before doing the task of blinking due to attention. Scientist found that the effect of low-frequency beats on the blinking task was not significantly different from the control group, while high-frequency beats significantly reduced blinking in individuals with low dopamine levels in the corpus striatum. Blinking due to attention has been attributed to excessive control (Olivers & Nieuwenhuis, 2006). This finding shows that high-frequency beats lead to a wider distribution of available resources and not a stronger power—greater cognitive flexibility. Such an explanation is consistent with the view that binaural beats in the γ range can improve function in a divergent thinking task rather than in a convergent thinking task (Reedijk et al., 2013) because divergent thinking typically benefits from the distributed sources more than convergent thinking (Hammel et al., 2016). Also, further studies have shown that the induction of high frequencies by binaural beats in the γ band leads to decreased hypervigilance and increased cognitive control flexibility. For example, Calzato et al. (2017) suggested that listening to binaural beats at frequencies above 40 Hz led to bias in the processing of individual attention and moved toward reduced attention. Lane et al. (1998) report states that exposure to binaural beats for 30 minutes reduces hypervigilance. This study assessed the participants' performance on the -1 back hypervigilance test while listening to binaural beats in 1.5 delta, 4 Hz theta, or 16 Hz β ranges. After the induction of frequencies, participants' performance improved in target recognition, and false hypervigilance reduced task-related confusion and fatigue when listening to the β binaural beats. Recently, another study (Beauchene et al., 2016) was performed on three different binaural beats (i.e. 5, 10, and 15 Hz) and their association with the hypervigilance delayed task in accordance with the sample for five minutes. The results have shown that the 15-Hz binaural beats increase response accuracy and improve connectivity between brain regions. Additionally, the largest electroencephalogram (EEG) steady-state responses have occurred across the γ band at the 40-Hz binaural beats and primarily have activated the frontal and parietal lobes (Draganova et al., 2007). Colzato et al. (2017) have suggested that listening to high-frequency binaural beats at 40 Hz leads to a bias in the processing of individual attention and its reduction (Al-Sharji et al., 2019). Therefore, inducing the binaural beats' γ band in patients reduces the severity of OCD symptoms by reducing attention and hypervigilance and increasing flexibility in cognitive control.

In the present study, working memory function was improved in patients with OCD by γ binaural beats (although not statistically significant). The γ band is the highest frequency in human brainwaves and can be generated at 30 Hz or higher. γ-band activity in human studies is correlated with cognitive function (Woo et al., 2010). It has been shown that brain function peaks at γ frequency. This high brain activity works very well while doing problem-solving tasks. In this regard, Jirakittayakorn and Wongsawat (2017) acknowledged that the γ-band neural oscillations helped maintain arousal levels during the state of consciousness. The EEG recording shows increased γ waves in the brain's central, frontal, and temporal regions.

While the underlying neural mechanisms of binaural beats are still unclear, recent studies have shown that beats stimulation significantly affects the functional connectivity of brain functions (Gao et al., 2014) and balances the intracranial pressure and synchronization of the phases (Becher et al., 2015). These findings support the idea that the connection and locking of neural stages due to binaural beats can affect ongoing cognitive processing (Karino et al., 2006).

The body of the existing literature regarding the effects of binaural beats in the γ band on executive functions, such as working memory, is low and limited (Khattak, 2021). For example, a meta-analysis by Garcia-Argibay et al. (2019) on working memory shows that binaural beats affect cognition. Also, a study (Jirakittayakorn & Wongsawat, 2017) on γ binaural beats at high frequency at 40 Hz and hypervigilance function was conducted on individuals who performed the word list recall task for 30 minutes. The findings of this study show that 20 minutes of listening to 40-Hz binaural beats increases working memory function and improves mood. In this regard, Khattak's (2021) research results show that participants receiving the γ band by the binaural beats method, compared to those who had received white noise, showed significantly better function in the working memory recall test. On the other hand, Lane et al. (1998) did not achieve the same results by using different protocols. Also, Goodin et al. (2012) evaluated theta at 7 Hz and β at 16 Hz, presented for 13 minutes in a 2-minute tone. This study did not report any significant difference in cortex frequency strength during the presentation of the binaural beats compared to the white noise signal. Such differences may be due to short-term stimulation, while the choice of carrier tone may also affect the binaural beats (Al-Sharji et al., 2019). Other studies have reported positive effects of binaural beats on Parkinson disease, attention deficit hyperactivity disorder (McMurray, 2004), creativity (Reedijk et al., 2013), and mood (Lane et al., 1998).

From a medical point of view, morphological and functional studies suggested the involvement of several cortical and subcortical circuitries in patients with OCD. These findings suggest that the use of binaural beats for improving working memory function in OCD patients may exhibit a positive effect on self-reported measures of working memory function. However, larger-scale randomized, placebo-controlled trials are needed to confirm our findings. Binaural beats provide potential consciousness-altering information to the brain's reticular activating system. The reticular activating system interprets and reacts to this information by stimulating the thalamus and cortex, thereby altering arousal states, attentional focus, and the level of awareness, i.e. the elements of consciousness itself (de Quincey, 1994).

Binaural beats stimulation appears to regulate neuronal activity and encourage access to propitious mental states. The effectiveness of binaural beats in creating state changes is supported by the consistent reports of thousands of users and the documentation of physiological changes associated with their use (Atwater, 1997). A review of the appropriate literature reveals that brain waves and related states of mental are said to be regulated by the brain's reticular formation stimulating the thalamus and cortex. The extended reticular-thalamic activation system is implicated in various functions associated with consciousness. This auditory sensation is neurologically routed to the reticular formation and simultaneously volume conducted to the cortex, where it can be objectively measured as a frequency-following response (Oster, 1973). The frequency-following response proves that the sensation of binaural beating has neurological efficacy. The reticular activating system interprets and reacts to information from internal stimuli, feelings, attitudes, and beliefs as well as external sensory stimuli by regulating arousal states, attentional focus, and the level of awareness: The elements of consciousness itself. How we interpret, respond, and react to information is managed by the brain's reticular formation, stimulating the thalamus and cortex and controlling attentiveness and level of arousal. "It would seem that the basic mechanisms underlying consciousness are closely bound up with the brainstem reticular system ....". Binaural beats influence consciousness by providing this information (Atwater, 1997).

In previous studies, the presentation time of binaural beats was mostly short, and working memory tasks were taken from participants immediately after stimulation. However, in our study, we increased the duration of the intervention phase to two weeks and the listening time to 30 minutes each time. The post-test was also taken one day after the end of the intervention rather than immediately. Some strengths of this research are as follows. First, most studies investigated the effects of α and β waves on working memory, and studies in the γ band range are very limited. In our study, we investigated the frequency changes of the brain under γ waves. Second, knowing that binaural beats are mostly a rehabilitation method rather than a treatment, we limited its effectiveness to cognitive functions, including working memory. We did not seek to discover a new therapeutic method for all OCD dimensions. Instead, we assumed that binaural beats in the γ band, through the reduction of inhibitions, would probably have a modulating effect only in the obsession dimension. Third, the gender variable was controlled in this study. Fourth, in this research, in addition to increasing the duration of each time of listening to the binaural beat (30 minutes) and increasing the frequencies to three times a week, a one-month follow-up period was also considered to examine the durability of the results. Finally, the usage of binaural beats has been investigated mainly in healthy subjects. The necessity of dealing with the interventional applications of this method in psychiatric disorders, determining the areas of effect (cognitive functions, etc.), and estimating its effect size are considered important issues that have been addressed in our study. The weaknesses of our research include the small number of samples and the unattended implementation of the intervention due to the COVID-19 condition.

In the present study, we investigated the effect of γ band induction on working memory and the severity of symptoms of OCD patients with the binaural beats method. Assessments show that the effectiveness of this method on OCD patients and their working memory has not been evaluated so far. Also, the available literature indicates that the γ frequency generates the highest levels of alertness, accuracy, and attention, i.e. the same trait that exists in OCD patients and is known as overthinking. Therefore, the induction of γ waves should lead to an increase in their symptoms. However, our study showed the opposite of this assumption. The γ band leads to decreased inhibition in patients through increasing cognitive flexibility. This finding should be further investigated, explained, and repeated, and it is considered one of the innovative aspects of the present study. Thus, synchronized γ oscillations appear to play a role in maintaining working memory information and are essential for its successful function (Roux & Uhlhaas, 2014; Yamamoto et al., 2014).

5. Conclusion

Overall, according to the results of the present study, binaural beats reduce the severity of OCD symptoms by inducing γ frequency through reducing cognitive control. It also improves working memory function in patients with this disorder, although this increase is not statistically significant. It is suggested that future studies investigate the effectiveness of this method in more detail by increasing the sample size and examining intermediate variables such as individual differences. It seems that anxiety disorders, as well as other psychological disorders that are associated with high cognitive control, can be a good representative of studying the effects of binaural beats in γ bands. Also, modifying other executive functions known in OCD, such as decision-making, attention, inhibition, and shifting, can be examined by this method and at other frequencies. Future studies should evaluate improving working memory function with γ binaural beats in OCD under high and low load with other memory tasks. Three to six months follow-up courses are also required. We recommend that the effectiveness of this method be compared to the efficacy of other neuromodulation and neurofeedback methods. The advantages of this non-invasive method are saving money and time, reversibility, and ease of implementation. This method can be used as a complementary treatment for OCD, along with pharmacotherapy and CBT. The underlying neural mechanism of binaural beats is still unknown. Brain imaging and EEG studies help identify the affected areas and how the induced waves are distributed in different brain areas. Further studies that eliminate methodological inconsistencies will better understand and recognize new practical applications of binaural beats.

Study limitations

In the present study, we faced several limitations. First, we included only female participants in the study. We suggest that future studies only examine the effects of binaural beats on male patients and compare men and women. Second, this study’s low sample size led to inaccurate results. Therefore, we recommend that future studies use a larger sample size. Third, the follow-up period in our study was one month. It is necessary to check the durability of the results in 3-, 6-, and 12-month periods. Despite these limitations, by examining the therapeutic effects of γ binaural beats in OCD, increasing the duration of the intervention period (two weeks), and the 1-month follow-up, the present study took an essential step in identifying new applications of this brainwave synchronization method.

Ethical Considerations

Compliance with ethical guidelines

This study was registered by the Iran National Committee for Ethics in Biomedical Research and received an ethical code from the Alzahra University (Code: IR.ALZAHRA.REC.1400.095).

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Authors' contributions

All authors equally contributed to preparing this article.

Conflict of interest

The authors declared no conflict of interest.

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