Research Article

Is There a Relationship between Sound Localization and Speech Processing Speed in the Elderly with Normal Hearing?

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Short running title: Is There a Relationship between Sound…

Highlights:
- Timing in ventral stream may plays an important role in the speech perception speed
- There is a negative correlation between localization (ITD error) and the TCST score
- There is a high correlation between ITDs (with low-pass noise) and the TCST score

ABSTRACT
Background and Aim: Many older adults experience difficulty in speech perception in noisy environments and fast speech. Speech perception is dependent on bottom-up and top-down auditory processing information. This study aimed to investigate the relationship between Interaural Time Difference (ITD) and speech processing speed in older adults with difficulty in speech perception in noise.
Methods: In this study, 36 Iranian older adults with normal hearing (23 men and 13 women) aged 65–75 years who had complaints about the difficulty with speech perception in noise, participated. The ITD test with two stimuli (high-pass and low-pass noise) was used to asess the auditory localization ability. Time-Compressed Speech Test (TCST) and reaction time test were used to measure their speech processing speed. Pearson correlation test was performed to examine the relationship between ITD and speech processing speed.

Results: The auditory localization errors were more significant for ITDs with low-pass noise than high-pass noise. The results showed a negative correlation between localization errors and the TCST score at time compression ratios of 40% ($p=0.005$) and 60% ($p=0.002$). The highest correlation was observed between ITD (low-pass noise) and the TCST score at the time compression ratio of 60% in the right ear ($r=-0.66$). The mean ITD errors were not significantly correlated to the reaction time test score ($p>0.05$).
Conclusion: Word recognition in the elderly declines with increasing speech rate. The findings of this study can be used in clinical practice for consultation and rehabilitation of older adults with communication difficulties.
Keywords: Sound localization; speed processing; speech perception; elderly

Introduction

Older adults often experience increased difficulties understanding speech in noise [1]. Speech perception depends on bottom-up auditory processing (e.g. spatial and temporal processing) and top-down processing (e.g. speed processing, memory, and attention) [2]. Successful speech perception in noisy environments is important for social, professional and educational activities [3]. Aging can lead to disturbance in auditory processes due to peripheral hearing loss, central auditory processing disorders, or cognitive impairment [4]. One of the most basic auditory processing types is spatial processing, which refers to the ability to localize sound sources. Spatial processing cues and other types of auditory processing play a key role in sound localization [5]. The spatial cues involved in sound localization include Interaural Time Difference (ITD) and Interaural Intensity Difference (IID) in azimuth and pinna/head-generated spectral cues in elevation and front-back discrimination [6]. For pure tones, ITDs are accompanied by Interaural Phase Differences (IPDs) that are reliable only up to 1.5 kHz in humans due to phase ambiguity coupled with declining neuronal temporal coding (phase-locking) at higher frequencies [7]. While ITDs dominate in horizontal localization when all spatial cues are available, the IIDs and spectral cues are effective primarily at higher frequencies [8]. Studies emphasize the greater importance of ITD compared to IID in speech perception in noise [9]. Degraded auditory input places an increased demand on limited processing resources. As a result, impaired spatial processing pathways and the lack of access to auditory localization cues inhibit the discrimination of sounds with different sources and appropriate sensory input for cognitive sources. The localization ability of a person with normal hearing is 5–15 dB [10]. Several studies have reported that the localization ability decreases with aging [11-13]. People with normal hearing thresholds but weak in localization have speech perception scores in noise less than 70% [14]. Therefore, there is a close relationship between sound localization and speech perception in noise.
Although age-related decline in speech perception can be due to peripheral sensory problems, cognitive aging can also be a contributing factor [15]. One of the potential sources of the reduction in fast speech recognition in the elderly is the reduced time in processing the acoustic information of the signal [16]. Timing information, which has a vital role in speech perception, is transmitted through neural discharges [17]. Temporal processing is essential for speech perception because the speech may contain important temporal information about vowels, consonants, syllables, and phrases [18]. Due to the impact of aging on neural synchrony, older people may have weaker temporal processing abilities [19]. Therefore, the ability of the auditory system to encode the subtle temporal structures of speech is impaired in these people [19, 20]. Since accurate temporal and spectral processing is crucial for identifying the signal in noise, deficits in spectrotemporal processing may cause older adults to experience difficulties with speech perception in real life [21]. Sufficient cognitive resources are needed when listening to clear speech; however, according to the information degradation hypothesis, when the quality of speech signals decreases, more attention is directed to recovering information lost in the noise, which impairs the efficiency and speed of other cognitive processes critical for speech perception [22]. In previous studies, the role of temporal processing in the dorsal pathway (identification of sounds) has been reported, but the importance of temporal processing in the ventral stream (localization) and its direct relationship with the speech processing speed have received less attention.
In this research, the importance of timing in the dorsal pathway was considered based on the ITD cues, and the relationship of the timing with the speech perception speed and other stimuli was investigated to highlight the role of sound localization ability in speech perception and identifying speed processing problems in the elderly.

Methods

In this study, 36 older adults (23 men and 13 women) aged 65–75 years (mean age: 66.83±2.49) who had complaints about the difficulty in speech perception in noise participated. They were selected from among those visiting the geriatric clinic and the audiology clinic of Rofeideh Rehabilitation Hospital in Tehran, Iran. After obtaining their written informed consent, their middle ear condition was evaluated using a tympanometer (GSI TympStar Pro, Interacoustic Co., Denmark). Pure tone and speech audiometry were performed using an audiometer (GSI AudioStar Pro) in an acoustic chamber (with a maximum ambient noise <30 dBA). Inclusion criteria were normal middle ear function (Type A tympanogram and presence of ipsilateral acoustic reflexes)

[23]. The pure tone average in both ears at 500–2000 Hz frequency was ≥25 dB HL, and high frequency hearing threshold in each ear (3000–8000 Hz) were ≥40 dB HL [23]. All participants had Mini-Mental State Examination (MMSE) scores >25, indicating no cognitive problems [24]. To present the words precisely at the fixed level of 70 dB HL, a laptop (HP Probook 4540s) and a supra-aural headphone (HS-800, A4TECH) were calibrated using an analog 1.3-octave band sound-level meter. The ITD test with two stimuli (high-pass and low-pass noise) was used to analyze the auditory localization ability. Moreover, the TCST and reaction time test were used to measure the speed of speech processing.

Localization ability test

In evaluating the localization ability of the participants, the high- and low-pass noise stimuli (cut off frequency=2 kHz) were presented through headphones to measure localization error. Stimulus duration and rise/fall time were reported at 250 ms and 20 ms, respectively. This duration is enough for correct perception of stimuli in people with normal hearing. In the evaluation of ITD, the stimuli were presented binaurally and by applying delay times of 880, 660, 440, 220, 0, –220, –440, –660, and –880 ms between the two ears at an intensity of 70 dB SL. Therefore, sounds were perceived in nine different positions in a semicircle. Number of errors were recorded and measured in each position.

Time-compressed speech test

The TCST is the most common monaural test to examine auditory closure and temporal discrimination skills. The test materials include 25 common monosyllabic words compressed with different compression ratios depending on the test's purpose, recorded by a male talker, and presented separately at the most comfortable level for each ear [25]. The listeners were asked to pay attention to each word list and repeat the presented words. The word recognition score was measured with three time-compressed ratios of 0 (no compression), 40%, and 60%, considering four seconds of silence for response time after each word. This research used the Persian version of the TCST, prepared by Jafari et al. [25].

Reaction time test

Reaction time refers to the interval between a stimulus's presentation and the appearance of a response by a subject. This study used a researcher-designed reaction time analysis App, which can measure the reaction time for non-speech and speech stimuli with an accuracy of one-thousandth of a second. The participants were taught to press specific keys on the laptop when they heard the stimuli. In this study, six types of stimuli, including 500 Hz pure tone, click stimulus, non-compressed monosyllabic word (with two different response forms, pointing to a picture or text), and compressed monosyllabic word with 40%-time compression (with two response patterns, pointing to a picture or text) were used. The average response time for each stimulus was calculated and recorded using the software.

Data analysis

To investigate the normality of data distribution, the Shapiro-Wilk test was used. To compare the localization errors with two types of noise, the paired t-test was used. Wilcoxon test was used to compare the results of the two ears in the TCST. Repeated measures ANOVA was used to exmaine between-group differences in the TCST score. The Pearson correlation test was used to measure the correlation between the study variables. The data analysis was done in SPSS v.17. The significance level was set at 0.05.

Results

The paired t-test results revealed that the auditory localization (ITD errors) were more significant for low-pass noise than for high-pass noise ($p<0.001$). Table 1 shows the mean and standard deviation of localization errors for low-pass and high-pass noises. With the increase in the percentage of speech compression, the scores of the TCST decreased in both ears (Table 1).

The repeated measures ANOVA results indicated a significant difference in the TCST between three time-compressed ratios of 0%, 40%, and 60% ($p<0.001$). The Wilcoxon test results revealed no significant differences between the left and right ears in any time-compressed ratio ($p>0.05$). Pearson correlation test results indicated a significant negative correlation between the TCST score at time compression ratios of 40% ($p=0.005$) and 60% ($p=0.002$) and the number of ITD errors (localization test), but there was no significant correlation at the ratio of 0% (p>0.05) (Table 2). The highest correlation was observed between ITD (low-pass noise) and the TCST score at the compression ratio of 60% in the right ear (r=–0.66). The Pearson correlation test results showed no significant correlation between the reaction time test scores (for different stimuli and different answer methods) and ITDs (p>0.05).

Discussion

Since timing is very important for speech perception, in this study we aimed to evaluate the temporal processing by using ITD cues (which is critical for sound localization) and the processing speed (as an important cognition ability for speech perception) in older adults with normal hearing who had complaints about the difficulty in speech perception in noise in order to investigate the correlation of ITD with TCST and reaction time test scores. The findings demonstrated that the auditory localization errors were more significant for ITDs with low-pass noise than ITDs with high-pass noise. These results are consistent with the results of a pervious study where it was found that the elderly had higher errors with low-pass noise for ITD than with high-pass noise [26]. The reason for this can be explained by the fact low-frequency signals have very precise temporal information for localization but the perception of high-pass noise is based on envelope cues [27]. In various studies, it has been reported that aging has a greater impact on temporal cues than envelope cues [28]. On the other hand, the age-related changes in peripheral and central auditory systems is mostly temporal [29].

In this study, the TCST was used to evaluate speech perception speed at different compression ratios (0%, 40%, 60%). The results showed that as the compression ratios increased, the TCST score significantly decreased. In a pervious study, a significant decrease in the TCST score at the compression ratio of 70% was reported. Word recognition reduced with increasing speech rate in the elderly; however, it was hardly affected by the speech rate in the youth, suggesting that aging may be the cause of cognitive decline [30]. It seems that the redundancy of upper brain structures and speech information can partially neutralize the negative effect of increased speech rate. At higher speeds of stimulus presentation, we need more signal-to-noise ratios to improve the speech recognition score [31], which can be achieved by improving localization ability. In our study, the scores at three compression ratios in the right ear were not significantly different from those in the left ear. Although the right-ear advantage has been observed under some dichotic stimulus presentations, clinically meaningful dominant auditory performance has not been reported for the right ear in monaural studies. Although the left hemisphere is dominant for language processing, the monaural stimulus, such as time-compressed speech, neutralizes the effect of the right ear advantage over the left ear by activating the ipsilateral and contralateral pathways in the central auditory system. From a clinical point of view, the TCST can be used to investigate monaural hearing skills without disruption by the lateral advantage of the brain. The results showed a negative correlation between localization errors and the TCST score at 40% and 60% ratios, but no significant correlation was found at 0% ratio due to the floor impact. The highest correlation between ITD (low-pass noise) and TCST was found at 60% ratio in both ears. It has been reported that the reduction of neural activity and dyssynchrony are the main reasons for the temporal and spatial cues encoding deficits in the elderly [19].

This study used the reaction time test to assess the processing speed. It has been confirmed that the auditory reaction time (140–160 ms on average) is faster than the visual reaction time (180–200 ms on average). This difference is probably due to the time (8–10 ms) needed for the auditory stimulus to reach the auditory cortex. Due to the longer path, the visual stimulus takes about 20–40 ms to reach the visual cortex [32]. Our findings showed that the reaction time increased with the increased complexity of the stimuli. The correlation between reaction time score and ITD was not significant. This can be explained by the fact that the reaction time test is a subjective test, and the answers of older adults are affected by their listening and movement skills

Conclusion

In older adults with normal hearing but difficulty in speech perception in noise, the auditory localization ability is more significant when low-pass noise is used rather than high-pass noise. Moreover, as the compression ratios increased, a significant decrease was seen in their Time-Compressed Speech Test (TCST) scores. Therefore, it can be said that their word recognition decreases with increasing speech rate. There is a negative correlation between Interaural Time Difference (ITD) errors and the TCST score at compression ratios of 40% and 60%. The highest correlation was observed between ITD (low-pass noise) and the TCST score at 60% ratio in the right ear. The findings of this study can be used in clinical practice for consultation and rehabilitation of older adults with communication difficulties.

Ethical Considerations

Compliance with ethical guidelines
The study protocol was approved by the Ethics Committee of the University of Social Welfare and Rehabilitation Sciences, Iran; (Code I.R.USWR.REC.1398.162).

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Authors' contributions
JA: Conceptualization, data collection, interpretation of the results, drafting the manuscript; SM: Conceptualization and design of the study, analysis and interpretation of data and editing; EB: Statistical analysis; TZ: Design of the study.

Conflict of interest
The authors declare that there is no conflict of interest regarding the publication of this paper.

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Table 1. Mean and standard deviation of localization error and mean time compressed speech test score with time-compressed ratios of 0%, 40%, and 60% in right and left ears

Variable	Stimuli	Mean±SD	p
Localization (error number)	ITD/low pass	20.31±2.40	p<0.001
	ITD/high pass	18.42±1.68	
TCST Right Ear	0	99.01±2.00	p<0.001
	40%	75.02±4.32	
	60%	53.10±6.51	
TCST Left Ear	0	98.12±2.17	p<0.001
	40%	74.20±4.63	
	60%	51.10±6.61	

ITD; interaural time difference, TCST; time compressed speech test

Table 2. The results of the correlation between time compressed speech test score and localization/error

Variable		ITD (low pass)		ITD (high pass)	
		r*	p	r*	p
TCST-right ear	0	–0.20	0.250	–0.18	0.290
	40%	–0.39	0.020	–0.46	0.005
	60%	–0.66	<0.001	–0.50	0.002
TCST- left ear	0	0.17	0.380	0.264	0.120
	40%	–0.46	0.005	–0.39	0.020
	60%	–0.60	<0.001	–0.58	<0.001

ITD; interaural time difference, TCST; time compressed speech test
* Pearson correlation coefficient

Table 3. The mean and standard deviation of different stimuli. The results of the correlation between reaction time score for different stimuli and localization errors

variable	Stimuli	Localization/error with ITD (low pass)		Localization/error with ITD (high pass)	
	Mean+SD	r*	p	r*	p
500 HZ	75.20±13.10	0.01	0.940	–0.24	0.150
CLICK	96.14±22.11	0.15	0.370	–0.01	0.930
Uncompressed monosyllabic word/pointing to the text	109.02±18.20	–0.27	0.110	–0.23	0.180
Uncompressed monosyllabic word/pointing to the picture	127.01±19.01	–0.09	0.610	–0.20	0.240
40% copmressed monosyllabic word/pointing to the text	127.31±23.03	–0.06	0.740	–0.11	0.530
40% copmressed monosyllabic word/pointing to picture	150.01±32.12	–0.06	0.710	–0.06	0.710

ITD; interaural time difference
* Pearson correlation coefficient