Title: The Effect of Brainwave Synchronization in Gamma Band Using Binaural Beats on Improving Working Memory Function and Reducing the Severity of Symptoms in Women with Obsessive-Compulsive Disorder

Authors: Zahra Hodhodi[1], Mehrangiz Pyvastegar[1,*], Peyman Hassani Abharian[1,2], Azam Farah Bidjari[1], Batool Ahadi[1]

1. *Department of Psychology, Faculty of Education and Psychology, Alzahra University, Tehran, Iran.*
2. *Department of Cognitive Rehabilitation, Institute for Cognitive Science Studies, Brain and Cognition Clinic, Tehran, Iran.*

***Corresponding Author**: Mehrangiz Pyvastegar, Department of Psychology, Faculty of Education and Psychology, Alzahra University, Tehran, Iran. Email: mpaivastegar@alzahra.ac.ir

To appear in: **Basic and Clinical Neuroscience**

Received date: 2022/05/30

Revised date: 2022/07/30

Accepted date: 2022/08/21

Please cite this article as:

Hodhodi, Z, Pyvastegar, M, Hassani Abharian, P., Farah Bidjari, A., Ahadi, B. (In Press). The Effect of Brainwave Synchronization in Gamma Band Using Binaural Beats on Improving Working Memory Function and Reducing the Severity of Symptoms in Women with Obsessive-Compulsive Disorder. *Basic and Clinical Neuroscience*. Just Accepted publication Aug. 15, 2022. Doi: http://dx.doi.org/10.32598/bcn.2022.4233.1

DOI: http://dx.doi.org/10.32598/bcn.2022.4233.1

Abstract

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

Method: Twenty-nine OCD women aged 25-40 years referring to psychological clinics in Tehran were selected by convenient method. After completing the symptom checklist 90 (SCL90) and the Yale-Brown severity scale (SS), participants were given the Wechsler memory scale (WMS) digit repetition subtests. Then, they were randomly assigned to the two experimental (n=15) and control (n=14) groups. The audio file of the binaural beats in gamma 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 posttest and one-month follow-up periods were obtained again from both groups.

Results: According to the results, the severity of OCD symptoms was significantly reduced by the gamma binaural beats in posttest and follow-up stages ($p<0.05$). 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.

Keywords: Binaural beats, Severity of OCD symptoms, Working memory, Gamma band

Plain Language Summary

To date, treatment methods known for OCD have been pharmacotherapy and cognitive-behavioral therapy (CBT). In addition to short-term positive effects, pharmacotherapy has possible complications, such as drug dependence, recurrence of symptoms after discontinuation, side effects specific to each drug, possible drug interactions, external control of the patient for treatment, and not attributing recovery to the patient's abilities and efforts. Psychotherapy is also effective, provided that the sessions continue weekly, permanently, and sometimes over a period of several years. Being time-consuming, having high costs, psychological resistance of the patient in accepting therapeutic strategies, and relying on the therapist's expertise and experience for achieving desired treatment outcomes are considered among the disadvantages of this method. It is better to know that according to research, both treatments are ineffective 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, that is why they keep checking to see if they have done something. We hypothesized that if we could induce gamma wave to the brain by beats, we would be able to generate the highest level of attention, accuracy, and alertness, and thus improve the memory. The results were amazing. The severity of OCD symptoms 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 treatments for individuals with OCD. Binaural beats is a safe, free, complication-free, and an easy to use method, and can be applied in any place and time. Also, binaural beats enhances the effect of other treatments and paves the way for achieving recovery.

Highlights

- Binaural beats in gamma band reduces the severity of OCD symptoms (in both dimensions of obsession and compulsion).

- Binaural beats in gamma band can be considered a potential amplifier to improve working memory function in OCD patients.

Introduction

Obsessive-Compulsive Disorder (OCD) is an inherited neuropsychiatric disorder characterized by disturbing and distressing thoughts made by 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-striato-thalamo-cortical (CSTC) dysfunction, mainly in the orbitofrontal cortex (OFC), the dorsolateral prefrontal cortex (DLPFC), and the caudate nucleus. This integrated circuit seems to be clearly related to cognitive executive functions, which are higher-level mental processes and modulate sensory, motor, cognitive, emotional, and memory capabilities (Yücel, Harrison, Wood, Fornito, Wellard, 2007; Cavedini, Gorini, Bellodi, 2006; Bechara, 2001; quoted by Kamaradova, Hajda, Prasko, Taborsky, Grambal, 2016). Among neurocognitive deficits, working memory function in OCD has been studied in several studies (Olley, Malhi, & Sachdev, 2007), and many cognitive neuroscientific studies have supported the role of the fronto-parietal network, including DLPFC, anterior cingulate cortex (ACC), and parietal cortex (PAR) as the neural network involved in working memory (Chai, Abd Hamid, & Abdullah, 2018). A review of the available literature suggests that working memory deficits may underlie the 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 be cause trouble for working memory (Williams, & Grisham, 2013; Brewin, & Smart, 2005; Tolin, Abramowitz, Przeworski, & Foa, 2002). It is assumed that working memory deficits play a role in compulsive checking and cause problems in monitoring and controlling measures (Harkin, Rutherford, Kessler, 2011; Harkin and Kessler, 2011a, 2011b, 2009). The above hypotheses are consistent with neuroimaging studies, which have found evidence of memory deficits in OCD (de Vries, de Wit, Cath, van der Werf, van der Borden, et al., 2013) and animal models have also confirmed the relationship between working memory and OCD (quoted by Shahar, Teodorescu, Anholt, Karmon-Presser, & Meiran, 2017).

First-line treatments for OCD are pharmacotherapy, cognitive-behavioral therapy (CBT) or cognitive reconstruction (Baldwin, Anderson, Nutt, Allgulander, Bandelow, et al., 2014). CBT is ineffective in 20% of cases and SSRIs in 40% of cases (Ferrão, Shavitt, Bedin, De Mathis, Lopes, et al., 2006), although other studies show that there is a higher percentage of ineffectiveness, i.e., about 40-60% for both treatments (Beşiroğlu, L., 2016). In fact, it can be said that about one-third of cases do not achieve the desired clinical response (Fineberg, & Gale, 2005).

Although many studies have been performed to date on the effectiveness of the mentioned methods, according to Moritz, Kloss, Jacobsen, Fricke, Cuttler, 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 lead to increased 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 a subset of it, specialized treatment programs are needed to specifically address such deficits (FitzGerald, Nedeljkovic, Moulding, & Kyrios, 2011).

New therapeutic strategies that have focused on the neuromodulation of OCD cognitive functions over the past few decades have their own complications. (Bais, Figee, & Denys, 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 they happen to rely on the interaction between multiple neural circuits, neuromodulation approaches need to be continually refined to further influence specific areas that are 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 in order to create the optimal benefit in regulating circuits and relieving symptoms (quoted by Lapidus, Stern, Berlin, & Goodman, 2014).

In this regard, the latter approach to non-invasive brain stimulation uses the notion that rhythmic magnetic or electrical stimulation can synchronize neural oscillations in a specific frequency band, such as gamma oscillations. As an alternative to electrical stimulation, rhythmic sensory stimulation is able to synchronize neural oscillations. In particular, binaural beats has been suggested as a beneficial stimulating sound because it involves the complex interaction of brain processes (Esther, 1973) and plays a critical role in increasing neural synchronization (Colzato, Steenbergen, & Sellaro, 2017; quoted by Lopez, 2019). In this method, two different frequencies are delivered 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. In 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 5 types of brainwaves), and the waves' synchronization is performed (Wahbeh, Calabrese, Zwickey, & Zajdel, 2007; quoted by Lopez, 2019).

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). This fact shows that high-frequency beats can facilitate attention control, a finding that is consistent with the effect of high-frequency neurofeedback waves on the frontal cortex and thus improved attention efficiency (Keizer, Verment, & Hommel, 2010). In fact, 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 exactly the opposite (Keizer, Verment, & Hommel, 2016; Reedijk, Bolders, Colzato, & Hommel, 2015). Therefore, considering the central role of cognitive control in executive functions such as working memory (Chen, Spagna, Wu, Kim, Wu, et al., 2019), it seems that induction of gamma frequency by the binaural beats method can improve the mentioned executive function. The effectiveness of this method in gamma 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's disease (Gálvez, Recuero, Canuet, & Del-Pozo, 2018) and attention deficit hyperactivity disorder (ADHD) (McMurray, 2004). Also, according to recent findings (Keizer, Verment, & Hommel, 2016; Reedijk, Bolders, Colzato, & Hommel, 2015), the binaural beats in gamma band leads to increased flexibility in cognitive control. Therefore, it can be assumed that this method will reduce the severity of OCD symptoms. On the other hand, research conducted to date 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, Tariq, Mir, Alawar, Babiloni, et al., 2019) are among the research proposals and gaps in this field. Also, differences in the effectiveness of binaural beats in different age and sex groups (Calzato, 2017) indicate the need to control such variables in studies.

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

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

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

Materials and Method

Participants

In the present study, the clinical sample was selected through Judgmental sampling from among the women referring to the two government 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 selected for the study due to their higher auditory sensitivity and also greater susceptibility to exposure to noise at high frequencies (McFadden, 2009).

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

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

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

S_1- Standard deviation of the studied variable in the first group (case, exposed, or intervention)

S_2- Standard deviation of the studied variable in the second group (control, unexposed, or comparison)

μ_1- Mean of the studied variable in the first group

μ_2- Mean of the studied variable in the second group

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

Conducting experimental interventions and writing and compiling the present study in Tehran, Iran, lasted from August 2021 to May 2022.

Demographic Characteristics

Table 1 shows the mean and standard deviation of OCD and working memory variables at the beginning of the study, in the total sample, and separately for the two groups. Based on the results reported in this table and concerning P-values higher than 5% for OCD (P-value = 0.629) and working memory (P-value = 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, it can be seen that most of the participants in this study were single, under the age of 30, with university education, and were university students. Also, based on the obtained P-values, it can be concluded that the two intervention and control groups are the same in terms of age, education, marital status, and occupation variables (P-value>0.05).

Inclusion criteria include female gender, the age range of 25-40 years, OCD development without comorbidity with other psychiatric disorders, no use of psychiatric drugs one month before entering the study, no use of other psychological and pharmacological treatments for OCD during research, and having informed consent. 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, and 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 relation of decline in cognitive and physical functions with age.

At the beginning of the research implementation phase and after diagnosing patients with OCD, the researcher introduced herself and the research plan during a short session and explained the research aim 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 form and committed not to use any 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 strictly confidential. Then, participants were randomly assigned to 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 sample, the audio file of the binaural beats in gamma band was provided to the experimental group, and the audio file that did not induce any of 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 each time at home or work, definitely 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-day period, 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 taken again.

It should be noted that at the end of the intervention, the time of taking the tests was adjusted according to the participants' suitable conditions and the hours announced by them. 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 stages of the experiment. The researcher agreed with the exclusion of 6 participants without any insistence or implicit emphasis on the continuation of the research.

This study was registered in and received research code from the Iran National Committee for Ethics in Biomedical Research (https://ethics.research.ac.ir) and an ethical code of IR.ALZAHRA.REC.1400.095 from the Alzahra University at 19 January 2022.

Measures

The Yale-Brown Obsessive-Compulsive Scale (Y-BOCS) (Goodman, Price, & Rasmussen, 1989): This scale 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 answered on a five-point Likert scale on a self-report basis. In the SS, each obsession and compulsion is estimated in five dimensions, including confusion level, frequency, interference, resistance, and symptom control. The Y-BOCS gives 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. Reliability between assessors and test-retesting 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, Steketee, & Chambless, 1995; quoted by Rajezi Esfahani, Mottaqipoor, Kamkari, Zahiruddin, and Jan Bozorgi, 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 of the halving method for SC and SS was 0.93 and 0.89, respectively; and the test-retest reliability was obtained at 0.99. In the present study, given the study aim, which was to examine the degree of changes in the cognitive dimension of OCD, i.e., obsession, only the SS was used.

The SCL90 (Derogatis, Lipman, & Covi, 1977): 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, Rickels, & Rock, 1976). The answers are assigned on a four-point Likert scale that shows the degree of discomfort from (none) to (severely). Ninety questions of this questionnaire evaluate 9 dimensions, including 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 of which shows the individual's psychological depth and weakness in terms of pathology with a score. These three indicators are the Global Severity Index (GSI), the Positive Symptom Distress Index (PSDI), and the Positive Symptoms Total (PST). Dergutis & Savitz, (1999) obtained internal consistency coefficients in the range of 0.77 to 0.90. Validation was obtained by test-retest within a one-week interval in the range of 0.68 to 0.90. Tomioka, Shimura, Hidaka, Kubo (2008) in SCL90 validity and reliability through confirmatory factor analysis that performed the analysis for all 9 dimensions showed that the goodness-of-fit index corresponds to all 9 factors that are considered the first signs of the test (quoted by Akhavan Abiri and Shairi, 2019). Validation estimated Cronbach's alpha between 0.76 and 0.86 by the internal consistency method, and estimated correlation coefficient between 0.81 and 0.90 by the retest method (Akhavan Abiri & Shairi, 2019). 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 WMS (Wechsler, 1954): This test was developed by Wechsler, (1945) and consists of seven subtests: General and personal information, orientation, mental control, logic memory, digit repitition, visual review, and learning associations (quoted by Tabatabai, Salimi, and Nadi, 2014). Reliability of the WMS test was obtained at 0.75 by the test-retest method in a group of normal individuals and 0.89 in a group of individuals with psychiatric-neurological disorders (Ryan, Morris. Yaffa. Peterson. 2006; quoted by the same). In Tabatabai et al.'s (2014) study, Cronbach's alpha coefficient of the WMS total score was calculated to be 0.87, and Cronbach's alpha 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).

Intervention

Binaural Beats: In this study, the binaural beats sound that contained 300 and 340 Hz frequencies was presented to both ears of the participants, and thus, the perceived tone was 40 Hz in gamma range. To prevent participants' mental fatigue, a sound was used in which the background sound of the sea waves had been added to the main audio frequency. The audio frequency was produced by Audacity and Audition Adobe software (Dadashi, Ahmadi, Bafandeh Gharamaleki, and Rasouli, 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 one-month follow-up period.

Data Analysis and Results

In order to evaluate the normality of the distribution of scores, a single-sample Kolmogorov-Smirnov test was first used, and then the homogeneity of the two groups was evaluated for the dependent variable by t-test. Considering P-values higher than 5% for OCD (P-value = 0.629) and working memory (P-value = 0.982) variables, it can be concluded that all variables in the pretest 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.

In our study, we used the GEE technique in SPSS22 software to investigate the effect of binaural beats on the severity of OCD symptoms and working memory between three times of pretest, posttest, 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 also the ability to analyze incomplete data. Interpretation of the results of the GEE model is the same as 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-value = 0.030). However, this decrease in the control group was not statistically significant despite a 2.16-unit decrease (P-value = 0.101). Further results showed that, in general, the variability of the intervention group from the control group was statistically significant (P-value = 0.007). Also, in the follow-up phase, a 3.57-unit decrease in the severity of OCD symptoms in the experimental group patients was statistically significant (P-value = 0.009); in the control group, also, a 3.37-unit decrease in the severity of OCD symptoms was statistically significant (P-value = 0.03). Further results indicate that in general, the variability of the intervention group from the control group was statistically significant (P-value = 0.044).

The numerical eta coefficient is between 0 and 1, and its higher values indicate a greater degree of 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 as 0.08 and improved. Also, in the follow-up period, the impact rate of experimental operation on the dependent variable was 0.1.

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-value = 0.1). However, the improvement of working memory function in the control group despite a 0.35-unit increase was not statistically significant (P-value = 0.25). Further results showed that, in general, the variability of the intervention group from the control group was not statistically significant (P-value = 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-value = 0.25); thus, in the control group, a 0.28-unit increase in working memory function was not significant (P-value = 0.38). Further results indicate that, in general, the variability of the intervention group from the control group is not statistically significant (P-value = 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.

Discussion

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

The finding that binaural beats leads to reducing 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 gamma 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 leads 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, Bolders, Colzato, & Hommel, (2015) in their study presented participants with a high-frequency binaural beats (gamma range), a low-frequency binaural beats (alpha range), or a continuous 340 Hz sound before doing the task of blinking due to attention. Riddick et al. (2015) 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 leads to a wider distribution, and not a stronger power, of available resources - that is, greater cognitive flexibility. Such an explanation is consistent with the view that binaural beats in gamma range can improve function in a divergent thinking task rather than in a convergent thinking task (Reedijk, Bolders, & Hommel, 2013) because divergent thinking typically benefits from the distributed sources more than convergent thinking (Hamel et al., 2016). Also, further studies have shown that the induction of high frequencies by binaural beats in gamma band leads to a decrease in hypervigilance and an increase in 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. A report by Lane, Kasian, Owens, & Marsh, (1998) states that exposure to a binaural beats for 30 minutes reduces hypervigilance. This study has assessed the participants' performance on the -1 back hypervigilance test while they were listening to a binaural beats in 1.5 delta, 4 Hz theta, or 16 Hz beta ranges. After induction of frequencies, participants' performance improved in target recognition and false hypervigilance reduced task-related confusion and fatigue when listening to the beta binaural beats. Recently, another study (Beauchene, Abaid, Moran, Diana, & Leonessa, 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 obtained results have shown that the 15Hz binaural beats increases response accuracy and improves connectivity between brain regions. Additionally, the largest electroencephalogram (EEG) steady-state responses have occurred across gamma band at the 40-Hz binaural beats and primarily have activated the frontal and parietal lobes (Draganova, Ross, Wollbrink, Pantev, 2007). Colzato et al. (2017) have suggested that listening to a high-frequency binaural beats at 40 Hz leads to a bias in the processing of individual attention and its reduction (quoted by Al-Sharji et al., 2019). Therefore, it can be concluded that inducing the binaural beats's gamma 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 gamma binaural beats (which, of course, was not statistically significant). Gamma is the highest frequency in human brainwaves and can be generated at 30 Hz or higher. Gamma-band activity in human studies is correlated with cognitive function (Woo, Spencer, & McCarley, 2010). In fact, it has been shown that brain function peaks at gamma frequency. This high brain activity works very well while doing problem-solving tasks. In this regard, Jirakittayakorn, & Wongsawat, (2017) acknowledged that the gamma-band neural oscillations helped maintain arousal levels during the state of consciousness. The EEG recording shows an increase in gamma waves in the central, frontal, and temporal regions of the brain.

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, Cao, Ming, Qi, Wang, Wang, et al., 2014) and balances the intracranial pressure and synchronization of the phases (Becher, Ho¨hne, Axmacher, Chaieb, Elger, 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, Yumoto, Itoh, Uno, Yamakawa, Sekimoto, & Kaga, et al., 2006).

The body of the existing literature regarding the effects of binaural beats in gamma band on executive functions, such as working memory, is low and limited (Khattak, 2021). For example, a meta-analysis by Garcia-Argibay, Santed, & Reales, (2019), focusing on working memory, shows that binaural beats affects cognition. Also, a study (Jirakittayakorn, & Wongsawat, 2017) on gamma 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 a 40 Hz binaural beats increases working memory function and improves mood. In this regard, the results of Khattak's (2021) research show that participants receiving gamma 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, Ciorciari, Baker, Carrey, Harper, & Kaufman (2012) evaluated theta at 7 Hz frequency and beta at 16 Hz frequency, which was 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 (quoted by Al-Sharji et al., 2019). Other studies have reported positive effects of binaural beats on Parkinson's disease (Esther, 1973), attention deficit hyperactivity disorder (ADHD) (McMurray, 2004), creativity (Reedijk, Bolders, & Hommel, 2013), and mood (Lane, Kasian, Owens, & Marsh, 1998).

From a medical point of view, Morphological and functional studies suggested involvement of several cortical and subcortical circuitries in patients with OCD. These findings suggest that use of using binaural beats on 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 in turn 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- beat stimulation appears to regulate neuronal activity and encourage access to propitious mental states. The effectiveness of binaural beats in engendering state changes is supported by the consistent reports of thousands of users, as well as the documentation of physiological changes associated with its 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 (ERTAS) is implicated in a variety of functions associated with consciousness (Newman, 1997). This auditory sensation is neurologically routed to the reticular formation (Swann, Bosanko, Cohen, Midgley & Seed, 1982) and simultaneously volume conducted to the cortex where it can be objectively measured as a frequency-following response (Oster, 1973; Smith, Marsh, & Brown, 1975; Marsh, Brown, and Smith, 1975; Smith, Marsh, Greenberg & Brown, 1978; Hink et al., 1980). The frequency-following response provides proof that the sensation of binaural beating has neurological efficacy. The reticular activating system (RAS) 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 (Empson, 1986; Tice & Steinberg, 1989). How we interpret, respond, and react to information then, is managed by the brain's reticular formation stimulating the thalamus and cortex, and controlling attentiveness and level of arousal (Empson, 1986). "It would seem that the basic mechanisms underlying consciousness are closely bound up with the brainstem reticular system ..." (Henry, 1992). Binaural beats appear to influence consciousness by providing this information (quoted by Atwater, 1997).

In previous studies, the presentation time of binaural beats was mostly short, and immediately after stimulation, working memory tasks were taken from participants. However, in our study, we increased the duration of the intervention phase to two weeks and also increased the listening time to 30 minutes each time. As well as, the posttest was also taken one day after the end of the intervention rather than immediately. Some strengths of this research include: 1- Most of the conducted studies investigated the effects of alpha and beta waves on working memory, and studies in the gamma band range are very limited. In our study, we investigated the frequency changes of the brain under gamma waves. 2- Knowing that binaural beats is 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 gamma band, through the reduction of inhibitions, would probably have a modulating effect only in the obsession dimension. 3- The gender variable was controlled in this study. 4- 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 so that the durability of the results was also examined. 5- Usages of binaural beats have 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 gamma 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 gamma 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 gamma waves should lead to an increase in their symptoms. However, our study showed the opposite of this assumption. In fact, the gamma band leads to decreased inhibition in patients through increasing cognitive flexibility. This finding should be further investigated, explained, and repeated and is considered one of the innovative aspects of the present study. Thus, in general, synchronized gamma oscillations appear to play a role in the maintenance of working memory information and are essential for its successful function (Roux, & Uhlhaas, 2014; Yamamoto, Suh, Takeuchi, & Tonegawa, 2014; quoted by Bai, Xia, Liu, & Tian, 2016).

Conclusion

Overall, according to the results of the present study, binaural beats leads to a reduction in the severity of OCD symptoms by inducing gamma 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 gamma band. 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 the improvement of working memory function with gamma binaural beats in OCD under high and low load with other memory tasks. Three to six month follow-up courses are also required. We recommend that the effectiveness of this method be compared to the effectiveness 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 lead to a better understanding and recognition of new practical applications of binaural beats.

Limitations

In the present study, we faced several limitations. First, we included only female participants in the study. We suggest that future studies examine the effects of binaural beats on male patients only and compare men and women in this regard. Second, low sample size of this study led to not achieving accurate results. Therefore, we recommend that future studies use a larger sample size. Third, the follow-up period in our study was 1 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 gamma binaural beats in OCD, increasing the duration of the intervention period (two weeks), and also the 1-month follow-up, the present study took an important step in identifying new applications of this brainwave synchronization method.

Acknowledgments

We would like to appreciate the support and help of the Department of Psychology and Educational Sciences of Al-Zahra University and the Institute of Cognitive Sciences. Also, we would like express our special thanks to the cooperation of counseling and psychological services clinics that helped us in identifying and introducing patients with OCD.

References

Al-Shargie, F., Tariq, U., Mir, H., Alawar, H., Babiloni, F., & Al-Nashash, H. (2019). Vigilance decrement and enhancement techniques: a review. *Brain sciences*, *9*(8), 178.

Akhavan Abiri, F., & Shairi, M. R. (2020). [Validity and reliability of symptom checklist-90-revised (SCL-90-R) and brief symptom inventory-53 (BSI-53) (persion)]. *Clinical Psychology and Personality, 17*(2), 169-195.

American Psychiatric Association, (2013). Diagnostic and Statistical Manual of Mental Disorders, 5th ed. APA, Washington, DC (DSM-5).

Atwater, F. H. (1997). Accessing anomalous states of consciousness with a binaural beat technology. Journal of scientific exploration, 11(3), 263-274.

Bais, M., Figee, M., & Denys, D. (2014). Neuromodulation in obsessive-compulsive disorder. *Psychiatric Clinics*, *37*(3), 393-413.

Baldwin, D. S., Anderson, I. M., Nutt, D. J., Allgulander, C., Bandelow, B., den Boer, J. A., ... & Wittchen, H. U. (2014). Evidence-based pharmacological treatment of anxiety disorders, post-traumatic stress disorder and obsessive-compulsive disorder: a revision of the 2005 guidelines from the British Association for Psychopharmacology. *Journal of Psychopharmacology*, *28*(5), 403-439.

Beauchene, C., Abaid, N., Moran, R., Diana, R. A., & Leonessa, A. (2016). The effect of binaural beats on visuospatial working memory and cortical connectivity. *PLoS ONE*, *11*(11), e0166630.

Bechara, A. (2001). Neurobiology of decision-making: risk and reward. In *Seminars in clinical neuropsychiatry, 6*(3), 205-216.

Becher, A. K., Höhne, M., Axmacher, N., Chaieb, L., Elger, C. E., & Fell, J. (2015). Intracranial electroencephalography power and phase synchronization changes during monaural and binaural beat stimulation. *European Journal of Neuroscience, 41*(2), 254-263.

Beşiroğlu L. (2016). Understanding treatment response and resistance in obsessive compulsive disorder in the context of cognitive neuropsychological model. *Turk Psikiyatr Derg, 27*(3),1–9.

Brewin, C. R., & Smart, L. (2005). Working memory capacity and suppression of intrusive thoughts. *Journal of behavior therapy and experimental psychiatry, 36*(1), 61-68.

Bullmore, E., Owen, A. M., McMillan, K. M., & Laird, A. R. (2005). N-back working memory paradigm: A meta-analysis of normative functional neuroimaging studies. *Human Brain Mapping*, *25*(1), 46-59.

Cavedini, P., Gorini, A., & Bellodi, L. (2006). Understanding obsessive–compulsive disorder: focus on decision making. *Neuropsychology review*, *16*(1), 3-15.

Chai, W. J., Abd Hamid, A. I., & Abdullah, J. M. (2018). Working memory from the psychological and neurosciences perspectives: a review. *Frontiers in psychology*, *9*, 401.

Chein, J. M., Moore, A. B., & Conway, A. R. (2011). Domain-general mechanisms of complex working memory span. *Neuroimage*, *54*(1), 550-559.

Chen, Y., Spagna, A., Wu, T., Kim, T. H., Wu, Q., Chen, C., ... & Fan, J. (2019). Testing a cognitive control model of human intelligence. *Scientific reports*, *9*(1), 1-17.

Colzato, L. S., Steenbergen, L., & Sellaro, R. (2017). The effect of gamma-enhancing binaural beats on the control of feature bindings. *Experimental Brain Research*, *235*(7), 2125–2131.

Dadashi, S. D., Ahmadi, E., Bafandeh Gharamaleki, H., & Rasouli, H. (2018). [Effectiveness of brainwave synchronization in beta band by binaural beats on improvement of visuospatial working memory in subjects with borderline personality disorder traits (persion)]. *Studies in Medical Sciences*, *29*(5), 327-335.

de Quincey, C. (1994). Consciousness all the way down? Journal of Consciousness Studies, 1,2, 217.

Derogatis, L. R., & Savitz, K. L. (1999). The SCL-90-R, Brief Symptom Inventory, and Matching Clinical Rating Scales.

Derogatis, L. R., Lipman, R. S., & Covi, L. (1977). SCL-90. *Administration, scoring and procedures manual-I for the R (revised) version and other instruments of the Psychopathology Rating Scales Series. Chicago: Johns Hopkins University School of Medicine.*

Derogatis, L. R., Rickels, K., & Rock, A. F. (1976). The SCL-90 and the MMPI: A step in the validation of a new self-report scale. *The British Journal of Psychiatry*, *128*(3), 280-289.

de Vries, F. E., de Wit, S. J., Cath, D. C., van der Werf, Y. D., van der Borden, V., van Rossum, T. B., ... & van den Heuvel, O. A. (2014). Compensatory frontoparietal activity during working memory: an endophenotype of obsessive-compulsive disorder. *Biological Psychiatry*, *76*(11), 878-887.

Draganova, R.; Ross, B.; Wollbrink, A.; Pantev, C. (2007). Cortical steady-state responses to central and peripheral auditory beats. J. *Cereb. Cortex*, *18*, 1193–1200.

Engle, R.W., Kane, M.J. (2004). *The psychology of learning and motivation: advances in research and theory*. Academic Press.

Esfahani, S. R., Motaghipour, Y., Kamkari, K., Zahiredin, A., & Janbozorgi, M. (2012). [Reliability and Validity of the Persian version of the Yale-Brown Obsessive-Compulsive scale (Y-BOCS) (persion)]. *Iranian Journal of Psychiatry & Clinical Psychology*, *17*(4).

Ferrão, Y. A., Shavitt, R. G., Bedin, N. R., de Mathis, M. E., Carlos Lopes, A., Fontenelle, L. F., et al. (2006). Clinical features associated to refractory obsessive-compulsive disorder. *Journal of affective disorders*, *94*(1–3), 199–209.

Fineberg, N. A., & Gale, T. M. (2005). Evidence-based pharmacotherapy of obsessive–compulsive disorder. *International Journal of Neuropsychopharmacology*, *8*(1), 107-129.

First, M. B., Williams, J. B. W., Karg, R. S., & Spitzer, R. L. (2015). SCID-5-CV: *Structured Clinical Interview for DSM-5 Disorders, Clinician Version*: American Psychiatric Association Publishing.

FitzGerald, K., Nedeljkovic, M., Moulding, R., & Kyrios, M. (2011). The relationship between neuropsychological performance, cognitive confidence, and obsessive-compulsive phenomena: A pilot study. *International Journal of Cognitive Therapy*, *4*(1), 51-65.

Gao, X., Cao, H., Ming, D., Qi, H., Wang, X., Wang, X., ... & Zhou, P. (2014). Analysis of EEG activity in response to binaural beats with different frequencies. *International Journal of Psychophysiology*, *94*(3), 399-406.

Garcia-Argibay, M., Santed, M. A., & Reales, J. M. (2019). Efficacy of binaural auditory beats in cognition, anxiety, and pain perception: a meta-analysis. *Psychological Research*, *83*(2), 357-372.

Goodin, P., Ciorciari, J., Baker, K., Carrey, A. M., Harper, M., & Kaufman, J. (2012). A high-density EEG investigation into steady state binaural beat stimulation. *PloS one*, *7*(4), e34789.

Goodman, W. K., Price, L. H., Rasmussen, S. A., Mazure, C., Fleischmann, R. L., Hill, C. L., ... & Charney, D. S. (1989). The Yale-Brown obsessive compulsive scale: I. Development, use, and reliability. *Archives of general psychiatry*, *46*(11), 1006-1011.

Grisham, J. R., & Williams, A. D. (2013). Responding to intrusions in obsessive-compulsive disorder: The roles of neuropsychological functioning and beliefs about thoughts. *Journal of Behavior Therapy and Experimental Psychiatry*, *44*(3), 343-350.

Harkin, B., & Kessler, K. (2009). How checking breeds doubt: Reduced performance in a simple workingmemory task. *Behaviour Research and Therapy*, *47*(6), 504-512.

Harkin, B., & Kessler, K. (2011a). How checking as a cognitive style influences working memory performance. *Applied Cognitive Psychology*, *25*(2), 219-228.

Harkin, B., & Kessler, K. (2011b). The role of working memory in compulsive checking and OCD: a systematic classification of 58 experimental findings. *Clinical Psychology Review*, *31*(6), 1004-1021.

Harkin, B., Rutherford, H., & Kessler, K. (2011). Impaired executive functioning in subclinical compulsive checking with ecologically valid stimuli in a working memory task. *Frontiers in psychology*, *2*, 78.

Hommel, B., Sellaro, R., Fischer, R., Borg, S., & Colzato, L. S. (2016). High-frequency binaural beats increase cognitive flexibility: evidence from dual-task crosstalk. *Frontiers in psychology*, *7*, 1287.

Jirakittayakorn, N., & Wongsawat, Y. (2017). Brain responses to 40-Hz binaural beat and effects on emotion and memory. *International Journal of Psychophysiology*, *120*, 96-107.

Kane, M. J., & Engle, R. W. (2002). The role of prefrontal cortex in working-memory capacity, executive attention, and general fluid intelligence: An individual-differences perspective. *Psychonomic bulletin & review*, *9*(4), 637-671.

Karami, A. (2011). [Guide to Wechsler adult intelligence scale (WAIS) (Persian)]. *Tehran Psychometric Publications*.

Karino, S., Yumoto, M., Itoh, K., Uno, A., Yamakawa, K., Sekimoto, S., & Kaga, K. (2006). Neuromagnetic responses to binaural beat in human cerebral cortex. *Journal of neurophysiology*, *96*(4), 1927-1938.

Keizer, A. W., Verment, R. S., & Hommel, B. (2010). Enhancing cognitive control through neurofeedback: A role of gamma-band activity in managing episodic retrieval. *Neuroimage*, *49*(4), 3404-3413.

Khattak, K. (2021). The Effects of Binaural Beats on Working Memory. *SLC Undergraduate Writing Contest*, *4*.

Kim, C., Kroger, J. K., Calhoun, V. D., & Clark, V. P. (2015). The role of the frontopolar cortex in manipulation of integrated information in working memory. *Neuroscience letters*, *595*, 25-29.

Lane, J. D., Kasian, S. J., Owens, J. E., & Marsh, G. R. (1998). Binaural auditory beats affect vigilance performance and mood. *Physiology & Behavior*, *63*(2), 249–252.

Lapidus, K. A., Stern, E. R., Berlin, H. A., & Goodman, W. K. (2014). Neuromodulation for obsessive–compulsive disorder. *Neurotherapeutics*, *11*(3), 485-495.

McCracken, C. B., & Grace, A. A. (2007). High-frequency deep brain stimulation of the nucleus accumbens region suppresses neuronal activity and selectively modulates afferent drive in rat orbitofrontal cortex in vivo. *Journal of Neuroscience*, *27*(46), 12601-12610.

McFadden, D. (1998). Sex differences in the auditory system. *Developmental Neuropsychology*, *14*(2-3), 261-298.

McMurray, J. C. (2004). *Auditory binaural beats enhance EEG-measured beta wave activity in individuals with ADHD* (Doctoral dissertation, California State University, Northridge).

Moritz, S., Kloss, M., Jacobsen, D., Fricke, S., Cuttler, C., Brassen, S., & Hand, I. (2005). Neurocognitive impairment does not predict treatment outcome in obsessive–compulsive disorder. *Behaviour Research and Therapy*, *43*(6), 811-819.

Morrell, M. J. (2011). Responsive cortical stimulation for the treatment of medically intractable partial epilepsy. *Neurology*, *77*(13), 1295-1304.

Oberauer, K. (2009). Design for a working memory. *Psychology of learning and motivation*, *51*, 45-100.

Olivers, C. N., & Nieuwenhuis, S. (2006). The beneficial effects of additional task load, positive affect, and instruction on the attentional blink. *Journal of Experimental Psychology: Human Perception and Performance*, *32*(2), 364.

Olley, A., Malhi, G., & Sachdev, P. (2007). Memory and executive functioning in obsessive–compulsive disorder: a selective review. *Journal of affective disorders*, *104*(1-3), 15-23.

Osaka, M., Osaka, N., Kondo, H., Morishita, M., Fukuyama, H., Aso, T., & Shibasaki, H. (2003). The neural basis of individual differences in working memory capacity: an fMRI study. *NeuroImage*, *18*(3), 789-797.

Oster, G. (1973). Auditory beats in the brain. *Scientific American*, *229*(4), 94-103.

Queen, J. P., Quinn, G. P., & Keough, M. J. (2002). *Experimental design and data analysis for biologists*. Cambridge university press.

Reedijk, S. A., Bolders, A., & Hommel, B. (2013). The impact of binaural beats on creativity. *Frontiers in Human Neuroscience*, *7*, 786.

Reedijk, S. A., Bolders, A., Colzato, L. S., & Hommel, B. (2015). Eliminating the attentional blink through binaural beats: A case for tailored cognitive enhancement. *Frontiers in Psychiatry*, *6*, 82.

Roux, F., & Uhlhaas, P. J. (2014). Working memory and neural oscillations: alpha–gamma versus theta–gamma codes for distinct WM information?. *Trends in cognitive sciences*, *18*(1), 16-25.

Ryan, J. Morris. J. Yaffa. S. Peterson. L, (2006), Psychodiagnostic processes: Objective test of ability test-retest reliability of Wechsler memory scale. Form I, *Journal of Clinical Psychology*, *37*(4), 847-848.

Shahar, N., Teodorescu, A. R., Anholt, G. E., Karmon-Presser, A., & Meiran, N. (2017). Examining procedural working memory processing in obsessive-compulsive disorder. *Psychiatry research*, *253*, 197-204.

Tabatabaei, M., Salimi, M., & Nadi, S. (2014). [Comparison of Short Term (Visual, Audio, Associative Learning) Active and Long Term Memory between Strong and Weak Students in Persian Language dictation (persion)]. *New Educational Approaches*, *9*(2), 103-120.

Tolin, D. F., Abramowitz, J. S., Przeworski, A., & Foa, E. B. (2002). Thought suppression in obsessive-compulsive disorder. *Behaviour Research and Therapy*, *40*(11), 1255-1274.

Tomioka, M., Shimura, M., Hidaka, M., & Kubo, C. (2008). The reliability and validity of a Japanese version of symptom checklist 90 revised. *BioPsychoSocial Medicine*, *2*(1), 1-8.

Turow, G., & Lane, J. D. (2012). Binaural Beat Stimulation: Altering Vigilance and Mood States: Gabe Turow and James D. Lane. In *Music, Science, and the Rhythmic Brain* (pp. 131-145). Routledge.

Vernon, D. (2009). *Human potential: Exploring techniques used to enhance human performance.* Routledge.

Wahbeh, H., Calabrese, C., Zwickey, H., & Zajdel, D. (2007). Binaural beat technology in humans: A pilot study to assess neuropsychologic, physiologic, and electroencephalographic effects. *The Journal of Alternative and Complementary Medicine*, *13*(2), 199–206.

Wechsler, D. (1945). Wechsler memory scale.

Woody, S. R., Steketee, G., & Chambless, D. L. (1995). Reliability and validity of the Yale-Brown obsessive-compulsive scale. *Behaviour research and therapy*, *33*(5), 597-605.

Woo, T. U. W., Spencer, K., & McCarley, R. W. (2010). Gamma oscillation deficits and the onset and early progression of schizophrenia. *Harvard review of psychiatry*, *18*(3), 173-189.

Yamamoto, J., Suh, J., Takeuchi, D., & Tonegawa, S. (2014). Successful execution of working memory linked to synchronized high-frequency gamma oscillations. *Cell*, *157*(4), 845-857.

Yücel, M., Harrison, B. J., Wood, S. J., Fornito, A., Wellard, R. M., Pujol, J., ... & Pantelis, C. (2007). Functional and biochemical alterations of the medial frontal cortex in obsessive-compulsive disorder. *Archives of general psychiatry*, *64*(8), 946-955.

Tables and Figures:

Table1| The study variables according to the two groups at first time of study

Variables	Group			P-value
	Control (n=14)	Experimental (n=15)	Total (n=29)	
	Mean± SD	Mean± SD	Mean± SD	
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

Table2| The frequency distribution of age, education, marriage and occupation according to the two groups

Variable	Level	Group			P-value
		Control (n=14)	Experimental (n=15)	Total (n=29)	
		N (%)	N (%)	N (%)	
Age	≤ 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)	

Table3| The result of GEE regression for OCD variable between two groups

Stage	Group	β	SE	ŋ2	Observed Power	P-value	
						With in	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	

Table4| The result of GEE regression for working memory variable between two groups

Stage	Group	β	SE	ŋ2	Observed Power	P-value	
						With in	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	

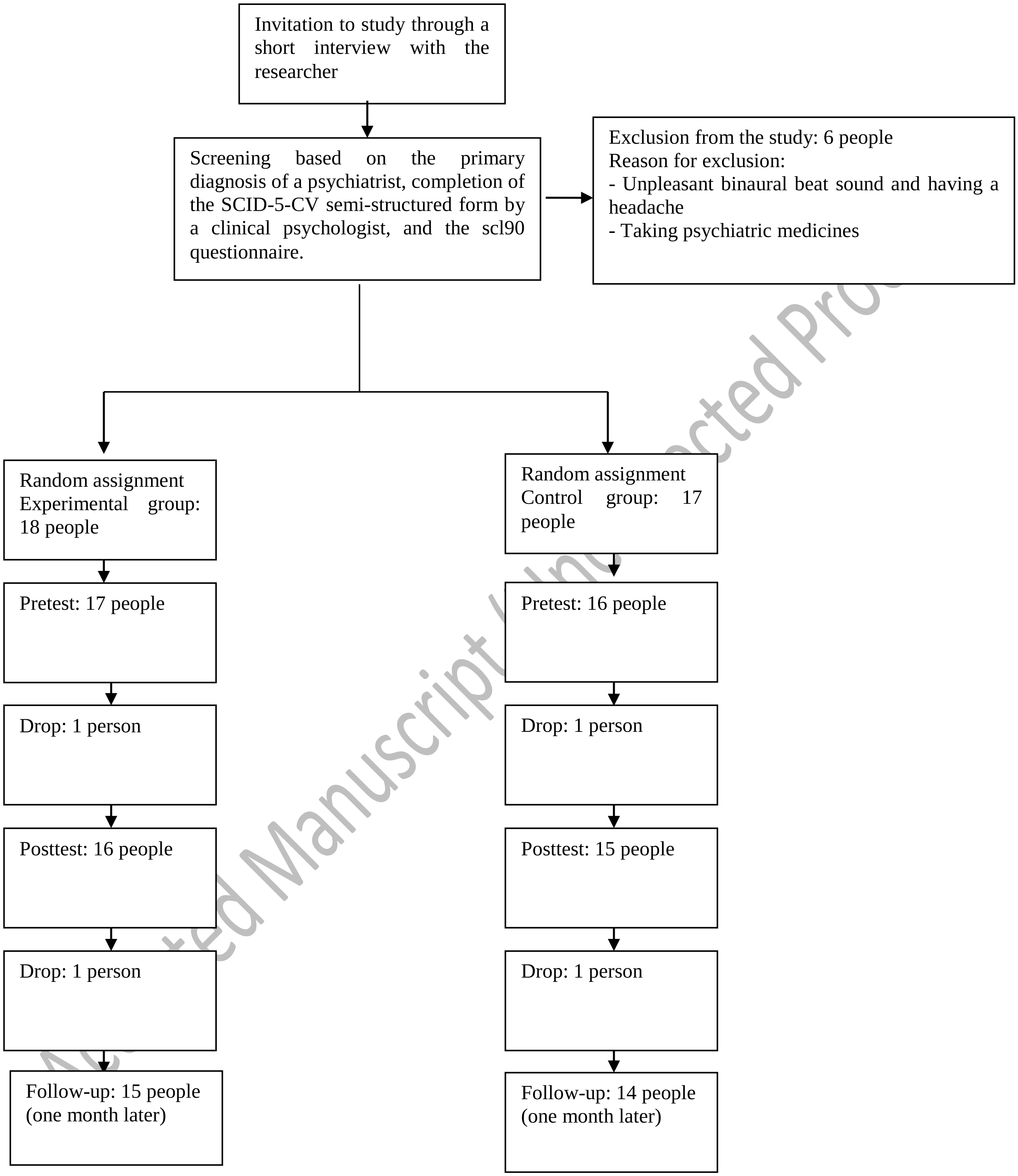

Figure 1: Consort flow diagram to illustrate the progress of patients through the trial