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RESEARCH ARTICLE

Recognition of stop consonants in babble noise in normal hearing individuals

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Abstract

Background and Aim: Speech understanding almost never occurs in silence. Verbal communication often occurs in environments where multiple speakers are talking. In such environments, babbling noise masks speech comprehension. Consonants, in comparison to vowels, are more sensitive to noise masking. Consonants provide most acoustic information needed for comprehending the meaning of the word. Since stop consonants have low intensity, they can be easily masked by noise, and finally tend to lead to speech disorder. This study determines the effect of babble noise on the recognition score of stop consonants.

Methods: This cross-sectional study was performed on 48 participants, males and females in equal number, aged between 19 and 24 years, with normal hearing. In addition to auditory and speech evaluation, recognition of stop consonants in a consonant–vowel–consonant syllable at the presence of babbling noise was tested.

Results: By increasing the noise, the recognition score of stop consonants at the beginning of the syllable was reduced. There was a meaningful difference between the recognition score of stop consonants at the beginning of the word and vowels in the signal-to-noise ratio of 0, -5, and -10 (p=0.000). Besides, the average recognition score of /b/, /d/, /k/, and /ʔ/ was found to be greater than /p/, /t/,/g/, and /q/ (p<0.0005). Gender had no significant effects.

Conclusions: Increased babble noise levels significantly reduce the recognition score of stop consonants, and this reduction is more in some voiced stop consonants as well as some voiceless stop consonants.

Keywords: Stop consonants; speech in noise; babble noise

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Introduction

In normal auditory conditions, understanding speech almost never occurs in silence. However, speech under real conditions mostly occurs in the presence of background noise, such as babble noise, which may reduce the speech signal [1]. Usually, verbal communication is performed when multiple speakers are talking at the same time; the babble noise that occurs in this condition works as a mask because it masks the speech comprehension, and some studies also refer to it as the “perception of speech in the presence of noise.” The effect of babble noise depends on the number of speakers who are talking at the same time. We believe that more masking energy due to an increase in the number of speakers reduces speech comprehension [2]. In auditory conditions, understanding speech accurately depends on the capacity of the auditory system for processing compound sounds in the presence of background noise.

Due to normal redundancy of speech signals, the listeners can understand distorted speech signals even in the midst of noise [3]. The human cognitive system has adapted to dominate over distorted speech and distorted discontinuous signals as well. As a result, speech recognition may even remain after omitting some speech signals [4]. Nevertheless, by increasing the amount of noise, it will be difficult to process even for those with normal hearing and cognitive skills of people [5].

Speech sounds are divided into two categories as vowels and consonants. There are six simple vowels in the Persian language as follows: /i/, /â/, /e/, /u/, /o/, /a/. Consonant can also be stop, fricative, affricate, liquid, nasal, and glide in nature. They are divided into two groups of voiced and voiceless consonants. Stop voiced consonants are: /b/,/d/,/g/,/q/ while voiceless consonants are /p/,/t/,/k/,/ʔ/. The phonetic placement of /b/, /p/ are bilabial, /t/ and /d/ dental, /g/ and /k/ palatal, /q/ velar while /ʔ/ is glottal [1]. In studies done by Kewley-Port et al., the amount of consonants and vowels in the data were shown to interfere with understanding sentences, while Li and Loizou wrote about the stop consonants that were involved in speech recognition in the presence of noise. They indicated that stop consonants—in comparison to vowels because of their low intensity and acoustical information—are more sensitive to masking noise, and may be distorted very quickly. Consonants provide most acoustical information needed for the meaning of words and play a greater role for better understanding of speech. Speech disorder will occur by losing the consonant sounds, therefore they are necessary for verbal communication [6,7]. Stop consonants are produced by plosive air and depend on the consecutive vowel sound. Since they are made by mid frequencies (approximately 2500–3000 Hz), they may be masked more in comparison to other consonants against babble noise. As the diagnosis of stop consonants in the beginning of the word depends on acoustical characteristics (e.g., fundamental frequency), we have tried to focus on this issue.

Several studies, such as that of Li and Louzou, about the recognition of consonants in noise have determined that stop consonants in noise were affected more than vowels [7]. Another investigation into consonant–vowel–consonant (CVC) in American language about speech spectra in noise in recognition of the beginning and ending consonant syllables in different amount of speech in noise ratio (SNR), by Wood et al. indicated that recognition of consonant in noise is a complex process and it is difficult to recognize the location of production, whether voiced, and how to produce the consonant in noise [8]. Babble noise in most communication environments and the importance of consonants in speech comprehension and most studies on consonants are in English. These studies have indicated that there is a lot of differences between English and Persian languages. Despite its importance, there is not much research in this subject, therefore, by conducting this research, we expect to have results that could be useful in auditory training programs, auditory verbal rehabilitation, speech therapy, and design of software for noise reduction in hearing aids. This study determines the effect of babble noise on recognition score of stop consonants.

Methods

The present cross-sectional study was performed on 48 students, equal male and female members (24 f and 24 m) of the Faculty of Rehabilitation in Shahid Beheshti University of Medical Sciences in Tehran. They had normal hearing and were aged between 19 and 24 years. They were selected using a nonrandomized method. The sample had normal pure tone audiometry (PTA) and speech recognition threshold (SRT) (equal or better than 25 dB HL) with normal functioning of the middle ear with type A tympanometry (that is, SC. 0.3-1.6 and +50-100 dapa); contra and ipsilateral acoustic reflexes in frequencies 500-4000 Hz was 85-100 dB SPL. All samples were right-handed based on the Edinburg questionnaire for handedness and monolingual Persian language. All subjects had no history of ENT disease or surgery, disorders in hearing, speech, language, neurology disease, head trauma (based on examinee's view), and no central speech processing disorders (based on history of CAPD and Binaural Masking Level Difference (MLD) test to ensure the health of the brainstem and Duration Pattern Sequence test (DPST) to ensure health of the temporal cortex). All hearing tests were performed by audiometer AC30 and tympanometry AT235, both made by Intra acoustic Company in Denmark. For all cases, confirmation of phonetic (for safety of production of speech) and discrimination (for the sake of healthy of the auditory system) tests were required.

Fifty monosyllabic words of CVC were selected in which all of the words begin with a stop consonant (Mosleh 2001) [9]. These words were recorded by a professional speaker in the TV studio, the interval time for responding by written matter was established as four seconds. This could increase the accuracy of the test. In this study, we used 12 subjects for babbling noise, and for the test, we used adobe audition software cs5.5 v4.0. The test's final version was transmitted from the laptop to the audiometer. SNR calibration was based on the subject MCL for every sample, and all of them signed for informed consent. After ensuring the individual's normal hearing, every subject was instructed by the examiner about how the test would be conducted and the method of responding to the test. Signals in 30 dBSL (above SRT) had been presented in the ipsilateral ear, first in silence (to make sure that subject could understand what the test is), then signals with babble noise in SNR 0, –5, and –10dB were presented. Ten seconds before saying the first word, we presented a sinusoidal wave for intensity calibration. To avoid reminding the subjects of the words, we had an interval time between every session. Finally, consonant speech recognition score for the above mentioned ratio was calculated (according to the list of 50 words, each word has two scores).

For analysis of the data, software of SPSS (v. 22) was used (in $p<0.05$). For comparing consonant recognition score test in 3 SNRs (0, –5, –10), we used the Friedman test, and the same test (comparing consonant recognition test in 3 SNR (0, –5, –10)) was repeated in females and males using the ANOVA method. Mann Whitney-U was also used for comparing the recognition score of stop voiced and voiceless consonant in noise. The present study was confirmed by the Vice Chancellor (Research) of SBUMS, and was mentioned as following all ethical aspects.

Results

The present study was performed on 48 subjects (24 f, 24 m), with average age of 21.40 (SD 1.38). In this study, the correct consonant score, which is calculated by percentages, was considered. Average of recognition scores of stop consonants in SNRs (o, –5, and –10) is shown in Table 1. By increasing the amount of noise, recognition score in the stop consonant at the beginning of the word decreased.

In Friedman method analysis, the stop consonant recognition score at the beginning of the word in the above 3 SNR showed significant differences ($p<0.0005$), which is shown in Table 2. In comparing consonant recognition score at the beginning of the word, between male and female in the 3 SNR (0, –5, –10) by the repeated measure ANOVA method analysis, there was no significant difference ($0.062<p<0.283$). In the score of stop voiced and voiceless consonants (which was equal from the point of location of production), in SNR 0 and -5 there was significant difference (Tables 3 and 4). The recognition score of all the stop voiced and voiceless consonants in SNR -10 was significantly different except /t/ and /d/, (Table 5). The SNR of 0, –5, –10 in average consonant

Table 1. Mean (SD) recognition score of stop consonants in the beginning of word in three SNRs

	mean (SD) consonant recognition score (%) in different SNRs		
Consonant	**0**	**-5**	**-10**
/b/	39.93 (19.67)	35.06 (17.27)	15.27 (13.68)
/p/	9.72 (15.31)	9.02 (11.88)	3.47 (8.39)
/d/	60.76 (19.29)	46.52 (22.27)	18.40 (19.21)
/t/	50.00 (13.31)	36.11 (14.31)	15.62 (10.54)
/g/	46.52 (19.43)	23.61 (15.69)	6.94 (12.31)
/k/	72.22 (16.60)	53.12 (16.72)	22.56 (14.37)
/q/	21.52 (16.82)	12.84 (13.85)	5.20 (9.19)
/ʔ/	64.58 (19.23)	60.06 (18.43)	48.61 (17.31)

recognition score was respectively more in: /b/ than in /p/, /k/ than in /g/, and /ʔ/ than in /q/. The average consonant recognition score of /d/ was also more than in /t/, in SNR at 0 and -5

Discussion

In the present study, we noticed that by increasing the amount of noise, recognition score in the stop consonant at the beginning of the word reduces. In the study done by Omidvar et al. they mentioned that by increasing the amount of continuous and interrupted noise, the recognition score of the word decreases. The present study confirmed these researches findings. Simpson and Cooke, in their survey, indicated that babble noise decreases the recognition score of the VCV syllable, while Parikh and Loizou also showed that babble noise and speech shaped decrease in the stop consonant recognition. Wood et al. showed that CVC syllables are affected by speech shape [2,8,10,11], which our study's findings confirm. Our research findings showed that babble noise with interference in aspects of sound acoustical and stop consonant comprehension in the beginning of speech syllable deflect their

Table 2. Comparing of mean (SD) recognition score of stop consonants in the beginning of the word with vowels in three SNRs

	Mean score (SD) in speech in noise ratio of 0, -5, -10			
Consonant	**0**	**-5**	**-10**	**p***
Stop vowel /i/	45.57 (11.38)	43.22 (10.61)	34.11 (15.62)	<0.0005
Stop vowel /e/	36.97 (17.28)	23.43 (14.03)	13.54 (10.88)	<0.0005
Stop vowel /a/	55.46 (16.89)	51.56 (16.43)	19.79 (9.59)	<0.0005
Stop vowel /â/	38.54 (11.76)	28.12 (10.47)	16.92 (8.74)	<0.0005
Stop vowel /o/	55.20 (16.67)	34.63 (13.20)	6.51 (8.92)	<0.0005
Stop vowel /u/	42.18 (11.92)	26.30 (12.69)	11.19 (11.60)	<0.0005

Meaningful for all three SNRs used by Friedman test
*Friedman test

Table 3. Comparing of mean (SD) recognition score of voiced and voiceless consonants in SNR=0

	Voiced		Voiceless		
Place of production	**Consonant**	**Mean (SD) score**	**Consonant**	**Mean (SD) score**	**p***
Bilabial	**/b/**	39.93 (19.67)	**/p/**	9.72 (15.31)	<0.0005
Dental	**/d/**	60.76 (19.29)	**/t/**	50.00 (13.31)	0.002
Palatal	**/g/**	46.52 (19.43)	**/k/**	72.22 (16.60)	<0.0005
Glottal	**/q/**	21.52 (16.82)	**/ʔ/**	64.58 (19.33)	<0.005

*Mann-Whitney U

recognition and affect correct comprehension. Finally, people cannot perceive the words correctly and auditory verbal communication is affected, which will cause defects in conducting the data from the sender to the receiver. It also showed that noise affects stop consonant such that by increasing the amount of noise, reduction of the recognition score of consonants occurs. The findings of Li and Loizou, who studied the amount of stop consonants in American language for detecting speech in noise, observed that stop consonants in noise are masked more than vowels [7]. Findings in this study, as also that of the Wood et al., showed that the masking properties of vowels can distort 85 percent of consonant recognition [8]. In relation to the role of stop voiced and voiceless consonants, the investigation of Benki indicated that voiced is more important than other properties, such as place and manner of production [3]. In this survey, we studied this characteristic just like Benki did. The average recognition score of consonants /b/,/d/,/k/, and /ʔ/ was more than the average recognition score of /p/,/t/,/g/, and /q/, which means that in place of bilabial and dental production, the score of voiced consonant, and in place of palatal and glottal production, voiceless consonants have more recognition score—this nearly replicated Benki's findings. Since in silence, voiced onset time (VOT) and fundamental frequency (F0) are important factors for discrimination of stop voiced against voiceless consonants, they may be the reasons for the increment in the recognition score of stop voiceless consonants in noise. More VOT and F0 is observed in the production of voiceless consonants vs voiced ones in the syllable [12]. It may be that a longer VOT increases the voiceless consonant recognition score. More score for the voiced consonant in place of bilabial and dental production may be due to vibration of the vocal cords. The mismatch of the present study's findings in comparison to Benki's may be due

Table 4. Comparing of mean (SD) in stop voiced and voiceless consonants recognition score in SNR= -5

	Voiced		Voiceless		
Place of production	**Consonant**	**Mean (SD) of score**	**Consonant**	**Mean (SD) of score**	**p***
Bilabial	**/b/**	35.06 (17.27)	**/p/**	9.02 (11.88)	<0.0005*
Dental	**/d/**	46,52 (22.27)	**/t/**	36.11 (14.31)	<0.0005*
Palatal	**/g/**	23.61 (15.69)	**/k/**	53.12 (16.72)	<0.0005*
Glottal	**/q/**	12.84 (13.85)	**/ʔ/**	60.06 (18.43)	<0.0005*

*Mann-Whitney U

Table 5. Comparing of mean (SD) in stop voiced and voiceless consonants recognition score in SNR= -10

	Voiced		Voiceless		
Place of production	**Consonant**	**Mean (SD) score**	**Consonant**	**Mean (SD) score**	**p***
Bilabial	**/b/**	15.27 (13.68)	**/p/**	3.47 (8.39)	<0.0005
Dental	**/d/**	18.40 (19.21)	**/t/**	15.62 (10.54)	0.910
Palatal	**/g/**	6.94 (12.31)	**/k/**	22.56 (14.37)	<0.0005
Glottal	**/q/**	5.20 (9.19)	**/ʔ/**	48.61 (17.13)	<0.0005

*Mann-Whitney U

to fewer samples or the different method that we used in our study. The test material of Benki's study was meaningless words, but in this study, we used meaningful words. Also, the findings of the Li and Loizou investigation indicated that by increasing the amount of noise, the recognition of lots of acoustical characteristics, such as voiced consonants, decreases [7], which confirms the results of our study.

Based on findings of this study, the recognition score in females and males was similar and gender had no effect on the results of research (p>0.05). We can describe these aspects of perception and processing of speech phonemes and diagnosis of these sounds in the central nervous system as being similar in females and males. The reason may be because the activities of neural innervation increase especially in the superior temporal gyri and left insula [13]. It means that these components, which are active in speech in noise and also in cognition and sense processing, function in a similar way in both genders.

Conclusion

In this study, when the noise levels increased, stop consonant recognition scores showed a significant decrease at the beginning of each word in babble noise at 0, -5, and -10 SNR levels. However, there was no significant difference between stop consonant recognition scores at the beginning of each word between males and females. Another finding of this study indicated higher scores in voiced consonant recognition at the bilabial and dental places of articulation and higher scores for voiceless consonants in palatal and glottal articulation places. As a result, babble noise affects word perception and leads to verbal communication disorder. Therefore, practicing speech in babble noise in auditory training plan and paying more attention to training of vulnerable consonants in noise is highly recommended.

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