Chapter 16

Evidence for Speech Sound Disorder (SSD) Assessment

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Additional information is available at the end of the chapter

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Abstract

Comprehensive studies on aspects related to the assessment of different biomedical parameters (acoustic and laryngeal signs and oral airflow amplitude), as well as parameters for speech disorders, articulation rate, speech inconsistency, and speech stimulability, are essential for better professional practice and to understand misarticulations in children with speech sound disorders (SSDs). Different equipments that enable noninvasive collection and analysis of data have become more common in speech-language pathology practice. Studies recently conducted by our research group have emphasized the evaluation of auditory-perceptual processing by means of assessments of central auditory processing, electrophysiology of hearing—considering that pure-tone, speech audiometry, and tympanometry are routinely used with children during the diagnostic phase and motor speech production performed by acoustic analysis of speech, electroglottography, aerodynamic measures, and ultrasound tongue imaging. This chapter presents the recent advances observed in studies with Brazilian-Portuguese speakers aiming to improve the assessment of speech sound disorders and to understand better the relationship between the different processing mechanisms involved in speech.

Keywords: speech sound disorder, ultrasound tongue imaging, auditory perception, speech, assessment

1. Introduction

Many studies demonstrating the need for speech-language pathologists to refine the assessment of speech sound disorders (SSDs) in children have been published. In this sense, the speech-language pathologists need to be able to specify more precisely the type of difficulty the child has. The search for more precise diagnoses that allow greater characterization of the clinical manifestations of children with SSD is constant, arising from the need to work according to the evidence-based practice. This practice emerged at the beginning of this century and refers to the combined use of different evidence to make the correct clinical decisions for a given individual [1]. The need to use clinical evidence to carry out a differential diagnosis, associated with the knowledge of speech-language therapists, appeared from the demand for more accurate diagnoses for the treatment of different human communication disorders. Recent studies in the area of speech and language disorders highlight the heterogeneity of SSD cases in terms of their manifestation, severity, and intelligibility [2–8].

SSD is defined in the diagnostic and statistical manual of mental disorders (DSM-5) [9] and ICD-10 [10] as difficulty in using age-appropriate speech sounds for an individual dialect and is the most prevalent speech and language disorder in children [11–13]. It is already known that children with SSD may present speech impairment caused by difficulty with auditory input (auditory processing of information) and/or cognitive-linguistic processing and/or motor speech processing. The interrelationship between these aspects [14–19] is the reason why studying them is of fundamental importance to better comprehend this disorder.

The greater the therapists' knowledge about instruments that can be used to describe better SSD cases, the more accurate their clinical decisions. Therefore, comprehensive studies into aspects related to evaluating different biomedical parameters (acoustic and laryngeal symptoms and signs of oral airflow amplitude), as well as of parameters of speech disorders, articulation rate, speech inconsistency and speech stimulability, are essential to better understand the changes in children with speech disorders.

In general, the diagnosis of SSD is performed by applying language and speech tests, such as spontaneous speech, picture naming, and imitation of words and sentences. These are submitted to phonological analysis to identify changes according to child age [20]. There is no requirement for specific equipment for the application of these language and speech assessments, except for the test procedures. Additionally, a camera for filming and a good quality microphone/recorder are usually used to record data collection and ensure that they can be reanalyzed as many times as necessary.

In the following studies that are going to be presented, phonological evaluations for the diagnosis of SSD were carried out based on the Phonology Test [21] from ABFW—Infantile Language Test [22], which was developed and standardized for native speakers of Brazilian-Portuguese [23]. This test includes a picture naming task composed of 34 pictures of objects with 90 consonants, and a word imitation task composed of 39 words with 107 consonants. The test allows the evaluation of the phonetic inventory and phonological processes and the results can be analyzed according to age (for children aged 4–7 years) for both the occurrence of phonological processes (**Table 1**) and sounds in the phonetic inventory [21, 23].

The application of complementary tests to verify biomedical parameters has been an increasingly used resource in speech-language pathology research and clinical practice. The aim of these tests is to refine SSD diagnoses, giving the speech-language pathologist a better understanding of the specific impairments presented by a particular individual, given that SSD is a heterogeneous disorder both in terms of its cause and its manifestation. The complementary tests most frequently used in our recent research include cognitive-linguistic, auditory-perceptual, and

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Phonological processes	Example in BP		Elimination of phonological processes
	Target	Production	(in years; months)
Syllabic reduction	/ˊgato/	[ˊga]	2; 6
Consonantal harmony	/saˊpato/	[paˊpat∪]	2; 6
Stopping	/ˊsala/	[ˊtal]	2; 6
Velar backing	/ˊt_la/	[ˊk_la]	3; 6
Palatal backing	/ˊsaco/	[ˊ∢ak∪]	4; 6
Velar fronting	/ˊk la/	[ˊt l]	3; 0
Palatal fronting	/ˊ∢eƱo/	[ˊseƱ∪]	4; 6
Liquid simplification	/ˊbala/	[ˊbaƱ]	3; 6
	/ˊkara/	[ˊkala]	
	/ˊpa a/	[ˊpaƱ]	
Cluster reduction	/ˊpreto/	[ˊpet∪]	7; 0
	/ˊbluza/	[ˊbuz]	
Final consonant deletion	/ˊpta/	[ˊp Ʊt]	7; 0
	/ˊpasta/	[ˊpat]	

BP, Brazilian-Portuguese.

Table 1. Phonological processes used in Brazilian-Portuguese, age of normalization of processes, and examples.

speech production assessments. This chapter highlights the evaluation of auditory-perceptual processing by means of assessments of central auditory processing (CAP), electrophysiology of hearing—given that pure-tone, speech audiometry, and tympanometry are routinely used with children during the diagnostic phase. It also considers speech production, investigated using speech acoustics, electroglottography (EGG), aerodynamic measures, and ultrasound tongue imaging.

1.1. Auditory perception

The auditory perception of speech allows children, through an active process, to organize their internal representations of the language to which they are exposed in order to produce the sounds of this language.

Speech perception can be defined as the process of continuous transformation of an acoustic signal into discrete linguistic units, which occurs through a multistage process permitting the extraction of acoustic information that relies on auditory processing mechanisms. Subsequently, the acoustic representation is transformed into phonetic units, and then a hierarchically organized phonological representation of phones is constructed [24]. Studies into auditory perception of speech have as their central theme the auditory comprehension of speech, but they also describe the organization of sublexical tasks, such as syllable discrimination [25].

Younger children present a need for a larger number of acoustic signals to understand the contrasts between speech sounds. The production performance of motor sequences increases and the variability in production decreases with child development. This regulation of movement and the learning of motor skills occur in a close and continuous connection between action and perception, and this connection is responsible for the development of the auditory and kinesthetic monitoring of articulatory gestures. Auditory perception as a function of language exposure selects some sound categories to be preserved, whereas others are neglected.

Difficulties in auditory perception may occur as a result of hearing loss, a change in central auditory processing or immaturity of the auditory system to process sounds properly. During their development, children gradually acquire the auditory-perceptual and speech sound production domains, as well as an understanding of the linguistic rules that govern their use in a particular language. Assessment of the auditory perception of children with SSD is of great importance insofar as problems in this area are seen by several authors as one of the possible causes of the disorder [19, 26–30]. In these cases, in addition to the standard set of audiological tests, it is possible to perform electrophysiological exams to evaluate the functional and structural integrity of the auditory pathway and the central and peripheral auditory systems [31–34]. Additional testing can also assess central auditory processing via auditory closure, figure-background, temporal ordering, and interhemispheric transfer capacities. It is worth mentioning that electrophysiological tests can be conducted at any age, but the standardization of expected responses is only possible in children aged 2 years and older, whereas evaluation of the CAP can be conducted only in children older than 7 years owing to the maturation of auditory structures, which is completed approximately at this age.

1.2. Speech production

The development of motor speech control is influenced not only by biological factors, but also by intrinsic (cognitive-linguistic and sensorimotor maturation) and extrinsic (auditory and visual stimulation and perception) forces [35]. Recent studies suggest that when children begin to produce their first words, the coordination of the muscular movements involved in speech is distinct from that presented in sucking and chewing [36].

To achieve the adult standard, vocal tract growth occurs not only in geometric proportion, but also in terms of anatomical restructuring, which refers to the physical changes that occur in the vocal tract structures throughout development [37]. It is worth emphasizing that motor speech control does not occur uniformly, that is, some articulators develop toward the adult pattern before others [38]. Studies indicate that control of the mandible occurs before that of the tongue and lips, perhaps because the mandible presents only vertical movements (lower degree of freedom) as opposed to the tongue and lips, which move more complexly (higher degree of freedom) [35, 37].

With respect to velocity of articulatory movements, a study [39] indicated an increase in the velocity of the mandible and lower lip between 9 and 21 months of age, indicating that both the growth and speed of the articulators present a very early increase toward the adult standard. The specific scientific literature also shows that motor speech skills begin to be refined from the age of 8, continuing up to the age of 16 [40]. Therefore, children at the beginning of speech production do not present sufficient neuromuscular control to produce sounds and, consequently, need to adopt strategies to approach the adult speech model [37]. Articulation rate is an interesting measure to assess the pace at which speech segments are produced. Because this measure can be easily obtained (it only requires a stopwatch to mark the time in which a given sentence is produced) and rapidly calculated (division of the number of produced phones by the time), it can be widely used in speech-language pathology practice.

In addition to the articulation rate, speech-language therapists have been using measures that are more objective over the years. To this end, instruments that produce more accurate results, such as acoustic speech analysis, EGG, aerodynamic measures, and ultrasound tongue imaging, have been increasingly used. Through the visualization of a spectrogram, speech acoustics allows verification of the acoustic properties of sounds that cannot be detected auditorily. In the case of children with SSD, this helps with the characterization of the phonological substitutions and mainly with a better understanding of the distortions usually present in the production of anterior sounds.

EGG allows the verification of vocal fold functioning by placing two electrodes on the thyroid cartilage and using specific software that indicates the opening and closing of the vocal folds. Aerodynamic measures also contribute in the verification of the control mechanism of vocal fold vibration, allowing the observation of intraoral airflow pressure. This occurs because the control of voiced sounds requires, among other conditions, appropriate glottal opening and sufficient airflow through the glottis to support vibration, and increased intraoral airflow pressure decreases the pressure ratio through the glottis, reducing vocal fold vibration (a condition for the occurrence of voicing) [41]. Both EGG and aerodynamic measures show quite interesting outcomes for children with SSD who present the phonological process of devoicing of fricatives and plosives, which is very common in Brazilian-Portuguese (BP) [42, 43]. Ultrasound tongue imaging (UTI) is a tool used in articulatory analysis because it allows real time visualization of tongue movement, allowing speech-language therapists to visualize how the lingual sounds are produced, mainly in cases of substitutions of anterior sounds by posterior sounds (or vice versa) [44–48], as well as in cases of distortions [49, 50]. Thinking of ways to address these interrelationships in children with SSD, our research group has conducted different studies seeking to equip speech-language therapists with innovative knowledge regarding the evaluation and treatment of this pathology. Therefore, the purpose of this survey is to present the recent advances observed in studies conducted with speakers of Brazilian-Portuguese aiming to improve the assessment of speech sound disorders and to better understand the relationship between the different processing mechanisms involved in speech.

2. Relationship between auditory and cognitive-linguistic processing

Speech perception is an important stage in the development of speech sounds in children [15, 25, 51, 52], and its role is described as a mediator for learning sound production. With this in mind and because of the difficulties observed in children with SSD, several studies have been conducted to investigate the central auditory processing (CAP) [18, 53] and electrophysiological responses obtained through auditory-evoked potentials in Brazilian-Portuguese speaking children with SSD. These studies seek to identify the auditory-perceptual characteristics of children with this speech disorder as well as the evidence of altered auditory processing and the lack of maturity-integrity of auditory pathways that could compromise auditory feedback, which is extremely important for phonological development.

For the identification of such characteristics, the application of tests involving these three processing mechanisms (auditory-perceptual, cognitive-linguistic, and motor speech) is important for the identification of major impairments and consequent selection of the treatment to be applied to the individual being assessed. The evaluation of CAP provides significant contributions to the diagnostics of SSD, as it helps with the identification of the speech impairments presented by children with this disorder. A CAP disorder could affect the ability to discriminate speech sounds and result in altered and/or less stable neural representations of these sounds, which may interfere with speech perception and production [54]. The CAP evaluation considers the interaction of the auditory information associated with the acquisition and organization of the phonological rules in this population, and it is important to guide speech-language pathology intervention. This contribution comes about because the central auditory processing disorder (CAP disorder)—defined as a difficulty with sound information processing—may result in language and learning disorders [55], as it interferes with the formation of a stable representation of phonemes in the brain and with speech perception, hindering the learning of phonology, syntax, and semantics [56].

There are few studies in the literature correlating SSD with CAP for either English or Brazilian-Portuguese. This can be explained by the fact that the diagnosis of SSD is most frequently performed between the ages of 5 and 7 and the application of CAP is conducted only after 7 years of age because of the maturation of the auditory structures involved, which is expected to be almost complete by this age.

A recent study [18] addressed the analysis of phonological and CAP measures in children with SSD. The study sample was composed of 21 individuals with SSD aged 7:0–9:11 years divided into 2 groups: participants with SSD and participants without CAP disorder. The assessment comprised tests of phonology, speech inconsistency, metalinguistic and motor speech abilities. The abilities assessed in the central auditory processing and the following behavioral phenomena are in **Table 2**.

CAP abilities	Behavioral phenomena
Auditory closure	Acoustic signal recognition when parts of it are omitted
Figure-background	Identifying the speech signal in the presence of other competitive sounds
Temporal ordering and interhemispheric transfer	Recognition of acoustic characteristics of the signal

Table 2. Abilities and behavioral phenomena assessed in the CAP.

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The results indicated that children with SSD and CAP disorder showed higher occurrence of the phonological process of consonant cluster reduction and greater difficulty in phonological awareness abilities: rhyme and alliteration. In addition, the group without CAP disorder presented lower values of percentage of consonants correct-revised (PCC-R) and higher values of process density index (PDI), and consequently greater severity of SSD (**Figure 1**).

A cutoff value was established for the PDI [57], indicating that children with an index value >0.54 showed a strong tendency toward presenting a CAP disorder (sensitivity of 0.73 and specificity of 0.90). This measure effectively indicated the need for CAP evaluation in children with SSD aged 7 years and older.

In addition, the authors verified in 2016 that the greater the severity of SSD and the greater the impairment with metaphonological skills of rhyme and alliteration, the larger the number of absent sounds in the child's phonetic inventory, and the larger the number of altered skills found in the CAP exam. Therefore, this reinforces the existing interaction between the three processing mechanisms.

Another recent study [53] was conducted to identify a cutoff value based on the PCC-R [58] metric that could indicate the likelihood of a child with SSD also having a CAPD. Language, audiological, and CAP evaluations were administered. Participants were 27 individuals with

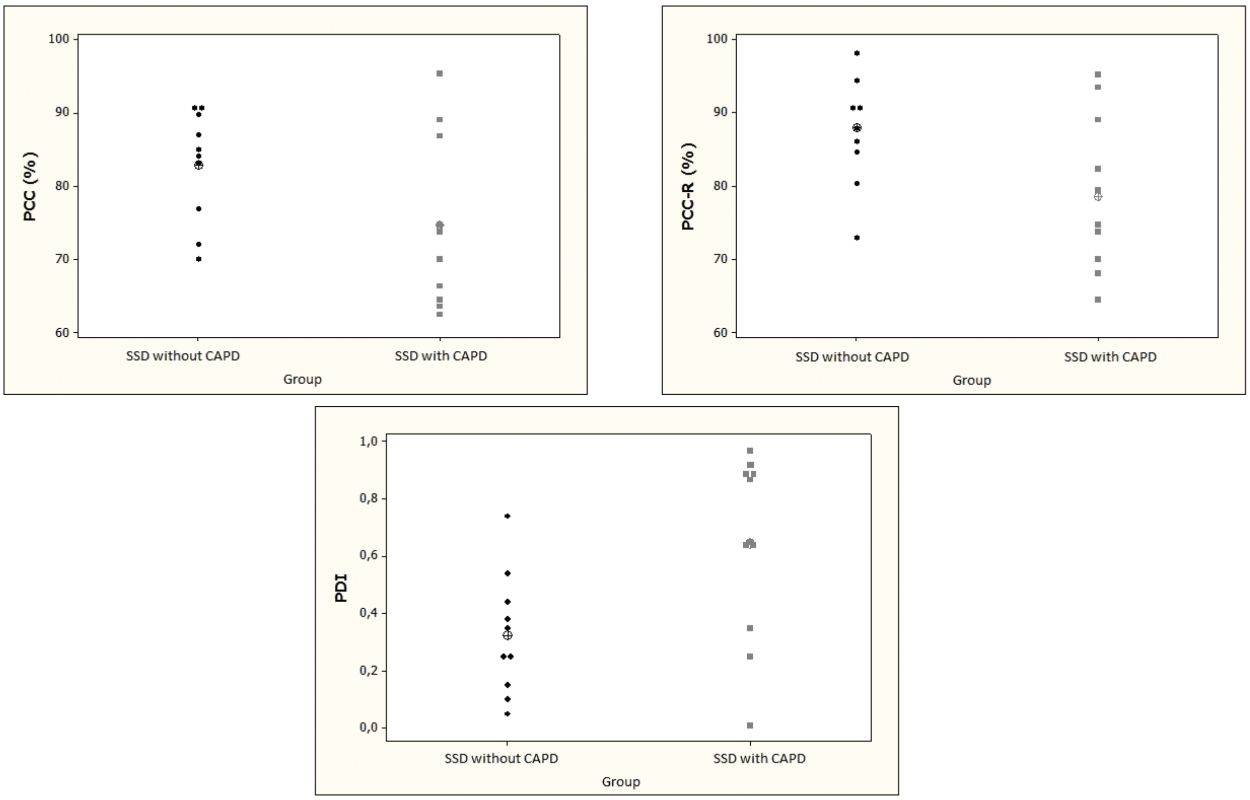

Figure 1. Values of percentage of consonants correct-revised (PCC-R), percentage of consonants correct (PCC), and process density index (PDI) in both group.

SSD aged 7–10:11 years divided into 2 groups according to their CAP evaluation. Three different auditory skills were assessed using the Brazilian versions of four CAP tests [59]. Auditory closure was assessed using the figure identification (with competitive ipsilateral noise) test; binaural integration was evaluated using the dichotic digits test; and temporal ordering was tested using both the pitch pattern sequence test and the duration pattern sequence test. The results indicated that SSD severity varied according to the number of impaired auditory skills. Greater severity of speech disorders in children was associated with a greater probability of presenting a CAP disorder. The cutoff values of 83.4% for the picture naming task (N) and 84.5% for the imitation of words task (I) successfully distinguished children with CAP disorder from those without.

In addition to the conventional audiological assessment composed of tonal audiometry, vocal audiometry, tympanometry measures, and central auditory processing exam, the central and peripheral auditory systems can be evaluated by auditory-evoked potentials (AEPs). As it is possible to assess the AEPs from the age of 2, these tests can be performed at the time of the SSD diagnosis, providing important information for the implementation of treatment in each case. The studies developed for Brazilian-Portuguese relating children with SSD and AEPs have applied both short latency potentials, using the click and speech stimuli, and long-latency potentials, with speech and tone burst stimuli.

The study of the short- and long-latency AEPs in two boys with SSD, speakers of Brazilian-Portuguese, aged 76 and 83 months [18]. The study characterized both the severity of SSD and the auditory responses. SSD severity was described by the PCC-R index calculated based on a specific test for Brazilian [21]. As for the brainstem auditory-evoked potential (BAEP), the click and speech stimuli were used, as well as the long-latency auditory-evoked potential (LLAEP) with speech and tone burst stimuli for analysis of the latency values of components P1, N1, P2, N2, and P300. The results showed PCC-R values of 84% for the younger individual and 71% for the older individual. As for the long-latency potentials with speech stimuli, the results showed alteration in the components N1, P1, N2, and P2 in both individuals, suggesting a delay in the latency of these components. This delay implies a decrease in the velocity of auditory processing of acoustic information in the cortical and subcortical regions. This change can hinder discrimination, integration, and auditory attention to verbal stimuli. In the P300 component, the individual with more severe SSD presented impaired results, suggesting that SSD severity is associated with the P300 cognitive potential.

Other research [60] investigated whether neurophysiologic responses (auditory-evoked potentials) differ between typically developing children and children with SSD, and whether these responses were modified in children with SSD after speech-language pathology intervention. Participants were 24 typically developing children and 23 children with SSD, aged 8–11 years. Of the 23 children with SSD, 12 were undergoing speech-language therapy and 11 were not. These children were re-evaluated after 12 weeks. All participants presented normal hearing thresholds and were submitted to the following procedures: conventional audiological, brainstem auditory-evoked response, auditory middle-latency response, and P300 assessments. Results of the electrophysiological responses indicated different latency between children with typical development and with SSD on both the BAEP and P300 tests. P300 responses improved in the children submitted to speech-language pathology intervention. The authors concluded that the children with SSD presented impaired BAEPs and cortical region pathways that could benefit from intervention.

Aiming to compare the neurophysiological brainstem responses for clicks and repeated speech stimuli of children with and without SSD aged 7–11 years, a group of researchers [61] observed that the early stages of the auditory processing pathway of acoustic stimuli were not similar in children with typical development and those with SSD. This finding suggests that alteration in the coding of speech sounds may be a biological marker of SSD without defining the biological origins of phonological problems (**Table 3**).

	Click evoked—ABR						**Speech evoked—ABR**			
	Wave I	**Wave III**	**Wave V**	**I–III interpeak**	**III–V interpeak**	**I–V interpeak**	**Wave V**	**Wave A**	**Wave C**	**Wave F**
Children without SSD	1.43	3.53	5.41	2.10	1.92	4.02	7.41	9.39	19.42	40.10
Children with SSD	1.50	3.64	5.54	2.14	1.91	4.04	8.58	10.32	18.76	40.00
p-Value	**0.01***	**0.01***	**0.02***	0.43	0.70	0.25	**<0.001***	**0.0003***	0.95	0.58

ABR, auditory brainstem responses; SSD, speech sound disorders.
*statistically significant values (significance level adopted: 0.05).

Table 3. Middle-latency values for both groups in the ABR with click and speech stimuli.

3. Relationship between motor speech and cognitive-linguistic processing

The factors that positively affect child speech production throughout the developmental phase are associated with biological factors and/or learning abilities. Biological factors (modified with age) include anatomical growth and neurological and neuromuscular maturity. Learning skills (acquired with speech and language development) include motor learning (motor planning and motor programming of speech movements) and cognitive-linguistic (semantic, lexical, and phonological access) processing. For a better understanding of SSDs, many studies [62–65] have attempted to define linguistic markers by using specific instruments, such as articulation rate (AR), acoustic analysis of speech (AA), aerodynamic measures, and ultrasound tongue imaging (UTI) that could contribute diverse objective evidence.

3.1. Articulation rate

Despite the fact that AR reflects the maturity of the motor speech system, it is not an isolated motor measure. AR incorporates aspects related to the cognitive-linguistic processing of information [39, 66], including an increased load in phonological and syntactic processing beginning at the age of 5 years [67].

Demands on oral language processing vary according to different speech tasks and depend on factors, such as attention, familiar sentence (word frequency and phonotactic probability), and size and syntactic complexity of the sentence. Previous studies have shown that children speak faster in simple speech tasks (such as repetition of syllables) than in tasks involving higher demand (such as spontaneous speech) [68]. Nip [69] noted that the velocity of articulatory movements was faster for speech tasks of low demand and slower for highly demanding ones.

Other studies have shown that children produce long sentences with higher AR in comparison with short sentences [70–72]. This phenomenon may be associated with AR control strategies, such as reducing effort to increase coarticulation, thus generating an increase in the number of phones per second produced during speech. These motor adjustments also seem to be associated with motor speech control maturity, considering that AR is only greater in longer sentences than in shorter ones for adults, but not for younger individuals [67].

The use of inappropriate AR may also hinder the articulation of sounds and reduce speech intelligibility in children with SSD, resulting in disfluency, articulatory problems, and/or language disorders, indicating difficulties in the formulation of language and/or in the recovery of words [69, 73, 74].

Studies with English [71, 73, 75] and Brazilian-Portuguese speakers [72] that analyzed AR in children with SSD indicated that these children present decreased AR compared with that of their typically developing peers. Decreased AR in children with SSD can occur due to motor speech control immaturity and/or may be caused by some form of compensation provided by these children, such as the occurrence of articulatory adjustments for certain problematic sounds in an attempt to improve speech intelligibility [73]. These studies also found no difference between boys and girls for the AR analysis.

The investigation of how linguistic complexity variables are related to age and phonological measures can provide important insights to understand the influence of biological and cognitive-linguistic factors on the development of speech production velocity, such as those measured by AR.

A recent study [76] aimed to quantify the articulation rate expected between typically developing children and those with SSD to determine whether this measure could be used as a marker to complete SSD diagnosis. The study sample was composed of 157 children, aged 60–119 months, distributed in two groups: a group of 70 participants with typical development (TDG) and a group of 87 participants diagnosed with SSD (SSDG). A phonology test developed for native speakers of Brazilian-Portuguese [21] was applied to verify phonological processes and calculate the PCC-R. AR was measured in a short sentence (ARSS) with 12 phones "The dog ran away"—[ˊu kaˊʃoxu fuˊʒiʷ] and in a long sentence (ARLS) with 22 phones: "Maria has a red ball"—[a maˊɾia ˊt˜e ˊuma ˊbɔla veɾˊmeʎa]. The long and short sentences were repeated three times each, with a total of 942 analyzed repetitions. Productions containing obvious disfluencies or intraphrase pauses (>250 ms) were also excluded. AR analysis was performed using the Praat 5.1 software.

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The results showed that AR values for children with SSD were lower than those for typically developing children [72, 73] and that the number of phones per second increased according to age in both groups. AR values can be used to distinguish children with SSD from those without, as well as to indicate increased difficulty in speech production in children with SSD [73]. There was a evidence that children with SSD who had PCC-R <65% performed differently to those with PCC-R ≥65% in the AR. Correlation was found between age and AR measured in the short and long sentences (biological factor) in the SSDG [67, 69, 75, 77, 78], but severity was only associated with the long sentence (learning factor) [68–70], demonstrating that the more severe the speech disorder, the lower the PCC-R value, and the slower the production of complex sentences.

AR measurement is important in two contexts in clinical practice. Firstly, it evaluates the speech of a child and verifies if the motor speech and cognitive-linguistic processing mechanisms are those expected for child development and appropriate age range. Second, it can be used as a measure of therapeutic monitoring of children with SSD [67]. Moreover, the study reported that the AR measure can be used to indicate whether modifications caused by speech-language therapy are the result of the intervention strategies selected or only a result of changes already expected during the normal maturation process of children [79, 80].

3.2. Acoustic analysis of speech

Acoustic analysis (AA) reflects the acoustic and articulatory characteristics of speech, thus contributing to a better characterization of the functioning of the motor speech system. In addition to the formant frequencies (with F_1, F_2, and F_3 as the most frequently used in speech analysis), AA allows measurements of speech segment duration, steady-state portion from the target sound, tone burst, silence interval, friction, noise, voice onset time (VOT) of formant transition in word production, and slope analysis [81, 82]. The presence of phonetic and acoustic distinctions provides evidence that children have more knowledge about the sound system than one might imagine based on descriptive phonological analysis alone [82, 83].

Pagan-Neves [81] described the acoustic characteristics of the liquid sounds /l/ and /P/ produced by 20 children with and without SSD. Speech production of the words /se'bola/-onion, /'lãma/-mud, /ʒaka´∡ɛ/-alligator, and /ʒi'∡afa/-giraffe were acoustically analyzed according to the following parameters: F1, F2, and F3, duration and steady-state portion from the target sound, and slope analysis. The results indicated that duration of the sound /l/ was an important measure to differentiate children with SSD from those without SSD. Duration of the sound /∡/ was longer for the children with SSD, who always substituted the target sound /∡/ for the sound /l/, in comparison with the group of children without SSD, who correctly produced the sound /∡/. Slope analysis demonstrated higher values for the children without SSD for the two target sounds /l/ and /∡/, indicating that the articulation velocity from the target sound to the following vowel for the children with SSD is slower for both the sound /l/ correctly produced by these children and for the sound /∡/, which was substituted for the sound /l/. An example of the duration of the transition measurement (between the two thick blak lines) is observed in **Figure 2**.

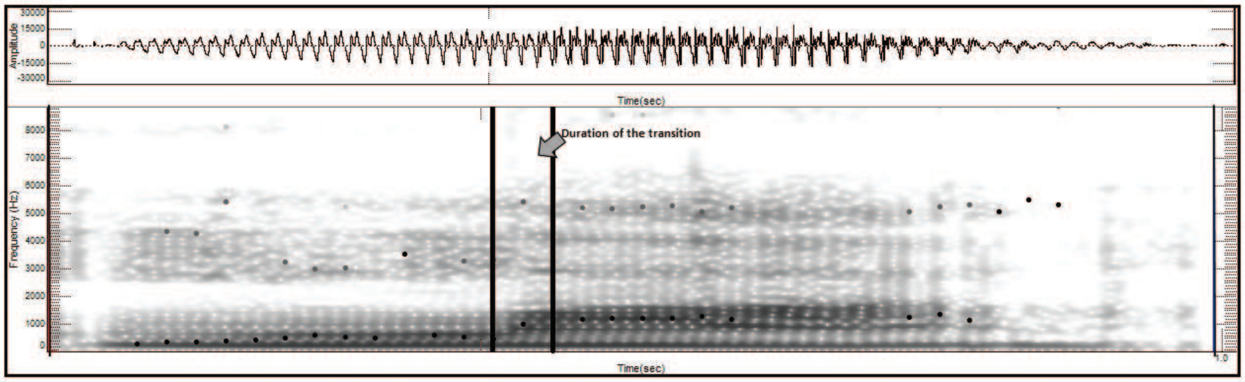

Figure 2. Example of the duration of the transition measurement during the production of the syllable [∠].

Results demonstrated that the longer the duration for the production of the target sound, the slower the slope measure. Even though children with SSD used the duration to differentiate the production of the sound /l/ from the same sound produced in substitution for the sound /P/ in the children without SSD, their speech presents slower speeds for transition between sounds, which may interfere with the listener's auditory perception. This study verified that the articulation accuracy of children without SSD was greater even when considering the sound /l/, which was correctly produced by the children with SSD, reinforcing the oral motor difficulties presented by the latter.

3.3. Aerodynamic measures

With the objective of verifying the production and maintenance of voicing of fricatives in Brazilian-Portuguese (BP) speaking children, a group of researchers [43] described the oral airflow characteristics of six BP speaking children aged 82 and 89 months for the voiced fricatives /v, z, Z/, for weak voicing. Comparison between the reference values of the voiced fricatives produced by adult speakers of European Portuguese and the production of BP speaking children showed greater occurrence of weak voicing. This measure is a classification of the voicing category of fricatives, which determines that when there is more than 70% relative reduction in the amplitude of oral airflow oscillations between the fricative and the surrounding vowels, the fricative is classified as having weak voicing. However, children seem to have acquired the phonological rules pertaining to voicing and employ them effectively.

Another study [42] described the properties of the fricative sound /v/ using the aerodynamic measure of weak voicing in 15 children with SSD, also speakers of PB, aged 60–95 months. Of these 15 children, 8 presented devoicing in more than 25% of their productions and 7 did not present devoicing of the fricative [v]. The results showed similarities in the strategies used for the production and maintenance of the voiced fricative sound /v/ in both groups investigated.

In a study [84] that analyzed the speech of 47 children aged 60 and 95 months, 22 with SSD and 27 without, the author recorded aerodynamic and EGG measures for the sounds /v, z, ʒ /.

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Overall, the results showed that the children in the age range studied do not make full use of the strategies for the production and maintenance of voicing of fricatives reported for adults. This fact was verified in the group of children without SSD, in which the participants presented no significant difference between the sounds for the aerodynamic and EGG measures. The same was observed for the comparisons between children with and without SSD. Specifically in children with SSD, the aerodynamic and EGG measures suggest greater difficulty in the voicing of the /ʒ/ sound and greater ease in the voicing of the /v/ sound. Furthermore, this finding also shows that children with SSD present difficulty in controlling vocal fold abduction, confirmed by the higher abduction quotient (AQ) found when compared with that of children without SSD.

3.4. Ultrasound tongue imaging

Several studies have revealed that the tongue contour visualized using ultrasound tongue imaging (UTI) during speech production can be used for various purposes. However, the specific use of these images as a complementary analysis for SSD diagnosis is still a recent issue in the literature. Although previous research has shown that ultrasound imaging of tongue shape can be used for various sounds, answering phonological questions, conducting phonetic fieldwork, and for use in speech rehabilitation [45, 85–88], the specific use of this technique as a complementary analysis for SSD diagnosis is recent. Moreover, much discussion about the qualitative and quantitative analysis of data persists, particularly concerning the most appropriate methods for comparing individuals. Few standardized measures enable analysis of tongue contour [86, 88, 89].

A qualitative study [48] of the tongue shape for the /s/ and /ʃ/ sounds in three different groups of children with and without SSD. Six participants aged 5 and 8 years, all speakers of Brazilian-Portuguese, were divided into three groups: Group 1, with two typically developing children; Group 2, with two children with SSD presenting other phonological processes except those involving the production of the /ʃ/ sound; and Group 3, with two children with SSD presenting phonological processes associated with the presence of palatal fronting (these two children produced /ʃ/ as /s/). The words /'ʃavi/ (key) and /'sapu/ (frog) were produced five times and tongue contour was individually traced for each production. **Figure 3** provides an example tongue contour of a child, the front of the tongue is on the right and the tongue root is on the left.

The study presented an initial analysis of the sounds /ʃ/ and /s/ produced by children with typical development and with SSD. The variables focused on were as follows: within-speaker variability, shape contour during the /ʃ/ sound production, shape contour of the /ʃ/ sound produced as /s/, and tongue shape during the /s/ sound production. As demonstrated in other studies conducted with English speaking adults and children [90], significant within-speaker variability was observed in articulatory patterns. General results (**Figure 4**) indicated that the speech variability observed in the groups of children with SSD (2 and 3) was greater than that found in the control group (1). Regardless of gender and the presence or not of the palatal fronting phonological process, the four children with SSD presented greater variability during the production of the target sounds. Analysis of the tongue contour showed that both the /s/ and /ʃ/ sounds were produced using distinct tongue contours for G1 and G2.

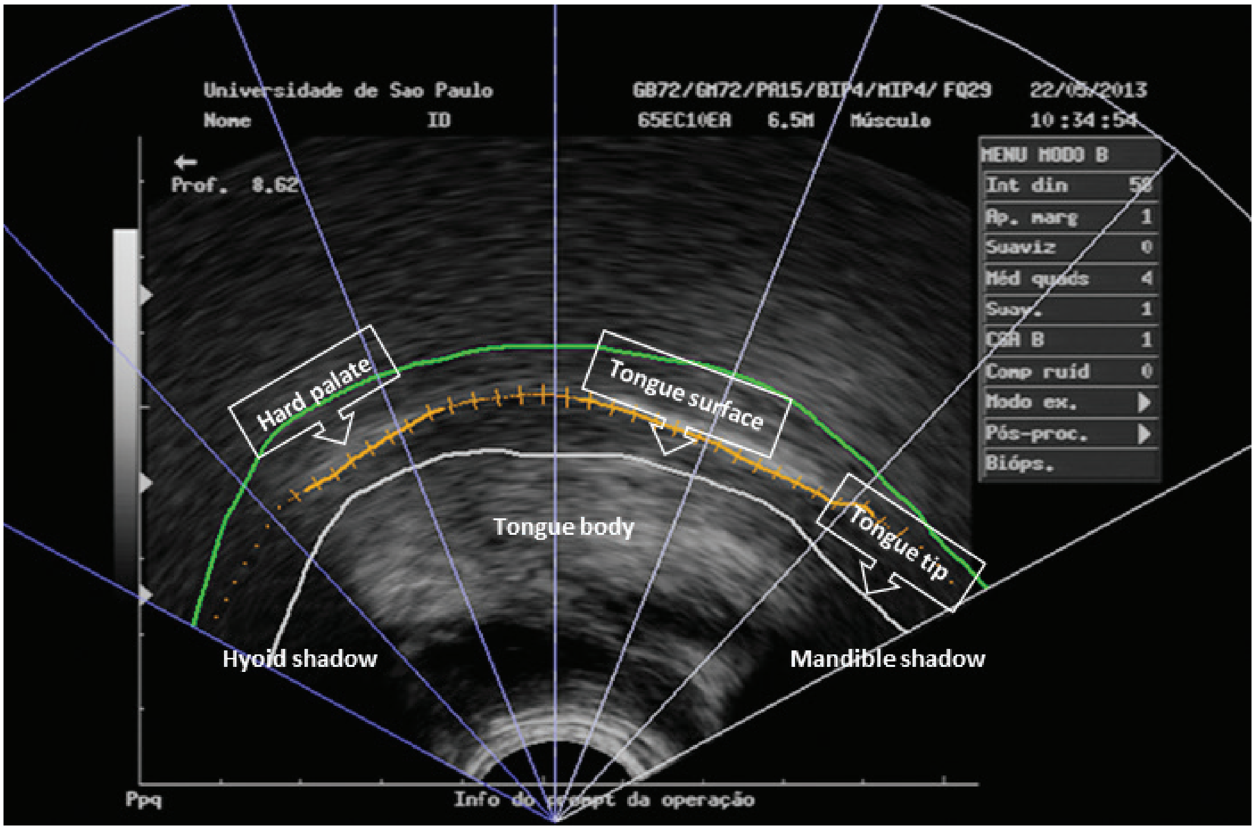

Figure 3. Ultrasound tongue imaging of a child.

The production of these two groups was more stable than that of G3. Tongue contour for the /s/ and /ʃ/ sounds in the children in G3 was similar, indicating that their production was undifferentiated. The authors concluded that the application of UTI to speech analysis was effective to confirm the perceptual analysis of the sound performed by the speech-language pathologist.

Observation of the articulatory pattern in normal adults is also of great importance as it provides information that allows comparative analysis of the variations in speech production expected during child development. It is worth pointing out that children are slower and more variable and that this may be associated with coarticulation [36, 40, 71].

A recent study [46] described ultra sonographic measures for tongue contours during the production of the sounds /s/ and /ʃ/ in adults, typically developing children (TD), and children with SSD with the palatal fronting phonological process. Overlapping images of the tongue contours that resulted from the production of the /s/ and /ʃ/ sounds of 35 individuals were analyzed to select 11 spokes on the radial grid that were spread over the tongue contour (**Figure 5**). The difference between the mean contour of the /s/ and /ʃ/ sounds was calculated for each spoke. The cluster analysis produced groups with some consistency in the articulation pattern between individuals and differentiated adults from children with normal development to some extent, and from children with SSD with a high level of success. Children with SSD were less likely to show differentiation of the tongue contours between articulation of the /s/ and /ʃ/ sounds (**Figure 6**).

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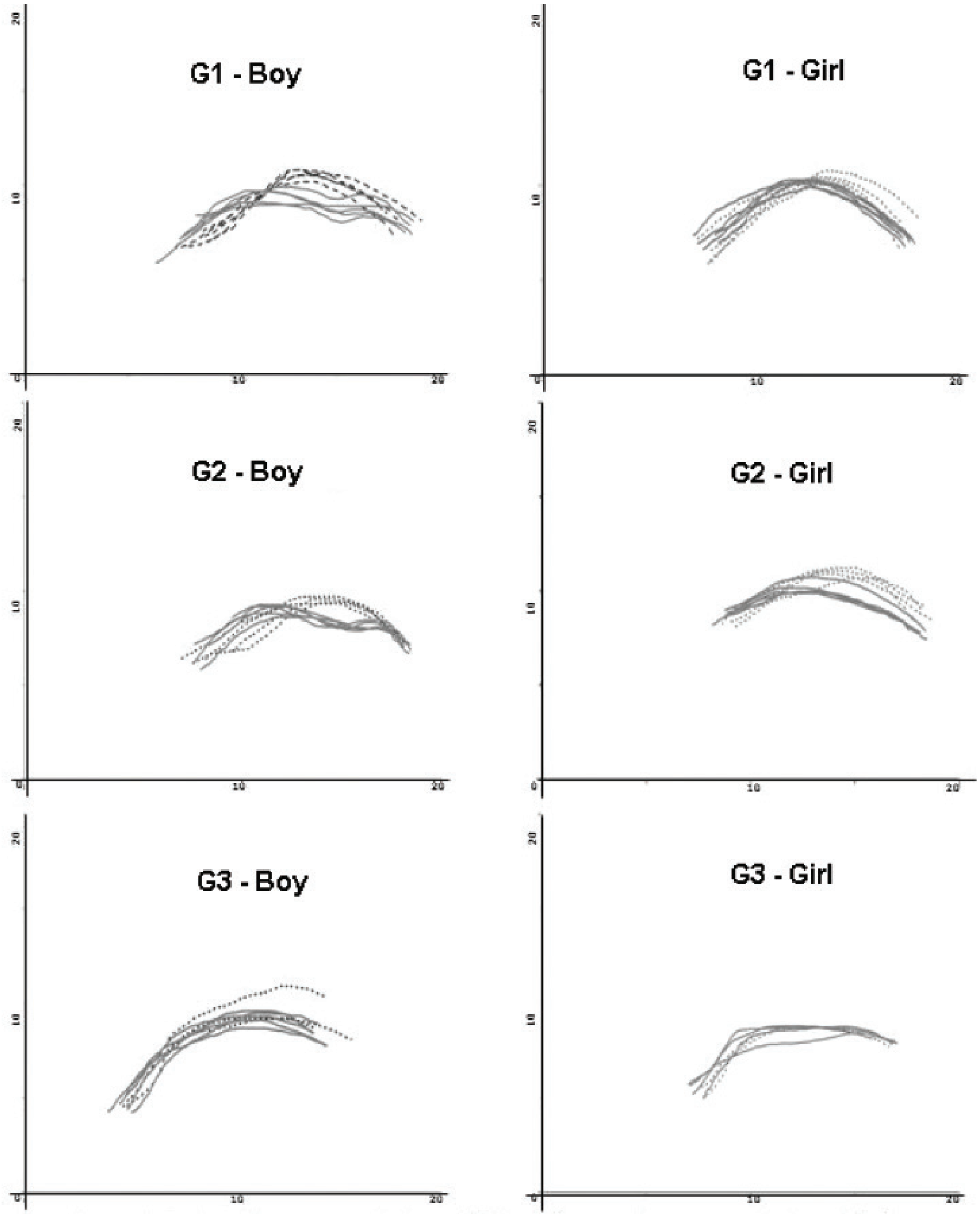

Figure 4. Overlapping images in the production of the sounds /ʃ/ and /s/ for each individual of the study sample.

The results showed that the measures of tongue contour differ in the 11 spokes when articulation of the [s] and [ʃ] sounds was effective to differentiate the full extent of the tongue (tip/blade, dorsum, and root). The values of the differences between the tongue contours allowed

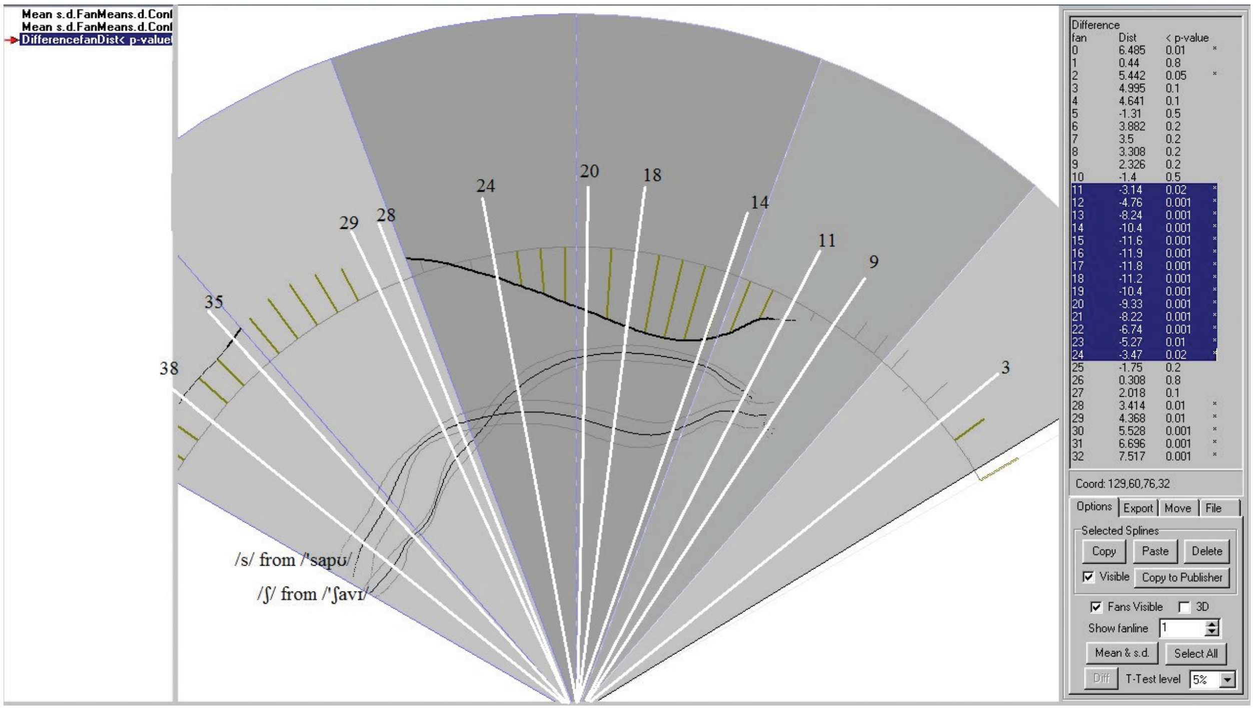

Figure 5. Example of mean tongue contours in the production of the [s] and [ʃ] sounds illustrating the 11 spokes chosen.

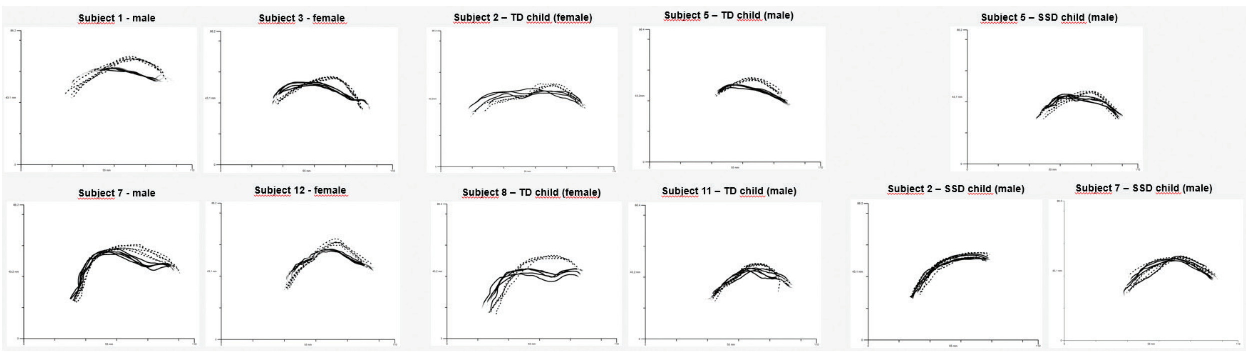

Figure 6. Overlapping of the mean tongue contours in the production of the [s] (solid line) and [ʃ] (dashed line) sounds for some subjects.

differentiation of the articulation patterns in adults, children with normal development, and children with SSD with palatal fronting. Thus, UTI is effective to assist research and in the supplementary diagnosis of children with SSD, therefore, contributing to the planning and prognosis of these children and making speech-language pathology assessments more objective and reliable.

4. Final comments

The presence of SSD in children is confirmed by the application of the imitation of words, picture naming, and spontaneous speech tasks that allow description of both the phonetic inventory and the phonological rules that children have properly mastered and those

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that they somehow simplify. Due to the intrinsic nature of the disorder, it is necessary to adapt the tests to the language spoken by the child. In the present chapter, we have addressed studies conducted with children who speak Brazilian-Portuguese and present SSD. These studies have contributed to diagnosis refinement and intervention practice for SSD. Identification and description of SSDs became more detailed with the possibility of applying more direct procedures with the use of noninvasive equipment for the evaluation of children with a suspected disorder. Studies that employ these procedures contribute with important information for more effective interventions with better and faster results. We strongly recommend that the methods presented at this chapter should be applied to other languages.

The main contributions of these studies are summarized as follows:

1. Children with speech sound and central auditory processing disorders present lower PCC-R and higher PDI values, indicating greater severity.

2. Studies on auditory-evoked potentials indicate differences between children with and without SSD, with increased latency in the presence of this disorder.

3. There is evidence that the articulation rate in children with SSD is lower than that in children without speech and language alterations, despite its increase with age. Also, children with lower PCC-R values are even slower in producing complex sentences.

4. Acoustic analysis—currently a procedure more easily accessed by speech-language pathologists—is also an interesting intervention strategy. The present study shows evidence that the speech of children with SSD is slower than that of children without SSD, with longer total segment duration and passage to the next sound. The study showed that by replacing the sound [ɾ] with the sound [l], children with SSD tend to produce a longer [l] sound seeking to mark the difference in production.

5. Aerodynamic and EGG measures present great potential to assist speech-language pathologists with understanding the mechanism of production and maintenance of voicing. The studies cited here suggest that children in the age range analyzed still do not have control of this mechanism, even when they are able to produce the voicing.

6. UTI assists with the identification of articulatory language gestures involved in the production of sounds. The study presented a measure of tongue contour that facilitates the identification of gestures used in the production of the [s] and [ʃ] sounds, providing speech-language pathologists with a more accurate description to use during interventions.

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