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Evaluation of Speech-In-Noise Skills with Temporal Fine Structure Test in Patients with Depression

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ABSTRACT

Introduction: Communication between individuals is based on communication in noisy environments. However, audiological tests used for the evaluation of hearing levels or determination of hearing loss are usually applied in a quiet environment. This study aims to evaluate whether depression has an effect on speech-in-noise perception and supra-threshold auditory processing abilities, even in individuals without advanced age or hearing loss.

Methods: The study group comprised 29 individuals who did not have hearing loss but were diagnosed with depression. The control group consisted of 29 individuals who did not have hearing loss or a depression diagnosis. All participants underwent the Temporal Fine Structure adaptive frequency (TFS-AF) test to assess supra-threshold auditory processing abilities. The results were then compared between the study and control groups.

Results: The study revealed significant differences in TFS sensitivity scores between the study and control groups, with test scores in the depression group being significantly lower than those in the control group (p=0.000).

Conclusion: Depression can significantly affect auditory performance. Depression, alongside factors like hearing loss and aging, can impact auditory functions like speech intelligibility. Therefore, a more holistic approach that considers emotional status is essential for comprehensively evaluating listening skills and auditory functions, even in individuals without hearing loss.

Keywords: Auditory performance, depression, speech-in-noise perception, suprahtreshold auditory

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INTRODUCTION

In daily life, communication often occurs in noisy environments rather than quiet ones, requiring individuals to process audible sounds while background noise persists (1). Audiological tests, whether subjective or objective, are typically conducted in quiet settings to evaluate hearing levels or detect hearing loss; however, these tests may not fully capture the hearing challenges that impact daily communication. While the audibility of stimuli is the primary requirement for speech comprehension in quiet conditions, noisy environments introduce additional factors such as age, mood, and cognitive skills, which are as influential as hearing levels (2). Consequently, in certain cases, suprathreshold or psychoacoustic/psychophysical tests become essential for assessing speech comprehension and discrimination abilities, particularly in noisy contexts (3).

In suprathreshold auditory processing disorder, communication problems may be observed even if hearing is at normal levels. The most common causes of this condition include spectral distortions and central effects of presbycusis resulting in impaired suprathreshold processing. Aging, noise-induced hearing loss (NIHL) and neurodegenerative pathologies such as dementia and Alzheimer's disease are the leading causes of impaired suprathreshold listening skills. With or without hearing loss, decrease in speech perception and word discrimination function in noise can negatively affect the quality of life, causing the person to experience social isolation and become risky for depressive disorders (4).

Highlights

- **Depression impairs supra-threshold processing despite normal hearing.**
- **TFS-AF provides insight beyond standard audiometry.**
- **Speech-in-noise is affected by cognitive and emotional factors.**

Depression, is a mood disorder which is quite common today and may affect cognitive functions and communication skills and may make the existing problems more prominent (5). The presence of depression is claimed to be a risk factor for communication disorder in individuals

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(6). Although there is not much information in the literature on this subject, especially auditory difficulties, speech and hearing perception of individuals, it is known that verbal fluency decreases in patients with major depressive disorder (7). Due to the attention and cognitive control problems seen in depression, impaired speech perception in a noisy environment can also be expected (8).

In a nonclinical sample, Chandrasekaran et al. (9) investigated the connection between depression and speech perception in noise and they exhibit that normal hearing young adults with self-reported elevated depressive symptoms show speech perception impairment in conditions with speech maskers, but not with non-speech maskers.

The results indicated that depression-related deficits in speech perception may be associated with heightened distractibility attributable to linguistic interference from background talkers.

The aim of this study was to investigate the effects of depression on speech perception in noise and suprathreshold processing skills. For this purpose, speech in noise comprehension and suprathreshold auditory processing skills were evaluated with the Temporal fine structure adaptive frequency (TFS-AF) test. It was hypothesized that individuals diagnosed with major depression would have impaired suprathreshold processing skills and, therefore, would have difficulty in speech in noise comprehension.

Temporal fine structure information aims to improve speech intelligibility, especially in the presence of background noise, by enabling the separation of the target stimulus and background noise based on differences in fundamental frequency (10). Binaural processing of TFS information facilitates the spatial discrimination of speech sounds in the presence of background noise (11). Temporal fine structure is not a language-dependent test. It can therefore be administered regardless of the native language of the participant.

Since the TFS-1 test, which evaluates the monaural sensitivity of the TFS test, is difficult to apply in elderly patients and the sensitivity of the test decreases at some frequencies. Therefore Hopkins and Moore (12) started to use the TFS-LF (Low Frequency) test developed in 2010 to evaluate the binaural TFS sensitivity of listeners. However, since the ability of this test to detect the phase difference between the ears decreases above a certain frequency, Fullgrabe et al. (13) modified the TFS-LF test and developed the TFS-AF (Adaptive Frequency) test in 2017. In this method called TFS-AF, the frequency changes adaptively. In the TFS-AF test, the sound intensity was adjusted to 30 dB SL (Sound Level) at all frequencies matching the participants' hearing thresholds in the HL (Hearing Level) unit in the frequency range of 0.125 kHz and 2 kHz (13). With the help of this method, even listeners who cannot fulfil the TFS-LF test are expected to perform the TFS-AF test at low frequencies (14).

The test consists of 2 intervals separated by 500 ms. In both intervals, 4 consecutive sounds of 400 ms are separated by 100 ms. While the interaural phase difference (IPD) of all tones in any randomly selected interval is 0° (standard), the IPD of one and three tones in the other interval (intended) is the same as in the standard interval, while the IPD of two and four tones is different due to the value of ϕ. An individual with normal TFS sensitivity perceives tones with IPD=0° in the center of the head. In contrast, tones with sufficiently large IPD can be perceived lateralized to one ear, so it is possible to identify a variable string with the information on the phase difference between the ears (14).

While the frequency was adaptively increased in the TFS test, the 2-ascending 1-descending digit rule was applied for a correct point estimate of 71% in the psychometric function (15).

Phase difference is defined as the discrimination of the onset times of the presented auditory signals, and TFS evaluates it. The interaural time difference and phase difference (IPD) of the sounds are changed to assess the sensitivity of binaural TFS.

Acoustic information in the auditory system is represented by cycle-by-cycle phase variations (TFS) and dynamic amplitude variations (envelope; ENV)(16). This information is transmitted through cochlear neuron spikes' firing rate and timing (rate-place vs. temporal coding). Neurons robustly phase-lock to TFS and ENV with TFS phase-locking extending up to at least 1000 Hz (16).

While peripheral rate-place coding is consistent throughout the auditory system, the upper limit of phase-locking shifts to lower frequencies along the ascending pathway (17).

Understanding how this metabolically costly initial temporal code affects everyday hearing and contributes to perceptual deficits are key question in auditory neuroscience and clinical audiology (18).

However, the significance of TFS coding and the importance of TFS for spatial or pitch-based masking release in noise is still under debate, particularly when other redundant cues can also provide information about pitch or location (19,20).

METHODS

Procedure and Sample

This study was approved by the Non-Interventional Clinical Research Ethics Committee of Başkent University (Project No: KA20/97) and found ethically appropriate with Decision No: 20/57.

Participants were enrolled consecutively as they met the inclusion criteria, ensuring an unbiased and systematic selection process. Patients between the ages of 18–45 who were part of a psychiatry outpatient clinic and were diagnosed with major depression were included in the study. The control group included individuals in a similar age range who had visited the otorhinolaringology outpatient clinic for another complaint and did not have a diagnosis of depression. Informed consent forms have been obtained from participants in both groups.

The patients in the case group and the control group underwent ear, nose and throat examination followed by pure tone audiometry evaluations. Beck Depression Scale was also administered to the patients in the case and control groups for mood assessment. Patients with neurological and/or additional psychiatric disorders and receiving medical treatment for these reasons, hearing thresholds worse than 25 dB, evidence of perforation of the tympanic membrane or external auditory canal on otological examination, chronic tinnitus and receiving medical treatment for this reason, and history of otological surgery were excluded. Temporal fine structure (TFS-AF) test was performed for the appropriate patients. Individuals were practised to learn the test before recording. The test was performed in a sound-protected room using Sennheiser HDA 200 headphones. The application temporal of the test was approximately 15–20 minutes. The starting frequency of the test is 200 Hz. The programme automatically adjusts the sound level at the matching frequencies to 30 dB SL, using the participant's audiometric hearing thresholds at 2 kHz and below as the loudness.

Materials

In our study, the binaural adaptive TFS –AF test was used. Participants were asked in which of the two audio sequences they listened to which of the two audio sequences the presented sounds 'seemed to move from

Table 1. Age and gender distribution of participants in the study and control group

Group	Number (n)	Age (Min; Max)	Age (Mean ± SD)	Female (n)	%	Male (n)	%
Case	29	26; 45	33.6±5.53	18	62.1	11	37.9
Control	29	26; 45	36.2±5.36	12	41.4	17	58.6
Total	58	26; 45	34.9±5.55	30	51.7	28	48.3

Mean, Standard Deviation (SD); Min: minimum score (or minimum value); Max: maximum score (or maximum value); Case Group: depression group; Control Group: healthy control.

Table 2. Pure tone audiometry test results comparison

Test	Group	Min		Max		Mean ± SD	
		Right	Left	Right	Left	Right	Left
Airway Hearing	Case	5	5	22	25	11.6±4.91	11.0±5.19
	Control	5	5	22	25	12.6±4.74	11.6±5.18
Bone Path Hearing	Case	0	0	15	15	8.8±4.75	8.3±4.07
	Control	0	0	15	20	8.8±4.36	7.7±3.92

Table 3. Comparison of TFS sensitivity test findings between groups

Group	TFS			
	Mean ± SD	Median (Min; Max)	Test	p
Case	664.63±470.86	549.1(123.7; 1754)	76.000	000*
Control	1526.05±486.92	1425(847.1; 2860.4)		

SD: standard deviation; *p<0.05; Case Group: depression group; Control Group: healthy control.

one side to the other' in the head (moving sound, still sound were asked to be differentiated) and the answers were recorded.

Beck Depression Inventory (BDI): The BDI is a self-rating scale developed by Beck et. al. (21).

The 21 multiple-choice items in BDI evaluate a range of cognitive, emotional, and somatic symptoms related to depression. Respondents score the severity of their depression symptoms for the last two weeks using a 0–3 answer range. Higher total scores indicate more severe depressive symptoms. The total score can vary from 0 to 63. In Türkiye, validity and reliability studies were carried out by Hisli (22). The Turkish version's reliability analysis yielded a Cronbach's alpha coefficient of 0.80 (23).

Statistical analysis

IBM Statistical Package for Social Sciences (SPSS) program version 26 software was used for statistical evaluation of the data. Descriptive statistics were calculated as number, percentage, mean, standard deviation, median and min-max. Shapiro-Wilk test was applied to determine whether the data set conformed to normal distribution.

RESULTS

A total of 29 participants, consisting of 12 females and 17 males, were included in the control group, while the study group included 18 females and 11 males (totaly 29 patients) who were diagnosed with depression.

Of the individuals in the study group, 62% (18) were female and 38% (11) were male, while in the control group, 41% (12) were female and 59% (17) were male. No significant difference was found between the study and control groups in terms of gender (p=0.189).

The mean age of individuals in the study group was 33.6±5.53 years, with an age range of 26–45, while the mean age in the control group was 36.2±5.36 years, also with an age range of 26–45.

No significant difference was found between the study and control groups in terms of age (p=0.076). (Table 1)

Pure tone audiometry test was applied to the participants. The results for the control and study groups are shown in Table 2.

The Mann Whitney-U Test was used to investigate whether the mean thresholds for the right and left ears of the pure tone audiometry test applied to the participants differed between the study and control groups. As a result of pure tone audiometry performed on the participants, the mean airway hearing thresholds of 0.125–8 kHz did not show statistically significant difference between the study and control groups (right ear p=0.500; left ear p=0.633). Similarly, the mean bone conduction hearing thresholds at 0.5–4 kHz did not show statistically significant difference between the study and control groups (right ear p=0.896; left ear p=0.594).

The difference in TFS Sensitivity Test scores between the study and control groups was analyzed using the Mann-Whitney U Test. A statistically significant difference was found between the TFS Sensitivity Test scores of participants in the study group and those in the control group (p=0.000). The TFS Sensitivity Test scores of the study group were found to be lower than those of the control group. (Table 3)

According to the Beck depression inventory results of the participants in the study group, it is seen that 7% of them have minimal depression, 38% have mild depression, 48% have moderate depression and 7% have severe depression. The mean value of Beck depression inventory was 18.7±6.51 for the study group. There was no statistically significant difference between Beck depression results and gender (p=0.650).

DISCUSSION

Communication between individuals is very important for the maintenance of daily life and high quality of life. The most important steps of communication are speech and hearing function. Hearing function is assessed in clinical practice by determining thresholds in pure tones using objective and/or subjective audiological tests. However, the ability to communicate in daily life is associated with many complex processes such as perception, processing and interpretation of not only simple and threshold sounds but also complex and suprathreshold sounds. Many listeners experience communication problems even though their hearing thresholds are within normal limits, and the reason for this is often not revealed. It is thought that this may be due to suprathreshold processing deficits despite normal hearing thresholds as in the 'hidden hearing loss' (24).

In addition to hearing loss, low auditory performance may be due to impairments in cognitive processing or coding at peripheral and central

levels or other different reasons and the problem may need to be more accurately revealed by suprathreshold tests that evaluate functional hearing skills (1).

For the auditory performance of the participants in both groups in our study; audiometric examination (pure tone mean determination) as well as the TFS test, which can evaluate speech understanding in noise and suprathreshold auditory processing function, were applied. It was observed that the TFS performance of patients followed up with a diagnosis of depression was lower than healthy controls.

Depression may impact cognitive and executive functions in many ways. In relation to memory and learning; semantic memory (memory based on learnt information), episodic memory (memory acquired through events or experiences), working memory (short-term storage and manipulation of information) may be affected in depression (25).

Regarding creative functions, it has been reported that psychomotor functions such as high-level cognitive processing, planning and decision-making, mental flexibility, multitasking, and basic sensory, perceptual and motor functions are impaired (26,27).

Executive function refers to a set of cognitive processes involved in managing and controlling one's thoughts, actions and emotions to achieve a specific goal and is one of the higher-level functions of the brain. Executive functions help in the completion of tasks and interpersonal interaction. Processes related to attention and memory are also intertwined with executive functions (28,29).

The communication disruption due to hearing loss is one of the main reasons for social isolation (30), which has evolved to be a growing epidemic that is linked to some other mental and physical challenges such as depression (31), heart disease (32), dementia, and Alzheimer's disease (33,34).

Although hearing assistive technologies such as hearing aids and cochlear implants (CI) could help restore near-normal audibility in quiet, people with hearing loss struggle to converse in noisy listening environments. The failure of current hearing assistive technologies to restore hearing functions in noise is partly due to our limited understanding of how sounds are coded in the human auditory system.

Difficulty in understanding and distinguishing speech in noise may occur for different reasons depending on the underlying pathology. Hearing is closely related to attention. Our auditory system helps us focus on relevant sounds while filtering out irrelevant or distracting noise. Paying attention is crucial for the clear comprehension of heard sounds. Additionally, aging can lead to a decline in cognitive functions (e.g., slowing of working memory and reduced attention control) and disruptions in perceptual processing. Therefore, to exclude the effects of aging, individuals over the age of 45 were not included in our study.

For example, in cases of aging or noise-induced hearing loss factors such as hair cell loss or structural deterioration starting with inflammation in the cochlea, cochlear synaptopathy, loss of phase locking capacity with auditory nerve loss, neuronal loss in the cochlear nucleus, decreased sensitivity to the auditory signal with a decrease in neural synchrony, and thus a decrease in the neural presentation of speech sounds are effective.

Although depression has a physiopathology that has effects at the central level, information on how and why it negatively affects hearing in noise is not yet sufficient and is a subject open to research.

In many studies, depression and speech fluency and speech impairment have been investigated and found to be associated with each other and some different psychiatric diseases (35,36). For example; Vocal prosody measures were found to explain 60% of the variation in depression scores, indicating their potential as a diagnostic tool (37).

However, there are studies evaluating the relationship between depression and understanding speech in noise. Different tests such as Mismatch negativity (MMN), speech in noise test, etc. were used in these studies. But there are not many studies on speech and hearing perception, especially those using the TFS AF test. (6, 38).

MMN, a test that evaluates the early cortical processing of speech and hearing discrimination, is an auditory evoked potential produced by the brain's automatic response to a random change in the presented auditory stimulus that exceeds a certain limit and corresponds to a noticeable behavioural discrimination threshold. The MMN test is thought to reveal various abnormalities in cognitive functioning (39). The changes in MMN results support the hypothesis of impairment in the frontal network in the early stages of depression (40).

Xie et al. (41) reported that depression without hearing loss may result in low scores in sentence recognition and that depression may lead to high error rates in certain masking conditions in noise backgrounds. In alignment with the present study, the investigation by Xie et al. (41) also evaluated patients diagnosed with depression without hearing loss. However, in contrast to the findings reported in the extant literature, the TFS AF test was implemented in the present study. The TFS-AF test demonstrated a significant correlation with speech understanding skills in noise, suggesting a decline in these abilities.

In the literature, there are many studies that have evaluated TFS tests in relation to age, hearing loss and hearing aid users, cognitive functions, cochlear implant users, epilepsy, noise-induced hearing loss (42–44). As a result of these studies, it has been noted that TFS test results are negatively affected by advancing age. Binaural TFS sensitivity is worse in older adults compared to younger listeners, particularly in the presence of low-frequency hearing loss, which also reduces binaural TFS sensitivity. It is believed that age has a greater impact on TFS than hearing loss itself (13).

However, there are no studies in the literature that have evaluated TFS tests in individuals with depression or anxiety disorders. In this regard, our study is expected to contribute to the literature.

Although our study is novel in dealing with speech comprehension and discrimination in noise in depression, it has certain limitations. Firstly, the cognitive functions of depressed patients have not been evaluated in detail. By evaluating the cognitive functions of all participants in the study, the relationship between cognitive skills and depression should be included.

The relatively small number of participants in each group represents a notable limitation of this study, and larger samples would considerably strengthen the reliability of the findings. Incorporating individuals aged 65 and over – both those with normal hearing and those with hearing loss – into the study design would also be valuable, given the well-known contribution of aging to auditory and cognitive decline. Within the patient group, classifying participants according to depression severity and comparing their temporal fine structure test performance across these subgroups could reveal whether the degree of depressive symptomatology corresponds to measurable differences in auditory processing. Beyond hearing-specific measures, relating speech comprehension and discrimination-in-noise performance to attentional

capacity and standardized cognitive test scores would shed further light on how cognitive functioning shapes performance on temporal auditory tasks.

As a result, depression can be considered as a clinical condition that can lead to problems in speech perception, speech intelligibility and discrimination, especially in noisy environments Peripheral hearing, central pathways and auditory processing functions should be considered as a whole in the evaluation of hearing. It should be kept in mind that individuals without hearing loss may have decreased speech perception and discrimination, temporal resolution of hearing, speech discrimination in noise and auditory sensitivity. Especially in depression speech perception and discrimination can be impaired although there is no hearing loss.

Ethics Committee Approval: This study was approved by the Non-Interventional Clinical Research Ethics Committee of Başkent University (Project No: KA20/97) and found ethically appropriate with Decision No: 20/57.

Informed Consent: Informed consent forms have been obtained from participants..

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