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The Relationship Between Formant Frequency and Duration Characteristics of Vowels and Speech Intelligibility in Turkish Hearing Impaired Children

Mehmet Cem Girgin and [1]Betül Özsoy

School for the Handicapped, Anadolu University, Eskisehir, Turkey
[1]Center for Speech and Language Disorders (DILKOM), Anadolu University, Eskisehir, Turkey

Abstract: The current study investigated the fundamental frequency (F0), first and second formant frequencies (F1 and F2) and duration of vowels produced by Turkish speaking hearing-impaired children along with their differences from normal hearing peers. The relationship between hearing impaired children's vowel production characteristics and their speech intelligibility was investigated as well. Twenty hearing (10 males and 10 females) and 20 hearing-impaired (10 males and 10 females) children between the ages of 7 and 12 participated in the study. For the acoustic analysis of vowels, the Windows based PRAAT (Version 4.4.20) acoustic analysis software was used. Findings suggested that the vowel duration of hearing-impaired children differed significantly from their normal-hearing peers. The most significant difference between the participants was observed in /o/ in each characteristic investigated. Production of /Λ/ showed significant differences in terms of F2; production of /u/ showed significant differences in terms of F1 and /y/ differed in terms of F0. However, except for duration, no significant differences in the production of /i/, /ɯ/, /œ/ vowels were observed between the two groups. The relationship between the hearing loss and vowel production characteristics (F0, F1, F2 and duration) did not differ between hearing impaired children who were in mainstream classrooms and those who were attending a school for the hearing impaired. Yet, the intelligibility scores of these two groups differed significantly. The level of hearing loss was found to be the most fundamental variable that affected speech intelligibility. Together with the duration of vowel production, hearing loss accounted for 64 percent of intelligibility. It is maintained that hearing-impaired children diverge from their normal-hearing peers in terms of vowel production characteristics. Finally, it is claimed that the duration of vowel production is a highly important variable influencing speech intelligibility.

Key words: Hearing impairment · Vowels · Formant frequencies · Acoustic analysis · Speech intelligibility

INTRODUCTION

Language makes human a social being and helps him think, speak and convey ideas. Children have problems in assigning meaning to the world without acquiring the symbolic systems of the language. Language can be defined as a set of organized symbolic relationships based on mutual agreement among individuals, which is used to facilitate communication [1]. The most important component of interpersonal communication is language, particularly its verbal dimension, speaking. Vowels have a very important place in communication, since they are the main information carriers of the prosodic information within the speaking signals [2]. Like most other languages, the nucleus of the syllable is a vowel in Turkish. More specifically, words and speech are not possible without vowels. This makes them indispensable for speech intelligibility.

Vowels are produced through an open configuration of the vocal tract, which leaves no build-up of air pressure above the glottis. On the other hand, consonants are produced through a closure at one or more points along the vocal tract. Vocal cords vibrate during the articulation of vowels in most languages, thus, they are also called voiced sounds [3].

Vowels are described in terms of three common features which are height (vertical dimension), backness (horizontal dimension) and roundedness (lip position). While classifying the vowels, the unstressed and toneless neutral vowel sound (schwa[ə]) is used as a reference point. Vowels are produced at the back or top of this neutral vowel, which helps classify the vowels [4].

Corresponding Author: Mehmet Cem Girgin, School for the Handicapped, Anadolu University, Eskisehir, Turkey

Through the movements of the chin, tongue and lips, variation among vowels is sustained [5]. Turkish can be regarded as a symmetric language with regard to its vowels as the number of back, round and high vowels are equal [6].

As a result of resonant frequencies in any acoustic system, peaks in an acoustic frequency spectrum might occur. These points where the peaks occur are called formant. Formants reflect the shape of the vocal track during vocalization of the vowels [7]. Vowels have five formants, but the most important of these are generally the first two or three. The first two formants to discriminate vowels from each other are F1 and F2. Most scholars in the field maintain that variations in the formant frequencies of vowels have a crucial role in perceiving and describing vowels [8, 9].

Hearing impairment, which can be defined as a full or partial decrease in the ability to understand sounds, might hinder children from utilizing the spoken language effectively [10]. This impairment hinders development and accommodation to the society's communication agreements [11]. Hearing carries an important role in the acquisition of speaking skills [12]. However, hearing loss occurring before the language acquisition severely interferes with the acquisition of speaking [13]. This situation influences hearing children's chance to acquire the culture of the society they live in along with creating an interruption in their intellectual development [14]. Such problems lead to defects in hearing impaired children's communication process [15].

Insufficiency or total lack of aural feedbacks stemming from sensory-neural hearing handicap leads to defects in hearing impaired individuals' ability to notice and correct their speech mistakes. As a result, speech patterns of hearing impaired individuals deviate from normality since they have not acquired the language before the critical age through natural developmental processes. The importance of hearing and listening is indisputable in language acquisition. Listening is a more complicated notion in comparison to hearing since it requires perceiving environmental noises and speech voices, discriminating them and assigning meaning to sounds.

Insufficiencies in hearing and listening lead to differences in speech production of hearing impaired children. Some can speak as effective as their hearing peers while some deviates from normality to a great extent, because of their deficiencies in syntax, phonology, semantics and morphology. Even though hearing impaired children are able to use their speech organs as effective as their hearing peers, they cannot develop these organs since they cannot participate in regular speech production contexts effectively.

Hearing impaired children make several mistakes while uttering both consonants and vowels. Hudgins and Numbers [16] list a set of common mistakes made by hearing impaired children. For instance, nasalization, adding unnecessary syllables, dropping voices and changing voices are quite common while producing consonants. On the other hand, confusing between voiced and voiceless sounds, neutralizing vowel sounds (producing schwa), lengthening vowels, replacing vowels with a wrong alternative, nasalization, producing more than one syllable with the same vowel are common mistakes made during vowel production. Several studies conducted reveal similar results regarding the speech production patterns of hearing impaired children [17, 18]. Along with above minor mistakes, hearing impaired children make some global mistakes such as insufficiency in controlling the fundamental frequency (F0), wrong breath control, slower speech, intonation differences, using different intonations, monotonous speech, different stress patterns and deficiencies in the voice quality [18-23]. In short, above mentioned problems in the speech production patterns of hearing impaired children interferes with the speech fluency and intelligibility to a serious extent.

Speech intelligibility can be defined as the accuracy of what hearing impaired individual delivers through speech; and intelligibility of this speech by a normal listener [13, 14, 24, 25]. It has been emphasized that there is a significant relationship between pre-lingual hearing-impaired children's speech intelligibility and the degree of hearing loss [16]. Speech intelligibility is a crucial feature in interpersonal communication. It can be considered as the most practical measure of communication skills. In this respect, evaluation of speech intelligibility carries utmost importance in investigating communication skills and planning interventions for children with hearing and speaking problems [19].

Bradlow *et al.* [26] asked what makes a speaker more intelligible than any other through conducting a study with 20 hearing individuals. Findings reveal that speech rate and fundamental frequency (F0) did not have strong correlations with the intelligibility scores. However, a negative correlation coefficient between the narrowing of the vowel space and general intelligibility was found, suggesting that the vowel space is a significant predictor of the intelligibility. Svirsky *et al.* [27] found that among pre-lingual hearing impaired children who were wearing hearing aids, the residual hearing was a significant predictor of the intelligibility. A recent study by Öster [28] reveals that the level of hearing loss measured through an audiometer cannot robustly predict speech intelligibility. Rather, children's proficiency of speech processing is a better predictor. More specifically, the proficiency of children to use the residual hearing in order to perceive speech and monitor speech production is a better predictor.

A study conducted by Waldstein [29] investigated the influence of auditory feedback deprivation on speech production. Findings revealed that the variability of the vowel production increased in hearing impaired children, vowel space was narrowed and the first two formant values of the vowels approached to the neutral vowel (shwa [/ə/]). It was revealed in several studies that in most hearing losses, the duration of auditory feedback deprivation influenced the level of speech. The variation in the deprivation of auditory feedback mostly influenced the fundamental frequency (F0) [27]. It was also found that increasing auditory feedback through cochlear implantation positively influenced speaking and voice parameters [30, 31]. Poissant *et al.* [30] conducted a study with six hearing impaired children using cochlear implants and compared cochlear implant and no-cochlear implant situations. It was found that following the first years after the cochlear implantation was realized, the auditory feedback increased and the levels of fundamental frequency, duration and other formants improved. It was also revealed that the vowel space was narrowed in all vowels; however, the statistically significant difference between hearing and hearing-impaired individuals was only in the /ε/ sound [7].

The duration is a significant element to discriminate and classify sounds. Under impaired hearing conditions, duration has an important role in discriminating sounds. Hearing impaired children are under impaired listening conditions because of their hearing loss. On the other hand, an individual listening to the speech of hearing impaired children is under an impaired listening condition as well. The duration of a sound serve as an indispensable clue to discriminate sounds in such conditions. Thus, the right sound duration is an important predictor of speech intelligibility [32]. John and Howarth [33] investigated the relationship between speech intelligibility and the use of abnormal duration in speech conducting a study with 29 children with Sevier hearing loss. These children were given a training to improve their speeches in terms of sound duration. In the end, it was revealed that children's speech intelligibility improved almost 56 percent. In addition, listeners' ability to understand these hearing impaired children's speech increased to a larger extent.

Studies conducted with hearing impaired children with a focus on language disorders are quite immature in Turkey. In addition, it is a common approach to examine consonants while studying speech disorders even though above studies reveal that vowel characteristics have important roles in speech intelligibility. The purpose of the current study is to investigate formant frequencies and duration of vowels produced by Turkish speaking hearing-impaired children along with the relationships between these characteristics and speech intelligibility. Differences between hearing and hearing impaired children were investigated as well. In addition, since the language learning environment can be an important predictor of language proficiency, differences were investigated between hearing impaired children who were in mainstream classrooms and those who were attending a school for the hearing impaired. Finally, predictors of speech intelligibility were investigated.

MATERIALS AND METHODS

Participants: Participants were randomly selected from available student groups who can understand the instructions of instruments and applications used in the study. Twenty hearing impaired (10 females and 10 males) and 20 hearing students (10 females and 10 males) participated in the study. The experiment group consisted of hearing impaired children who had either born hearing loss or hearing loss before acquiring the language. All of them were enrolled at a special center for speech and language disorders in Istanbul. They all had bilateral hearing loss, that is, both ears were affected. They all used hearing aids and they did not have any additional impairment other than the hearing impairment. Children with cochlear implants were not included in the study. Hearing loss of the children varied between 40 and 124 dB. The value of the better hearing ear was considered as the level of the hearing loss. The control group consisted of normal hearing students who did not have any learning or mental problem. It was sustained that the number of males and females were equal in each group without any significant variation in terms of age as well.

Instruments: In order to collect demographic information about children, a personal information form was prepared to be filled in by their parents. The information provided by parents was compared with the information provided

Table 1: Demographic information of participants

	Hearing Impaired		Hearing	
	N	Age (Mean & SD)	N	Age (Mean & SD)
Female	10	9.43 1.59	10	9.45 1.40
Male	10	9.03 1.47	10	9.32 1.48
Total	20	9.23 1.51	20	9.38 1.40

Table 2: Vowels examined in the study

Vowel	Vowel-Consonant	Consonant-vowel-consonant	Consonant-vowel
/Λ/	/Λt/	/citΛp/	/tsΛntΛ/
/ε/	/εv/	/ cœpϵc /	/dϵvϵ/
/i/	/ip/	/diʃ/	/cϵdi/
/ɯ/	/ɯspΛnΛk/	/kΛʃɯk/	/kΛpɯ/
/o/	/ok/	/top/	/palto/
/œ/	/œrdϵc/	/tsœp/	/cœpϵc/
/u/	/un/	/koɭtuk/	/kutu/
/y/	/yts/	/gyl/	/yty/

by their institutions. Questions included in the personal information form addressed children's birthdates, type and level of hearing loss, the beginning date of the hearing loss, the diagnosis date, the duration of using a hearing aid, whether they used the aid regularly and how long they have been provided with special education opportunities. The level of hearing loss was determined through audiometer measurements conducted by their institution in June 2007.

To analyze acoustic features of vowels, several vocabulary items were selected representing vowel-consonant, consonant-vowel-consonant and consonant-vowel couples. Pictures were prepared to represent these sets. Such a design helped researchers to analyze vowels with regard to their location within the syllable. A total of 23 colorful pictures were used to represent selected words. While determining the words, special attention was given to the criterion that the words were within the current lexical levels of students. Selected words are provided in Table 2 with their phonetic representations. The syllable examined for the acoustic properties of a vowel is underlined in the table.

In order to evaluate the speech intelligibility of participants, ten simple statements were selected. Language capacity of hearing impaired children was taken into account while determining the statements along with all words within the statements. Long or morphologically complicated words were avoided. A simple picture for each statement was prepared and approved by three instructors experienced in hearing impaired education. Statements are given below:

1. Çocuk atı seviyor (The child is caressing the horse).
2. Çocuk kediye süt (mama) veriyor (The child is feeding the cat).
3. Kız ip atlıyor (The girl is jumping a rope).
4. Adam (baba) kitap okuyor (The man is reading a book).
5. Çocuklar okula gidiyorlar (Children are going to school).
6. Annesi kızı öpüyor (Her mother is kissing the girl).
7. Çocuklar parkta oynuyorlar (Children are playing in the playground).
8. Adam (ressam) resim yapıyor (The man is drawing a picture).
9. Çocuk süt içiyor (The child is drinking milk).
10. Kadın (anne) ütü yapıyor (The women is ironing clothes).

Data Collection Procedure: The pictures prepared to address vowels were shown to both hearing and hearing impaired children. Then, they were asked to name the object in the picture. Children's responses were recorded through PRAAT Version 4.4.20 software for acoustic analysis, which helped researchers to collect information about vowel duration, fundamental frequency, F1 and F2. Recordings were realized in a silent room through high quality microphones located 10 centimeters from participants mouths with a 45 degree angle. Children's mistakes were not corrected during recording. When a child could not name an object, researchers named the object once and asked the child to repeat.

The data addressing speech intelligibility was collected through asking hearing impaired children to explain what was happening in a specific picture. Hearing children's speech intelligibility was regarded as 100 percent and hearing impaired children's deviation from normality was examined as suggested by Conrad [34]. No interruption was made during the production of children. Ten pictures were randomly shown to children and recorded so that the speech intelligibility scores given by listening researchers would not be influenced. In order to evaluate speech intelligibility a 6-level Likert scale was prepared ranging from completely intelligible to completely unintelligible. Three jury members, who are language and speech disorder therapists, rated each sentence on the scale and their average was taken as the intelligibility score.

Data Analysis: SPSS 15.0 for Windows was used for data analysis. In order to determine parametric tests to be used in the study, several resources were used [35, 36, 37, 38]. The significance level (alpha) was determined as .01 in order to reduce the likelihood of committing a type I error, which is the error of finding a statistically significant result when the result is actually not significant. Hearing and hearing impaired children's vowel production characteristics were compared through independent-samples t-tests. Hearing impaired children in mainstream classrooms and special education settings were compared through t-tests as well. Relationships between speech intelligibility, level of hearing loss and vowel production characteristics were examined through correlation coefficients. Finally, in order to examine the best predictors of speech intelligibility, a multiple regression analysis was conducted.

RESULTS

Findings comparing hearing and hearing impaired children with regard to F0, F1, F2 and duration

Independent-samples t-tests were conducted for each vowel in order to compare hearing and hearing impaired children in terms of vowel production properties, which are, F0 (fundamental frequency), F1, F2 and duration. For eight vowels and four variables, a total of 32 independent-samples t-tests were conducted. In order to save space, means, standard deviations, t values and significance levels will be given. The summary table for all above comparisons is given below. Significant differences at the .01 level or below are given in bold:

As summarized in Table 3, hearing and hearing impaired children's vowel production durations differed significantly for all vowels. More specifically, the vowel production times of hearing impaired children were always longer than those of their hearing peers. Hearing and hearing impaired children differed in terms of the F2 value of /Λ/ which indicated that hearing impaired children had problems in configuring their mouth and tongue to produce the sound. Such differences were observed in the F1 value of /u/ indicating problems in locating lips and tongue and fundamental frequency of /y/ indicating problems in locating the tongue. Interestingly, hearing impaired children differed from their hearing peers in terms of all dimensions of the vowel /o/. That is, hearing impaired children had problems with producing /o/.

Findings comparing hearing impaired children in mainstream and special classrooms

Two further t-tests were conducted to see whether hearing impaired children who were in mainstream classrooms and those who were attending a school for the hearing impaired differed in terms of F0 (t_{18}=.300), F1 (t_{18}=1.307), F2 (t_{18}=2.226) and duration (t_{18}=-1.457) all which revealed insignificant results at a probability value of .01. Their hearing loss did not differ as well (t_{18}=-2.035; $p>.05$). However, their speech intelligibility differed statistically. More specifically, the scores of hearing impaired children who were attending an ordinary school (Mean: 33.30, SD: 13.71) was higher than those of hearing impaired children attending a special school (Mean: 13, SD: 12.710) at a statistically significant level (t_{18}=3.433; $p<.003$).

Findings investigating the predictors of speech intelligibility

In order to investigate the best predictors of speech intelligibility, Pearson correlation coefficients among continuous variables obtained in the study were calculated, which are summarized in Table 4.

As indicated in the table, there was a significantly high correlation coefficient between speech intelligibility and hearing loss ($r=-.699$; $p<.001$) and between speech intelligibility and vowel production duration ($r=-.555$; $p<.01$). The relationship between hearing loss and vowel production duration was not significant. Such findings gave researchers the opportunity to conduct multiple regression analysis to investigate independent predictors of speech intelligibility since the assumption of multicollinearity was met. That is, there should not be significant correlations between predictor variables in order to explain a higher and uncontaminated amount of

Table 3: Comparison of hearing and hearing impaired children regarding vowel production characteristics

		Hearing children		Hearing impaired children			
		M	SD	M	SD	t	sig.
/ʌ/	F0	258.10	23.60	293.45	61.51	-2.400	0.021
	F1	828.78	45.48	879.55	155.02	-1.406	0.168
	F2	1478.35	89.58	1625.21	179.23	-3.278	0.002
	Duration	0.13	0.02	0.19	0.07	-3.934	0.001
/ɛ/	F0	263.10	28.99	289.05	59.45	-1.755	0.087
	F1	617.48	42.62	674.12	112.33	-2.108	0.042
	F2	2174.84	203.24	2050.90	235.05	1.784	0.082
	Duration	0.13	0.02	0.21	0.06	-5.600	0.001
/i/	F0	272.02	26.31	307.10	59.10	-2.426	0.020
	F1	422.36	56.58	476.86	90.34	-2.286	0.028
	F2	2111.97	348.55	2254.62	211.79	-1.564	0.126
	Duration	0.10	0.02	0.19	0.05	-7.351	0.001
/ɯ/	F0	259.64	50.02	296.44	57.28	-2.164	0.037
	F1	487.74	231.23	542.35	130.93	-0.919	0.364
	F2	2048.99	368.25	1941.39	170.56	-1.186	0.243
	Duration	0.11	0.02	0.17	0.07	-4.330	0.001
/o/	F0	258.10	25.17	291.48	48.83	-2.717	0.010
	F1	575.63	37.74	662.06	92.30	-3.876	0.001
	F2	1180.73	117.71	1341.58	175.63	-3.402	0.002
	Duration	0.13	0.02	0.20	0.05	-4.330	0.001
/œ/	F0	264.91	23.06	290.48	49.99	-2.077	0.045
	F1	568.10	46.90	608.83	87.75	-1.831	0.075
	F2	1695.75	115.78	1747.78	187.47	-1.056	0.298
	Duration	0.11	0.01	0.17	0.04	-5.531	0.001
/u/	F0	271.25	27.56	294.64	56.75	-1.658	0.105
	F1	443.31	49.61	509.91	97.87	-2.714	0.010
	F2	1320.79	244.90	1413.83	213.92	-1.280	0.208
	Duration	0.12	0.02	0.23	0.07	-7.419	0.001
/y/	F0	272.23	25.18	311.38	55.52	-2.871	0.007
	F1	395.27	32.97	448.45	86.33	-2.574	0.014
	F2	1899.11	257.53	1905.77	280.95	-0.078	0.938
	Duration	0.12	0.02	0.25	0.09	-6.177	0.001

Table 4: Relationships between speech intelligibility. level of hearing loss and vowel production characteristics

	Hearing loss	Speech intelligibility	F1	F2	F0
Speech intelligibility	-0.699***				
F1	0.035	-0.073			
F2	-0.084	0.049	0.578**		
F0	0.337	-0.154	0.481*	0.267	
Duration	0.191	-0.555**	0.318	-0.289	-0.025

Correlation is significant at the .05 level (*), .01 level (**) and .001 level (***)

Table 5: Multiple regression analysis to predict speech intelligibility

		B	Standard Error	Beta	t	P	R^2	R^2 change	Significance of the change
1	Constant	60.38	9.38		6.44	0.001	0.49	0.49	0.001
	Hearing loss	-0.42	0.10	-0.70	-4.15	0.001			
2	Constant	85.46	11.19		7.64	0.001	0.67	0.18	0.007
	Hearing loss	-0.37	0.08	-0.62	-4.36	0.001			
	Vowel duration	-146.91	47.45	-0.44	-3.10	0.007			

variance in the target variable. To reveal the best predictors, multiple regression analysis was conducted through the stepwise method. Hearing loss explained 49 percent of the variability in speech intelligibility with a significant F value (F=17.202; p>.001). Vowel production duration explained an additional 18 percent of the speech intelligibility (F=9.586; p<.007). Coefficients, B and Beta values, corresponding t values, significance of the change created by each predictor and R square values are provided in Table 5. The adjusted R square was .635 indicating that approximately 64 percent of speech intelligibility can be explained by the level of hearing loss and duration of vowel production.

DISCUSSION

Some researchers focus on consonant characteristics rather than vowels. However, the current study reveals that vowel production of hearing impaired children differs from that of hearing children and it has a significant influence on speech intelligibility. Lengthening vowels is an abnormality occurring as a result of hearing impairment. Findings revealed that the vowel production duration of hearing impaired children was significantly longer than their hearing peers, which is consistent with several studies conducted before [18, 39-42). Deviations from normality in vowel production were observed particularly in /Λ/, /o/ and /u/ which were consistent with previous research [18]. Markides suggests that hearing impaired children makes most mistakes in back vowels. Smith [42] also suggests that hearing impaired children produce low and rounded vowels better, which is consistent with the current findings. Schenk *et al*. [7] examined /e/, /Λ/ and /o/ and found that F1 values of /e/ and /o/ were higher in hearing impaired children. In terms of /Λ/, F1 values were lower than those of hearing children. In terms of F2, only /e/ values differed between hearing and hearing impaired children. In the current study, in terms the F1 and F2 values of /e/, groups did not differ. In addition, the difference in /Λ/ was observed in the F2 values rather than F1 values. Finally, in terms of /o/, all properties differed as indicated in a previous study [43]. Differences between the current study and the Schenk *et al*. [7] study might stem from the differences between Turkish and German.

Neutralizing vowels and producing them like a schwa is a common thing in most languages. Turkish does not have a schwa sound. Thus, neutralization was not examined in the current study. However, during the implementation process, it was observed that children neutralized the /Λ/ sound. It was also observed that children used /ɯ/ and /i/ interchangeably, which was observed in a previous study [42]. Smith [42] also indicates that children used /Λ/ rather than /u/. In contrast, participants of the current study used /u/ and /Λ/ rather than /ɔ/. Previous studies suggest that hearing impaired children have higher values in terms of the fundamental frequency (F0) [18, 20-24]. The current study reveals that hearing impaired and hearing children differed only in terms of the F0 values of /y/ and /o/. That is, participants of the current study had fewer problems with exaggerated articulatory posture.

The type of school was not an important variable differentiating the formant characteristics of vowels. However, speech intelligibility differed in accordance with the type of school. This finding is consistent with that of John *et al*. [32] indicating that hearing impaired children in mainstream classrooms are better in terms of speech intelligibility in comparison to their peers in special education classrooms. That is, even though students had serious levels of hearing loss, they could make use of the verbal communication opportunities taking place in mainstream classrooms. Thus, rather than the type of school, approaches followed in a specific institution seem important for speech intelligibility. Studies like Tobey *et al*. [31] and Svirsky *et al*. [27] suggest that auditory oral approaches have a positive influence on speech intelligibility of hearing impaired children. In this respect, it is important to provide hearing impaired children as many conversation chances as possible.

A strong negative correlation between speech intelligibility and hearing loss was found in the present study. Several studies revealed that there is a negative correlation between the level of hearing loss and speech intelligibility [18, 24]. Smith [42] maintains that children whose speech intelligibility ranges between 75 and 100 percent have a less serious hearing loss. Conrad [34] and Monsen [44] suggest that trivial levels of hearing loss are related with high levels of speech intelligibility. However, serious hearing loss does not always mean unintelligible speech. In contrast with the current study and several previous researches, John *et al*. [32] maintain that speech intelligibility and hearing loss are weakly related. Öster [28] suggests that rather than the level of hearing loss, the proficiency of children to use their hearing residual to perceive speech and monitor production is a better predictor of intelligibility. In Turkey, Tüfekçioğlu [14] examined the relationship between hearing loss and the number of unintelligible words which led to a weak relationship. Girgin [21] and Çeliker and Ege [45] on the other hand, reported a negative and moderately significant relationship. In the Girgin [21] study, hearing impaired children were trained through the auditory oral approach to develop good speaking abilities which might have led to a moderate relationship, whereas the current study's participants were not trained with such an approach leading to a stronger relationship between the variables.

The next important predictor of the speech intelligibility was found to be the production duration of vowels, which was in line with the Miller's (1956) suggestion that duration is a discriminating feature to diagnose vowels [33]. Lengthening vowels lead to slow speech, which might have led to unintelligible production as indicated in many previous studies [16, 18, 20-24, 42].

None of the formant values had significant relationships with the speech intelligibility. Hudgins and Numbers [16] and Smith [42] claim that there is a negative relationship between speech intelligibility and formant values. However, the studies do not specify the name of the formant as realized in the current study. Monsen [44] suggested that the F2 values of /i/ and /u/ were related with speech intelligibility. Sakayori *et al.* [46] also maintained that F1 and F2 values are related with speech intelligibility. None of these findings were retained in the current study. Brown and Goldberg [47] suggest that formant frequencies of vowels are the least important predictors of speech intelligibility. Similarly, Markides [18] suggests that consonants are more important in intelligibility than vowels. Both studies are supported through the current study.

The current study poses some limitations. There should be more participants to conduct a more robust multiple regression analysis; however, there are few available students enrolled in the special education institutions, which prevented researchers from conducting a better analysis. In this respect, results of the multiple regression analysis could be considered as suggestive rather than definitive. The current study only focuses on vowel production which still leaves a need for studies focusing on vowel comprehension. Since the starting age to use a hearing aid could not be determined definitely, its influence on intelligibility could not be investigated. Further studies should also examine the influence of starting to use a hearing aid at an early age. The same study might be conducted before and after therapy to investigate the effects of specific interventions on speech and intelligibility development.

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