Journal of Language Research
ZABANPAZHUHI

Journal of Language Research, *Alzahra University*
Vol. 17, No. 57, Winter 2026, pp.9-28
Research Article

Investigating the acoustic features of stress in children with autism spectrum disorder compared with typically developing children

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Received: 2023/11/04 Accepted: 2024/03/03

Abstract

Autism Spectrum Disorder (ASD) is a social communication disorder that includes repetitive behaviors/stereotyped interests, and impairment in social interaction and communication. The present study is designed to investigate the acoustic behavior of vowels in stressed/unstressed positions and males/females in the Persian language in children with autism compared to typically developing children (TD). For this purpose, a minimal pair word [tɒbeʃ] (light)/ [tɒb-'eʃ] (his/her swing) was selected, and 15 children with ASD and 15 TD children (five girls and ten boys) were asked to repeat them for two times. Data were recorded by a Shure microphone. Then a Text Grid was made for each word and the amount of fundamental frequency (F0), the first and second formants F1, F2), duration, and intensity of vowels [ɑ] and [e] were measured using PRAAT software. The collected data were then analyzed using SPSS software. Eventually, results demonstrated that DISABILITY had a significant effect on F0 and duration of vowels [ɑ, e] and F1, F2, and intensity of vowel [e]. Moreover, GENDER had a significant effect on the F2 of the vowel [e]. Results also indicated that the impact of STRESS on the F0 of the vowel [e] and the duration of the vowel [ɒ] was noticeable. The interaction between two factors "DISABILITY X STRESS" showed that the mean F0 of the vowel [e] and duration of vowel [ɑ] in ASD children in stressed and unstressed positions were more than those in TD ones. Therefore, fundamental frequency and duration of vowels had a great effect in judging the position of the stress in both ASD children and TD children.

Keywords: autism spectrum disorder, stress, fundamental frequency, formants, duration, intensity.

How to Cite:
Damansouz, A; Abolhasanizadeh, V (2026), Investigating the acoustic features of stress in children with autism spectrum disorder compared with typically developing children, *Journal of Language Research*, 17 (57), 9-28.
https://doi.org/10.22051/jlr.2024.45472.2373 homepage: https://zabanpazhuhi.alzahra.ac.ir

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1. Introduction

Autism spectrum disorder (ASD) is a kind of social communication disorder that manifests in the first 36 months of life (American Psychiatric Association, 2000) and occurs in about 1 in 110 children (Kogan et al., 2009). The "autism spectrum" includes several disorders: autism, ranging from low functioning to high functioning (HF), Asperger syndrome, and Pervasive Developmental Disorder-Not Otherwise Specified (PDD-NOS) (Paul et al., 2009). Social interaction impairment, communication impairment, and repetitive behaviors/stereotyped interests are the characteristics of ASD (Belmonte et al., 2004; Volkmar et al., 2004). Individuals with autism who function in the normal range of IQ are typically referred to as having high-functioning autism (HFA) (Paul et al., 2009). The communication deficits in these higher-functioning individuals are in conversational pragmatics and social communication. There are two language phenotypes among verbal children with autism: children who have normal linguistic abilities, e.g., phonological skills, vocabulary, syntax, and morphology, and children with language impairment. Some children with autism never acquire speech (Tager-Flusberg and Joseph, 2003). The use of morphology and syntax in the spontaneous speech of individuals with ASD is limited. They produce fewer prepositions, conjunctions, articles, verb tenses, auxiliaries, embedded sentences, sentence complements, and relative clauses (Bartolucci et al., 1980; Cantwell et al., 1978; Menyuk and Quill, 1985; Scarborough et al., 1991). Prosody, including pitch, rhythm, or stress, is unusual in ASD individuals (McCann and Peppé, 2003).

Stress is the linguistic property of a word that shows the stronger syllable in a word (Sadeghi, 2011). Kahnemuyipour (2003) maintained that in the Persian language, the final syllable of the word receives stress. This rule applies to all verbs without a prefix, nouns, and adjectives. Ferguson (1957) examined the position of word stress and its role in Persian morphology. He declared that if a word is expressed in isolation, it has 'inherent' or 'potential stress' or word stress. If the dictionary entry form of words is considered, word stress in Persian is on the final syllable. If inflected forms of nouns and verbs are included, the above statement about the predominance of final stress is not true. Persian words contain one to five or more syllables. Stress in monosyllabic words is on their only syllable, and in two- to five-syllable words, it is on any one of the syllables.

Previous research on acoustic features of stress was conducted in different languages or on adults with Down syndrome in Persian. Khaloeipour (2017) studied adults with Down syndrome to acoustically study the vowels in stressed/unstressed syllables; however, there is not a sufficient survey of those features of stress in children with ASD in Persian, and a lack of information in this field can be felt. Therefore, this research aims to investigate the effect of DISABILITY, GENDER, and STRESS on F0, F1, F2, duration, and intensity of vowels [ɑ] and [e] in a minimal pair word.

2. Review of the literature

Investigating the acoustic features of stress has been highlighted by previous studies. In many languages, stress is connected with frequency. The most important cue for the presence of stress is fundamental frequency. The stressed syllable has a higher fundamental frequency than the unstressed syllable (Lehiste, 1970). Moreover, both duration and intensity of vowels are factors that influence the stress. The long and intense syllables are more likely to be marked as stressed (Abolhasanizadeh et al., 2012; De Jong and Zawaydeh, 1999; Lehiste, 1970; Liberman, 1960; Morton and Jassem, 1965). However, the role of duration is more important than intensity (Fry, 1954; Lehiste, 1970; Sadeghi, 2011). Prieto and Ortega-Llebaria (2006) placed emphasis on the fact that in Catalan and Castilian Spanish, duration and intensity are reliable acoustic correlates of stress in the absence of pitch accent. In the research carried out by Abolhasanizadeh et al. (2012), the intensity of accented [a] in two minimal pairs [tɒbéʃ] 'light' vs. [tɒ́b-eʃ] 'swing+his/her' and [tɒpéʃ] '(nonsense word)' vs. [tɒ́p-eʃ] 'tank-top+his/her' is 2.06 dB higher than unaccented [a], and the intensity of accented [e] is 1.96 dB higher than unaccented [e]. In another research done by Masoumi and Abolhasanizadeh (2015), the mean F0, F1, and F2 of minimal pairs, ['tɒr] (means web) and ['dɒr] (means tree), and their plural in stressed and unstressed syllables in ten Persian subjects with Kermani accent were measured. Results demonstrated that there is a significant difference in the mean F0 of the vowel [ɑ] between stressed and unstressed syllables, while there is no significant difference in F1 and F2 of the vowel [ɑ] between stressed and unstressed positions. Results also indicated that the mean F0 and F1 of the vowel [ɑ] in a stressed syllable are more than those in an

unstressed syllable. But the mean F2 of vowel [ɑ] in the unstressed position is more than that in the stressed one. De Jong and Zawaydeh (1999) also measured formants in stressed position in Jordanian Arabic, and they asserted that the stressed syllable has a systematically higher F1. Previous studies made a distinction between males and females in different languages. Most studies emphasized that the higher F0 of vowels is produced by women (Ghorbani et al., 2006; Hou et al., 2002; Izadi, 2019; Pépiot, 2015). The duration of vowels in females is longer than in males (Pépiot, 2015). Another factor that distinguishes females from males is formants. Females produce significantly higher F1 and F2 than the same-aged males (Busby and Plant, 1995; Huber et al., 1999; Izadi, 2019). However, Hou et al. (2002) argued that the first and second formant values of males are higher than females.

Some researchers investigated the voice characteristics of people with Disability. Khaloeipour (2017) performed an acoustic study on vowels in stressed/unstressed syllables produced by adults with Down syndrome. For this purpose, 18 participants pronounced two minimal pairs [tɒbeʃ] (light), [tɒb-eʃ] (his/her swing), and [tɒpeʃ] (nonsense word), [tɒp-eʃ] (his/her top). Results showed that there was no significant difference in F0, F1, F2, and duration of vowel [e] between stressed and unstressed positions. But the effect of STRESS on F2 and the duration of the vowel [ɑ] in stressed syllables is significantly different from that in unstressed syllables. Moreover, the effect of stress on the mean intensity of both vowels is significant. Results also demonstrated that the mean F0, duration, and intensity of vowels in stressed syllables were more than those in unstressed one. But the mean F1 and F2 of vowels in stressed syllables were less than those in unstressed syllables. In another research on the vowel space of words with a CVC pattern in children with Down syndrome, the amount of F1 and F2 of vowels [ɑ, e] was measured. Results indicated that there was no significant difference in the mean F1 of vowels [ɑ, e] and the F2 of the vowel [ɑ]. However, there was a statistically significant difference in the mean F2 of the vowel [e]. The mean F1 of vowel [e] and F2 of vowel [ɑ] in children with disability were more than F1 and F2 of these vowels in TD children. Moreover, the mean F1 of vowel [ɑ] and F2 of vowel [e] in TD children were more than the mean F1 and F2 of these vowels in children with disability (AbolhasaniZadeh et al., 2018). In a study on hearing-aided, cochlear-implanted, and client children, Izadi (2019) measured the F0, F1, F2, intensity, and

duration of vowels in words with CVC patterns. Results showed a significant difference in the mean F0, F2, intensity, duration of vowels [ɑ, e], and F1 of the vowel [ɑ] between CL, HA, and client children. The effect of GENDER on the intensity of vowels was also significant. Results also indicated that the mean F1 of vowel [e], F2 of vowel [ɑ] in children with DISABILITY was more than in client children. The mean intensity of the vowel [ɑ] in the client was more than the intensity of this vowel in children with DISABILITY. The mean F0, F2, and duration of vowels and F1 of the vowel [ɑ] in females were more than those of males. But the mean intensity of the vowel [ɑ] in males was more than in females. In another research, word and sentence duration were measured in cochlear implant and TD ones in imitation and reading tasks. Results showed that the difference in duration between the group with DISABILITY and the TD group is significant. The mean duration in all modes (word imitation, word reading, sentence imitation, sentence reading) was longer in cochlear implants compared to normal hearing children (Hasanvand et al., 2018). Recent studies on autism and typical development age-matched speakers showed that both groups produced longer durations for stressed than unstressed syllables, but the duration in stressed and unstressed syllables was greater in TD subjects than subjects with ASD (Paul et al., 2008).

3. Methodology

3.1. Design

This study adopted a quasi-experimental design, where the participants were divided into two groups. The control group included TD children, and the experimental group included ASD children.

3.2. Setting and participants

The current study was conducted in a speech therapy center and in a primary and secondary school in Kerman, Iran. The 15 autistic children (5 girls and 10 boys) were located through the speech therapy center they attended. Autism was diagnosed based on ICD-10 (Anderson, 2012), which identifies children by unusual responses to the environment, delays and deficits in language development, repetitive or stereotyped behaviors, and impairments in social interaction. Moreover, the medical history and information in the subjects' files were considered. Only relatively high-functioning autistic children were selected for this study. They were

also at least 10 months under speech therapy, and they were living at home with their parents. The 15 TD children (5 girls and 10 boys) came from primary and secondary schools, and they were selected randomly. All participants' mother tongue was Persian, and their age range was between 7 to 16 years old, because there was not a sufficient survey of this age range in Persian, and a lack of information can be felt.

3.3. Instrumentation

Three instruments were used in this study to measure F0, formants, duration, and intensity of vowels: A Shure microphone to record individuals' productions and speech analysis software Praat (Boersma, 2011) that enabled the researcher to analyze sound waves and spectrograms at the same time. Moreover, SPSS software was used to categorize and analyze data.

3.4. Procedure

To conduct the study, the following steps were undertaken. At the outset, the researcher provided a consent form to the participants' parents and invited them to take part in the research. Participation was voluntary. Next, all children with ASD were given some cookies to help them relax and participate more comfortably. Afterwards, the meanings of the words [tɒbeʃ] and [tɒb-eʃ] were explained to the children by showing them pictures—one of the sun and one of a swing that belonged to a girl and that she sat on. Because the children with ASD had varying levels of literacy, they were asked to repeat the words rather than read them. Next, individual productions were recorded by a Shure microphone in a quiet room with thick walls and without windows to reduce background noise. The microphone was put 20-30 cm from the mouth. So, the ambient noise was controlled. The data were analyzed by PRAAT software (ver. 22.0.6). The researcher created a Text Grid of the words, where boundaries between consonants and vowels were determined, and each feature was labelled specifically. Finally, Excel software, SPSS software, and the repeated measure ANOVA were used to compare the F0, F1, F2, duration, and intensity of vowels [ɑ, e] between ASD children and TD children, between males and females, and between stressed and unstressed syllables.

4. Results

In this section, the results of the impact of DISABILITY, GENDER, and

STRESS on F0, F1, F2, duration, and intensity of vowels [ɑ, e] will be reported.

4.1. Fundamental frequency (F0)

The presented results of Table 1 showed that the effect of DISABILITY on F0 of both vowels [ɑ, e] is significant ($p<0.05$). However, there is no noticeable difference between males and females. The impact of STRESS on F0 of vowel [ɑ] is not significant ($p>0.05$), but there is a noticeable difference between stressed and unstressed syllables for vowel [e] ($p<0.05$). The results of a Post Hoc Bonferroni test revealed that the mean F0 of vowel [ɑ] and [e] in ASD children is 72.938 Hz and 80.594 Hz more than the mean F0 of these vowels in TD ones. These results also presented that females produce the F0 of vowel [ɑ] 15.938 Hz and vowel [e] 9.156 Hz more than males. Moreover, the mean difference of F0 of the vowel [ɑ] in stressed syllables and unstressed ones is 13.938 Hz. The mean F0 of this vowel in a stressed syllable is more than that in an unstressed one. Furthermore, the mean F0 of vowel [e] in the stressed position is 43.219 Hz more than the mean F0 of this vowel in the unstressed position.

Table 1.

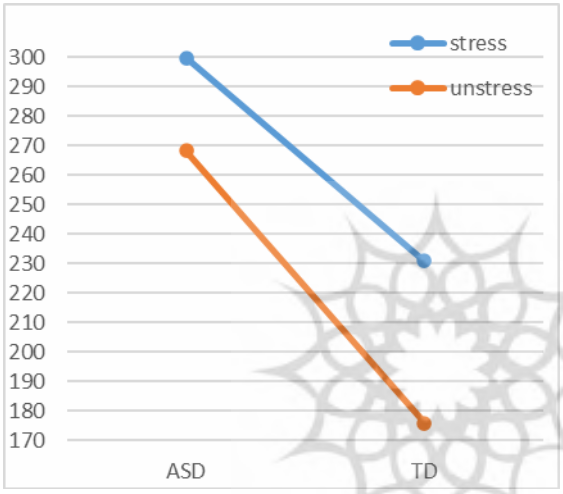
Analysis of variance to evaluate the effect of DISABILITY, GENDER, and STRESS on the F0 of vowels

VOWEL			Mean	Standard deviation	DF	F	Sig
[ɑ]	DISABILITY	ASD	299.531	7.540	1	20.159	0.003
		TD	226.594	9.572			
	GENDER	Male	255.094	6.735	1	2.142	0.187
		Female	271.031	5.519			
	STRESS	Stressed	270.031	6.130	1	3.221	0.116
		Unstressed	256.094	3.020			
[e]	DISABILITY	ASD	283.938	6.667	1	19.154	0.003
		TD	203.344	12.033			
	GENDER	Male	239.062	10.864	1	0.225	0.650
		Female	248.219	9.380			
	STRESS	Stressed	265.250	5.968	1	17.002	0.004
		Unstressed	222.031	6.244			

The interaction between two factors "DISABILITY X STRESS" showed that the mean difference of F0 of vowel [e] in ASD children and TD children for stressed syllables is 68.875 Hz, and for unstressed syllables is 92.313 Hz. ASD children produce vowel [e] higher than TD ones in both stressed and unstressed syllables. (Figure 1).

Figure 1.

Interaction of DISABILITY X STRESS on F0 of vowel [e]



The interaction between three factors "DISABILITY X GENDER X STRESS" showed that ASD females produced the highest f0 of the vowel [ɑ] in stressed syllables. However, ASD males had the highest f0 of the vowel [e] in stressed syllables.

4.2. F1

Based on the information in Table 2, having a disability does not have a noticeable impact on the F1 of the vowel [ɑ]. However, there is a noticeable difference between children with ASD and TD children for the vowel [e]. Furthermore, the impact of being male or female and stress does not have a notable effect on the first formant (F1) of either vowel. The Post Hoc Bonferroni test showed that children with ASD have higher average frequencies (Hz) for the vowel sounds [ɑ] and [e]. Specifically, the mean F1 for [ɑ] is 10.525 Hz higher in ASD children compared to typically developing (TD) children, and the mean F1 for [e] is

57.042 Hz higher in ASD children compared to TD children. The average F1 of the sounds [ɑ] and [e] is higher in females compared to males. Girls make the sounds [ɑ] and [e] at a frequency of 271.031 Hz and 248.219 Hz, which are 26.925 Hz and 9.792 Hz higher than boys. The Post Hoc Bonferroni test showed that the average pitch of the vowel [ɑ] is 24.725 Hz higher when it is stressed compared to when it is unstressed. However, the average frequency of vowel [e] in an unstressed syllable is 8.833 Hz higher than in a stressed syllable.

Table 2.

Analysis of variance to evaluate the effect of DISABILITY, GENDER, and STRESS on F1 of vowels

VOWEL			Mean	Standard deviation	DF	F	sig
[ɑ]	DISABILITY	ASD	736.525	12.565	1	0.828	0.387
		TD	726.000	10.988			
	GENDER	Male	717.800	16.475	1	1.160	0.309
		Female	744.725	15.898			
	STRESS	Stressed	743.625	13.401	1	1.992	0.192
		Unstressed	718.900	13.623			
[e]	DISABILITY	ASD	604.333	5.645	1	35.867	0.000
		TD	547.292	8.648			
	GENDER	Male	570.917	13.560	1	0.249	0.628
		Female	580.708	8.377			
	STRESS	Stressed	571.396	4.193	1	0.401	0.539
		Unstressed	580.229	11.873			

4.3. F2

The results, as presented in Table 3, indicated that the impact of having a DISABILITY does not have a notable effect on the second formant (F2) of the vowel [ɑ]. However, the effect of DISABILITY on the F2 of the vowel [e] is significant. Moreover, there is no noticeable difference between males and females for the vowel [ɑ]. However, the impact of GENDER on F2 of vowel [e] is significant. Furthermore, there is no notable difference between stressed and unstressed syllables for both vowels [ɑ, e]. Post Hoc Bonferroni test revealed that

children with ASD have higher average frequencies for the vowel [ɑ]. The mean F2 of vowel [ɑ] is 45.750 Hz higher in ASD children compared to TD children. However, the mean F2 of vowel [e] in TD children is 129.636 Hz more than ASD children. Results also indicated that the mean F2 of both vowels [ɑ, e] in females and in stressed syllables is more than the mean F2 of these vowels in males and in unstressed one. Females produce F2 of vowel [ɑ] 48.841 Hz and vowel [e] 224.727 Hz more than males (Figure 8). The average frequency of both vowels [ɑ] and [e] in stressed syllables is 16.523 Hz and 76.045 Hz higher than in an unstressed syllable.

Table 3.

Analysis of variance to evaluate the effect of DISABILITY, GENDER, and STRESS on F2 of vowels

VOWEL			Mean	Standard deviation	DF	F	sig
[ɑ]	DISABILITY	ASD	1436.772	38.121	1	0.944	0.354
		TD	1391.022	23.298			
	GENDER	Male	1389.477	29.665	1	2.374	0.154
		Female	1438.318	22.565			
	STRESS	Stressed	1422.159	33.938	1	0.308	0.591
		Unstressed	1405.636	13.369			
[e]	DISABILITY	ASD	1946.727	47.665	1	5.132	0.047
		TD	2076.363	30.439			
	GENDER	Male	1899.181	47.836	1	23.069	0.001
		Female	2123.909	19.168			
	STRESS	Stressed	2049.568	37.432	1	3.626	0.086
		Unstressed	1973.522	30.939			

4.4. Duration of vowels

The results of Table 4 showed that the effect of DISABILITY on the duration of both vowels [ɑ] and [e] is noticeable. But there is no significant difference between women and men for either vowel. The impact of STRESS on the duration of vowel [ɑ] is significant. However, there is no noticeable difference

between stressed syllables and unstressed syllables. The Post Hoc

The Bonferroni test showed that children with ASD have a higher average duration for the vowel sounds [ɑ] and [e]. Specifically, the mean duration for [ɑ] is 43.156 (m/s) higher in ASD children compared to typically developing (TD) children, and the mean duration for [e] is 90.812 (m/s) higher in ASD children compared to TD children. Moreover, from the results, it is obtained that the mean duration of vowel [ɑ] in males is 20.469 (m/s) more than in females. But females produce vowel [e] 5.250 (m/s) longer than males. The Post Hoc Bonferroni test showed that the average pitch of the vowel [ɑ] is 62,781 (m/s) more when it is stressed compared to when it is unstressed. However, the average duration of vowel [e] in a stressed syllable is 28.188 (m/s) less than in an unstressed syllable.

Table 4.

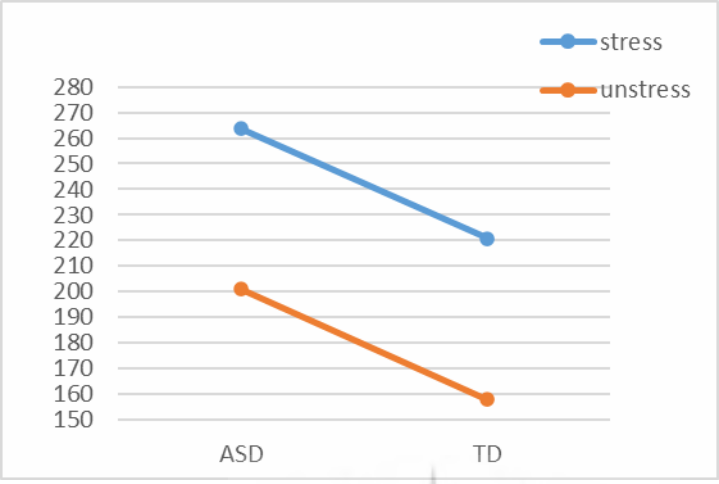
Analysis of variance to evaluate the effect of DISABILITY, GENDER, and STRESS on the duration of vowels

VOWEL			Mean	Standard deviation	DF	F	sig
[ɑ]	DISABILITY	ASD	232.375	14.429	1	9.796	0.017
		TD	189.21	2.743			
	GENDER	Male	221.031	9.003	1	1.114	0.326
		Female	200.562	15.088			
	STRESS	Stressed	242.188	10.626	1	78.283	0.000
		Unstressed	179.406	5.737			
[e]	DISABILITY	ASD	220.500	13.836	1	46.910	0.000
		TD	129.688	5.798			
	GENDER	Male	172.469	11.359	1	0.080	0.785
		Female	177.719	13.391			
	STRESS	Stressed	161.000	11.462	1	3.537	0.102
		Unstressed	189.188	10.866			

The interaction between "DISABILITY X STRESS" indicated that children with ASD make the sound [ɑ] 43 (m/s) longer in stressed syllables compared to typically developing children. Moreover, ASD children produce this vowel 43.313 (m/s) higher than TD children in an unstressed syllable (Figure 2).

Figure 2.

Interaction of DISABILITY X STRESS on duration of vowel [a]



The interaction between three factors "DISABILITY X GENDER X STRESS" indicated that ASD males produced the longest duration of vowel [ɑ] in stressed syllables. However, for vowel [e], ASD females had the longest duration in the unstressed syllable.

4.5. Intensity

Table 5 provides data on that having a disability does not have a notable effect on the intensity of the vowel [ɑ]. However, there is a noticeable difference between children with ASD and TD children for the vowel [e]. Moreover, the effect of being male or female and stress does not have a noticeable impact on the intensity of either vowel. The results of a Post Hoc Bonferroni test revealed that children with Autism make the sound [ɑ] at an intensity of 84.281 dB, which is 0.844 dB less than typically developing children. But the intensity of the sound [e] in ASD children is 3.656 dB more than TD children. The amount of intensity of the vowel [ɑ] produced by males is higher than females. The mean difference of intensity of this vowel in females and males is 0.594 dB. However, females produce vowel [e] 0.344 dB higher than males. These results also show that the amount of intensity of vowel [ɑ] and [e] in stressed syllables is 1.656 dB and 1.094 dB more than the mean intensity of these vowels in unstressed syllables, respectively.

Table 5.

Analysis of variance to evaluate the effect of DISABILITY, GENDER, and STRESS on the intensity of vowels

VOWEL			Mean	Standard deviation	DF	F	sig
[ɑ]	DISABILITY	ASD	84.281	1.242	1	0.696	0.432
		TD	85.125	0.518			
	GENDER	Male	85.000	1.416	1	0.177	0.687
		Female	84.406	0.541			
	STRESS	Stressed	85.531	0.788	1	1.184	0.313
		Unstressed	83.875	1.355			
[e]	DISABILITY	ASD	81.125	1.135	1	10.601	0.014
		TD	77.469	0.636			
	GENDER	Male	79.125	1.177	1	0.082	0.783
		Female	79.469	0.631			
	STRESS	Stressed	79.844	1.021	1	0.777	0.407
		Unstressed	78.750	0.889			

5. Discussion and conclusion

5.1. F0

The first question of the study aimed at delving into the effect of DISABILITY, GENDER, and STRESS on the F0 of vowels [ɑ] and [e]. As indicated, the results of this study showed that the effect of DISABILITY on the mean F0 of vowels [ɑ] and [e] is significant. This result is in line with Izadi (2019). She concluded that DISABILITY has a notable effect on the F0 of either vowel. The present study proved that there is no noticeable difference in the F0 of vowels [ɑ] and [e] between males and females. Also, females produce F0 of both vowels higher than males; this finding supports previous results obtained by Ghorbani et al. (2006), Hou et al. (2000), Izadi (2019), and Pépiot (2015). Results also indicated that the effect of STRESS does not have a significant impact on F0 of the vowel [ɑ], but there is a significant difference in F0 of the vowel [e] between stressed and unstressed syllables. The mean F0 of vowels [ɑ, e] in stressed syllables is more than that in unstressed one. This result is the same as the results of the study done by Abolhasanizadeh et al. (2012), De Jong and Zawaydeh (1999), Khaloeipour (2017), Lehiste (1970), Liberman (1960), and Morton and Jassem (1965), which found that

the F0 of vowels increased in stressed syllables compared to unstressed syllables. Masoumi and Abolhasanizadeh (2015) also proved that the F0 of the vowel [ɑ] in a stressed syllable is more than that in an unstressed syllable. The interaction between two factors "DISABILITY X STRESS" showed that children with ASD produce a higher fundamental frequency of vowels [e] in stressed and unstressed syllables compared to typically developing children.

5.2. Formants (F1 & F2)

The second question of this study aimed at delving into the effect of DISABILITY, GENDER, and STRESS on F1 and F2 of vowels [ɑ] and [e]. The results of this research showed that having a disability does not have a significant impact on the mean F1 and F2 of the vowel [ɑ]. However, it has a notable effect on the first and second formants (F1 and F2) of the vowel [e]. The effect of GENDER on the mean F1 of either vowel and the F2 of vowel [ɑ] is not noticeable, but there is a notable difference between males and females on the mean F2 of vowel [e].

Results also indicated that STRESS does not have a significant effect on the mean F1 and F2 of vowels [ɑ, e]. The effect of DISABILITY on F1 and F2 of vowels in this research is the same as the results of the study done by AbolhasaniZadeh et al. (2018), which proved there was no significant difference in mean F1 and F2 of vowel [ɑ] but there was a significant difference in mean F2 of vowel [e] between children with DISABILITY and TD children. Izadi (2019) also proved that there was a notable difference in the mean F2 of the vowel [e] between children with DISABILITY and clients. The results of the effect of stress on the mean F1 and F2 of vowels in this research are consistent with the findings of Masoumi and Abolhasanizadeh (2015), who showed that there was no noticeable difference in the mean F1 of the vowels [ɑ] and [e] between stressed and unstressed syllables. Khaloeipour (2017) also demonstrated that the effect of stress on the mean F2 of the vowel [e] is not significant.

Moreover, this study revealed that children with ASD produce higher F1 of vowels [ɑ, e] and F2 of vowel [ɑ] than typically developing children. Izadi (2019) also showed that the mean F1 of vowel [e] and the F2 of vowel [ɑ] in children with DISABILITY were more than those in clients.

In this research, the average F1 and F2 of vowels [ɑ, e] in girls is higher than in boys. This finding supports the results of Busby and Plant (1995) and Huber

et al. (1999). Izadi (2019) also proved that the mean F2 of vowels [ɑ, e] and F1 of vowel [ɑ] in females was more than males. The present study results showed that the average frequency (F1) of the vowel [ɑ] in stressed syllables is more than that in unstressed ones, which is the same as the results of Masoumi and Abolhasanizadeh (2015), De Jong and Zawaydeh (1999). The results of the present study as the results obtained by Khaloeipour (2017), showed that the average pitch of the vowel [e] is higher when it is unstressed compared to when it is stressed. Results also indicated that the mean F2 of vowels [ɑ, e] in stressed syllables is higher than that in unstressed ones. Furthermore, vowels [ɑ] and [e] in ASD children and in females are produced in a lower place in the vowel space compared to TD children and males. Furthermore, vowel [ɑ] in the stressed position is produced in a lower place in the vowel space compared to the unstressed position, but vowel [e] in the stressed position is produced in a higher place in the vowel space compared to the unstressed position. Vowels [ɑ] and [e] in females and in the stressed position are produced in an anterior place in the vowel space compared to males and unstressed position. ASD children produced vowel [ɑ] in an anterior place in the vowel space compared to TD children, while TD children produced vowel [e] in an anterior place in the vowel space compared to ASD children. This result is the same as the results of the study done by Abolhasanizade et al. (2018).

5.3. Duration of vowels

The third research question intended to investigate the effect of DISABILITY, GENDER, and STRESS on the duration of vowels [ɑ] and [e]. Results indicated that having a disability has a significant impact on the duration of either vowel. This result is similar to Izadi (2019) and Hasanvand et al. (2018), who proved there was a significant difference in the duration of vowels between the group with DISABILITY and the TD ones. The results of the present study showed that the average duration of vowels [ɑ, e] in ASD children is more than the average duration of these vowels in TD children. This supports the former result obtained by Hasanvand et al. (2018) that the duration of vowels in the group with DISABILITY was longer than that of the TD ones. In this research, the impact of being male or female does not have a notable effect on the duration of vowels [ɑ] and [e]. The mean duration of the vowel [ɑ] in males is more than that in females. However, females make the sound [e] for a higher duration than males. Pépiot (2015) also

showed that the mean duration of vowels in females is more than that of males. This research also proved that the impact of STRESS on the mean duration of vowel [ɑ] is noticeable, while the effect of STRESS on the mean duration of vowel [e] is not significant. The results of the present study on the duration of vowels in stressed and unstressed syllables are the same as the results proved by Khaloueipour (2017). STRESS has a significant effect on the duration of the vowel [ɑ]. The results of the present research also indicated that the average duration of the vowel [ɑ] in a stressed syllable is more than that in an unstressed syllable. This result is not far from previous studies done by Khaloueipour (2017), Paul et al. (2008), Sadeghi (2011), De Jong and Zawaydeh (1999), Fry (1954), and Liberman (1960). The interaction between the two factors DISABILITY × STRESS showed that children with ASD produce the vowel [ɑ] with a longer mean duration in both stressed and unstressed positions compared to typically developing children.

5.4. Intensity

The final question of this study looked at how DISABILITY, GENDER, and STRESS affect the strength of vowel sounds [ɑ, e]. The results of this research indicated that DISABILITY does not affect the intensity of vowel [ɑ], while the effect of DISABILITY on the intensity of vowel [e] is noticeable. Moreover, TD children make the sound [ɑ] more intense than children with ASD. This result is the same as the result obtained by Izadi (2019). On the other hand, in this research, the average intensity of the vowel [e] in ASD children is more than that of TD children. Results also indicated that there is no significant difference in the mean intensity of vowels [ɑ, e] between males and females. The mean intensity of the vowel [ɑ] in males is more than that of females, but the average intensity of the vowel [e] in females is more than that of males. Izadi (2019) also showed that males produce vowel [ɑ] more intensely than females. This research also proved that the impact of STRESS on the intensity of vowels [ɑ] and [e] is not significant. Besides, the mean intensity of vowels [ɑ] and [e] in stressed syllables is 1.656 dB and 1.094 dB more than that in unstressed syllables, respectively. This is the same as the results of the study done by Lehiste (1970) that proved the difference between stressed and unstressed syllables was approximately 2 dB. Fry (1954), Abolhasanizadeh et al. (2012), and Khaloueipour (2017) also showed that the intensity of a stressed syllable was more than that of an unstressed syllable.

Author Contributions

V.A. was responsible for the conceptualization, methodology, validation, formal analysis, data curation, supervision, and project administration. A.D. contributed to software development, investigation, and resources, and prepared the original draft of the manuscript. Both V.A. and A.D. contributed to software development and visualization, and V.A. undertook the review and editing of the manuscript. All authors have read and approved the final version.

Data Availability Statement

Data supporting the findings of this study are available from the corresponding author upon reasonable request.

Acknowledgments

The authors are grateful to the children and families who participated in this research. We also thank Sokhan Speech Therapy Center and an ASD primary school, where the data for this project was collected.

Ethical Considerations

The authors avoided data fabrication, falsification, plagiarism, and misconduct.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Conflict of Interest

The authors declare no conflict of interest.

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