In: Clinical Linguistics and Phonetics, released: December, 2014

Speech processing in children with functional articulation disorder

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Abstract

This study explored auditory speech processing and comprehension abilities in 5- to 8-year-old monolingual Hungarian children with functional articulation disorders (FAD) and their typically developing peers. Our main hypothesis was that children with FAD would show co-existing auditory speech processing disorders, with different levels of these skills depending on the nature of the receptive processes. The tasks included (i) sentence and non-word repetitions, (ii) non-word discrimination, and (iii) sentence and story comprehension. Results suggest that the auditory speech processing of children with FAD is underdeveloped compared to that of typically developing children, and largely varies across task types. In addition, there are differences between children with FAD and controls in all age groups from 5 to 8. Our results have several clinical implications.

Keywords: *children with functional articulation disorder, sentence and non-word repetitions, sound discrimination, story comprehension*.

Introduction

Children with articulation disorders have been found to display difficulty with auditory speech processing and comprehension, which affect first language acquisition (e.g., Bishop, Carlyon, Deeks & Bishop, 1999; Diehl, Lotto & Holt, 2004; Holt & Lotto, 2008; Piers & Bishop, 2010). At all stages of typical speech development, auditory speech processing skills and speech production demonstrably interact, a fact that is also supported by neurophysiological data (Diamond, 2000; Guenther, 2006).

Expressive disorders are identified when a person has difficulty with any form of speech production. One of the types of expressive disorders concerns articulation (Ingram, 2012) which is claimed to originate from underdeveloped motor skills, and means an inability to produce the necessary articulation gestures of the language despite hearing within normal limits, typical cognitive abilities, and typical proficiency in all the other aspects of the language. In cases where there are no organic reasons behind the developmental articulation disorder it is called functional articulation disorder (Rvachew & Jamieson 1989; Shriberg, Austin, Lewis, McSweeny & Wilson, 1997; Ozcebe & Belgin, 2005). Functional articulation disorder (FAD) shows residual speech errors without any delay in speech acquisition onset. Children with FAD show omissions, substitutions or additions of a sound or several sounds when producing words and word strings (McReynolds, 1990). Studies involving children with FAD have shown that they perform more poorly on specific phoneme awareness tasks than children with typical articulation, and researchers have reported significant associations between speech production and speech perception (Sénéchal, Ouellette & Young, 2004; Kenney, Barac-Cikoja, Finnegan, Jeffries & Ludlow, 2006; Miniscalco & Gillberg, 2009).

A number of studies have confirmed that auditory speech processing may be delayed in some language and speech disorders, as well as in the case of some speech motor deficits (e.g. Bavin, Wilson, Maruff & Sleeman, 2005; Boets, Wouters, Wieringen, & Ghesquière, 2007). Theoretically, this means either that auditory speech processing disorders may be a consequence of developmental articulation deficit, or that the two kinds of deficits may share a common but unknown root. The basic questions, however, are whether the auditory speech processing disorders are characteristic of children with FAD and whether they involve several, all, or just some of the auditory speech processes, and whether children with FAD show a progression of their auditory speech processing skills across age groups.

The present study investigates the auditory speech processing (via sentence and non-word imitation and perceptual non-word discrimination), as well as comprehension abilities (by using sentence and story tasks) of monolingual Hungarian-speaking children with FAD as compared to their monolingual peers with typically developing speech and language between the ages of 5 and 8. There is a considerable difference between perceptually differentiating between speech sounds in nonsense words, as opposed to having to process the semantic and morphological/syntactic information that full-fledged sentences contain. We assume that children with FAD would show deficiencies both in auditory processing of speech and in comprehension of sentences and stories. It is important to understand whether children show deficits only in the identification of speech sounds in non-words, repetition of non-words and sentences, and comprehending sentences and stories. While research on the above-named issues in monolingual English-speaking children is available (Nijland, 2006; Kenney et al., 2006; Boets et al., 2007), auditory speech processing and comprehension in monolingual Hungarian-speaking children with FAD is virtually unknown (Gósy & Horváth, 2006). Considering that Hungarian phonology, morphology, and syntax are vastly different from their English counterparts, investigating auditory speech processing in Hungarian children with FAD not only has significant clinical implications for a new population (Hungarian children with FAD), but results of our investigation also have implications for basic research, because such remarkable differences exist between the two languages. Furthermore, the implications of our study are also critical for education, because deficits in speech perception and comprehension have ramifications for Hungarian-speaking children with FAD, including better understanding the nature of the underlying problem and possibly preventing unnecessary delays in academic performance in this population.

In addition to the analysis of the data obtained in the experiment, our aim was to discover whether it is possible to differentiate between children with and without FAD using additional statistical methods (feature selection and neural algorithm methods). The motivation for this analysis was (i) the relatively large individual differences among the children in all groups, (ii) the differences in some tests between the participants with and without FAD which did not prove to be significant, and (iii) the intention of finding the features among those tested that were most responsible for the distinction between children with and without FAD. The successful classification of children into groups with and without FAD would strengthen our assumption that the data obtained in the tests used confirm the delayed auditory speech processing development of children with FAD.

The sound inventory of Hungarian

Hungarian is an agglutinative language with an inventory of 25 phonologically short and 25 phonologically long consonants, as well as 7 phonologically short and 7 phonologically long vowels (where 5 short–long pairs involve qualitatively similar vowels). All vowels are oral monophthongs that do not undergo regular vowel reduction, irrespective of their stress or phonetic position. The consonant system includes voiced and voiceless stops (8), voiced and voiceless fricatives (7), voiced and voiceless affricates (4), nasals (3), approximants (2), and a voiced trill. In spontaneous speech, the average number of syllables per word is 3.5. Word stress invariably falls on the initial syllable (although in connected speech not all words are stressed).

Hypotheses

Based on the existing body of work on children with and without FAD reported in the literature, we posit two hypotheses: (i) children with FAD are expected to show co-existing deficits both in auditory speech processing and sentence and story comprehension, and (ii) the auditory speech processing skills of children with FAD would show delayed development across ages compared to their typically developing peers.

Methodology

Subjects

One hundred and twenty monolingual Hungarian-speaking children with a clinical diagnosis of FAD made by a certified Hungarian speech-language pathologist (recruited from speech therapy caseloads) participated in the study. The term FAD will be used here to describe our participants' speech at the time of their enrolment in this study. The children were grouped by ages as 5-, 6-, 7- and 8-year-olds (30 participants in each group). School-age children with FAD showed delay in their reading and writing performance according to their teachers' report. An equal number of age-matched typically developing Hungarian-speaking children were recruited as control participants for each age group (n = 30 per group), whose parents and teachers showed no concern regarding their speech, language, and cognitive development. A hearing screening was administered to each participant before the data were collected. All of the children who participated in this study scored within normal hearing limits on a pure tone hearing screening that was administered bilaterally at 20 dB HL, using pure tones of 500, 1000, 2000, 4000, and 8000 Hz (measured in a sound-treated room). The IQ and cognitive functions of all participants were within normal limits.

All children in this study had a typical onset of language acquisition meaning that the occurrence of their first words was around age one (as reported by their parents). They were examined prior to enrolment into the study on a test battery (developed for Hungarian), which assessed articulation and formulation of grammatical structures (Test for Language Proficiency and Test for the Examination of Articulation Disorders; Juhász, 1999). The only disorder that our participants in our experimental group had was FAD, and there was no indication of any co-occurring condition on the clinician's referral, the parent report, or any of the assessments we administered as part of our battery. As a measure of extra precaution, the participants' speech and language abilities were verified by a second licensed speech language pathologist that corroborated the results of the original evaluation at a 99% agreement level, and in the case of the 1% disagreement, a third certified speech-language pathologist was consulted to make a final determination of group membership. Children with FAD articulated all vowels properly but they failed to articulate appropriately nine of the 25 Hungarian consonants (four fricatives, four affricates, and the trill). They articulated the fricatives and affricates by either a lateral or an interdental gesture instead of the required alveolar and postalveolar articulation gestures. The trill was substituted by all of these children with approximants (either with [l] or [j]). Children with FAD exhibited consistency in their articulation errors. All of the children in the control group demonstrated age-appropriate articulation skills.

The children in this study all had a similar socio-economic status and came from working-class or middle-class backgrounds. It also must be noted that Hungary is a relatively small country in Central Europe with a standardized national educational curriculum. The children with FAD formed 4 groups based on their ages; comparable groups were also formed of the control children (Table 1).

Table 1. Number and age of children

Exeprimental groups	Number of children		Mean age (year; month)	Range of age (year, month)
	girls	boys		
5-year-olds FAD	10	20	5;5	5;2–5;7
5-year-old controls	10	20	5;4	5;2–5;7
6-year-olds FAD	10	20	6;7	6;3–6;8
6-year-old controls	10	20	6;7	6;2–6;9
7-year-olds FAD	8	22	7;5	7;2–7;8
7-year-old controls	8	22	7;4	7;1–7;8
8-year-olds FAD	8	22	8;6	8;3–8;9
8-year-old controls	8	22	8;5	8;1–8;8

FAD = functional articulation disorder

At school, the seven-year-olds were first graders and the eight-year-olds were second graders. All school-age children diagnosed as having functional articulation disorders had undergone speech therapy for 10 months, one year before they started school. This was also the case of therapy with the six-year-olds. None of the five-year-olds had participated in a speech therapy course.

Materials

The materials used in this study comprised 7 tests taken from the Hungarian GMP standardized diagnostic tool for the evaluation of children's speech processing (Gósy, 1999). Data from 4 repetition tasks, a speech sound discrimination task and two listening comprehension tasks were analyzed. All stimuli were tape-recorded by a male speaker (see Appendix). Test 1: This assessment tool consisted of ten well-formed simple sentences (statements, questions, and commands) of various lengths containing 3 to 5 words, which corresponded to 7 to 12 syllables, e.g., "*The lion is chasing the deer*." These sentences were masked by white noise (the signal-to-noise ratio was 4 dB on average); this set will be referred to as the 'noisy sentences'. Sentences presented in noise offer an opportunity to obtain information about the receptive processing skills concerning acoustic cues of speech sounds (Boets et al., 2007). Test 2: This measure consisted of sentences, similar in length to those in Test 1 but they had a complex morpho-syntactic structure, and they were artificially sped up by 1.5 times of their original speech tempo. The average tempo of these sentences was 14 sounds/s. This set will be referred to as the 'fast sentences'. The purpose of compiling these sentences was to check the children's accurate detection of rapid acoustic changes in speech. Test 3: The third test consisted of ten nonsense words of varying length (between 5 and 12 speech sounds, such as *galalajka*) that were entirely consistent with Hungarian phonology and phonotactics. Non-word repetition is seen also as a measure of working phonological memory (Montgomery, 2003; Rvachew & Grawburg, 2008). Test 4: The test material consisted of 16 minimal pairs of non-words that adhered to Hungarian phonology (containing 3 to 5 speech sounds), e.g., *gev/bev* (this test also contained 7 identical non-word pairs). This test served to evaluate the children's ability to discriminate between speech sounds. Test 5: A picture to sentence matching task was administered in which the children heard a sentence and had to identify the closest matching picture of two choices. The sentences were constructed so that one picture clearly represented the correct choice, but the other picture was only minimally different. For example, the child heard the sentence "*There are a few apples on the tree*." One of the pictures displayed a tree with few apples while the other image showed a tree with lots of apples in it. Ten sentences and twenty pictures were used for the 5- and 6-year-old children and another set of 10 sentences and 20 pictures for the school-age ones. The difference between the two sets of test sentences was in their morphological/syntactic complexity (see Gósy, 1999). Test 6: Short (2.5-minute long) recorded stories were played to the children (one for the 5-and 6-year-olds and another one for the school-age children) in order to assess their ability to comprehend a story. Their story comprehension was checked using 10 questions. The questions referred to various aspects of the story: location, time, object, instrument, characters, cause and effect, problem and solution.

Procedure

All children were tested individually in a silent room in the morning using the same speech material. Sessions lasted 20 minutes, on average. The children's task in Tests 1, 2 and 3 was to repeat the sentences and the nonsense words they heard. Their answers were recorded and documented according to criteria based on the manual of the GMP standardized diagnostic tool, which were (i) the appropriate repetition of the non-words and the sentences preserving the original word order in the sentences, (ii) the proper repetition of the speech sounds in the words of the sentences and in the non-words. The identification of the children's errors was made by the two authors[1] marking the inappropriate word order and omissions and insertions of speech sounds and words using phonetic transcription. Inter-rater reliability on the phonetic transcriptions was 98% (in cases of a few disagreements a third expert was consulted). Test 4 (speech sound discrimination) was used only with the school-age children (the reason for that was that Hungarian-speaking, typically developing children younger than the age of 7 cannot reliably perform this test). Their task was to judge whether the two non-word sound sequences were identical. Their *yes* or *no* answer was documented for each sound sequence pair. In Test 5 (sentence comprehension), the children had to select the appropriate picture that corresponded to the meaning of the sentence they had heard. The selection of the picture was documented in each case as 'appropriate' or 'inappropriate'. In Test 6 (story comprehension), the children's task was to answer 10 questions concerning the contents of the story they had heard. The answers as being either 'appropriate' or 'inappropriate' were judged by the present authors based on the criteria

[1] Both of the authors are phoneticians with long years of experience in labelling various types of (typical and disordered) speech. In addition, both of them are licensed users of the GMP standardized diagnostic tool for the evaluation of children's auditory speech processing.

written in the manual of the GMP diagnostic tool.

Statistical analyses

The independent variables for our planned analyses, based on our hypotheses, were articulation skills (differentiating between children with and without FAD) and age. The dependent measures were the children's scores on the various tests described above and summarized in Tables 2 and 3. A MANOVA (and Bonferroni post hoc test) as well as the Kruskal–Wallis test as appropriate were used, and linear regression analysis was conducted to investigate the accuracy of the two hypotheses (at the 95% confidence level).

A two-step statistical analysis was performed in order to discover whether it is possible to tell apart children with and without FAD on the basis of their auditory speech processing data. A feature selection method by a decision tree method and a classification decision by a neural network algorithm were used.

The decision tree method is commonly used in data mining, where the goal is to create a model that predicts the value of a target variable based on several input variables. The name of this method of analysis – the Decision Tree – refers to a tree which shows the separation ability of the relevant features. For the sake of our study, a J48 algorithm for feature selection from a set of training samples was used (Sugumaran, Muralidharan & Ramachandran, 1997). The features with poorer separation abilities appear further away: the greater the distance from the root, the smaller is the separation ability of the feature concerned. After feature selection an artificial neural network was developed with a systematic step-by-step procedure which optimizes a criterion commonly known as the learning rule. Neural networks, with their remarkable ability to derive meaning from complex data, can be used to extract patterns and detect trends that are too complex to be noticed by either humans or other computational techniques (Bishop, 1995). The developed neural network was used to extract patterns characteristic of children with and without FAD based on experimental data. We used multilayer perceptron (MLP) with backpropagation (Bishop, 1995) for classification of children with and without FAD. We used tenfold cross-validation for both training and testing.

Results and discussion

According to the first hypothesis, we predicted that children who have FAD would display co-existing deficits both in auditory speech processing and in sentence and story comprehension compared to their peers without FAD. In order to test this hypothesis, we conducted a MANOVA analysis with 'disorder' (i.e., FAD versus control) and 'age' as the independent variables and six tests' scores as dependent variables (Tables 2 and 3). Statistical analysis showed that there were significant differences between the groups with and without FAD in all the tests performed. The performances of all children also showed significant differences depending on age.

Table 2. Statistical data (MANOVA) for groups of children with FAD and control groups in repetition tests

Source	Dependent variable	df	F	Sig.	Partial Eta Squared
Corrected model	NS	7	17.035	0.000	0.339
	FS	7	19.736	0.000	0.373
	NW	7	19.768	0.000	0.374
Age	NS	3	18.744	0.000	0.195
	FS	3	17.393	0.000	0.184
	NW	3	8.787	0.000	0.102
Disorder	NS	1	52.846	0.000	0.186
	FS	1	84.064	0.000	0.266
	NW	1	107.075	0.000	0.316
Age*disorder	NS	3	3.436	0.018	0.043
	FS	3	0.579	0.630	0.007
	NW	3	1.666	0.175	0.021

NS = noisy sentences, FS = fast sentences, NW = nonsense words

Table 3. Statistical data (MANOVA) for groups of children with FAD and control groups in verbal comprehension tests

Source	Dependent variable	df	F	Sig.	Partial Eta Squared
Corrected model	StC	7	8.922	0.000	0.212
	SeC	7	10.865	0.000	0.247
Age	StC	3	4.653	0.004	0.057
	SeC	3	16.638	0.000	0.177
Disorder	StC	1	46.141	0.000	0.166
	SeC	1	25.327	0.000	0.098
Age*disorder	StC	3	0.777	0.508	0.010
	SeC	3	0.367	0.777	0.005

StC = story comprehension, SeC = sentence comprehension

Our second hypothesis predicted that children with FAD would show a delayed development in their auditory processing skills across ages compared to that of children without FAD. Figure 1 demonstrates the children’s performance in repetition of sentences and non-words while Table 4 summarizes their data in sentence and story comprehension tests confirming delayed development of children with FAD.

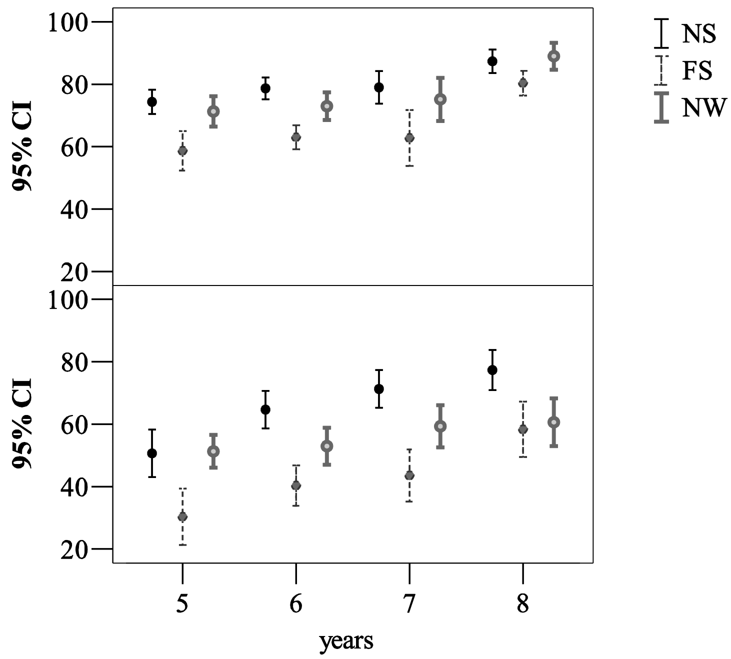

Figure 1
Performance of children with FAD (bottom) and control subjects (top) (NS = noisy sentences, FS = fast sentences, NW = non-words)

Table 4. Speech comprehension results of children with and without FAD

Age (years)	Dependent variable	Data	StC (%)	SeC (%)
5	FAD	mean	51.00	70.00
		std.	25.09	18.56
	Controls	mean	68.66	80.66
		std.	20.12	12.57
6	FAD	mean	61.00	82.00
		std.	17.68	15.84
	Controls	mean	76.00	90.33
		std.	14.76	8.50
7	FAD	mean	60	83
		std.	28.1	18.5
	Controls	mean	74	91
		std.	19.4	10.2
8	FAD	mean	61	86
		std.	24.8	10.6
	Controls	mean	85	93
		std.	12.5	8.7

std. = standard deviation, StC = story comprehension, SeC = sentence comprehension

Five- and six-year-old children's data

The performance of five- and six-year-old children with FAD (Fig. 1) was significantly poorer than that of the control groups in all repetition tests (MANOVA, factor of 'disorder': $F(1,599) = 129.11$, $p = 0.001$; factor of 'age': $F(1,599) = 22.332$, $p = 0.001$; the interaction of these two factors was not significant). The results of five-year-olds with FAD were the poorest when repeating fast sentences (mean 30.33%, std. 24.13). Both the repetition of noisy sentences (mean 50.55%, std. 20.49) and that of non-words (mean 51.33%, std. 14.07) yielded statistically significant results (p = 0.002). The performance of six-year-olds with FAD was only partially similar: they also performed least well in repetition of fast sentences (mean 40.33%, std. 17.31), but in their case, the correct repetition of non-words was also poor (mean 53.0%, std. 15.78). They performed best when they were required to repeat noisy sentences (mean: 64.6%, std. 16.13).

The performance of the five-year-olds' in the control group was the poorest with respect to repeating fast sentences (mean 58.66%, std. 12.96). Their data were almost the same for noisy sentences (mean 74.33%, std. 10.40) and for non-words (mean 71.33%, std. 13.06). The control group of six-year-olds' poorest performance came, again, under the condition of fast sentence repetition (mean 63%, std. 10.22), followed by that of non-word (mean 73%, std. 11.78), and noisy sentence repetition (mean 78.66%, std. 9.37).

The differences between children with and without FAD were significant in all three tests (for fast sentences and non-words for both the 5- and 6-year-olds: $p = 0.001$; for noisy sentences in the case of 5-year-olds: $p = 0.001$ while in the case of 6-year-olds: $p = 0.005$). Errors in the repetition of noisy and fast sentences involved words being omitted from and inserted into the original sentences. Incorrect repetition of non-words involved the substitution of speech sounds, as well as omissions from or insertions into the original sequence.

The results of children with FAD in the sentence comprehension task were lower in both age groups compared to those of the control children (Table 4). The difference between the children with and without FAD proved to be significant in the case of the five-year-olds ($p = 0.024$), but not in the case of the six-year-olds. Results for the story comprehension task were poorer than those for the sentence comprehension task in all groups (Table 4). There was again a significant difference between children with and without FAD in both age groups (for 5-year-olds: $p = 0.013$, for 6-year-olds: $p = 0.021$).

There were no significant differences in either of the three repetition tests (noisy, fast sentences and non-words) across ages in the control groups. The same applies the children's groups with FAD with the only exception in the performance of the repetition of noisy sentences between 5- and 6-year-olds ($p = 0.002$). In the sentence comprehension test, the difference across age groups was significant in groups of children with FAD ($p = 0.005$). However, no significant difference was found between the five- and six-year old control groups. For story comprehension, there was no significant difference in performance across the ages in either group of subjects.

School-age children's data

Compared to the respective control groups, school-age children with FAD exhibited a delay in sentence and non-word repetition tests (MANOVA for the factor 'disorder': $F(1,599) = 90.455$, p = 0.001; and for the factor 'age': $F(1,599) = 22.143$, $p = 0.001$; there was no significant interaction between them). In the repetition of noisy sentences, the difference between the seven-year-old children with and without FAD was not statistically significant (mean of subjects with FAD was 71.3%, std. 16.48, and of controls 78.9%, std. 13.7), but in the case of the eight-year-olds, the delay could be statistically confirmed ($p = 0.047$). The eight-year-old control subjects' mean score was 87.3% (std. 10.14), whereas that of participants with FAD was 77.3% (std. 17.1). In the repetition of fast sentences, we found significant differences in both age groups. In the case of seven-year-olds, the mean performance of the control group was 62.7% (std. 23.58), while that of the group of children with FAD was 43.54% (std. 22.88); the difference is statistically significant ($p = 0.004$). The mean performance of eight-year-old controls in this task was 80.3% (std. 10.66) while that of children with FAD was 58.3% (std. 23.79), and the difference turned out to be significant ($p = 0.001$). Errors in the repetition of the noisy and fast sentences involved word deletion or a word order which differed from that of the original sentence.

The performance of children with FAD in the non-word repetition test was poor; the difference between groups of children with and without FAD is significant (for seven-year-olds: $p= 0.003$; for eight-year-olds: $p = 0.001$). The mean performance of seven-year-old children with FAD was 59.3% (std. 18.42); that of the control group was 75.2% (std. 18.24), and the mean performance of eight-year-old children with FAD was 60.7% (std. 20.49) while that of the control group was 89% (std. 11.55). There were errors involving speech sounds that differed in terms of a single distinctive feature from the target segment as well as omissions from or insertions into the original sequence.

The speech sound discrimination task was administered only to school-age children. Their data obtained from this test showed significant differences between seven-year-olds with FAD and the control group (χ^2: (1, 30) = 6.378, $p = 0.012$). Seven-year-old children with FAD made mistakes in 27.4% of the cases (std. 4.3) while members of the control group produced 16.5% mistakes of the cases (std. 3.4). The difference in speech sound discrimination performance between eight-year-olds with and without FAD was still significant (χ^2: (1, 30) = 11.403, $p = 0.001$). Control eight-year-olds made mistakes in 4.3% of the cases (std. 2.2), whereas children with FAD made mistakes in 17.4% (std. 3.2). Errors of discrimination primarily concerned pairs of short vs. long consonants in both groups of children with and without FAD. Failure to discriminate between the trill and the lateral approximant as well as between the voiced and voiceless consonants was mainly characteristic of children with FAD.

There was no significant difference in sentence comprehension performance between children with FAD and controls at the ages of 7 and 8 (Table 4). The story comprehension performance of seven-year-olds with FAD did not differ significantly from that of their peers in the control group. However, the eight-year-old controls showed significantly better results in this test than the eight-year-old children with FAD ($p = 0.001$).

There was no significant age-based improvement in either group in the repetition of noisy sentences. No significant difference could be found in the performance of the children with FAD in the repetition of fast sentences between the ages of 7 and 8 but significant differences were found with control children in this test. The results of eight-year-olds with FAD in the non-word repetition test showed no improvement compared to their younger counterparts, whereas the control groups' performance improved considerably with age, and the change was statistically significant ($p = 0.019$), see Fig. 1). The discrimination ability of children both with and without FAD improved between 7 and 8 years of age: their mean error count decreased significantly (children with FAD: χ^2: (1, 29) = 6.438, $p = 0.011$, and controls: χ^2: (1, 29) = 4.270, $p = 0.039$).

No statistically significant differences were found in children either with or without FAD between the ages of 7 and 8 in sentence comprehension. In story comprehension, children with FAD did not show any difference between the ages of 7 and 8 while the controls' performance turned out to be significant between the ages of 7 and 8 ($p = 0.003$).

No significant differences were found in the repetition of noisy sentences, fast sentences and non-words as well as in sentence comprehension between the 6- and 7-year-old children either with or without FAD. In the story comprehension test, children with or without FAD did not show any statistically relevant differences between the ages of 6 and 7, either.

Looking at all data of the participants, we can see that children both with and without FAD showed development in speech processing skills between the ages of five and eight years, but participants with FAD showed a delayed development and did not reach the performance level of their typically developing peers on any test that we performed in this research (Figures 2 and 3).

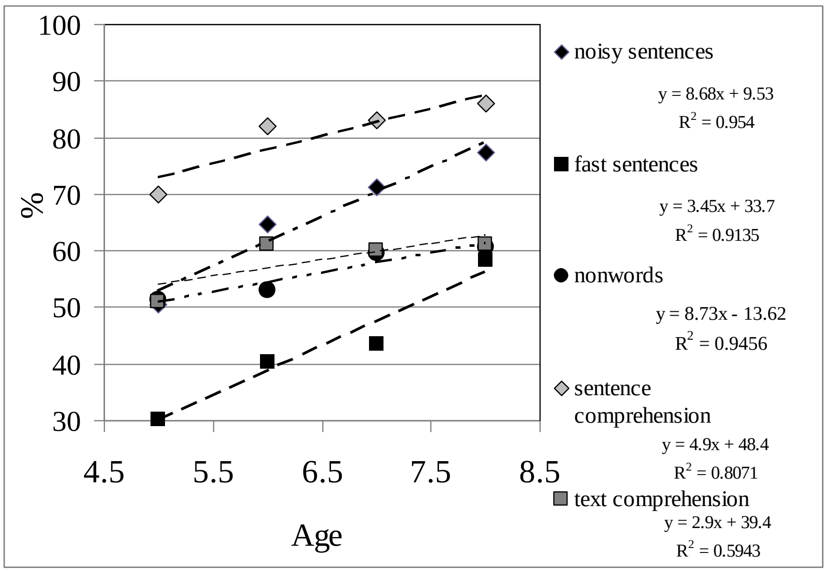

Figure 2

Auditory speech processing data for children with FAD across ages (R2 represents the estimated relationship between a scalar variable (y) and one or more variables (x). The figure shows also the equitation of the linear regression)

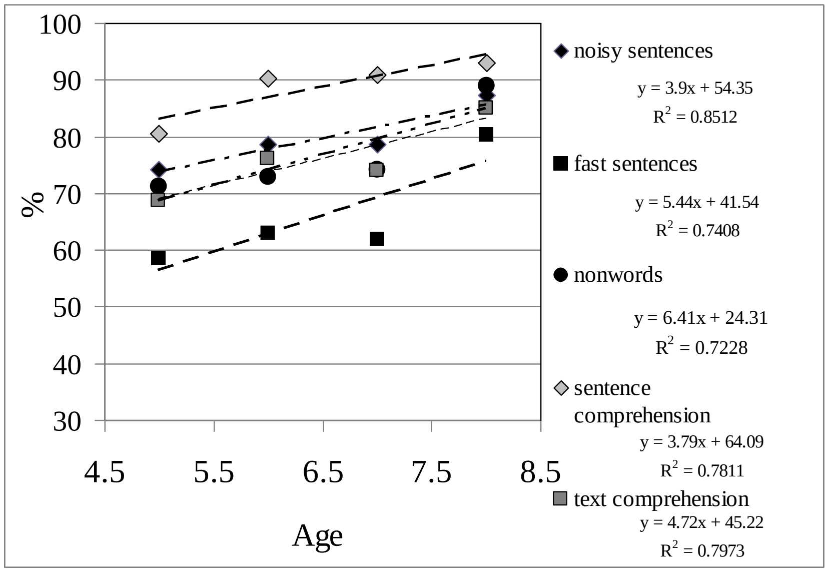

Figure 3
Auditory speech processing data for control children across ages (R2 represents the estimated relationship between a scalar variable (y) and one or more variables (x). The figure shows also the equitation of the linear regression)

Confirmation of data by artificial neural network approach

Since it is not self-evident that children with FAD would have delay in their auditory speech processing, we performed this additional statistical analysis to strengthen the experimental data. These results supported our findings concerning the developmental delay in auditory speech processing of children with FAD. The three best predictors, as indicated by the feature selection in the decision tree analysis, were non-word repetition, repetition of noisy sentences, and story comprehension. Non-word test data are at the root of the decision tree in the decision tree analysis, meaning that this feature is responsible for the best separation between the children with and without FAD. Repetition of noisy sentences, story comprehension and then fast sentence repetition follow suit, showing less separation ability than the non-word test data.

Results of the feature selection analysis to tell apart children with and without FAD yielded a 71% successful classification in the case of children with FAD, meaning that 71.1% of children in the test set were classified by the algorithm as participants with FAD while 80.7% of controls were unambiguously classified by the algorithm as controls (precision value: 0.733, *F*-measure value: 0.768, ROC-value: 0.835 in the case of children with FAD; precision value: 0.789, *F*-measure value: 0.748, ROC-value: 0.835 for controls).

The confusion matrix shows that the classifier took 28.5% of all children with FAD to be children without any such condition. This means that the speech processing performance of almost a third of the children with FAD was similar to that of those without any articulation disorder. In the control group, the classifier took 19.3% of all children to have functional articulation disorders; this means that these children's data fell within the FAD range. The classifier works with a smaller margin of error for repetition task data compared to speech comprehension data; therefore the results are less reliable with respect to the comprehension data.

Conclusions

Studies on children with speech production disorders found that these children also have disorders in auditory perception and comprehension (Kenney et al., 2006; Nijland, 2009), and there are also individuals who display receptive disorders but not expressive ones (Friel-Patti, 1999; Phillips, Comeau, & Andrus, 2010). Our research on monolingual Hungarian-speaking children with FADs provides further evidence for auditory processing and comprehension deficits in this population, potentially suggesting cross-language tendencies that may indicate a universal trait of having perceptual and comprehension issues underlying FADs.

In our study, children with FAD showed developmental delay in their auditory speech processing (on all our tasks) including difficulties in sentence and story comprehension. We suggest that functional articulation disorder and delayed auditory speech processing development may share a common but unknown root. We think that one noteworthy finding of this study was that the clinical picture of children with FAD is more complex than was earlier assumed meaning that they have not only articulation deficits but also delay in auditory speech processing development. This implies that a substantial amount of communication is missed by children with FAD (see also Diehl et al., 2004).

Although children with FAD showed development across ages in the tests used – with the exception of story comprehension where the 8-year-olds' abilities are the same as the 6-year-olds' – their performances showed differences depending both on the tests and the ages but did not reach the performance level of children without FAD. One potential reason for the lack of progress regarding story comprehension of children with FAD between the ages of 6 and 8 could be that the demands of beginning school stress the resources and shift their focus to other academic tasks that further hinders academic performance. Our results suggest that the auditory speech processing development of children with FAD seems to be slow and the years from the age of 5 until the age of 8 are not sufficient for them to make up for their auditory speech processing and comprehension difficulties.

The fact that 71.1% of the participants with FAD could be successfully classified shows that the auditory speech processing difficulties of children with FAD is really characteristic of them. This result of automatic analysis seems to support our assumption that poor auditory speech processing skills might be concomitant with FAD. The fact that almost one-third of all children with FAD were classified as typically developing ones shows that these children did not exhibit large deficits in all tests used in this study. In addition, close to 20% of children from the control groups were classified as having FADs, indicating that this proportion of the control group was also low-performing on measures of auditory speech processing and comprehension. This is consistent with Gósy's (2007) results who found a similar proportion of typically developing Hungarian children experiencing speech processing problems.

Our results have several clinical implications. Children's delay in auditory speech processing performance across various tasks might cause further difficulties with respect to them fulfilling academic expectations at school (Bradlow, Kraus & Hayes, 2003; Boets, Vandermosten, Poelmans, Luts, Wouters & Ghesquière, 2011). Specifically, we found that children with FAD experienced no measurable progress in story comprehension between ages 6 and 8, possibly due to strained resources due to academic demands. Even if the cause were different, knowing that children with FAD may experience delays makes early identification and treatment critical. Our measures can be used to assist in identifying children with FAD that, in turn, will allow relatively earlier intervention than they would have received if such identification were not made in a timely fashion. Children with FAD require additional support from the classroom teacher in relation to reading and learning in general, without which their understanding of the written language and comprehension of academic tasks will be impeded (Gierut, 1998; Boets et al., 2007; Grizzle & Simms, 2009).

It is clear from our results that assessing auditory speech processing and comprehension along with expressive language for children who are at risk for having FAD is critical, because expressive measures alone may miss underlying speech perception and comprehension problems in cases when the manifestations of the disorder are more subtle. Findings supported that a multi-faceted and multi-disciplinary effort is needed to provide appropriate clinical assessment and effective intervention for children with FAD, and our study provides initial guidelines and measures as to how to approach assessment and intervention for this population. Finally, our results also shed light on the possibly non-language-specific underpinnings of FAD, because Hungarian is remarkably different from English, yet Hungarian children with FAD display auditory processing and comprehension problems as to their peers learning other languages. Future research should focus on expanding our work as well as making more specific and accurate suggestions for the assessment and treatment of Hungarian-speaking children with FAD to help them reach their full potential.

Declaration of interest: The authors report no conflicts of interest.

Acknowledgments

We would like to thank Susan Rvachew, Ferenc Bunta, András Beke, and two anonymous reviewers for their helpful comments on the earlier versions of the text.

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APPENDIX

Test 1. Noisy sentences	
Noisy sentences in Hungarian	Noisy sentences in English
A sütemény nagyon finom volt.	The cookie was very good.
A rádióban zene szól.	There is some music on the radio.
Terítsétek meg az asztalt!	Lay the table!
A repülőgép most szállt le.	The aeroplane landed just now.
Menjünk holnap kirándulni?	Shall we take a trip?
Az őzikét kergeti az oroszlán.	The deer is chased by the lion.
Rakjátok össze a játékokat!	Tidy away your toys!
A strand ma be van zárva.	The beach is closed today.
Ki akar lemenni vásárolni?	Who wants to go shopping?
Tavasszal sokat esik az eső.	It rains a lot in spring.

Test 2. Fast sentences	
Fast sentences in Hungarian	Fast sentences in English
Az irigység rossz tulajdonság.	Envy is a bad trait.
Őt is beidézték a tárgyalásra?	Has he been summoned to the court hearing?
A forgalmat rendőrök irányítják.	The traffic is directed by the police.
Ne gyártsatok selejtet!	Do not make garbage!
A galamb a szabadság jelképe.	The dove is the symbol of freedom.
A katonák felesküdtek a zászlóra.	Soldiers swear on the flag.

Ki akart számot adni a munkájáról?	Who wanted to account for his work?
Átkokat szórt mások fejére.	Curses were put on people.
Gyorsan megitatták az állatokat.	They got the animals to drink quickly.
Fejtsétek ki a véleményeteket!	Express your opinion!

Test 3. Nonsense words	
Nonsense words	IPA transcriptions
galalajka	[gɔlɔlɔjkɔ]
zseréb	[ʒɛreːb]
trankün	[trɔŋkyn]
siszidami	[ʃisidɔmi]
feréndekek	[fɛreːndɛkɛk]
bakőgy	[bɔkøːɟ]
menelékej	[mɛnɛleːkɛj]
jacolov	[jɔtsolov]
vucsityó	[vutʃicoː]
kriszposztyüvan	[krisposcyvɔn]

Test 4. Sound discrimnination test	
Meaningless speech sound sequences differing in one segment	IPA transcriptions
ib and íb	[ib] and [iːb]
azsá and asá	[ɔʒaː] and [ɔʃaː]
begi and begi	[bɛgi] and [bɛgi]
fész and fész	[feːs] and [feːs]
móz and nóz	[moːz] and [noːz]
voka and vokka	[vokɔ] and [vokːɔ]
adü and atü	[ɔdy] and [ɔty]
szug and szug	[sug] and [sug]
nőcs and nöcs	[nøːtʃ] and [nøtʃ]
nyér and nyér	[ɲeːr] and [ɲeːr]
taj and taj	[tɔj] and [tɔj]
lefi and levi	[lɛfi] and [lɛvi]
ómi and omi	[oːmi] and [omi]
hem and hem	[hɛm] and [hɛm]
oszú and ozú	[osuː] and [ozuː]
íppi and ípi	[iːpːi] and [iːpi]
ogyóra and onyóra	[oɟoːrɔ] and [oɲoːrɔ]
rad and rad	[rɔd] and [rɔd]
gev and bev	[gɛv] and [bɛv]
nazirú and nazilú	[nɔziruː] and [nɔziluː]
nét and nét	[neːt] and [neːt]
teggő and tegő	[tɛgːøː] and [tɛgøː]
ise and isse	[iʃɛ] and [iʃːɛ]

Test 5. Sentence comprehension test (for children ages 5 and 6)		
Test sentences in Hungarian	Test sentences in English	The opposite meaning shown in the other picture

Néhány alma van a fán.	There are some apples in the tree.	There are a lot of apples in the tree.
Az oroszlán kergeti a nyuszit.	The lion is chasing the rabbit.	The rabbit is chasing the lion.
Az anyuka kislánya mosogat.	The woman's daughter is washing the dishes.	The girl's mother is washing the dishes.
A nyuszi nem vette fel a kockás nadrágot.	The rabbit did not put on a pair of checked trousers.	The rabbit put on a pair of checked trousers.
A maci evett, azután ivott egy pohár vizet.	The bear had eaten the bread then he drank a cup of chocolate.	The bear had drunk a cup of chocolate then he ate the bread.
A felhő alá szállt egy madár.	A bird was flying beneath the cloud.	A bird was flying above the cloud.
A medve azért szalad, mert fél, hogy utolérik a méhek.	The bear is running because he is afraid of the bees that will catch him.	The bear is running but the bees do not want to catch him.
Kiömlött a víz, mert eldőlt a pohár.	The water spilled because the glass had fallen.	There is some water on the table and the glass has fallen.
A kislány szánkózni akart, de mégis otthon maradt.	The girl wanted to go sledding but she stayed at home.	The girl is sitting on the sled.
A kislány megenné a süteményt, ha elérné a tálat.	The girl would eat the cake if she could reach the plate.	The girl can reach the plate.

Test 5. Sentence comprehension test (for school-age children)		
Sentences in Hungarian	Sentences in English	The opposite meaning shown in the other picture
Az egérke majdnem eléri a sajtot.	The mouse has not reached the cheese.	The mouse has just reached the cheese.
A maci és a nyuszi fára másztak, és az egyikük leesett.	The bear and the rabbit were both climbing the tree and one of them fell.	The bear and the rabbit were both climbing the tree and nobody fell.
A macska az asztal mögül húzza az egeret.	The cat is dragging the mouse from behind the table.	The cat is not dragging the mouse from behind the table.
A kislánynak oda kell adnia a könyvet a kisfiúnak.	The book is going to be given to the boy.	The book is going to be given to the girl.
Mielőtt a maci ivott, evett egy kicsit.	Before the bear drank, he ate the bread.	Before the bear ate the bread, he drank.
Az asztalról leeső gyertyáról beszélnek.	They are discussing the candle falling off the table.	They are discussing the candle which is lying on the table.
Nem a nyuszi vette föl a kockás nadrágot.	It is not the rabbit who has put on a pair of checked trousers.	It is the rabbit who has put on a pair of checked trousers.
A medve szalad, nehogy megcsípjék a méhek.	The bear is running in order not to be bitten by the bees.	The bees do not want to bite the bear.
Mivel nagyon esett a hó, a kislány mégsem ment el szánkózni.	Although it is snowing heavily, the girl has not gone sledding.	It is snowing heavily but the girl has gone sledding.
A kislány megette volna a tortát, ha elérte volna a tálat.	The girl would have eaten the cake if she could have reached the plate.	The girl can reach the plate.