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A Proposal to Support Schizophrenia Patients: Mobile Application Based on Binaural Beats and 3D Avatar

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ABSTRACT

There are studies that show that abnormalities in processes and dynamics in the brains of schizophrenic patients cause high-frequency neural oscillations. Patients may experience instantly developing hallucination crises because of these oscillations, and there is no health service that patients can receive support from at any time in these sudden crises. In this study, the first results of the avatar-based mobile application that is supported by binaural beats (BB) are shared, which provides positive effects in other diseases and will reduce the high-frequency abnormal oscillations in the brains of schizophrenia patients to the range seen in healthy individuals. Audio files that contained motivational phrases supported by BBs shaped by semi-structured interviews with patients were created in the first step. These files were added to the designed three-dimensional avatars and transferred to the mobile application in the second step. The study results were evaluated using qualitative and quantitative methods. While the qualitative tools consisted of semi-structured interviews conducted with patients and their relatives and clinical observations by the responsible physician, the quantitative tools were four psychiatric scales. These evaluation methods were applied before and after the voice therapy and before and after the avatar therapy. Four schizophrenia patients were included in the study, designed in a cross-sectional design. The effects that improved the quality of life of two patients who adhered to therapy were observed. This study presents the first results of an avatar-supported mobile application that uses BBs and that schizophrenia patients can access at any time.

Index Terms— Avatar, binaural beats, schizophrenia, mobile health, mHealth

I. INTRODUCTION

The brain is constantly active and has an organized structure in itself. It performs all sensory perceptions with complex processes and dynamics. Studies show that schizophrenia may be the result of abnormalities occurring in these processes and dynamics rather than being defects in brain regions [1]. Interneurons, which make up the neural circuits, play roles in the formation of neural oscillations [2]. These interneurons that establish connections with receptors such as gamma-aminobutyric acid and *N*-methyl-D-aspartate create high-frequency oscillations in the brain [1], [3]. These high-frequency oscillations, which correspond to beta and gamma activities, are especially associated with positive symptoms in schizophrenia. There are electroencephalography (EEG) studies that show that abnormal activity is associated with auditory hallucinations [4]–[10]. Also, magnetoencephalography (MEG) studies associate abnormalities in theta, delta, alpha, and beta bands with auditory hallucinations, except for gamma, which has the highest frequency [11], [12]. Kumar et al. [13] examined the brain activity of a patient who suffered from musical hallucinations and, based on the MEG results, found that there was an increase in the power in the gamma, beta, and alpha frequency bands when the patient heard musical hallucinations. Similarly, Baldeweg et al. [14] also observed increased gamma oscillations according to the EEG results of a patient suffering from somatic hallucinations. There are studies that show that all these frequency abnormalities cause disruptions in cognitive and perspective paradigms in patients (as well as hallucinations) [7] and cause disorders in connection and attention functions along with perceptual disorders [9]. Results of previous studies prove that abnormalities in neural oscillations are an open subject for studies in the treatment of schizophrenia [1], [15], [16].

Schizophrenia mainly manifests as positive and negative symptoms. Although regular antipsychotic use is sufficient in cases with positive symptoms [17], cognitive-behavioral therapies and

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social skills training are used as supportive modalities in addition to antipsychotics in cases showing negative symptoms and irregular behaviors [18]. Since regular use of antipsychotics is uncommon, therapy is applied to patients who show positive symptoms to offset this situation. In cases with positive and negative symptoms or irregular use of antipsychotics, uninterrupted availability of supportive therapy methods is important because of the dynamic nature of the disease, which may, however, not always be possible. The requirement for accessible methods emerged as a result, and studies were conducted to provide support through virtual platforms, especially mobile applications, based on the 70% participation of psychosis patients in mobile health services [19]. High success rates of mobile applications such as FOCUS [20], PRIME [21], and A4I [22] that were developed for the treatment and follow-up of schizophrenia patients also support this. However, the constant renewal of mobile platforms that incorporate rapidly developing technologies necessitates regular updates to these mobile applications. As a result, additional costs appear as the newer mobile applications are made in tandem with the most recent devices, which prevents accessibility [23]. Another limitation is that such mobile applications are text based; patients, especially those who are illiterate, may not be able to reap the full extent of the benefits as self-expression is inhibited [20], [24]. Studies using avatars achieved effective results and eliminated these problems [25], [26]. However, the problem with avatars is that they are not on a mobile platform and do not provide access at all times.

In this study, the initial results of the treatment support and follow-up application are shared with the avatar-based mobile structure accessible at any time, reducing high-frequency neural oscillations to a healthy frequency range by using binaural beat (BB) tones.

II. AIMS AND OBJECTIVES

The purposes of the mobile application design that was based on BB tones and a three-dimensional (3D) avatar developed for schizophrenia patients were:

1. Although a neural oscillation in the low-frequency range such as theta, delta, and alpha are detected in the brains of healthy individuals, this increases to beta and gamma levels in schizophrenic patients [1]. There are studies that show that the use of BB tones in diseases such as depression, anxiety, and attention disorder in which neural oscillations are impaired reduces the symptoms of these diseases [27]. Based on this point of view, the first purpose of this study was to examine the positive effects of the BB tones detected in other diseases on the symptoms of schizophrenia.
2. Healthcare services do not have a structure that can always provide support for psychosis situations such as schizophrenia, bipolar disorder, and paranoia. For this reason, many studies are conducted based on mobile applications and virtual platforms to provide instant support remotely in sudden exacerbations. Mobile applications cannot be used effectively because of their text-based structure and constant cost requirement [28], and avatars are limited because they cannot be reached at all times, increasing the quality of life that is instantly impaired because of their clinic-based structure [29]. Since the avatar-based mobile application designed in the scope of the proposed study is created with Unity 3D infrastructure, it provides solutions to the costs and update problems. It aims to transform the weakened object relations into positive ones in conditions when negative symptoms emerge by combining two separate methods with the addition of avatar support.

III. METHODOLOGY

The present study was approved by İstanbul University Clinical Research Ethics Committee with the decision number 1416 on 22.11.2019.

A. Settings

In line with the two objectives mentioned in the previous sections, patients diagnosed with schizophrenia who were treated at the İstanbul University (IU) Faculty of Medicine Hospital Psychiatry Clinic were included in the scope of the study. The study consisted of 10 stages.

1. Assessment of the situation and application of psychiatric scales accompanied by the guidance of a physician,
2. Creation of the BB sound frequency-based motivational phrases,
3. Teaching the use of BB voice therapy to the patients and their relatives,
4. Binaural beat frequency voice therapy (2 months),
5. Clinical evaluations of the feedback of the participants on the audio files they listened to in individual environments under the follow-up of the psychiatrist and practitioner,
6. The design of the avatar was supported by BB tones.
7. Transferring the avatar to the mobile application,
8. Installing the mobile application to the phone of the participant, and teaching the patient/relatives how to use it,
9. Binaural beat frequency-supported avatar therapy (1 month),
10. Performing clinical and technical evaluations of the feedback of the participants about the mobile application they used in individual environments under the follow-up of the psychiatrist and the practitioner.

B. Participants

The study was conducted with patients who had schizophrenia, who received outpatient treatment in the Faculty of Medicine of the Psychiatry Clinic of xU, followed up regularly by the same physician, who had not undergone any significant changes in terms of drug treatments recently, and whose sociodemographic data are given in Table I. Four schizophrenic patients and their relatives, who participated in the study, were informed that the study, accompanied by the responsible physician, is a supportive treatment, and consent forms were signed by reading these forms. In the same interviews, a preliminary interview was made with the patient, the patient's relatives, and the physician about the disease, and detailed information was obtained about the history of the disease, the content and frequency of the hallucinations, and the factors that triggered the disease.

C. Creation of Binaural Beat Sound Frequency-Based Motivation Phrases

1) Binaural Beat Sound Frequencies

When two different frequency tones are given separately to ears with normal hearing, the person perceives a third tone, which has a frequency equal to the difference between these two tones. This third tone, which occurs in the inferior colliculus, is called the binaural beat tone [30]. Binaural beat tones cause changes in signal morphology in the brain [31]–[34].

TABLE I. SOCIODEMOGRAPHIC PROFILE OF PATIENTS

Patient No.	Age	Sex	Education	Duration of Illness (Years)	Work Situation	Comorbidity
1	26	Male	High school	9	Employed	None
2	63	Female	University	40	Retired	None
3	25	Male	High school	8	Unemployed	None
4	25	Male	High school	10	Unemployed	None

To observe the psychological and physiological effects of BB tones, Wahbeh et al. [35] conducted a study with 8 healthy individuals who listened to BB in the delta (0–4 Hz) band for 60 days. They reported decreased anxiety and dopamine values and increased quality of life. In similar studies, decreased anxiety and stress levels and a state of relaxation were observed in healthy individuals with delta and alpha bands [27], [36]–[40]. In BB studies conducted with higher frequencies such as beta and gamma, improvements were detected in cognitive abilities such as working memory, attention, and concentration [37], [41]–[43]. Studies conducted on neural oscillations reported higher frequency oscillations in schizophrenia patients when compared to healthy controls [44]–[46]. Based on this point of view, in the present study, BB frequencies, which aim to approximate the neural oscillations that are disrupted by schizophrenia, to healthy reference signal values, were created. Motivational phrases that were created specifically for each hallucination were superimposed on BB tones.

2) Motivational Phrases and Themes

The topographic model, which was proposed by Freud, claims that there is an underlying childhood trauma in every neurotic conflict and that it is later thrown out of awareness at a conscious level, and the individual is protected from painful experiences [47]. Humans face many micro- and macro-level traumas from birth to death. They cope with some in a healthy way with the defense mechanisms they create, while they cope with pathology in others. In the present study, special motivational phrases were created for each patient with the view that the different contents of hallucinations are the output of the defense mechanisms, moral anxiety, reality anxiety, etc.

There were four different hallucination contents in the participants, which included;

1. Religious pressure and discomfort due to crowds,
2. Sexual pressure and discomfort due to strangers and/or people they have just met,
3. Masochistic thought dominance and tension in crowds,
4. Avoidance of crowds and fear of losing one's family.

In the study conducted with alpha frequency, an increase was detected in the relaxation state and the amount of serotonin in individuals [48]. There are studies that show that beta frequency increases attention and focus, suggesting that learning and memory retention are strengthened [49]. There are also several other studies that show that theta and delta frequencies decrease depression and anxiety [35], [37], [50]. Based on all these data, these frequencies were superimposed on individual motivational phrase contents. The examples of sample motivational phrases created specifically for the participants and some of the BB frequency values that support the effects of these phrases are given in Table II.

Turkish text-to-speech commercial products were used in the vocalization of the motivational phrases. To do this, the Generate Speech feature of the Adobe Audition CC 2019 (©2019 Adobe) application was used. An approximately 3-minute-long positive and motivating hallucination was simulated by adding echoes and male-female mixed voices, similar to the hallucinations heard by the patients, to the spoken phrases, in contrast to the hallucinations the patients were suffering from.

The Multitrack feature of Adobe Audition CC 2019 (©2019 Adobe) was used again to combine these audio files with BB tones. Sound files that were prepared with Generate Speech were placed on a layer in the Multitrack Application, and a sound recording was created. Echoes and repetitions were added to another layer for simulation purposes, and BB frequencies were added to the final layer (Fig. 1).

TABLE II. SAMPLE MOTIVATIONAL PHRASES THAT WERE PREPARED SPECIFICALLY FOR THE PARTICIPANTS, SUPPORTIVE BINAURAL BEAT FREQUENCY VALUES, AND THE REASONS FOR CHOOSING THE FREQUENCIES

Sample Motivational Phrase	Supporting Binaural Beat Frequency	Reason for Choosing This Frequency
"You are very precious. You are so special. Every life is precious, and you are very precious. No one can make you feel worthless without your consent."	Theta	Reduction of the anxiety about painful thoughts
"Recognize your own value. Realize what you can do. Realize that you can succeed."	Alpha	Improving the mood of the patient, and providing the patient with a state of relaxation
"You can love men. You may like men. You can be with men. All of these very natural and beautiful things. Do not let your emotions scare you"	Delta	Reducing the anxiety about the problem of the patient, and naturalizing the situation
"Everyone around you is human, just like you. There is nothing to refrain from people. You are a strong individual. Rely on yourself"	Beta	Increasing the self-confidence of the patient by enabling him/her to focus on the phrase

Fig. 1. Adobe Audition CC 2019 (©2019 Adobe) Multitrack screenshot (green waves represent motivational phrases, purple waves represent echoes and repetitions, and yellow waves indicate binaural beat frequencies).

3) 3D Avatar Design

An application with Unity 3D version 2019.1.4f1 (©2019 Unity Technologies) was used for the 3D avatar design. Unity 3D is a versatile and comprehensive game engine using 2D and 3D graphics. It can be shaped to suit various platforms because it is a game engine. Unity 3D was chosen for reasons such as having wide application support for character design and being easily applicable in animation and voiceover control.

The avatars were voiced with audio files containing BB tones that were prepared beforehand. A natural image was obtained by changing the facial expressions of the avatar in line with the words. In this way, four avatars that had the same avatar image and that spoke in different themes were obtained. These avatars were computerized for clinical therapies and were then adapted to the mobile environment so that the patient could benefit from them outside of the examination.

4) Procedure

The therapy procedure was applied as described in the "Settings" section.

The clinical status of the patient before the study was evaluated with the Brief Psychiatric Assessment Scale [51], the Global Assessment Scale [52], the Scale for Assessment of Positive Symptoms [53], and the Visual Analog Scale by psychiatry residents with the recommendation of the responsible physician. The qualitative data obtained from the patients and their relatives and the quantitative results of the scales applied were used for qualitative and quantitative analyses. The intention was not to draw any conclusions regarding treatment. Also, information was obtained about the course of the disease, daily routine, and socioeconomic status of the individuals from the patients and their relatives through semi-structured interviews. All these measurements and evaluations were repeated three times: before the voice therapy and before and after the avatar therapy. The general follow-up of the process was provided with semi-structured telephone conversations with the patients (daily) and their relatives (weekly) (Fig. 2).

The participants listened to BB tones that contained special motivational phrases from the application that was set up on their mobile phones for at least 15 minutes a day for 2 months with stereo headphones. The minimum amount of time needed for drug treatment is approximately 8 weeks [54]. Binaural beat tones also have similar effects with drugs and affect neurotransmitters such as serotonin and dopamine [35]. For this reason, the process of voice therapy was determined to last 2 months. At the end of the process, the psychiatric scales were re-administered. Semi-structured interviews were repeated with patients and their relatives, and the effects of voice therapy on the quality of life were evaluated. Previous data and findings from these interviews, the effects of the therapy, and its contribution to treatment were evaluated by the research team.

In the next step, the avatar therapy application was initiated as described in the procedure. Similar steps were repeated again at the end of the process.

IV. RESULTS AND DISCUSSION

The results of the psychiatric scales are given in Table III. Different results were obtained for the 4 patients who participated in the study. For this reason, the therapy process of each patient was examined individually.

For patient 1, with whom the theme "Religious oppression and crowd discomfort" was examined, clinical findings and complaints before the study were as follows:

1. The patient had an auditory crisis that lasted for an average of 1–1.30 hours, which disturbed him every Monday at approximately 17.00.
2. Auditory hallucination accompanying questioning of belief in religious rituals with despising expressions.

Fig. 2. Final state of the 3D avatar designed.

3. The patient felt uneasy in crowded environments.

After the voice therapy;

1. The patient stated that the crisis period shortened every Monday and that he did not feel the discomfort he had previously felt. He also stated that the regular crisis starting time became irregular.
2. Reduced discomfort experienced in religious rituals and relief in questioning beliefs,
3. The patient also stated that he felt more comfortable in crowds.

After the avatar therapy, the patient said that the relief continued after voice therapy; however, he also experienced a more pronounced effect than in voice therapy. The relatives of the patient also said that the treatment was good for the patient and that the patient started listening to music, although he did not used to do so. The patient, who was interviewed at the end of the avatar therapy, said that he was more satisfied with the voice therapy because he listened longer and thought that it had better effects. The clinical observation findings of the psychiatrist who followed the patient were consistent with the statements of the patient and relatives.

Patient 2, with whom the "Sexual pressure and discomfort from strangers and/or new acquaintances" theme was examined, heard sexual voices that were offensive and insulting for both the patient and for the people around. The patient left the study because she did not feel well 9 days after starting voice therapy in addition to treatment.

Patient 3, with whom the "Masochistic thought dominance and tension in crowds" theme was examined, suffered from auditory hallucinations, which ranged from negative statements such as "you must suffer" to guidance in daily life, especially in public transportation. The patient was followed up only by communicating with the patient's relatives during therapy, on his request. Shortly after, the patient was excluded from the study because she left the İstanbulx University Psychiatry Clinic treatment unit.

For patient 4, with whom the "Fear of crowds and fear of losing family" theme was examined, the clinical findings and complaints included the following:

1. Fear of harm to his family because of the voices of his relatives threatening the life of the patient's family,
2. The patient felt uneasy because of the vocalizations and remarks he heard from the crowd in auditory hallucinations.

After the voice therapy,

1. The patient started asking a close relative to accompany him to hospital appointments.
2. The patient also started the painting course again, which he had left by the order of his hallucinations before the therapy.

After the avatar therapy, the auditory hallucination contents of the patient turned into contents that made the patient feel valued. In the interview conducted after the avatar therapy, the relative of the patient said that the music changed from a sombre religious genre to a more cheerful popular one. At the end of the study, the patient said that the avatar therapy was more convincing because it felt as if he was talking to a human. The results of the psychiatric scale also support the patient's opinions.

In conclusion, positive effects were seen in patients who adhered to this palliative therapy during the defined period. Patient 3, who started a separate treatment process at another facility, was excluded from the study, and patient 2 left the study voluntarily.

TABLE III. RESULTS OF THE PSYCHIATRIC SCALES

Patients	Patient 1			Patient 2			Patient 3			Patient 4		
Scales	Pre-BB Therapy	Pre-Avatar Therapy	Post-Therapy	Pre-BB Therapy	Pre-Avatar Therapy	Post-Therapy	Pre-BB Therapy	Pre-Avatar Therapy	Post-Therapy	Pre-BB Therapy	Pre-Avatar Therapy	Post-Therapy
BPRS	35	36	33	40	0	0	53	43	0	40	33	31
GAS	65	65	65	55	0	0	25	40	0	65	65	70
SAPS	10	7	6	21	0	0	22	21	0	21	13	11
Visual Analog Scale (VAS)*												
Auditory hallucinations												
Severity	7	3	3	8	NA	NA	10	10	NA	3	5	3
Discomfort Degree	7	3	3	8	NA	NA	8	7	NA	4	2	1
Visual hallucinations												
Severity	2	0	0	0	NA	NA	0	10	NA	0	0	0
Discomfort Degree	0	0	0	0	NA	NA	0	7	NA	0	0	0

Note: BB = binaural beat; BPRS = Brief Psychiatric Assessment Scale; GAS = Global Assessment Scale; SAPS = Scale for Assessment of Positive Symptoms; VAS = Visual Analog Scale.*VAS is a scale in which the patient evaluates the severity of hallucinations and discomfort by choosing between 0 (the lowest) and 10 (the highest).

The other two patients reported that they were satisfied with the therapy and that they wanted to continue. The patients' relatives also observed that their conditions noticeably improved. It was reported that one of the patients previously did not even want to go to hospital appointments, but then he went to the hospital more regularly and willingly. The self-talk behavior that the hallucinations induced was also minimized in the same patient. Also, the patient, who dropped out of the painting course because of the directions of hallucinations, started to attend the course again during therapy, which indicates that the patient started to enjoy daily life and to feel comfortable in crowded environments, and made an effort to get better. The other patient said that "their voices," which bothered him during therapy, no longer caused as much discomfort. The patient's relatives also reported that he was more cheerful and sociable than before, and even the type of music he now listened to was more lively.

When the literature was reviewed, this was the first study in which BB tones were used in the treatment of schizophrenia patients. Also, both voice therapy and avatar therapy were prepared separately for each patient and can be adjusted according to the changing demands and needs of patients. The application was transferred to various platforms with the infrastructure provided by the game engine used in the avatar design, and consequently, the problems encountered in terms of updates were eliminated.

There were some limitations that affected the present study. The relatively small scale of sampling used in this study was one of the drawbacks that disallowed the generalization of the results. Also, the therapy process took place over a period of 3 months; nevertheless, a longer duration would have allowed for a more consistent and reliable outcome. For these reasons, including a larger sampling and observing the results of therapy longer will provide better scientifically viable data regarding the success of therapy outcomes.

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