Human Research in Rehabilitation, 2023, 13(1): 102-109 ISSN 2232-996X/ISSN 2232-9935

DOI: 10.21554/hrr.042312

PHONEME RECOGNITION AND CONFUSIONS IN PATIENTS WITH SENSORINEURAL HEARING LOSS

Original scientific paper

Zora Jachova[1], Lidija Ristovska[2], Jasmina Kovacevic[3], Nerxhivane Krasniqi[4]

[1]Faculty of Philosophy,Ss. Cyril and Methodius University in Skopje, Institute of Special Education and Rehabilitation, Skopje, North Macedonia
[2] Division of Audiology , Department of Otorhinolaryngology, City General Hospital "8th September", Skopje, North Macedonia
[3] Faculty of Special Education and Rehabilitation, University of Belgrade, Belgrade, Serbia
[4] Faculty of Education, University"Kadri Zeka", Kosovo

Received: 2022/12/28
Accepted: 2023/02/25

ABSTRACT

Hearing impaired listeners show different phoneme confusions during speech recognition testing. The aim of the study was to analyze phoneme recognition in patients with sensorineural hearing loss during word recognition testing with monosyllabic words, as well as, to compare consonant confusions in different vowel context. Recognition of 18 initial and final consonants was analyzed in a total of 698 presentations of the words. There were 1154 (82.7%) correct recognitions and 100 consonant confusions (7.2%). The patients did not response at a total of 71 presentations of the words which means that consonants in 142 cases (10.2%) were not recognized, nor confused. There are no consonant confusion patterns during suprathreshold testing with real words. In cases of phoneme confusions, listeners replace the stimulus word with another word from the lexical neighborhood. In terms of the vowel context, the consonants are the most easily identified in the context of the vowel /a/.

Keywords*: phoneme, recognition, sensorineural hearing loss, speech audiometry*

INTRODUCTION

Speech is a complex acoustic signal that is continuously changing in frequency, intensity, and time. The acoustic speech signal received by a listener is a function of the source, distance, early reverberation, late reverberation, and noise (Boothroyd, 2004). Unlike speech production which is a process of converting a linguistic message into speech, speech perception is the process of determining the message from the speech (Taylor, 2009). Communication by speech is the transmission of thoughts or feelings from the mind of a speaker to the mind of a listener. Listeners use more than acoustic information when they receive a spoken message. They use their knowledge of the speaking situation and their knowledge of the speaker, as well as visual cues obtained by watching the face and gestures of the speaker. No matter how a listener analyzes a message, the data on which he or she operates are the acoustic patterns of speech. The essential step, then, is that

Correspodence to: Prof. Ass. Dr. Nerxhivane Krasniqi, Faculty of Education, University"Kadri Zeka", Kosovo
Email: nerxhivane.krasniqi@uni-gjilan.net, tel: +38344193961

the listener hears the speech (Raphael et al., 2011). Speech perception can be influenced by information from different senses. The McGurk effect is one example of audiovisual speech perception. Although auditory information is the major source of information for speech perception, visual information can also exert a strong influence on what we hear. Another example is the way people routinely use information provided by the speaker's lip movements to help understand speech in a noisy environment (Goldstein, 2010). The phoneme is the smallest unit of sound which can differentiate one word from another, in other words, phonemes make lexical distinctions (Ogden, 2009). Vowels and consonants are two categories of speech sounds existing in all languages. Vowels contribute most of the energy, which occurs mostly at low and mid frequencies, while consonants contribute most of the intelligibility, which is largely dependent upon middle and higher frequencies. Vowels generally are of longer duration than are consonants (Lawson & Peterson, 2011). We cannot define speech perception very narrowly in terms of phoneme perception or nonsense syllable identification. It is important to analyze how we identify spoken words and comprehend sentences in connected fluid speech (Cleary & Pisoni, 2005). A large amount of research has shown it is easier to perceive phonemes that appear in a meaningful context. If a phoneme is at the beginning of a real word, it is identified faster than when it is at the beginning of a meaningless syllable. Just as the perception of phonemes is aided by the meanings of words, the perception of words can be aided by the sentences in which they occur (Goldstein, 2010). There are three lines of experimental evidence indicating that listeners do not, and indeed cannot perceive phonemes in running speech directly, but that their presence is inferred following prior identification of larger units: (1) an inability to distinguish between speech sounds that are "heard" when replaced by noise (the phonemic restoration effect) and those physically present; (2) the need to identify syllabic organization before identifying constituent phonemes; and (3) the inability to identify brief phonetic components (steady-state vowels) when chained together into a sequence, even though they are readily recognizable when presented singly (Warren, 2008). Any model of speech perception for running speech must account for the modifications that may be introduced by prosodic factors, by the introduction of enhancing gestures, and by gestural overlap (Stevens, 2005). The prosodic features of speech, including intonation, stress, and juncture, are perceived by listeners in terms of variations and contrasts in pitch, loudness, and length (Raphael et al., 2011). The main problem in understanding speech perception is that there is a variable relationship between the acoustic signal and the sounds we hear. A particular acoustic signal can produce a number of different sounds. The acoustic signal associated with a phoneme changes depending on its context. The formant transitions, which are the acoustic signals associated with the same consonant, are very different depending on the vowels in the context. This effect of context occurs because of the way speech is produced (Goldstein, 2010). Coarticulation, the modification of the speech signal associated with a particular sound by prior and subsequent phonetic segments, significantly influences word recognition processes (Archibald & Gathercole, 2007). Coarticulation can be partially understood as a necessary result of the articulators moving into position for an upcoming sound even while the current sound is still being produced. Both anticipatory and perseverative types of coarticulation exist (Cleary & Pisoni, 2005). The second variability between phonemes and the acoustic signal is the variability from different speakers. People say the same words in a variety of different ways. Some people's voices are high pitched, and some are low pitched; people speak with accents; some talk extremely rapidly, and others speak extremely slowly (Goldstein, 2010). Speech intelligibility is a relative measure of the degree to which a speaker's speech signal is understood, the relatively depending at a minimum on the identities of speaker and listener, what is spoken and where it is spoken (Weismer, 2008). A frequency of 2000 Hz is the key frequency for speech intelligibility. At 2000 Hz, plus or minus ½ octave, the following speech information is available: F2 and F3 information for vowels, consonant-vowel (CV) and vowel-consonant (VC) transition information, acoustic information for the laterals, plosive bursts, affricate bursts, and fricative turbulence. The important acoustic cues for place of articulation are available at 2000 Hz (Flexer, 1993). Most of the information transmitted by speech lies above 1000 Hz. Intelligibility concentrates on the information-carrying content of the speech because it is a measure of how understandable the speech is. Speech intelligibility is measured by the ability of listeners to correctly identify words, phrases or sentences. It may be also tested in terms of phonemes, syllables, and paragraph meaning. In general we can say that the smaller the unit tested, the more able we are to relate the results to individual parts of speech. Several factors play an important role in the understanding of speech. Contextual information compensates for an ex treme lack of original information. Redundancy, in which information is imparted in more ways than would normally be necessary, has effects similar to contextual constraint. Spoken vocabulary size has the effect on the intelligibility of speech. There is a large improvement in recognition when vocabulary size is constrained whether artificially, or by context (McLoughlin, 2009). There are different test for speech intelligibility assessment. Speech audiometry is a method used to evaluate how well a patient can hear and understand specific types of speech stimuli (Kramer & Brown, 2019). The threshold for speech can mean the lowest level at which speech is either just audible or just intelligible. The lowest level at which the presence of a speech signal can be heard 50% of the time is called the speech detection threshold (SDT). In contrast, the lowest level at which the speech signal is intelligible enough to be recognized or identified 50% of the time is the speech recognition threshold (SRT). The SRT is usually obtained by asking the patients to repeat spondee (or spondaic) words, which are two-syllable words that have equal stress on both syllables (Gelfand, 2016). Word recognition testing can be used for assessment of suprathreshold speech understanding. Word recognition score (WRS) is the most common suprathreshold measure (DeRuiter & Ramachandran, 2017). There are two scoring methods in speech audiometry: whole-word scoring and phoneme scoring. Phoneme recognition is studied by presenting nonsense syllables and real words. Erroneous phonemic replacements in CVC words are highly affected by linguistic knowledge. Consonant confusions are best predicted by lexical information, that is, when part of the upcoming speech signal is missing, listeners tend to fill in the gap by picking out one of the stimulus word's phonological neighbors which are part of their mental lexicon (Coene et al., 2015). The errors produced during phoneme recognition are categorized as substitution, deletion, and insertion (Bhatt et al., 2020). Woods et al. (2015) found that most of the older hearing impaired listeners with mild to moderately severe hearing loss showed significant elevations in consonant identification thresholds. The listeners were more accurate in identifying consonants in syllables containing the vowel /ɑ/, than in syllables containing the vowel /u/, or particularly the vowel /i/. The aim of the study was to analyze phoneme recognition and confusions in patients with sensorineural hearing loss during word recognition testing with monosyllabic CVC words, as well as, to compare consonant confusions in different vowel context.

METHODS

This prospective study included a sample of 86 patients with hearing loss, aged 14 to 75 years (mean age of 58.7±12.1 years), examined at the Department of Otorhinolaryngology, Division of Audiology, City General Hospital "8th September" Skopje. Inclusion criterion was unilateral or bilateral sensorineural hearing loss. Patients with conductive and mixed hearing loss were excluded because of the possibility to obtain normal word recognition scores at higher intensity levels in cases of conductive hearing loss. Pure tone audiometry and speech audiometry were performed with MADSEN Astera2 audiometer (GN Otometrics, Denmark) and Sennheiser HDA 300 (Sennheiser electronic, Germany) circumaural earphones in sound proof booth. Hearing threshold was obtained with modified Hughson-Westlake technique for frequencies from 125 to 8000 Hz. Word recognition score was determined at the level 25 to 40 dB above the speech recognition threshold with recorded speech materials: Ristovska and Jachova Monosyllabic Test 1 and Test 2. The words were pronounced by a female speaker. Word recognition testing was performed in quiet with whole-word scoring method. We conducted additional analysis of phoneme recognition in nine monosyllabic CVC words in context of the vowels /a/, /u/, and /i/: шал (ʃal / scarf), час (ʧas / hour), пат (pat / road), југ (jug / south), сув (suv / dry), туѓ (tuɉ / foreign), рид (rid / hill), ѕид (ʣid / wall), and вир (vir / puddle). Transcription of Macedonian Cyrillic letters into International Phonetic Alphabet (IPA) symbols and English translation are provided in parentheses. The study was approved by the Ethics committee of City General Hospital "8th September" Skopje. The Protocol number of Ethical approval is: 24/89-1/2019.

RESULTS

Baseline demographic and clinical characteristics of patients are displayed in Table 1. Unilateral sensorineural hearing loss was present in 16 patients (18.6%) and 70 patients (81.4%) had bilateral hearing loss. A total of 156 ears were analyzed. Sixteen ears of patients with unilateral sensorineural hearing loss were excluded. In terms of the degree of hearing loss, mild hearing loss was the most common (75%). Sloping was the most common audiometric configuration (58.3%).

Table 1. Baseline demographic and clinical characteristics of the patients

Characteristics	**No (%)**
Age (Years)	58.7±12.1 (Mean±SD)
Gender	
Male	37 (43)
Female	49 (57)
Side of hearing loss	
Unilateral right	4 (4.7)
Unilateral left	12 (14)
Bilateral	70 (81.4)
Degree of hearing loss (156 ears)	
Mild	117 (75)
Moderate	29 (18.6)
Severe	10 (6.4)
Audiometric configuration (156 ears)	
Rising	1 (0.6)
Sloping	91 (58.3)
Flat	26 (16.7)
Notch	27 (17.3)
"U"-shaped	11 (7.1)

Recognition of 18 initial and final consonants was analyzed in a total of 698 presentations of the words. There were 1154 (82.7%) correct recognitions and 100 consonant confusions (7.2%), i.e. replacement of the stimulus phoneme with another phoneme. Consonant confusion matrix with responses on the stimulus phoneme (S) is displayed in Table 2.

Table 2. Confusion matrix for initial and final consonants

	Response																	
S	t	d	s	v	r	ʧ	l	p	j	g	ɟ	ʃ	ʤ	f	ʒ	k	b	z
t	135	4	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
d	2	129	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
s	0	5	127	0	0	0	0	0	2	0	0	0	0	0	0	0	4	3
v	0	2	0	124	0	0	3	0	0	0	0	0	0	9	0	0	0	0
r	0	0	0	3	121	0	9	0	0	0	0	0	3	0	0	2	0	0
ʧ	0	0	0	0	0	75	0	0	0	0	0	0	0	0	0	0	0	0
l	0	0	0	0	0	0	69	0	0	0	0	0	0	0	0	0	0	0
p	0	0	0	0	0	0	0	66	0	0	0	0	0	0	0	0	3	0
j	0	0	0	0	0	0	6	0	64	0	0	0	0	0	0	0	0	0
g	0	0	0	0	0	0	0	0	0	64	0	0	0	0	0	6	0	0
ɟ	0	0	0	0	0	0	7	0	0	0	64	2	0	0	0	0	0	0
ʃ	0	0	0	0	0	0	0	0	0	0	0	61	0	0	8	0	0	0
ʤ	0	0	0	7	5	0	0	0	0	0	0	0	55	0	0	0	0	0

The patients did not response at a total of 71 presentations of the words which means that consonants in 142 cases (10.2%) were not recognized, nor confused. In Figure 1 we displayed frequency of occurrence of Macedonian phonemes in order to compare the frequency of occurrence of the phonemes and their recognition rate. The most frequent consonant in Macedonian language is the plosive /т/ (t). This consonant has high recognition rate. The most frequent phoneme in Macedonian language is the vowel /a/ (a).

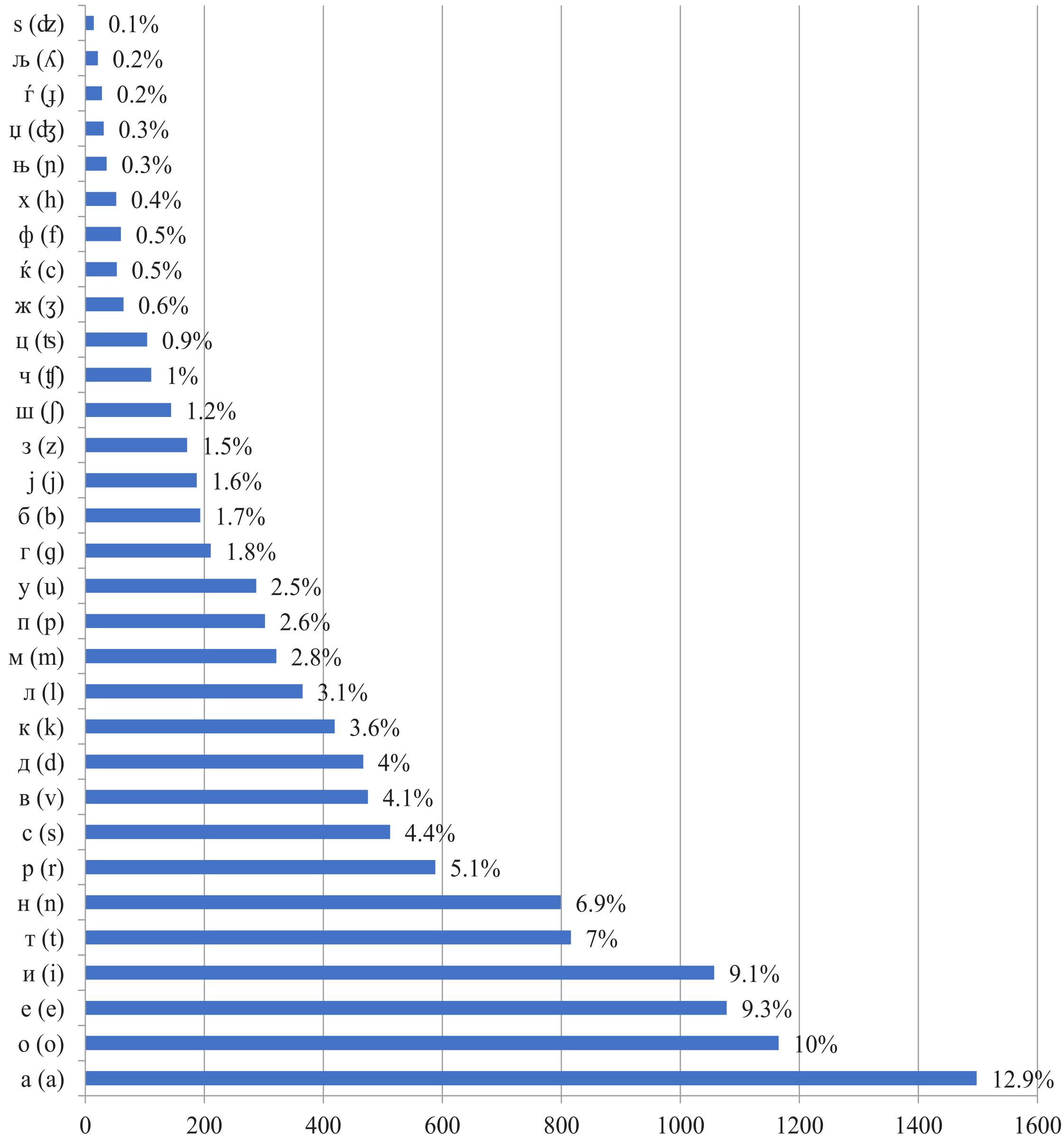

Figure 1: Frequency of occurrence of Macedonian phonemes

Consonant recognition was analyzed according to the manner of articulation (Table 3). Some consonants were recognized as consonants with a different manner of articulation.

Table 3. Consonant recognition according to the manner of articulation

Stimulus phoneme	Fricative		Affricate		Plosive		Lateral		Total	
	No	%	No	%	No	%	No	%	No	%
Fricative	522	41.6	3	0.2	13	1	18	1.4	556	44.3
Affricate	14	1.1	194	15.5	/	0	7	0.6	215	17.1
Plosive	5	0.4	/	0	409	32.6	/	0	414	33
Lateral	/	0	/	0	/	0	69	5.5	69	5.5
Total	541	43.1	197	15.7	422	33.7	94	7.5	1254	100

Fricative /с/ (s) was confused with plosives /д/ (d) and /б/ (b). Plosive /т/ (t) was confused with fricative /с/ (s). Fricative /j/ (j) was recognized as lateral /л/ (l). Fricative /в/ (v) was confused with fricative /ф/ (f) and lateral /л/ (l). Affricate /ѓ/ (ɟ) was confused with fricative /ш/ (ʃ) and lateral /л/ (l). Fricative /р/ (r) was confused with affricate /s/ (ʣ), plosive /к/ (k) and lateral /л/ (l). Plosive /д/ (d) was recognized as fricative /с/ (s). Affricate /s/ (ʣ) was confused with fricatives /в/ (v) and /р/ (r). There were frequent fricative confusions in cases of sloping audiometric configuration. Consonant recognition was analyzed according to the place of articulation (Table 4). Stimulus phoneme sometimes was confused with a consonant with a different place of articulation.

Table 4. Consonant recognition according to the place of articulation

Stimulus phoneme	**Alveolar**		**Dento-alveolar**		**Bilabial**		**Palatal**		**Velar**		**Total**	
	No	**%**	**No**	**%**	**No**	**%**	**No**	**%**	**No**	**%**	**No**	**%**
Alveolar	265	21.1	12	1	3	0.2	/	0	2	0.2	282	22.5
Dento-alveolar	5	0.4	534	42.6	11	0.9	2	0.2	/	0	552	44
Bilabial	/	0	5	0.4	202	16.1	/	0	/	0	207	16.5
Palatal	2	0.2	13	1	/	0	128	10.2	/	0	143	11.4
Velar	/	0	/	0	/	0	/	0	70	5.6	70	5.6
Total	272	21.7	564	45	216	17.2	130	10.4	72	5.7	1254	100

In terms of the voicing, voiced consonants were confused with their unvoiced counterparts and vice versa. There were also confusions with other voiced or unvoiced consonants or sonants. Consonant recognition was compared in different vowel context. In Figure 2 we displayed mean consonant recognition score with standard deviation error bars. Consonants in context of the vowel /а/ (a) were slightly better recognized than consonants in vowel context /у/ (u) and /и/ (i). The vowels were rarely confused. The vowel /у/ (u) was confused with the vowel /о/ (o) three times. Other vowels were correctly recognized except the vowels in 71 presentations with no response at the stimulus word.

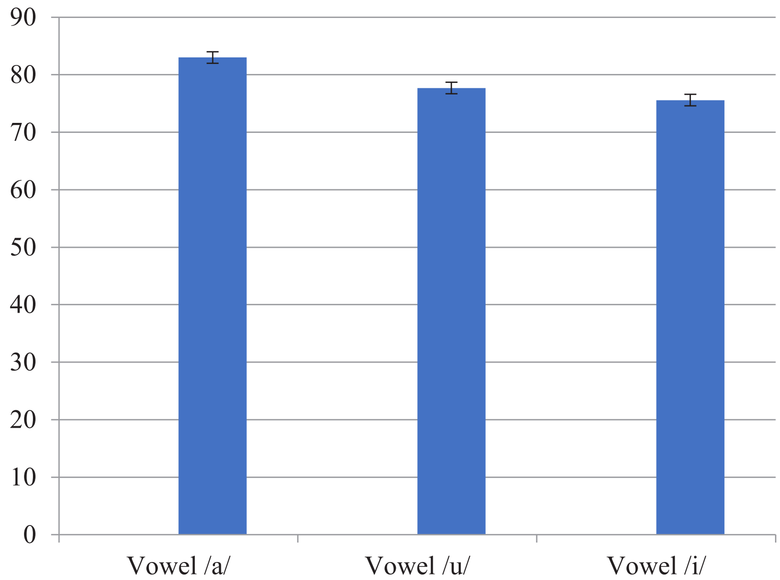

Figure 2: Mean consonant recognition score in different vowel context with SD error bars

DISCUSSION

We analyzed phoneme recognition and confusions in patients with sensorineural hearing loss. The monosyllabic CVC words were presented during word recognition testing. There was a correct consonant recognition in majority of cases. We could explain this with the high percentage of mild hearing loss in the sample. Majority of patients with mild hearing loss have normal word recognition performance. Normal WRSs are also obtained in cases of moderate hearing loss (Ristovska & Jachova, 2021). In terms of the frequency of occurrence of Macedonian phonemes we can notice that the most frequent phonemes in the language are easily recognized. Frequency of occurrence of the phonemes was calculated in our previous research (Ristovska & Jachova, 2021). Woods et al. (2015) divided a total of 21 consonants in three groups based on the signal-to-noise ratios (SNRs) required for their identification. Group A consonants (/t/, /s/, /ʃ/, /ʧ/, /z/, /ʤ/ and /r/) are identified at the lowest SNRs. Group B consonants (/k/, /f/, /d/, /g/, /m/, /n/ and /l/) are of intermediate difficulty, and group C consonants (/p/, /ɵ/, /b/, /v/, /h/, /ð/ and /ŋ/) are the most difficult to identify. Group A and Group B consonants are somewhat more common in conversational speech than group C consonants. Consonant recognition was analyzed according to the manner of articulation and the place of articulation. Some consonants were recognized as consonants with a different manner of articulation or different place of articulation, but there was no typical pattern in this recognition. Analysis of voicing showed that voiced consonants were confused with their unvoiced counterparts and vice versa. There were also confusions with other voiced or unvoiced consonants or sonants. The perceptually significant consonant confusions are /m/-/n/, /b/-/v/, /s/-/z/, and /b/-/c/ (Phatak & Allen, 2007). Word recognition may be influenced by phonetic variables (place, voicing, manner) and lexical variables (word familiarity, word frequency, neighborhood frequency, and neighborhood density) (Jerger, 2008). Psycholinguistic experiments typically make the simplifying assumption that two words are “similar” if they differ by a single phoneme (insertion, substitution, or deletion). Such pairs are referred as neighbors. Early on, it was shown that both the number of neighbors of a word and the frequency of those neighbors are significant predictors of recognition performance (Goldwater et al., 2010). There were frequent fricative confusions in cases of sloping audiometric configuration. Given a similar degree of loss, the configuration of hearing loss also affects the ability to use speech in formation in different frequency regions (Hornsby et al., 2011). The identification of consonants depends on the audibility of mid- and high-frequency acoustic cues that are directly related to the listener’s corresponding audiometric thresholds (Fogerty et al., 2012). Most of the acoustic cues that differentiate consonants lie in the interval of about 1500 to 6000 Hz, and although the intensity of these cues is weak in absolute terms compared to those of vowels, the human auditory system’s increased sensitivity in this range partially compensates for this fact (Cleary & Pisoni, 2005). Consonant confusion matrix showed good recognition of several plosives and fricatives. The plosive perception provides the best example of how listeners use the acoustic overlapping of phonemes in the speech stream to perceive speech. The acoustic cues for the plosives overlap the acoustic cues to neighboring vowels and consonants. As result of this overlap, listeners perceive plosives and the sounds adjacent to them on the basis of their acoustic relationship to one another. Listeners identify a fricative because they hear a noisy, aperiodic component of relatively long duration. Because affricates are plosives with a fricative release, they contain the acoustic cues to perception that are found in both plosives and fricatives. The silence, the release burst, the rapid rise time, the frication, and the formant transitions in adjacent sounds are all presumably used by listeners in identifying affricates. For the perception of laterals usually the first three formants are required (Raphael et al., 2011). There were no lateral confusions in our sample. Consonant recognition was compared in different vowel context. Consonants in context of the vowel /a/ (a) were easily recognized than consonants in vowel context /y/ (u) and /и/ (i). The vowels were rarely confused in our sample. Vowels are among the most perceptually salient sounds in language. They are usually voiced and thus relatively high in intensity. Listeners usually required only the first and the second formants to identify a vowel, but they can use also information from the fundamental frequency (Fo) and from the third formant (Raphael et al., 2011). Formants are concentrated regions of acoustic energy created through the enhanced intensity of certain harmonics of Fo and the attenuation of other harmonics due to the natural resonance characteristics of the vocal tract. The relative positioning of the two or three lowest frequency formants over time helps to perceptually distinguish the different vowel sounds (Cleary & Pisoni, 2005).

CONCLUSION

There are no consonant confusion patterns during suprathreshold testing with real words. In cases of phoneme confusions, listeners replace the stimulus word with another word from the lexical neighborhood. In terms of the vowel context, the consonants are the most easily identified in context of the vowel /a/.

REFERENCES

Archibald, L.M.D., & Gathercole, S.E. (2007). Nonword repetition and serial recall: Equivalent measures of verbal short-term memory? Applied Psycholinguistics, 28, pp.587-606.

Bhatt, S., Dev, A., Jain, A. (2020). Confusion analysis in phoneme based speech recognition in Hindi. Journal of Ambient Intelligence and Humanized Computing, 11, pp.4213-4238.

Boothroyd, A. (2004). Room acoustics and speech perception. Seminars in Hearing, 25(2), pp.155-166.

Cleary, M. & Pisoni, D.B. (2005). Speech perception and spoken word recognition: research and theory. In: E.B. Goldstein, ed. (2005). Blackwell Handbook of sensation and perception. Malden: Blackwell Publishing. Ch.16.

Coene, M., van der Lee, A. & Govaerts, P.J. (2015). Spoken word recognition errors in speech audiometry: a measure of hearing performance? BioMed Research International, 2015, ID 932519.

DeRuiter, M. & Ramachandran, V. (2017). Basic audiometry learning manual. 2nd ed. San Diego: Plural Publishing.

Flexer, C. (1993). Management of hearing in an educational setting. In: J.G. Alpiner & P.A. McCarthy, eds. 1993. Rehabilitative audiology: children and adults. Philadelphia: Williams & Wilkins. Ch.8.

Fogerty, D., Kewley-Port, D., & Humes, L.E. (2012). The relative importance of consonant and vowel segments to the recognition of words and sentences: Effects of age and hearing loss. Journal of the Acoustical Society of America, 132(3), pp.1667-1678.

Gelfand, S.A. (2016). Essentials of audiology. New York: Thieme Medical Publishers.

Goldstein, E.B. (2010). Sensation and perception. 8th ed. Belmont: Wadsworth, Cengage Learning.

Goldwater, S., Jurafsky, D., & Manning, D. (2010). Which words are hard to recognize? Prosodic, lexical, and disfluency factors that increase speech recognition error rates. Speech Communication, 52, pp.181-200.

Hornsby, B.W.Y., Johnson, E.E. & Picou, E. (2011). Effects of degree and configuration of hearing loss on the contribution of high- and low-frequency speech information to bilateral speech understanding. Ear & Hearing, 32(5), pp.543-555.

Jerger, J. (2008). Factors affecting word recognition. Journal of the American Academy of Audiology, 19(6): p.460.

Kramer, S., & Brown, D.K. (2019). Audiology: science to practice. 3rd ed. San Diego: Plural Publishing, Inc.

Lawson, G. D., & Peterson, M. E. (2011). Speech audiometry. San Diego: Plural Publishing.

McLoughlin, I. (2009). Applied speech and audio processing. New York: Cambridge University press.

Ogden, R. (2009). An introduction to English phonetics. Edinburgh: Edinburgh University Press.

Phatak, S.A., & Allen, J.B. (2007). Consonant and vowel confusions in speech-weighted noise. Journal of the Acoustical Society of America, 121(4), pp.2312-2326.

Raphael, L.J., Borden, G.J., & Harris, K.S. (2011). Speech science primer: physiology, acoustics, and perception of speech. 6th ed. 2011. Baltimore: Lippincott Williams & Wilkins.

Ristovska L, & Jachova Z. (2021). Speech audiometry: Development of tests in Macedonian language. Skopje: Studio KRUG [In Macedonian].

Ristovska L, & Jachova Z. (2021). Word recognition performance in relation to type and degree of hearing loss. Medicus, 26(3), pp.292-297.

Stevens, K.N. (2005). Features in speech perception and lexical access. In: D.B. Pisoni & R.E. Remez, eds. (2005). The Handbook of speech perception. Malden: Blackwell Publishing. Ch.6.

Taylor, P. (2009). Text-to-speech synthesis. New York: Cambridge University Press.

Warren, R.M. (2008). Auditory perception: an analysis and synthesis. Cambridge: Cambridge University Press.

Weismer, G. (2008). Speech intelligibility. In: M.J. Ball, M.R. Perkins, N. Müller & S. Howard, eds. (2008). The Handbook of clinical linguistics. Malden: Blackwell Publishing. Ch.35.

Woods, D.L., Arbogast, T., Doss, Z., Younus, M., Herron, T.J. & Yund, E.W. (2015). Aided and unaided speech perception by older hearing impaired listeners. PLoS ONE, 10(3), e0114922