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Acoustic Analysis of Onset F0 of Word-Initial Plosives in the Speech Production of Autistic Children and Typically Developing Peers

[1]Rahimeh Roohparvar*
[2]Ali Asghar Rostami Abusaeedi
[3]Mahdieh Karami

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Abstract

Autism is a neurodevelopmental disorder which is characterized by difficulty in social interaction, language and communication. In the present study, F0 of onset as a feature which can distinguish voiced from voiceless plosives has been acoustically analyzed in the speech production of two groups of autistic and normal developing children. The first group containing 7 girls and 13 boys with autism spectrum disorders (ASD), and the second group seven girls and 13 typically developing (TD) boys. Children were six to ten years old. Monosyllabic CVC words having oral plosives /p, b, t, d, k, g, G/ in the initial position followed by back vowel /æ/ were recorded in a sound-proof room using Praat Software. Acoustic analysis of uttered syllables confirmed that the speech of ASD children was different from that of TD peers. Significantly more plosives produced by ASD children were deleted because of unusual production. The differences between voiced and voiceless plosives were much more in TD children, which means ASD children distinguished these plosives slightly. Concerning gender, there were not significant differences between girls and boys of ASD and TD because they were before puberty. Considering different places of articulation, the onset F0 of ASD children was significantly lower than TD peers. The total results demonstrate that ASD children need more training and practice to become similar to TD peers in the production of initial plosive consonants.

Keywords: fundamental frequency (F0) of onset, Acoustic Analysis, Autism Spectrum Disorders (ASD), typically developing children (TD), plosives

1. Introduction

Autism spectrum disorder (ASD) as a genetically based neurodevelopmental disorder is characterized by impairments in social communication and restricted interests and repetitive behaviors (American Psychiatric Association [APA], 2013). ASD individuals have some characteristics in common, but vary in central ways, so it is assumed that there is a spectrum of autistic disabilities ranging from low functioning autism (LFA) to high functioning autism (HFA) and Asperger's Syndrome (AS). The distinction between LFA and HFA consists mainly of the fluency and flexibility of expressive language skills (Lord & Paul, 1997). Approximately 50% of autistic individuals are able to speak (Minshew et al., 1995); but even those who speak, have some problems using language. In the domain of social communication, prosody, which includes intonation modulation (changes in how 'high' or 'low' the voice sounds, based on rate of vocal fold vibration), rhythm (how evenly-timed syllables are in speech), and rate (how rapidly syllables are uttered in speech), have been noted as main areas of impairment in ASD (Patel et al, 2020).

The frequency at which vocal folds vibrate in vowels and voiced consonants is called fundamental frequency (F0) which is a physical property of sound. Pitch is used to refer to how F0 is

[1]Assistant Professor of Linguistics (Corresponding Author), roohparvar@uk.ac.ir; Department of Foreign Languages, Faculty of Literature and Humanities, Shahid Bahonar University of Kerman, Kerman, Iran.

[2] Professor of Linguistics, rostamiabu@uk.ac.ir; Department of Foreign Languages, Faculty of Literature and Humanities, Shahid Bahonar University of Kerman, Kerman, Iran.

[3] Assistant Professor of cognitive sciences, karami_m@icss.ac.ir; Institute for Cognitive Science Studies, Tehran, Iran.

perceived by the listener. When a vowel follows an obstruent consonant, the fundamental frequency in the first few tens of milliseconds of the vowel is known to be influenced by the voicing characteristics of the consonant (Hanson, 2009). It means that F0 of onset is a feature which can distinguish voiced from voiceless plosives (Trolinger, 2003; Francis et al, 2008; Winn et al, 2013).

Some researchers have pointed out that F0 of the onset is related to the phonological features of initial-stop voicing and thus varies according to laryngeal timing; that is, the onset F0 coming after voiceless stops is higher than the onset F0 coming after voiced stops (House & Fairbanks, 1953; Lehiste & Peterson, 1961; Haggard, Ambler & Callow, 1970; Hombert, 1978; Löfqvist, Baer, McGarr & Story, 1989 and Whalen, 1990). Francis et al (2008) have claimed that in English, voiced and voiceless syllable-initial consonants differ in both fundamental frequency at the onset of voicing (onset F0) and voice onset time (VOT). According to Lea (1973), F0 decreases after voicing onset in voiceless aspirated stops, while it increases after voiced stops. He has also mentioned that this rise-fall trend in F0 is a good indicator to differentiate between voiceless and voiced stops. Ohala (1978) and Hombert (1978) believed that this is an intrinsic pattern which is not controlled by the speaker but rather by physiological and aerodynamic properties. Hombert, Ohala and Evan (1979) examined aerodynamic theory and showed that changes in F0 of onset were mainly related to vertical tension in the larynx. In their study on Thai and Yoruba, Gandour (1974) and Hombert (1977) showed that changes in F0 of onset were shorter in tonal languages than in non-tonal languages. In addition, some other researchers expressed that non-tonal languages like English, French and Dutch had higher changes in F0 of onset (100 ms or more) (House and Fairbanks, 1953; Hombert, 1978; Lehiste and Peterson, 1961; Whalen,1990 and Löfqvist et al, 1989).

Another object attributed to onset F0 changes is physiological mechanisms found in vocal tract of speakers. Ewan and Krones (1974) and Kent and Moll (1969) have shown that the position of larynx as well as the hyoid bone location are higher in voiceless stops than in voiced ones. As Ohala (1978) pointed out, lowered larynx causes lowered F0.

2. Review of Literature

In different languages, numerous researches have been done on the linguistic properties of ASD people. The results of Shadra et al. (2010), in which the speech intonation of 15 ASD children were compared with 10 TD peers, showed that exaggerated pitch, pitch range, pitch excursion and pitch contours were observed in the speech of children with ASD, but absent in age-matched controls. Peppe' et al. (2011) compared the expressive prosodic abilities of school-age children with AS and HFA, with their TD age mates. While the AS showed impairment only on phrasing and imitation, the HFA group showed impairment on all the prosody tasks. Diehl and Paul (2012) studied the ability of ASD adolescents and children to imitate prosodic patterns and compared the results with two groups of persons: one group having learning disabilities (LD) and one TD comparison group. The results showed that distinguishing and imitating prosodic patterns were significantly worse in ASD and LD groups than the TD comparison group.

Adams (2008) examined the speech of ASD children and found that a number of children had difficulty producing polysyllabic structures and consonants. Paul et al. (2008) compared the ability to put stress in repeating syllables that were not necessarily meaningful in autistic individuals with TD peers. They proved that there was a significant difference between TD and ASD groups. By examining the speech of ASD children and comparing the results with TD group, Baltax (2005) found that ASD children were more likely to put stress on inappropriate syllables than TD ones. Nakai et al. (2014) acoustically compared the speech tone of ASD children with TD peers. The results showed that no significant difference was observed between F0 of onset of ASD and TD group at pre-school age, but TD subjects at school age produced significantly more and better pitch than ASD ones. Regarding the CV pitch, range and standard deviation of each participant’s speech, no significant difference was observed between the two groups. Diehl and Paul (2012) examined the ability of ASD children and adults to mimic intonational patterns and compared the results with those with learning disabilities and TD individuals. They found that ASD group and people with learning disabilities significantly perceived and imitated the sound patterns improperly. In addition, the duration of speech in ASD people was significantly longer than those in the other two groups.

In Iran, Roohparvar, Karami and Madadi (2014) compared phonetic, phonologic, morphologic and syntactic characteristics of ASD children with TD ones. The results showed that consonant deletion, substitution of phonemes, using stress on inappropriate syllable, atypical intonation, incorrect use of tense, incorrect use or not using prepositions, problems in making the nouns plural and not using complex sentences were significantly different in ASD children and TD peers ($p<0.05$), while epenthesis, metathesis, violating subject-verb agreement, having difficulty with making the verbs negative, and using demonstratives were not significantly different.

The present study tries to acoustically analyze Fo of onset in the speech production of ASD Persian children and to compare the results with TD peers. As was said ASD children have problems with speech and language; and because F0 of onset is a feature that makes distinction between voiceless (p, t, k) and voiced (b, d, g, G) plosives, it can be useful to see whether ASD children can make distinction between voiced and voiceless plosive consonants. To do so, three main variables of voicing of consonants, gender and status of children were taken into account. As it is for the first time that such research is done, the results can be used to improve the phonetic and phonologic characteristics of oral plosive consonants in the speech production of ASD children. By doing acoustic analysis, it becomes clear ASD children are most likely to have difficulty in producing which plosives and guides speech therapists and parents to help and train children properly. Moreover, the results can be generalized to the similar sounds in other languages and provide the basis for preparing universal sound databases for ASD children.

3. Methodology

3.1. Participants

The present study is a cross-sectional cmparative-analytic study. It consisted of two groups: the first group included 20 children with ASD containing seven girls and 13 boys, six to ten years old. The mean age of this group was 8.50. All of these children were identified to have autism by psychiatrists. These children were selected from the rehabilitation centers for ASD children in Kerman and Tehran. In the second group, there were TD children containing seven girls and 13 six- to ten-year-old boys who were selected from elementary schools in Kerman. This group's mean age was 8.55.

In order to have the best sound waves, all participants attended a sound-proof room and their utterances were recorded. The uttered words were [par], [bar], [tar], [dar], {[car], [kɑr]}, {[ɟar], [gɑr]}, [Gar] in which oral plosives were placed in the initial position of monosyllabic words (CVC) followed by a back vowel, with the final consonant being trill. In standard Persian, there are 23 consonants and six vowels. Eight of these phonemes are plosives which are as follows (based on the place of articulation):

/p,b/: bilabial plosives, /t,d/: dental plosives, /k,g/: dorsal plosives, /G/: uvular plosive and /ʔ/: glottal plosive. The phonemes /k/ and /g/ have two allophones: [c] and [k] for /k/, and [ɟ] and [g] for /g/. The allophones [k] and [g] (velars) appear just in the onset of syllable followed by back vowels. In all other positions, [c] and [ɟ] (palatals) are used. The plosives being analyzed in this study are oral ones, thus the glottal plosive /ʔ/ has been deleted from the investigation. Sounds /b, d, ɟ, g, G/ are categorized as voiced and /p, t, c, k/ as voiceless.

After all the utterances were recorded, Praat software was used to measure F0 of onset of recorded words. Five places of articulation including bilabial, dental, palatal, velar and uvular were also analysed. In order to measure F0 of onset, four pitch periods from the beginning of vibration were measured. Then, data entered SPSS software. First of all, test of normality was done for all data. If data was considered normal, the Independent Samples T-Test was performed; otherwise, Mann-Whitney Test was used.

3.2. Instruments

1- Questionnaire: The questionnaire contained demographic information about each child, such as age, place of birth, physical and mental health of the child, parent's age, parent's education level, and children's language ability.

2. Word List: A tool for conducting this research was a list of words that were: ([par] **,** [bar] , [tar], [dar], [car], [kɑr], [ɟar], [gɑv], [Gar]).

3. Microphone: A Sony microphone was used to record the data.

4. Praat software: Praat software version 6.0.29 (Boersma & Weenink, 2017) was used to record the data and extract F0 of onset.

4. Results

The results showed that comparing with TD group, significantly more plosive consonants produced by ASD children were deleted because of atypical production (27 plosives in ASD children and just 2 plosives in TD peers). From the 27 abnormal plosive consonants produced by ASD children, 24 belonged to boys and 3 to girls that made significant differences between ASD boys and girls, concerning this point (p=0/000).

Table 1: The Number of Omitted Plosives in The Production of ASD And TD Children

	p	b	t	d	c	ɟ	k	g	G
ASD	3	3	4	1	3	5	0	2	5
TD	0	0	0	0	1	1	0	0	0

Another result was that the mean F0 of onset of all voiceless plosives in ASD children was less than TD peers. Regarding voiced plosives similarly, the mean F0 of onset in ASD children was less than TD ones. As can be seen in table 2, the F0 range differences in ASD children were more than TD ones. These differences were so great in all voiceless plosives (p, t, c, k) that made significant differences between ASD and TD children (p<0/05) but in voiced plosives (b, d, ɟ, g, G), the differences were not so great to make significant difference.

Table 2: the mean amount of F0 (Hz) of onset in ASD and TD children in terms of voicing

	Children status	Voiceless plosives	Voiced plosives
mean (standard deviation)	ASD	2828/1 (70)	278 (63/8)
	TD	387/4 (28/8)	300 (12/4)
range differences	ASD	265	244/7
	TD	117/4	49/1

In terms of gender and voicing, in ASD children the mean F0 of onset was higher in girls than in boys, both in voiceless and in voiced plosives (table 3). But in neither of these, the differences between girls and boys were significant (p>0/05). Also, in TD children, the mean F0 of onset was higher in girls than in boys, both in voiceless and in voiced plosives. But in neither of them, the difference between boys and girls was significant (p>0/05).

Table 3: The Mean Amount of F0 (Hz) Of Onset in ASD And TD Children in Terms of Gender and Voicing

	Children status	Gender	Voiceless plosives	Voiced plosives
mean (standard deviation)	ASD	Girl	393/2 (34/8)	297/7 (34/3)
		Boy	280/2 (75/1)	274/4 (67/8)
	TD	Girl	393/2 (30/1)	302/3 (2/6)
		Boy	386 (29/4)	299/4 (13/4)
range differences	ASD	Girl	66/8	60/5
		boy	26	24/7
	TD	Girl	552	4/5
		Boy	117/4	49/1

In all the places of articulation, the mean F0 of onset was lower in children with autism than in TD children (table 4), and the minimum and maximum difference (range differences) was very greater in children with autism than in TD ones (table 4).

Table 4: The Mean Amount of F0 (Hz) Of Onset in ASD And TD Children in Terms of Place of Articulation

	Children status	bilabial	dental	palatal	velar	uvular
Mean (standard deviation)	ASD	279/7 (68/8)	284 (76/2)	263/3 (60)	285/8 (75/5)	278 (63/8)
	TD	355/5 (28/8)	336/2 (34/3)	336/6 (25/1)	337/8 (24)	316/6 (23/4)
range differences	ASD	252/2	264/2	223/5	297/4	244/7
	TD	93	117/1	84/1	83/3	80

The differences between ASD and TD children in all places of articulation were so much that made significant differences between children in both groups (table 5).

Table 5: Level of Significance of F0 (Hz) Of Onset Between ASD And TD Children in Terms of Place of Articulation

	bilabial	dental	palatal	velar	uvular
Level of significance	0/000	0/006	0/000	0/007	0/039

Regarding the interaction of gender and place of articulation, in the production of ASD children in all places of articulation, the mean F0 of onset was higher in girls than in boys, and the minimum and maximum difference (range of variation) was much greater in boys than in girls (table 6). But this difference was not so much to make significant difference between girls and boys of this group (p>0/05). In the production of TD children in all places of articulation, the mean F0 of onset was higher in girls than in boys (table 6), but this difference was not significant in any of the places except in uvular place that made a significant difference between girls and boys.

Table 6: The Mean Amount of F0 (Hz) Of Onset in ASD And TD Children in Terms of Gender and Place of Articulation

	Children status	gender	bilabial	dental	palatal	velar	uvular
Mean (standard deviation)	ASD	Girl	303/4 (57/3)	294 (47/6)	285/6 (25/5)	290/6 (27/4)	278 (3/5)
		Boy	275/5 (71/3)	282/3 (75)	259/2 (64/1)	285 (81/7)	272/4 (72/3)
	TD	Girl	376/5 (22/8)	338/8 (43/2)	338/8 (14/4)	339/7 (20/5)	299/4 (4/44)
		Boy	351/8 (28/7)	335/7 (34)	336/2 (27)	338/5 (25)	319/6 (24/2)
range differences	ASD	Girl	107/2	94/6	46	53	4/95
		Boy	252/2	264/1	223/5	297/4	264
	TD	Girl	45/1	86	25/7	36//5	8/32
		Boy	93	117/1	84/1	83/3	80

5. Discussion

The results of the present study showed that significantly more plosive consonants produced by children with autism were omitted because of irregular production (p=0/000). This shows that ASD children had more problems in the production of plosives and need more training and practice to produce oral plosives correctly. As from the 27 atypical plosive consonants produced by ASD children, 24 belonged to boys and just 3 ones to girls. Previous studies also have proved that females with ASD have a greater ability to use language, communicate and socialize than males (Hiller et al. 2014; Sedgewick et al. 2016).

Another point was that the mean amount of F0 of onset in voiced plosives was 277/9 Hz in ASD and 300 Hz in TD peers which shows there was not a significant difference between the two groups (p = 0.144). The F0 of onset of voiceless plosives was 282 Hz in ASD and 387/4 Hz in TD children that means there was a significant difference between the two groups (p = 0.000). The mean amount of F0 of onset for both voiced and voiceless plosives was lower in ASD children. As was seen, in both ASD and TD children, the F0 of onset in voiceless plosives was higher than those of voiced plosives which confirms the results of House and Fairbanks, 1953; Haggard, Ambler, and Callow, 1970; Lehiste and Peterson, 1961; Hombert, 1978; Ohde, 1984; Löfqvist, et al, 1989; and Whalen, 1990. But the important point here is that the differences between voiced and voiceless plosives were much less in ASD children than the amounts in TD peers. This means that TD children were more able to make distinction between voiced and voiceless plosives but ASD children had produced voiced and voiceless plosives more similarly. So, they need more trainings.

In terms of gender, the F0 of onset in voiceless plosives was 293/2 Hz and in voiced plosives was 297/7 Hz in ASD girls, while for ASD boys, it was 280/2 Hz in voiceless plosives and 274/4 Hz in voiced plosives. These amounts show that there was not a significant difference (p=0/776) between ASD girls and boys in the production of voiceless plosives. Also, in the production of voiced plosives, the difference between ASD girls and boys was not significant (p=0/574). Regarding the TD children, the F0 of onset in voiceless and voiced plosives were respectively 394 Hz and 386 Hz in girls and 302/3 Hz and 299/6 Hz in boys. The results of ASD and TD children were in consistent with the previous findings (House and Fairbanks, 1953; Lehiste and Peterson, 1961; Haggard, Ambler, and Callow, 1970; Hombert, 1978; Ohde, 1984; Löfqvist et al, 1989; and Whalen, 1990). It has been proved that in females, the amount of F0 is higher than men and it might be due to the anatomical and physiological differences that happen during puberty (Fant, 1966). Males have longer and thicker vocal folds, thus they tend to vibrate them more slowly than women (Kahane, 1981). Another anatomical issue is vocal tract length. The distance from the vocal folds to the lips differs in both genders. The average length of the adult female vocal tract is about 14.5 cm, while the average male vocal tract is 17 to 18 cm long (Simpson, 2009). Therefore, longer vocal tract means lower resonant frequencies (Fant, 1970). In the present research, the mean amounts of F0 of onset in girls were higher than those of boys which is in accordance with the aforementioned reasons, but the differences between the onset F0 of girls and boys were not so much in order to make significant differences. The reason can be that voice is characterized by its frequency, intensity and harmonics (which are hormonally dependent); Changes that happen during male and female puberty are different (Raj, Gupta, Chowdhury, and Chadha, 2010). The female voice changes from childhood to menopause under the varied influences of estrogen, progesterone, and testosterone and these hormones are the main reason for voice changes throughout life (Raj, et al, 2010). As the ages of boys and girls of this study were before puberty, there were not significant differences between the F0 onset of girls and boys of both ASD and TD groups.

Considering the mean amount of F0 of onset in all places of articulation, it was showed that the amount of F0 of onset in ASD children was lower than TD peers. The differences were significant in all places of articulation (bilabial=0/000, dental=0/006, palatal=0/000, velar=0/007, uvular=0/03). This shows that the ASD children need more training and practice of plosives in order to become similar to TD children in the production of plosive consonants.

For the effect of gender and place of articulation on the F0 of onset in the two groups of children, the following results were obtained: Although in the ASD children, the mean amounts of F0 of onset in all places of articulation were higher for girls than boys, they were not significant (bilabial=0/533, dental=0/8, palatal=0/5, velar=0/9, uvular=0/63). Concerning TD children, in all places of articulation except uvular, the mean amounts of F0 of onset were higher in girls than boys. The differences were not significant for bilabial=0/178, dental=0/913, palatal=0/813, velar=0/737 places of articulation, but significant for uvular place=0/006. Totally, significant differences were not observed between girls of ASD and TD and boys of ASD and TD in all places of articulation (p>0/05). This result shows that considering the effect of gender and place of articulation together on the F0 of onset, although the place of articulation had a significant effect on the production of ASD and TD children; with the exertion of gender, the differences disappeared.

6. Conclusion

The results of the present study demonstrated that the speech of ASD children was different from that of TD peers regarding the onset F0 of Persian oral plosives in the initial position. Significantly more plosive consonants produced by ASD children were deleted because of abnormal production that shows ASD children had more problems in the production of initial plosives and need more practice and training to produce oral plosives correctly. Also, it was shown that the differences between voiced and voiceless plosives were much more in TD children than the related amounts in ASD ones, which means that TD children were able to make more distinction between voiced and voiceless plosives but ASD children distinguished voiced and voiceless plosives slightly. In terms of gender, there were not significant differences between girls and boys of ASD and TD children because they were before puberty. Regarding different places of articulation, it was showed that the onset F0 of ASD children was significantly lower than TD peers that proves ASD children need more training and practice to become similar to TD peers in the production of plosive consonants.

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