Research Article

Comparison of Spectral and Temporal Processing Abilities between Adults with Stroke and Healthy Peers

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Highlights

- Stroke leads to disturbances in auditory temporal and spectral processing
- People with stroke have difficulty understanding speech in noise (SIN)
- Spectral and temporal cues play an important role in SIN perception

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ABSTRACT

Background and Aim: Perception of speech in noise (SIN) is based on the accurate extraction of spectral and temporal cues. Disruption of this process can reduce the productivity of the spectral and temporal features of the target stimulus and speech recognition in noise. Auditory processing disorder is one of the main challenges of people with stroke, which leads to social, mental, and even physical failures. This study aimed to investigate the spectral and temporal processing abilities of people with stroke compared to healthy peers.

Methods: In this study, participants were 15 patients with stroke referred to the neurology clinic of Imam Khomeini Hospital and 30 healthy people aged 20–60 years. Spectral Modulation Detection Test (SMDT), Pitch Pattern Sequencing Test (PPST), Random Gap Detection Test (RGDT) and QuickSIN tests were performed for all participants. The mean scores of the two groups were compared.

Results: Patients with stroke had poorer performance in SMDT, PPST, RGDT and QuickSIN tests ($p<0.001$) compared to healthy subjects. The results showed that there was a significant correlation between SIN test with temporal and spectral processing in the normal group, but the correlation pattern was different in people with stroke. The scores of all the tests were not significantly different between the right and left ears.

Conclusion: The results showed that people with stroke have poorer performance in all tests compared to normal people and have more problems in speech perception in challenging areas.

Keywords: Auditory processing disorder; speech perception in noise; spectral modulation; temporal processing; stroke

Introduction

Stroke is one of the disorders of the nervous system, and is known as the third cause of death (after heart attack and cancer) and the first cause of disability in the world [1]. A stroke is caused by an interruption in the blood flow to cerebral vessels following bleeding, thrombosis, or embolism. Based on the cause of occurrence, stroke has two types: ischemic stroke and hemorrhagic stroke. Ischemic stroke is caused by a thrombus or a blood clot that develops in an artery and travels along with the blood flow to one of the blood supply arteries in the brain, blocking the blood flow and causing a stroke. Ischemic stroke accounts for about 85–90% of all stroke cases [2]. Hemorrhagic stroke, which is also called bleeding stroke, accounts for 10–15% of all stroke cases. Hemorrhagic stroke is often caused by the rupture of a blood vessel and leads to a decrease in blood flow and oxygen to the brain tissue [3]. According to a study, the prevalence of stroke in Iran is much higher than in other countries and occurs at a younger age [4]. The prevalence of this disease in the population under 60 years is also increasing due to the increase in blood pressure, diabetes, obesity, drug use and smoking [1].

A stroke can cause various symptoms, which vary depending on the extent and degree of vascular involvement in different areas of the brain. One of the complications of a stroke is the involvement of the auditory system. Different types of hearing disorders, such as peripheral hearing loss, central auditory processing disorder, and sudden hearing loss (which is less common) occur in people who have had a stroke [5]. Due to the involvement of the cerebral hemispheres in auditory processing and language functions, as well as the anatomical location of the lesion, different negative effects can be seen in the auditory processing of people with stroke. These effects are more pronounced in the temporal lobe and anterior frontal lobe [4, 6]. Approximately 1 in 5 patients with stroke has a serious complaint of difficulty understanding speech, especially in the presence of background noise [7].

The central auditory system uses spectro-temporal cues as the most important factors along with other auditory information such as spatial information to separate auditory targets and streams, leading to speech clarity, selective attention, and facilitation of detecting target stimulus from among unwanted stimuli [8-11]. Normal auditory hearing and processing leads to better understanding of speech, especially in challenging situations, and creates efficient communication between patients, caregivers, and specialists. Any disorder in the hearing system and weakness in speech perception can also limit the stroke patient's participation in rehabilitation programs and lead to the risk of physical deterioration [12]. People with stroke are more likely to develop dementia and cognitive problems than their peers. More than 50% of stroke patients develop some degree of cognitive impairment [13].

Auditory processing refers to a wide range of sensory and perceptual skills to extract meaningful information from sound. These skills include auditory discrimination, pattern recognition, and temporal processing (resolution, integration, and sequencing) [14, 15]. One of the most important problems caused by auditory processing disorder is temporal processing impairment. Temporal processing is directly related to speech perception, since understanding different speech sounds requires understanding their temporal difference [16, 17]. Temporal processing is defined as the perception of sound changes at a given time. Impaired temporal processing causes problems in understanding fast speech, distinguishing phonemes, understanding music and rhythm. Temporal processing such as temporal ordering and resolution play a decisive role in the recognition of acoustic features of speech such as prosodic, accent and rhythm features [18, 19]. The auditory system distinguishes the components of the target sound from the competing sounds based on differences in Spectral Modulation (SM) level and improves speech perception in environments with multiple sound sources. Therefore, sensitivity to SM is directly related to speech perception [20-23]. In this study, we aimed to investigate and compare spectral and temporal processing abilities of people with stroke and healthy individuals with normal hearing and to investigate the relationship of temporal and spectral processing with speech perception in noise. The Pitch Pattern Sequencing Test (PPST) and Random Gap Detection Test (RGDT) were used to evaluate the temporal processing of people, and the Spectral Modulation Detection Test (SMDT) was used to evaluate their spectral processing.

Methods

Two groups participated in this study. The control group was composed of 30 healthy people (9 males and 21 females; mean age: 33.43 years (SD: 4.57), ranged 20–60 years). The experimental group included 15 subjects with an acute history of ischemic or hemorrhagic stroke based on their brain MRI who had a stroke 4 weeks before the study (9 males and 6 females; mean age: 46.13 years (SD: 6.38), ranged 20–60 years) and referred to the neurology clinic of Imam Khomeini Hospital in Mahallat County, Markazi Province, Iran from February 2021 to August 2021. All participants were right-handed, Persian-speaking, with no aphasia or history of head trauma and seizures, and were able to cooperate in the tests. Their pure-tone hearing thresholds were ≥20 dB at 500–2000 Hz frequencies. The Mini-Mental State Examination (MMSE) test was carried out for all participants in both control and experimental groups, and those with cognitive problems were excluded from the study. A written consent was obtained from all participants.

Measures

Pitch pattern sequencing test

The PPST included 30 pitch patterns for each ear. It consisted of three 150-ms tones with a rise-fall time of 10 ms and two 200-ms time intervals. The tones in each pattern were presented at two frequencies of 880 Hz (low) and 1122 Hz (high). Therefore, six possible answer combinations were obtained from three tone sequences. The time interval between the presentation of each pattern was approximately 6 seconds.

Random gap detection test

The RGDT measures the shortest time gap between sound stimuli that a person can detect, and the stimuli included experimental tones containing silent pauses at different times. The duration of each tone was 17 ms with a rise-fall time of 1 ms. The interval between test options was 4.5 seconds. The silence interval between the test tones was in the range of 0–40 ms. To perform the test, the subject was asked whether s/he heard one or two tones. The results were recorded as the minimum interval detected between stimuli in ms at each frequency. Also, the overall average of the results for 4 frequencies of 500, 1000, 2000, and 4000 Hz was recorded in ms. Thresholds above 20 ms were considered abnormal.

Spectral modulation detection test

For the SMD, two SM densities of 0.5 and 4 cycles per octave were used. The 3-interval-3-alternative forced-choice (3I-3AFC) method was used to perform the SMDT [10]. Each attempt consisted of three intervals containing the sound stimulus and two silence intervals between the sound stimuli. Two intervals contained a stable noise stimulus (reference signal) and a modulated noise (target signal) that were randomly placed at one of the three stimulus intervals. The duration of reference and target signals was 500 ms and the duration of silence interval between the target and reference stimuli was 500 ms. The participants were asked to choose an interval that sounded generally different from the other two intervals [11]. In this test, higher negative (lower) thresholds indicate better performance.

Quick speech-in-noise test

In the QuickSIN test, five sentences are presented at different Signal-to-Noise Ratios (SNRs) from comfortable to difficult, and the person is asked to repeat the presented sentence. The test has 3 equivalent and stable lists. In this study, lists 1 and 2 were used for the left and right ears randomly. By maintaining the SNRs, they were presented through the headphone at a comfortable level using Adobe audition software in a coherent manner (signal and noise to one ear). In all tests, the loudness of the stimuli was 50 dB higher than the individual's hearing threshold [24].

Statistical analysis

Data analysis was performed in SPSS v.17. The significant level was set at 0.05. Descriptive statistics (mean, standard deviation, and percentage) were used to describe the data. Levene's test was used to examine the homogeneity of variance, and the Shapiro-Wilk test was used to evaluate the normality of data distribution. A multivariate test (ANOVA) was used to compare the two groups of control and experience. Independent t-test was used to compare the mean score of SMDT, PPST and RGDT between control and experimental groups. Paired t-test was used to compare the results between the left and right ears. Spearman correlation test was used to determine the correlation between QuickSIN test and PPTS, between QuickSIN and RGDT, and between QuickSIN and SMDT scores. Lower scores in this test indicate a better speech perception in the presence of noise.

Results

This study compared temporal and spectral auditory processing abilities of 15 patients with stroke and 30 healthy individuals. The mean SMDT, PPST and RGDT scores in both groups are presented in Table 1. There was a significant difference in the mean scores between the two groups ($p<0.001$). People with stroke had lower scores than healthy people. The results showed no significant difference in the mean scores between the two ears in any groups ($p<0.05$). The mean score of the QuickSIN test in experience group was significantly different from the control group (Table 1). Also, there was no significant difference in the QuickSIN test scores between the right and left ears in the two groups ($p>0.05$). The correlation between the scores of SMDT, PPST and RGDT with QuickSIN test score in two groups was examined separately. Spearman test was used to examine the correlation (Table 2). As can be seen, there was a strong correlation between the scores of SMDT, PPST, and RGDT and the QuickSIN test score in the right ear of control group. The results in experience group showed a moderate correlation between the right-ear QuickSIN test score and the left-ear PPST score, and a moderate correlation between the left-ear QuickSIN test score and the right-ear PPST and RGDT scores (Table 2).

Discussion

Stroke can cause central auditory processing disorder in addition to various auditory system disorders such as tinnitus and vertigo. To investigate the effects of stroke on temporal and spectral processing abilities, we used RGDT, PPST, SMDT and QuickSIN tests in this study and the results were compared between control group and experimental group.

In the PPST, the mean score in the control group was 90.75% for the right ear and 88.29% for the left ear. In the experimental group, the score was 74.45% for the right ear and 76.83% for the left ear, which indicates poor performance in pitch pattern sequencing in this group. The comparison showed a significant difference

Table 1. Comparison of the mean score of the pitch pattern, gap detection, spectral modulation detection test and quick speech in noise test for left and right ears between control and experience groups

Variable			Mean(SD) Experience	Mean(SD) Control	p
PPST	Right		74.45(13.98)	90.75(9.77)	<0.001
	Left		76.83(11)	88.29(10.75)	<0.001
RGDT	500 Hz		19.67(8.75)	10.57(4.47)	<0.001
	1000 Hz		17.33(8.63)	9.30(4.30)	<0.001
	2000 Hz		15.33(6.67)	8.70(4.79)	<0.001
	4000 Hz		17.67(5.30)	8.93(5.48)	<0.001
SMDT	Right	0.5 Hz	–5.26(3.66)	–12.20(4.96)	<0.001
		4 Hz	–3.46(3.34)	–12.78(5.88)	<0.001
	Left	0.5 Hz	–4.55(2.65)	–12.19(5.38)	<0.001
		4 Hz	–3.79(3.28)	–12.19(5.18)	<0.001
QuickSIN	Right		4.23(4.16)	–0.35(1.86)	<0.001
	Left		4.43(4.21)	–0.28(1.74)	<0.001

PPST; pitch pattern sequencing test, RGDT; random gap detection test, SMDT; spectral modulation detection test, SIN; speech in noise

Table 2. Correlation of quick speech in noise test with pitch pattern, gap detection, and spectral modulation detection test in control and experience groups

Variable			Control group		Experience group	
			QuickSIN (R)	QuickSIN (L)	QuickSIN (R)	QuickSIN (L)
			r(p)	r(p)	r(p)	r(p)
PPST	Right		-0.568(<0.001)	-0.638(<0.001)	-0.215(0.441)	-0.562(0.029)
	Left		-0.616(<0.001)	-0.639(<0.001)	-0.501(0.057)	-0.267(0.336)
SMDT	Right	0.5 Hz	-0.631(<0.001)	-0.301(0.106)	0.080(0.776)	-0.149(0.596)
		4 Hz	-0.411(0.024)	-0.347(0.060)	-0.029(0.919)	-0.231(0.407)
	Left	0.5 Hz	-0.511(0.004)	-0.290(0.120)	0.115(0.683)	-0.251(0.367)
		4 Hz	0.674(<0.001)	-0.608(<0.001)	0.072(0.800)	-0.123(0.662)
RGDT	500 Hz		0.817(<0.001)	0.656(<0.001)	0.003(0.991)	0.577(0.024)
	1000 Hz		0.492(0.006)	0.502(0.005)	0.116(0.681)	0.459(0.085)
	2000 Hz		0.515(0.004)	0.346(0.061)	0.162(0.565)	0.579(0.024)
	4000 Hz		0.705(<0.001)	0.623(<0.001)	0.290(0.294)	0.531(0.042)

QuickSIN; quick speech in noise, R; right ear, L; left ear, PPST; pitch pattern sequence test, SMDT; spectral modulation detection test, RGDT; Random gap detection test

between control group and experimental group for both ears. In the study by Foxton et al. on 10 adults with congenital amusia, it was seen that the ability to describe pitches decreased and there were deficits in the perception of pitch patterns, which can be caused by incomplete processing in the cerebral cortex [9]. This is consistent with our results, indicating a deficit in the temporal processing in people with stroke. The results of Bamio et al.'s study on 8 people with a history of stroke showed poor temporal processing using the duration pattern test and PPST [6]. The results of Jafari et al.'s study on patients with right- and left-brain stroke showed that in all stroke patients, the performance of temporal processing decreased which was greater in the ear opposite to the affected hemisphere [17]. The results of the present study are consistent with these studies.

In the SMDT using the SM densities of 0.5 and 4 cycles per octave, the results showed that the ability to detect SM in both densities and in both right and left ears in experience group was lower than incontrol group, indicating poor performance of experimental group in spectral processing. No similar study was found on SM detection in people with stroke, but other studies have examined the ability to detect SM in a variety of groups, including healthy children, children with hearing loss, healthy adults, hearing-impaired adults, and cochlear implant users [9, 14, 21, 24]. Studies on the SM sensitivity in individuals with hearing impairment and cochlear implant users indicated impaired SM sensitivity in their auditory system. They had poor performance in speech recognition, especially in noise. Impaired phase locking, reduced frequency selectivity, and temporal fine-structure damage were reported as the causes of decreased SM sensitivity in these individuals [22, 23]. Botticelli et al. conducted a study on 19 children and adolescents with stroke to investigate their central auditory processing ability using behavioral and electrophysiological tests. Based on their findings, children and adolescents with stroke had lower scores in these tests compared to the controls, which is consistent with the results of the present study [14].

The QuickSIN test was used in this study to evaluate the ability of participants to understand speech in noise. The findings showed a significant difference between experimental group and control group in their ability to understand speech in noise. In this test, experimental group achieved a 50% speech recognition score at higher SNRs, which increased as the test became more difficult (reduced SNRs). Raymer et al., in a study on the speech perception in noise of people with aphasia, concluded that this ability in these people is impaired and can be improved with Trivia Game [15]. Their results are consistent with our results.

In the present study RGDT, SMDT, PPST, and QuickSIN tests in both ears were performed separately and their results were compared. Findings showed no significant difference between the two ears in the two groups. Furthermore,the results of the present study about the correlation of temporal and spectral processing abilities with speech perception in noise in control group showed a strong correlation between them. In other words, encoding spectral and temporal clues is important in auditory processing related to speech perception. It seems that distorted representations of spectral and temporal clues in the auditory system can lead to speech perception in noise problems. Evaluation of the correlation between temporal and spectral processing levels and the QuickSIN test score in experimental group showed a moderate correlation between the right-ear QuickSIN test and left-ear PPST scores and between the left-ear QuickSIN and right-ear PPT scores. There was also a moderate correlation between the RGDT (at all frequencies) and left-ear QSIN test scores. Changes in the correlation level between different tests in experimental group can be due to differences in the variety and extent of the lesion in different patients. However, further studies using a larger sample size of people with stroke and examining other hearing processes along with temporal and spectral processing abilities are needed.

Based on the findings, the auditory problems caused by stroke are different depending on the extent of the auditory system involvement and the location of the brain damage. According to the findings of the present study, it seems that a deficit in the processing of spectral and temporal clues in the hearing system of people with a history of stroke can be a possible cause of their speech perception in noise. Difficulty in extracting spectral and temporal cues can lead to increased challenges in understanding speech in noisy environments [19]. In addition, weaker performance in central auditory processing tests indicates impairment in hearing performance, which has a significant impact on people's daily lives. As the limitations of this study, the exact location of lesions in stroke patients was not known in their medical records, and it was not possible to examine other spectral and temporal processing abilities due to the limited time of the tests and the tiredness of the participants.

Conclusion

Experimental group have poorer performance in random gap detection test, pitch pattern sequencing test, spectral modulation detection test, and quick speech in noise tests compared to control group. This can be due to the inability of the auditory system to encode and integrate spectral and temporal cues. Since the used temporal and spectral processing tests have non-verbal content, they are less dependent on cognitive processes and are easily applicable to individuals regardless of their academic and cognitive performance. Therefore, the use of these tests is recommended in the battery of tests for measuring auditory processing disorder of people with a history of stroke.

Ethical Considerations

Compliance with ethical guidelines

This study has received approval from the ethics committee of the University of Social Welfare and Rehabilitation Sciences (Code: IR.USWR. REC.1399.252).

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Authors' contributions

FMAA: Study design, acquisition of data, interpretation of the results, drafting the manuscript; SM: Study concept and design, interpretation of the results, administrative, technical support, study supervision; PJA: Analysis and interpretation of data, study supervision; EB: Statistical analysis.

Conflict of interest

There are no competing financial interests.

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