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ORIGINAL ARTICLE

Observations on speech characteristics associated with childhood apraxia of speech in a dynamic motor speech assessment

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Abstract

The assessment of a child's speech problem should incorporate several tasks and sampling methods to identify the difficulties appointing the speech production level/s involved. This study aimed to investigate how a dynamic motor speech test contributed to a naming test in observing speech characteristics consistent with deficits of speech motor planning. Participants were 28 children, 3 to 9 years, diagnosed with childhood apraxia of speech (CAS). Speech samples from two tests for each child were used for perceptual identification of types and number of characteristics and correlated to age. The results showed that CAS characteristics (i.e., deviant articulatory transitions and groping) were significantly more often observed in the dynamic test (p <0.001; 95% CI [-2.4, -1.6]), and that number of distinct characteristics correlated with age, but not severity. This indicates that a dynamic speech assessment adds information on discriminative speech characteristics of CAS representing overt expressions of the underlying deficit.

Keywords: speech sound disorder; childhood apraxia of speech; dynamic assessment; discriminative characteristics; speech motor planning

Abstract

Bedömning av ett barns talsvårigheter behöver baseras på flera uppgifter och testmetoder för att möjliggöra identifiering av den eller de talproduktionsnivåer som är inblandade. Syftet med studien var att undersöka hur ett benämningstest och ett dynamiskt motoriskt taltest bidrog till observationer av talbeteenden förenliga med brister i talmotorisk planering. Deltagarna var 28 barn mellan tre och nio år som diagnostiserats med utvecklingsrelaterad taldyspraxi. Utfallet från två tester för varje barn användes för perceptuell identifiering av typer och antal talkaraktäristika och korrelerades till ålder. Resultaten visade att beteenden associerade med taldyspraxi (till exempel avvikande artikulatoriska övergångar och artikulatoriskt trevande) observerades signifikant oftare i det dynamiska testet (p <0,001; 95% CI [-2,4, -1,6]), och att antalet distinkta talkaraktäristika korrelerade med ålder, men inte med svårighetsgrad. Resultaten indikerar att en dynamisk talbedömning tillför information om diskriminerande talkaraktäristika vid taldyspraxi, det vill säga talbeteenden som representerar observerbara uttryck för underliggande svårigheter.

Keywords: utvecklingsrelaterad talstörning, taldyspraxi; dynamisk bedömning; diskriminerande talkaraktäristika; talmotorisk planering

Introduction

Childhood apraxia of speech (CAS) is a motor speech disorder with a core deficit in planning and/or programming spatiotemporal parameters of movement sequences (American Speech-Language-Hearing Association [ASHA], 2007). This impaired ability to convert abstract phonological codes into motor speech commands (Terband *et al*., 2019) results in several different speech characteristics as well as different degrees of severity (Chenausky *et al*., 2022). However, as many children have characteristics indicating more than one type of speech sound disorder (SSD), it is important to be aware of the characteristics that are commonly present and which are more discriminative. Speech characteristics referred by most researchers and clinicians as often present in CAS are consonant and vowel distortions, increased difficulty with multisyllabic words, slow rate, and inconsistency across repeated trials. Characteristics reported as being more discriminative are difficulty in transitioning between sounds and syllables (e.g., syllable segregation and intrusive schwa), articulatory groping, prosodic errors, and inconsistent voicing errors (Strand, 2017).

Childhood apraxia of speech may coexist with impairments, such as other SSDs, including phonological disorder (Strand, 2017), developmental language disorder (DLD) (Rex *et al*., 2021b) fine and/or gross motor deficits (Iuzzini-Seigel, 2019), and often several comorbid conditions (Chenausky *et al*., 2023; Teverovsky *et al*., 2009). Lately, great advances in the knowledge of genetics and neurobiology in CAS (Morgan *et al*., 2018) have been made, parallel to important progress regarding the clinical criteria for diagnosing CAS (Murray *et al*., 2021). The diagnostic process is often challenging due to the overlap in speech characteristics between CAS and other SSDs as well as a wide variety in combinations of overt CAS characteristics and the severity of those characteristics (Strand and McCauley, 2019).

In order to identify the presence of speech characteristics consistent with the underlying deficits of linguistic/phonological encoding on the one hand or speech motor transcoding on the other, the therapist is required to use several tasks and speech sampling methods (Terband *et al*., 2019). The clinical decision regarding type of SSD is critical for choosing interventions aimed at appropriate speech production level (Maassen and Terband, 2024; Strand *et al*., 2013).

Tasks that are frequently used in the assessment of SSD are spontaneous speech samples, word, or phrase repetition, and most commonly, a single word picture naming task (often standardised articulation tests or tests of phonological development). While these tests often are the primary evaluation tools, they seldom offer

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enough data for observing behaviours consistent with difficulties in speech movement planning. In their article on a process-oriented profiling of speech sound disorders, Diepeveen and colleagues (2022, pp. 21, 22) stated that problems with interpretation could arise if a clinician uses a naming task alone in the assessment procedure of SSD as it will "… not provide enough information to differentiate a linguistic deficit from a speech motor deficit based on speech errors alone…." Traditionally, if a child produces, for example, the word bat (bæt) as (æk), the substitution of /t/ with (k) will be seen as a phonological process of backing, but it could also be an expression of a simplification of the word because of difficulties with the articulatory gestures needed to differentiate the phonemes (Cleland *et al*., 2017).

Another assessment tool, important in the assessment of motor speech deficits, is a motor speech examination (MSE). The MSE is a word and/or phrase repetition task that is hierarchically organised to gradually increase in length and phonetic complexity. This allows the clinician to make observations across speech complexity. It is frequently used in adults but is not typically included in most assessment protocols for SSDs. An MSE, however, may be an important tool to determine the presence of, or to rule out difficulty with, speech motor planning and programming in adults and children (Yorkston *et al*., 2010).

Dynamic assessment

In extension to traditional assessment tasks, dynamic assessment has been shown to add important information in the assessment process of speech and language (Lidz and Peña, 1996; Terband *et al*., 2016). A dynamic assessment differs from more traditional approaches, sometimes referred to as static assessments, where observations are made after one response with no cueing from the clinician (Hasson and Joffe, 2007). In dynamic assessment, however, both clinician and child are actively engaged during the assessment procedure and the clinician gives tailored support to measure the learning potential of the child (Lidz and Peña, 1996). The method originates from Vygotsky's (1978) theoretical approach on learning and development described as the zone of proximal development (i.e., the distance between production with and without support).

There are two main types of dynamic assessment in speech-language pathology: a test-teach-retest format and a successive cuing format (Camilleri and Botting, 2013). Dynamic assessment also has been used in studies on multilingual children (Hasson *et al*., 2012), word learning (Camilleri and Botting, 2013), and phonological disorders (Glaspey and Stoel-Gammon, 2007). Recently, dynamic motor speech assessment has been suggested as an important tool in both differentiating CAS from other speech sound disorders and providing additional information regarding severity and prognosis (Rex, *et al*., 2021b; Strand and McCauley, 2019; Strand *et al*., 2013).

A dynamic approach for motor speech skills evaluates the child's ability to move closer to a particular spatial or temporal target, involving cuing designed to elicit accurate jaw, tongue, and lip movement for speech production. Dynamic assessment may be especially important in evaluating SSDs and CAS (Strand *et al*., 2013). For children who are hesitant to try due to previous failures, even modest support may allow them to produce the utterance more accurately, showing emerging skills and building their confidence in attempting further assessment trials (Feuerstein *et al.*, 2002; Tzuriel, 2000).

Most importantly, dynamic motor speech assessment allows observations of segmentation, timing errors, groping, or other characteristics frequently associated with CAS that are usually not evident in spontaneous utterances or in non-cued repetitions (Strand, 2017). Another advantage to adding dynamic motor speech testing to an assessment protocol for CAS is the use of different cueing strategies, which have the potential to facilitate judgements of severity and therefore prognosis and potentially useful therapy strategies. For example, if a child needs a great deal of cuing to correctly produce a target or even get closer to accurate jaw, tongue, or lip movements, the clinician knows that he or she has a more severe problem and will be more cautious in predicting rapid improvement (Peña *et al.*, 2006). Dynamic assessment also facilitates treatment planning in several ways. Examining types of errors across syllable length and shape helps the clinician to choose appropriate content and complexity of early stimulus sets. The types of cues that were helpful while testing suggest the use of these cuing strategies in treatment.

At this point, there is one published and validated dynamic assessment protocol for differentiating CAS, that is Dynamic Evaluation of Motor Speech Skills (DEMSS) (Strand and McCauley, 2019; Strand *et al.*, 2013) in English. In Sweden, Dynamisk motorisk talbedömning (DYMTA), using DEMSS as a model, was developed (Rex *et al.*, 2016, 2021a) and validated (Rex *et al.*, 2021b). DYMTA, like DEMSS, is an MSE with dynamic assessment in a successive cuing format, scoring the performance on articulatory accuracy, vowel accuracy, prosody, and consistency. In addition, the total speech sample is judged for characteristics of CAS. Determining the number of different CAS characteristics as well as the frequency of those characteristics could be a way to indicate the degree of severity of the disorder (Chenausky *et al.*, 2022). For example, if a child produces the word bat (bæt) as (æk), the clinician provides cuing, starting with minimum assistance (i.e., visual/verbal model; look at my mouth, we will start with the lips together) moving to additional cues (i.e., simultaneous production and tactile cues) guiding the child to the right starting position of the word with lips together and then producing the word together with the child having to look at the clinicians speech movements throughout the word). The child may at some level be able to achieve the initial articulatory position and produce the word with a stable transitionary movement gesture from /b/ to /æ/. The engagement in voluntarily seeking for correct movements of the target will reveal observable behaviours (characteristics) commonly not seen in non-cued repetitions or in spontaneous speech. These observed behaviours stand as characteristics associated with difficulties in planning and programming of speech movements. Dynamic motor speech assessment has been described to have numerous advantages in the assessment procedure. However, an investigation of how a speech test with a dynamic assessment method adds observations of speech movement behaviours to a more typically used naming test in the assessment procedure of CAS has not been described.

The primary aim of this study was to investigate the contribution from a dynamic motor speech test to a single word phoneme test in observations of speech characteristics consistent with deficits of speech motor programming. Additionally, the total number of distinct CAS characteristics has been associated with the impact or severity of a speech disorder, and it has been questioned whether the number would decrease with age. This led us to also investigate the correlation of the total number distinct CAS characteristics of a child to speech measures commonly associated with impact or severity of a speech disorder (i.e., percent consonants correct (PCC), percent vowels correct (PVC), and percent words correct (PWC)), and age. The following research questions were asked:

- Does the dynamic motor speech task complement the single word phoneme test in detecting distinct CAS characteristics, and the frequency of each?
- Is there a correlation between number of CAS characteristics and speech measures?
- Is there a correlation between the number of CAS characteristics and age?

Methods

Participants

A total of 28 children with a primary diagnosis of CAS participated in the study. Participants (10 girls/18 boys) aged 3;8 - 8;10 (years; months) were recruited at the Medical Unit in Speech and Language Pathology, Skåne University Hospital within a larger project on assessment and differential diagnosis of CAS (Rex, *et al*., 2021a, 2021b). For a diagnosis of CAS, children had to show at least five of the characteristics of CAS across a set of speech tasks from a modified list (Table 2) of the one presented in Iuzzini-Seigel *et al*. (2015), according to the judgements of two speech-language pathologists (SLPs) experienced in pediatric motor speech disorders. Diagnosis was also verified as consistent with difficulties in motor planning for speech, based on the observed characteristics of CAS and results from phonology testing, oromotor performance during speech, and anamnestic information. Speech tasks used for processing outcome measures were the phonology test Linköpingsundersökningen (LINUS; Blumenthal and Lundeborg Hammarström, 2014) and the motor speech assessment DYMTA (Rex *et al*., 2016). See further information on these tests in the "Speech Materials and Measures" section.

In addition to the speech tasks, children also received standardised tests of language. Eight children (4 boys and 4 girls) scored below cut-offs on language tests and were considered to show coexisting developmental language disorder (DLD) to the CAS diagnosis. An examination of orofacial anatomy and function was also made to rule out an SSD based on deficits in orofacial anatomy. The Verbal Motor Performance Assessment for Children (VMPAC; Hayden and Square, 1999) was a part of the overall test battery, and a non-verbal oral motor score was derived from the first 37 items in the VMPAC comprising results on oromotor integrity and function. See Table 1 for participant information on group level. All speech and language assessments were administered by a certified SLP (first author) and video- and audio-recorded using a Canon Legria FS200 camera.

Speech materials and measures

All participants completed the phoneme test LINUS, which is a standardised naming test for assessment of phonology, containing all Swedish consonants and

Table 1. Participant information.

	Age (months)	Oromotor score (percent)	DYMTA score (total)	LINUS CC (percent)	LINUS VC (percent)	LINUS WC (percent)
Mean (Sd)	69.5 (17.3)	92.5 (9.3)	252 (67.0)	50.7 (17.4)	88.2 (10.7)	14.7 (12.2)
Range	44–106	71–100	110–335	14–82	62–99	0–52

Notes. SD = standard deviation. Oromotor score derived from VMPAC. DYMTA: Dynamisk Motorisk talbedömning (scores from DYMTA-B) and the maximum score is 461; CC: consonants correct; VC: vowels correct; WC: words correct. See "Methods" section for more details.

vowels. LINUS is elicited through picture naming (Blumenthal and Lundeborg Hammarström, 2014) and includes different word structures, word lengths, syllable, and stress patterns. The first 40 words used in this study comprised a short version closely mirroring the full version, including one- to four-syllable words (Blumenthal and Lundeborg Hammarström, 2014). Performance on the naming test was transcribed with narrow transcription. The transcription was analysed for PCC (Shriberg and Kwiatkowski, 1982) and PVC, using the same method as for PCC. PWC was calculated by dividing the number of words pronounced correctly with the total number of words.

The participants also completed DYMTA, a test focusing on speech motor performance, assessing speech from a coarticulatory and speech movement perspective (Rex *et al*., 2016). The test development was motivated from the Dynamic Evaluation of Motor Speech Skills (DEMSS) (Strand *et al*., 2013). However, DYMTA was created for Swedish conditions, expanded with stimuli and subtests, and incorporating the second, more articulatory and prosodically demanding set of tasks. Consequently, DYMTA comprises two tests, DYMTA-A and DYMTA-B. DYMTA-A aims for children with moderate to severe SSD, with a hierarchical structure focusing on early developing syllables and phonemes in eight subtests comprising 55 words. DYMTA-B was designed for children with moderate to mild SSD and includes 71 words representing all Swedish phonemes, syllable shapes, and prosodic word patterns in nine subtests. Words in both DYMTA-A and DYMTA-B are judged on repetition with respect to articulatory accuracy, vowel accuracy, prosody, and consistency. The test procedure is based on dynamic assessment, where systematic cuing (i.e., visual cues, simultaneous production, or tactile cues) is added to incorrect speech productions, facilitating accuracy to support change and learning. DYMTA also includes a picture based on some words in the test to facilitate a connected speech sample (Rex *et al*., 2016). For a more comprehensive description of DYMTA and for evidence on validity and reliability of the test, see Rex *et al.* (2021a, 2021b).

The LINUS and DYMTA-B speech samples of all participating children were targeted for audio–video observations on characteristics associated with CAS. For the perceptual rating of CAS characteristics, the checklist presented in Iuzzini-Seigel *et al.* (2015) was chosen and used with some modifications. Nine CAS characteristics (vowel error, consonant distortion, syllable segregation, groping, intrusive schwa, voicing error, slow rate, inconsistent nasality disturbance, and deviant articulatory transitions) were rated according to the definitions in Iuzzini-Seigel *et al.* (2015), see Table 2. The modification was an adaption of the definition of stress error to Swedish prosody, as well as relabeling it to prosody errors with examples in Swedish.

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Table 2. Speech characteristics with operational definitions used for the perceptual rating of CAS characteristics.

CAS characteristics	Definition
Vowel error	The vowel is substituted for another vowel or is recognisable as a specific vowel, but not produced correctly and may sound like it is in-between two vowels. It is not considered an error if the vowel is substituted with another phoneme that is consistent with an identified adult-like model.
Consonant distortion	A consonant production error in which the production is recognisable as a specific consonant, but it is not produced correctly (e.g., an /s/ that is produced with lateralisation or dentalisation).
Prosody errors	An error in which the appropriate stress or *tonal accent* is not produced correctly. For example, *ba'nan (banana)* (weak–STRONG) and *'banan (the path)* (STRONG–weak) have different stress patterns. It is considered an error if the stress is inappropriately equalised across syllables or placed on the wrong syllable. *For word tonal accent, tòmten (Santa) and tómten (the garden) have different accents. It is considered an error if the tonal accent is inappropriate equalised or the one substituted with the other.*
Syllable segregation	Brief or lengthy pause between syllables that is not appropriate.
Groping	Silent articulatory searching prior to onset of phonation, possibly in an effort to improve the accuracy of production. This feature must be assessed live or from a video recording.
Intrusive schwa	A schwa (epenthesis) is added in between consonants. For example, it may be inserted in between the consonants in a cluster (e.g., *blå (blue) /blo:/* becomes */bælo:/)*. This is not considered a vowel error.
Voicing error	A sound is produced as its voicing cognate (e.g., a /p/ that is produced as a /b/). In addition, this could also describe productions that appear to be between voicing categories.
Slow rate	Speech rate is slower than expected. It is slower during production of part or the whole word. May be quantitatively measured as articulation rate in syllables/second.
Nasality disturbance	Sounds either hyponasal (not enough airflow out of nose/"stuffy"), or hypernasal (too much airflow out of nose for non-nasal phonemes [e.g., plosives]). A child with CAS may alternate between hypo- and hypernasality.
Difficulty in achieving initial articulatory configurations or transitionary movement gestures, *in this study labelled deviant articulatory transitions for short*	Initiation of utterance or initial speech sound may be difficult for child to produce and may sound lengthened or uncoordinated. Also, child may evidence lengthened or disrupted coarticulatory gestures or movement transitions from one sound, syllable, or word to the next.

Notes. Definitions are adapted to Swedish conditions from Iuzzini-Seigel and Murray (2017) (in Supplementary Material 1), originally published in Iuzzini-Seigel *et al*. (2015). Italic text represents adapted parts (additions or changes to Swedish examples). The characteristic *increased difficulty with multisyllabic words* was not included in this study and the definition is therefore excluded in the table.

See Table 2 for all definitions used in the present study. Increased difficulties with multisyllabic words are also commonly observed in CAS and in the Iuzzini-Seigel and Murray checklist (2017) this speech characteristic should be analysed using a formula to get a magnitude of change score. This was done in a master thesis project on a larger group of children, including the present participating children (Hjalmarsson and From, 2018). The results showed that no child presented with increased difficulty on the multisyllabic words than on the monosyllabic words. This was not expected, but it may be because of differences in the phonotactic complexity of included words in the English and Swedish speech samples. It was therefore not possible to include this speech characteristic in the present study. Token-to-token inconsistency was used for coding of inconsistency.

The scoring procedure of CAS characteristics was done by the first author and a second rater, both with long prior experiences in assessing children with CAS. Definitions and scoring principles were calibrated between the raters. The raters then independently coded present CAS characteristics over the targeted speech samples for all participants, and a consensus was made in the second tier. A CAS sign was counted as present if there was at least one occurrence of the sign across tasks. Interjudge reliability was calculated using point-by-point agreement (i.e., agreements/[agreements + disagreements] × 100) between the two SLP's ratings of CAS characteristics from video-recordings of 13 randomly selected participants. Ratings were made independently for the two tests. The interjudge agreement was 94.4% (range: 0.818–1.0) for the dynamic sample and 90.9% (range: 0.818–1.0) for the naming sample. Intrajudge agreement was assessed for the same randomly selected participants by the first author and was 96.5% (range: 0.909–1.0) for the dynamic sample and 93.8% (range: 0.800–1.0) for the naming sample.

Statistical analysis

Descriptive and inferential statistics were used. Descriptive statistics were used for the number and proportion of children identified with each CAS characteristic in the two tasks, the number of distinct CAS characteristics identified per child and the frequency of each CAS characteristic. The frequency of occurrence of each CAS characteristic per child and task was illustrated using a heatmap. A heatmap is a general data visualisation technique used to illustrate three-dimensional (3D) information. In the present study, the heatmap is a compact way to group the frequency of distinct CAS characteristics relative to each other per child, for each assessment task and across tasks.

The inferential statistics used were a Student's *t*-test for paired samples on the number of distinct CAS characteristics identified per child and test, a paired samples *t*-test for types of CAS characteristics observed in the naming test and dynamic test, and bivariate correlations between CAS characteristics, age, and speech measures using nonparametric statistics (Spearman's rho) due to a small sample. Data analysis was carried out in R (R_Core_Team, 2017).

Ethics approval and patient consent statement

Data were handled according to data protection rules. Approval was given by the Regional Ethical Review Board in Lund (Dnr: 2013/24). The participants were informed that participation was voluntary and that they could withdraw from the study without explanation at any point. An informed consent was obtained from parents/legal guardians of the participants prior to testing.

Results

Results were first reported for identified types and number of distinct CAS characteristics; results for the frequency of those characteristics were reported, and finally the relationship of identified CAS characteristics to speech measures and age was established.

Types of distinct CAS characteristics observed

Table 3 illustrates the types of CAS characteristics identified for the participants in the two tests, and in total. As can be seen, some observations of speech characteristics increased using the dynamic motor speech test. Exceptions were vowel error and slow rate, which were identified in the same individual child in both tests.

Four times more children demonstrated articulatory groping (SD = 0.567; t_{27} = 3.7, p = 0.001; 95% CI [0.2, 0.6]) and almost two times more children demonstrated deviant articulatory transitions (SD = 0.508; t_{27} = 4.8, $p \leq 0.001$; 95% CI [0.3, 0.7]) and syllable segregation (SD = 0.535; t_{27} = 2.8, p = 0.009; 95% CI [0.1, 0.5]) when tested with the dynamic motor speech test, compared to the naming test, representing significant differences. More children were identified with prosody error and consonant distortion with the same difference in percentage points (SD = 0.418; t_{27} = 2.7, p = 0.011; 95% CI [0.05, 0.4]). For intrusive schwa (SD = 0.591; t_{27} = 1.3, p = 0.212; 95% CI [-0.1, 0.4]) and voicing error (SD = 0.262; t_{27} = 1.4, p = 0.161; 95% CI [-0.03, 0.2]), there was no significant difference between tests.

The number of distinct CAS characteristics identified per child across tasks

The mean number of distinct CAS characteristics observed per child in the dynamic test was 7.1 (SD = 1.2) and 5.1 (SD = 1.2) in the naming test (token-to-token variability was not included, as this was not observed in the naming test). The mean CAS characteristics in total over all tasks were 7.25 (median 7, SD = 1.1). More distinct CAS characteristics were identified in the dynamic test than in the naming test for 25 of the 28 children (89%), and the difference was confirmed with *t*-test analysis (SD = 0.999; t_{27} = -10.4, $p < 0.001$; 95% CI [-2.4, -1.6]). Each child's number of CAS characteristics is shown on the right side of Left panel and Right panel in Figure 1, which will be described in more detail below.

Frequency of occurrences of each distinct CAS characteristic per child across tasks

The CAS characteristics were identified with different frequency in the dynamic motor speech test and the naming test. A heatmap was used to illustrate the relative frequency of distinct CAS characteristics (see Figure 1). In the two panels of Figure 1,

Table 3. The number of children demonstrating each type of CAS characteristic per assessment method.

CAS characteristic	In both	Only in dynamic	Only in naming	Absent both	Dynamic test, *n* (%)	Naming test, *n* (%)	Difference %-points	95% CI	Total, *n*
Deviant articulatory transitions	15	13	0	0	28 (100)	15 (54)	46	(27, 66)	28
Prosody error	22	6	0	0	28 (100)	22 (79)	21	(5, 38)	28
Vowel error	28	0	0	0	28 (100)	28 (100)	0	(0, 0)	28
Voicing error	25	2	0	1	27 (96)	25 (89)	7	(-3, 17)	27
Consonant distortion	19	6	0	3	25 (89)	19 (68)	21	(5, 38)	25
Syllable segregation	9	9	1	9	18 (64)	10 (36)	29	(8, 49)	19
Articulatory groping	3	12	1	12	15 (54)	4 (14)	39	(17, 61)	16
Nasality disturbance	9	5	0	14	14 (50)	9 (32)	18	(3, 33)	14
Intrusive schwa	4	7	3	14	11 (39)	7 (25)	14	(-9, 37)	14
Slow rate	4	0	0	24	4 (14)	4 (14)	0	(0, 0)	4

Note. The first four columns indicate the number (n) of children who had a CAS characteristic (row) on both assessment tasks, only the dynamic test, only the naming test, or were absent in both tests. The next two columns give the number and percentage of children with a present CAS characteristic per test. The next column is the difference, in %-points in the identified children for both tasks. The last column is the 95% confidence interval (CI) (lower limit, upper limit) around the difference in proportion calculated when taking repeated measures into account, and the last column shows the total number of children with each CAS characteristic.

the colour coding in each cell illustrates the frequency that the CAS characteristic (column) was identified for the child (row). Dark red colours illustrates that the CAS characteristic had a higher frequency. See a legend of the colour coding on the left-hand side of Right panel in Figure 1. As can be seen, most CAS characteristics were identified more frequently in the dynamic than the naming test. In particular, deviant articulatory transitions, prosodic error, voicing error, and consonant distortion were more noticeable in the dynamic motor speech test. A heatmap illustrating the total number and frequency of distinct CAS characteristics for each child on both tests is presented in Appendix A. See Appendix B for the exact frequency of each CAS characteristic per child and test as well as total overtasks.

Correlations for identified CAS characteristics, speech measures, and age

We found that the number of total distinct CAS characteristics does not correlate with PCC, r = -0.190 and p = 0.332, with PVC, r = -0.311 and p = 0.107, or with PWC, r = -0.270 and p = 0.164. The speech measures correlate with age: for PCC, r = 0.479 and p = 0.010; for PVC, r = 0.553 and p = 0.002, and for PWC, r = 0.555 and p = 0.002. Number of distinct CAS characteristics had a (negative) correlation with age, r = -0.447 and p = 0.017 (see Figure 2).

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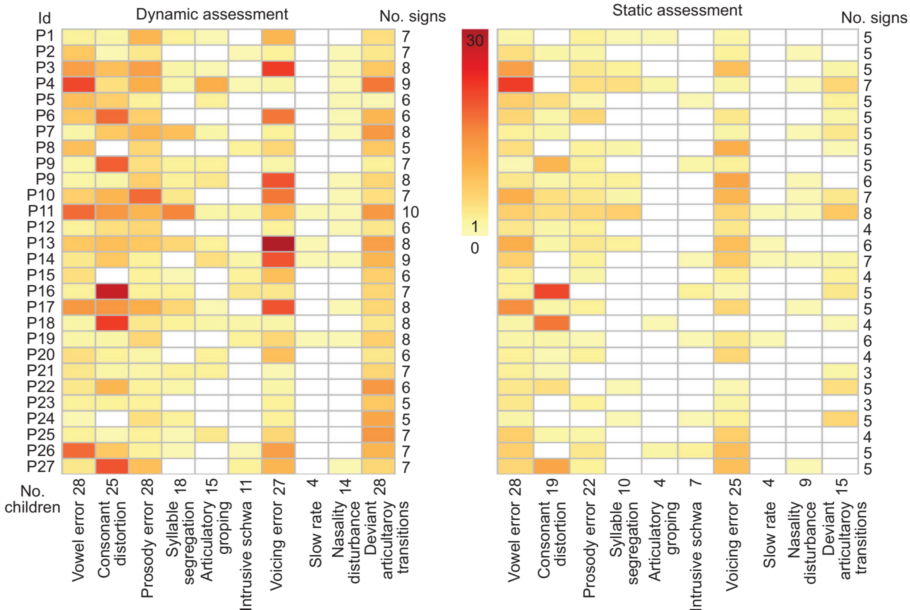
Figure 1. Left panel illustrates the CAS characteristics (columns) that were identified for which child (rows) and in what frequency (colour coding) in the dynamic speech motor test. More frequently occurring CAS characteristics are in dark red; see legend on the left-hand side of Right panel. The number of children identified with each CAS characteristic is shown along the bottom of the panel. The number of CAS characteristics identified per child is shown along the right-hand side of the panel (excluding *token-to-token inconsistency*). Right panel shows the same information as the Left panel, but for the naming test.



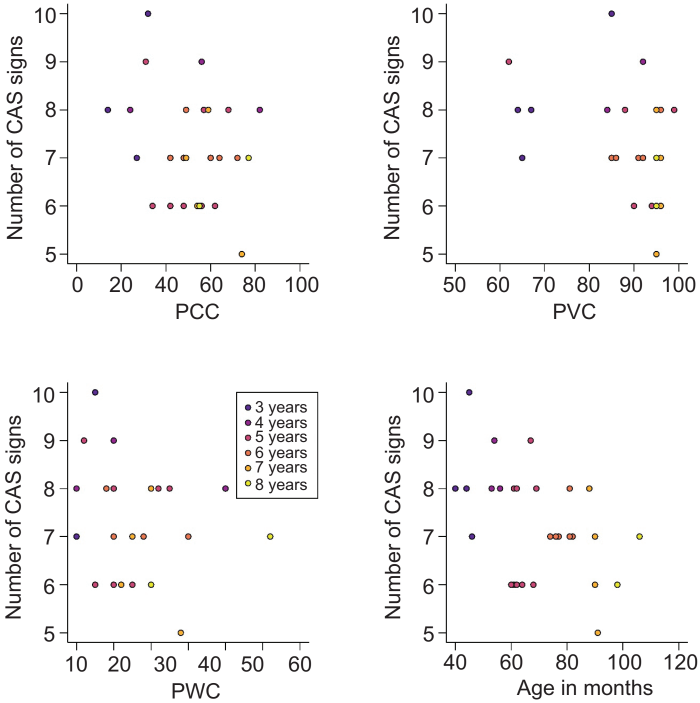
Discussion

The purpose of this study was to investigate the contributions from two types of tests with different sampling methods in the process of identifying CAS characteristics and relate the outcome to age and other speech measures of the participants. Several results emerged that illuminated the benefits of adding a dynamic motor speech assessment to the evaluation of speech motor performance in children with CAS. These benefits are discussed below.

Our results showed that the dynamic motor speech test was useful in detecting difficulties with speech motor planning characterising children with idiopathic CAS. Since children with CAS do not exhibit every sign or the same characteristic across assessment tasks, it is important to use tests and sampling methods that help identifying the presence of speech characteristics consistent with the underlying deficit of speech motor planning and programming. Earlier work on parameters of speech performance argued that speech outcome might depend on the elicitation task and the method used (Klintö *et al.*, 2011; Iuzzini-Seigel *et al.*, 2017).

Terband *et al.* (2016) described a process-oriented model for the assessment of pediatric speech disorders, characterised as a neuropsychological approach. In their model, the first step was to administrate a test battery, and from the resulting

Figure 2. Panels 1–3 illustrate the correlation between the number of distinct CAS characteristics and the speech measures PCC, PVC and PWC. Panel 4 illustrates the correlation between number of distinct CAS characteristics and age in months. Each circle represents a specific participant, and the age group for individual child is colour-coded.



speech profile, deduct disrupted underlying processes. They suggested that the next step would be to directly manipulate speech processes by, for instance, speeding up, using masking noise, distorting kinesthetic feedback, or doing short learning tasks. While doing these manipulations, where dynamic assessment (e.g., short learning tasks) is one of them, you could discover characteristics not always evident in typical tests - characteristics that may reveal deficits in speech motor control. Our findings are in accordance with their suggestions.

Identification of discriminative characteristics of CAS

More distinct CAS characteristics were observed using the dynamic test than the naming test, with a mean of 7.1 and 5.1 CAS characteristics, respectively. Thus, information was added when using the dynamic assessment method and especially regarding characteristics indicating speech movement and coordination difficulties, such as deviant articulatory transitions, syllable segregation, and articulatory groping. These CAS characteristics are often referred to as discriminative for diagnosis (Strand, 2017; Strand and McCauley, 2019).

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Deviant articulatory transitions (i.e., difficulty achieving initial articulatory configurations or transitionary movement gestures) would be the most prominent discriminative sign if you consider it as consistent with the core deficit in CAS described by the ASHA (2007) consensus statement as "lengthened and disrupted coarticulatory transitions between sounds and syllables." Among our participants, all diagnosed with CAS, this speech characteristic was observed in everyone in the dynamic assessment task, asking the child for the best effort in producing the spatial and temporal targets of the word. For instance, if the child tried to produce a word like bat [bæt], difficulties to find the correct starting position for /b/ and to make the transitionary movement from /b/ to /æ/ was observed. However, deviant articulatory transitions were often not possible to observe in the naming test as the child only named the picture in the way s/he wanted using the speech production that was most accessible. Other speech characteristics that could signal difficulty with lengthened and disrupted coarticulatory transitions between sounds and syllables are syllable segregation, and articulatory groping. These characteristics were also observed more often in the dynamic test for most children and for the same reason.

We should also be aware that some characteristics, quite often present in CAS, may not be discriminative (i.e., slow rate, sound omission, and sound substitutions) as they are also seen in children who exhibit other types of SSD (Strand, 2017). For example, slow rate, although a characteristic commonly associated with dysarthria, was observed in four children in our study across assessment tasks. The characteristic is often included in checklists for CAS. The fact that the sign has been included in those lists might be because slow rate is a simple way for the speech system to adapt to an impairment by compensating, making the speech control easier despite the underlying deficit (Terband *et al.*, 2019). It might also be a sign of comorbidity in these children.

In terms of inconsistency, token-to-token inconsistency was evident in the dynamic test sample for all children in our study. Contradictory, the naming test, like most typically used phoneme test in the clinical setting, only displayed the same picture/word once and the testing did not result in any information on inconsistency. As inconsistency was appointed as one of the core characteristics of CAS (ASHA, 2007) and suggested an important characteristic in the diagnostic procedure (Iuzzini-Seigel *et al.*, 2017; Malmenholt *et al.*, 2017; Murray *et al.*, 2015), we should be sure to include tasks addressing this speech feature. However, although inconsistency is considered a major characteristic of CAS, it is important to note that some children with severe CAS may seem consistent, as the severity and minimal phoneme inventory impedes changes over repeated productions. A test using a dynamic motor speech assessment facilitates the child's best performance using specific cues that allows the clinician to observe articulatory potential. Inconsistent speech may then be revealed as the child benefits from support (Strand and McCauley, 2019).

Frequency of occurrence of CAS characteristics and severity

Childhood apraxia of speech is often referred to as a severe speech disorder and may present in a continuum of severity (Rex *et al.*, 2021b; Strand and McCauley, 2019). Different measures are often used in the literature when severity of a speech disorder is discussed, as there is no one widely agreed-upon metric to characterise

CAS severity (Stein *et al*., 2020). The two assessments in our study gave different opportunities, not only to observe the distinct types of CAS characteristics evident in each child but also to get information about the incidence of those CAS characteristics. Consequently, it is valuable to add all observations across tasks. For example, comparing two children with eight types of distinct CAS characteristics over the two tests (P7 and P14), we learnt that the frequency of those characteristics differed (see Figure A1 in Appendix A, and Tables B1–B3 in Appendix B). P7 had a frequency total of 59 CAS characteristics and P14 had a frequency total of 106 CAS characteristics. The measure of frequency could increase our understanding of the severity of a child's speech disorder. The frequency of CAS characteristics probably also impedes intelligibility. Caregivers are often enquiring about a prognosis of their child's speech development regarding social-emotional level, participation, and learning in school. Estimating severity enables the clinician to predict progress and provide a prognosis (Chenausky *et al*., 2022).

Also, looking at how frequent a distinct CAS characteristic occurred could reveal different speech profiles that could inform on treatment planning. P7 could then be described as having a speech profile with more frequent difficulties with prosody, groping, and articulatory transitions, and P14 a profile with more frequent difficulties in voicing and articulatory transitions, as seen in Figure A1 in Appendix A. This may affect several parts of the intervention, such as selected words, types of cuing, number of repetitions, and the level of feedback used (Strand and McCauley, 2019). We address this further in the "Clinical Implication" section.

The relationship of distinct CAS characteristics, speech measures, and age

Our results showed that the number of total distinct CAS characteristics did not correlate with the speech measures PCC, PVC, or PWC for the participating children. That means that children with poorer results on consonant and vowel production and whole words do not necessarily have more different distinct CAS characteristics than those with better speech performance. The PCC measure has been used as an indicator of severity for several decades (Shriberg and Kwiatkowski, 1982) and is still in use as such (Waring *et al*., 2022). In our study, PCC varied from 14 to 82, appointing a continuum of severity of speech disorder from severe to mild.

However, PCC alone may not be sufficient to describe all aspects of severity across the continuum of severity in CAS. For example, in a study on severity and intelligibility in a group of 30 children with CAS, a combination of measures was used to describe speech severity (Chenausky *et al*., 2022). The measures they used were *mean perceptual severity rating* (from certified SLPs and master students) based on VAS ratings on single words, *total frequency of CAS signs* judged over the speech sample from an articulation test, *number of distinct CAS signs*, and the *standard score* of the articulation test. Accordingly, our results indicate that we cannot replace PCC with the number of distinct CAS characteristics, since there was no significant relationship between the two. This is in line with the viewpoint of describing severity with a combination of measures, and as one of these measures, the total number of distinct CAS characteristics would be important as it represents the various overt expressions of the underlying deficit.

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Although our results showed that the number of distinct CAS characteristics does not correlate with speech measures, they do correlate with age. This implies that the difficulties in speech motor planning were more expressed in younger children than the older ones. There could be several explanations for that. One explanation could be effects of speech therapy, where the older group of children have had more years for practice and retention. Furthermore, the natural development and refinement of articulatory synergies facilitate finer control over jaw, lips, and tongue as illustrated in a timeline map by Namasivayam *et al.* (2020). In infancy and early preschool years, there is a limited independence between the articulators, and as differentiation emerges, the variability of articulatory synergies decreases in early school years with protruded refinement. Consequently, while the children with CAS present with atypical speech errors, there is also an ongoing psychosocial, physical, and physiological maturation and development through experience that might contribute to fewer different CAS characteristics for older participants.

Clinical implications

Dynamic assessment for speech production may be used for various purposes depending on the clinical situation, such as being part of the process in identifying speech characteristics appointing underlying speech motor planning deficits, support treatment planning, or even help build confidence in a hesitant child. All of these various purposes need to be recognised by the clinician, since a thorough assessment is the prerequisite for choosing an appropriate intervention.

Dynamic assessment in a process-oriented framework

Assessment of SSD, and especially CAS, is still challenging for many SLPs, and as research in the field has increased and new knowledge been added, it is even more difficult to keep up with new findings. Although dynamic assessment of speech production has been available for clinical use in Swedish for more than 8 years now, there is still an expressed need for more training of dynamic assessment and of process-oriented interpretation of the speech deficits. Clinicians need, and want, to be more confident in assessment and diagnosis to be equipped to offer evidence-based speech interventions. Therefore, educational opportunities via courses, seminars, and tutorials must be offered to the clinicians as well as prerequisites, such as time and support, for the implementation of new structures and procedures in every-day practice.

As mentioned earlier, observations of the number of different CAS characteristics, as well as their frequency, would likely aid in determining severity and prognosis. Clinicians may also use the child's particular responses to cueing in a dynamic assessment to provide helpful information to treatment planning.

Dynamic assessment and treatment planning

Dynamic assessment scores depend on a multidimensional cueing procedure that help clinicians determine severity. This contrasts with static testing where the same standard scores or phonological status (e.g., inventory or phonological processes) might be achieved for two children with different levels of overall speech severity. The structural hierarchical cueing used in DYMTA allows clinicians to examine the number and types of cues needed for improved production of a word. These test results are the indicators for prognosis and the overall length of therapy.

Dynamic assessment offers yet another important advantage with respect to treatment planning. The targets need to be individualised in the intervention program to ensure the best progress and treatment results (Hasson and Joffe, 2007; Strand, 2017). A test for dynamic assessments of motor speech skills uses carefully constructed stimuli that systematically vary syllable shape, word length, and phonetic complexity. By examining performance across the items in the test, it can improve clinical decision-making regarding early treatment targets, an important aspect when treating CAS (Strand, 2017). Our results also demonstrated a correlation between distinct speech characteristics and age, appointing the need to individualise and adjust the focus of treatment targets as the child develops and speech characteristics change in character.

Further, observations of type and amount of cuing enable the process of determining which cues may be most helpful early in treatment, and which are most tolerated by the child. For example, a child was assessed on the word bat [bæt], and it was found that simultaneous production and tactile cuing was most effective for the child to produce the targeted articulatory positions and speech movements. However, he was not very comfortable with the clinician touching his face, and after talking it through, they made an agreement that the clinician should only use a tactile cue on the first repetition for each practiced word and otherwise mainly use gestural cues and simultaneous production.

Within the group of children with CAS, there are different levels of ability or willingness to engage in and tolerate the assessment procedure. Studies on children with CAS have found many children to have coexisting functional difficulties (Teverovsky *et al*., 2009). Using a dynamic assessment tool makes it possible to adjust for children's needs, since children learn through collaboration (Feuerstein *et al*., 2002). Based on trust in having someone help them, they become more willing to try something that is hard. In a test situation using dynamic assessment with an active assessor, trust is built through a lot of established and honest feedback. With the initial trust garnered from the improvement experienced during dynamic testing, the child is often willing to try again. With this newfound feeling of success already in the assessment phase, it is possible to build an intervention routine with a motivated child.

Limitations and future directions

As discussed above, the two investigated assessments in our study were chosen to give different opportunities to observe the distinct types and frequency of CAS characteristics evident in each child. However, the two tests have different numbers of target words, which was a limitation for a direct comparison of the outcome from the two tests. Choosing these specific tests was a consequence of a convenience selection of available tests in the Swedish clinical practice – a commonly used naming test and the only available dynamic speech motor test. In this study, we made a comparison of the two included tests to investigate how the dynamic test complements the other test in observing CAS speech characteristics. Based on our results, as well as on prior studies, we hope and believe that SLPs observing signs for CAS while performing an initial assessment with a phoneme test will subsequently add a dynamic motor speech assessment, for example, DYMTA.

As the focus of our study was single-word speech samples, we did not report on CAS characteristics evident in connected speech. However, connected speech samples are important to include in the assessment procedure and have been described to be complimentary to single words (Glaspey *et al.*, 2022). Therefore, it should be encouraged to always include connected speech samples in the assessment of suspected motor speech deficits. A further limitation would be that the present study did not include an analysis on the responses to cuing. It would be interesting to analyse and relate these results to different speech measures in a future study.

Conclusions

Assessing children with CAS poses unique challenges to clinicians and researchers. This study discussed the findings on speech characteristics from two test procedures and the combination of these in a group of children with CAS. The results support the benefits of using a dynamic approach to target the level of motor speech planning when assessing children with motor speech difficulties, adding information on discriminative characteristics, such as deviant articulatory transitions and articulatory groping. Subsequently, we found that the combination of distinct CAS characteristics across tasks, and the severity of those, varied for the individual child and revealed various overt expressions of the disorder. This could have several implications in clinical practice, such as the importance of individualising treatment targets, starting with words in the range of challenge for learning, and selecting cues that are functional for the child. We also need to be aware that number and type of distinct speech characteristics change with age and that our focus in motor speech treatment needs to be modified accordingly.

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Disclosure statement and declaration of interest

The first and last authors were involved in the development of DYMTA. The DYMTA test manual is now published in its second edition and the authors do not receive any royalties. The authors alone are responsible for the content and writing of this paper.

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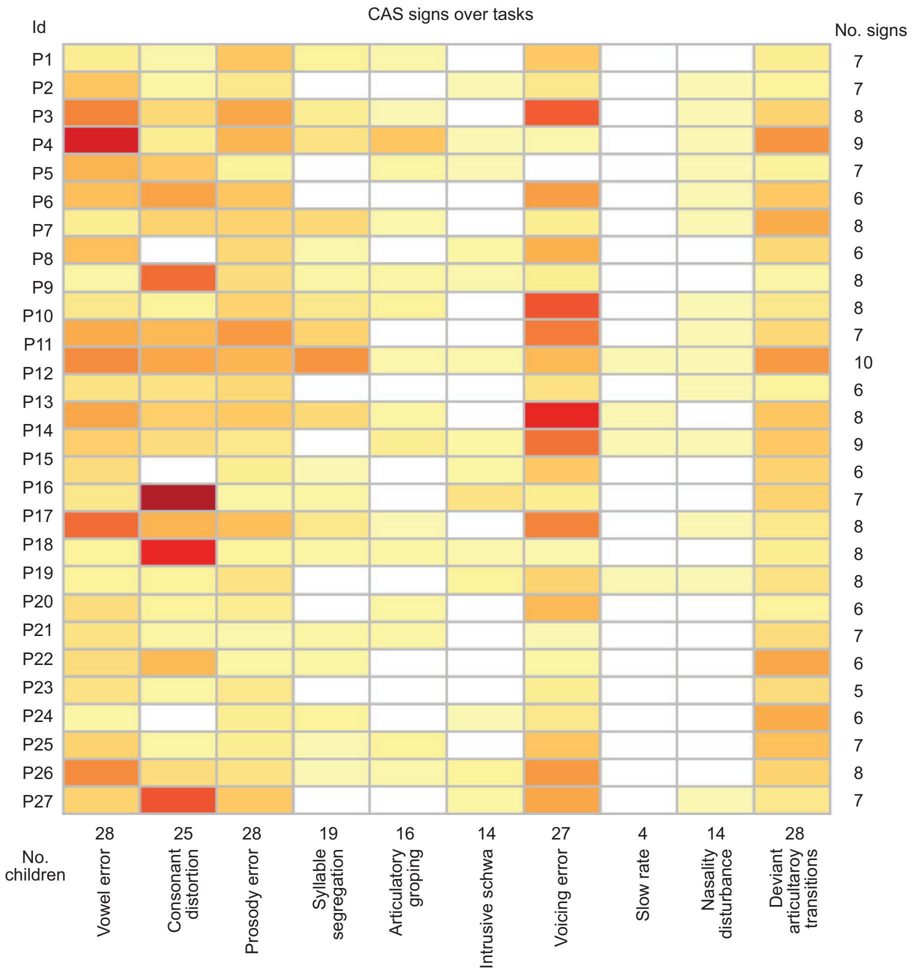
Appendix A

Figure A1. The panel illustrates the CAS characteristics (columns) that were identified for which child (rows) and in what frequency (colour coding) across tests. More frequently occurring CAS characteristics are in dark red. The number of children identified with each CAS characteristic is shown along the bottom of the panel. The number of CAS characteristics identified per child is shown along the right-hand side of the panel.



Appendix B

Table B1. Observed frequency of occurrence of CAS characteristics for each child in the dynamic test.

	Observed frequency of CAS characteristics in dynamic task										
ID	Vowel error	Consonant distortion	Prosody error	Syllable segregation	Groping	Intrusive schwa	Voicing error	Slow rate*	Nasality disturbance*	Deviant articulatory transitions	Inconsistency
P1	3	2	10	3	1	0	10	0	0	5	25
P2	8	1	4	0	0	1	3	0	1	4	31
P3	13	9	13	2	1	0	22	0	1	8	37
P4	21	5	11	2	11	1	2	0	1	17	43
P5	9	7	3	0	3	0	0	0	1	1	20
P6	8	18	7	0	0	0	17	0	1	10	33
P7	2	8	10	9	2	0	3	0	1	14	22
P8	9	0	6	0	0	3	6	0	0	8	16
P9	2	19	5	3	3	0	2	0	0	3	14
P10	2	2	7	3	4	0	20	0	1	6	34
P11	7	10	18	4	0	0	17	0	1	5	23
P12	18	14	10	16	2	2	9	1	1	14	47
P13	3	5	6	0	0	0	3	0	1	4	18
P14	8	9	8	6	3	0	30	1	0	13	34
P15	4	8	3	0	5	2	20	1	1	10	30
P16	5	0	3	1	0	3	9	0	0	7	19
P17	3	28	3	3	0	4	4	0	0	6	15
P18	14	14	11	6	1	0	20	0	1	6	33
P19	2	22	4	3	2	2	2	0	0	4	33
P20	2	2	6	0	0	3	6	1	1	7	16
P21	5	3	2	0	3	0	9	0	0	4	17
P22	4	2	2	3	3	0	1	0	0	6	12
P23	4	10	3	2	0	0	2	0	0	14	24
P24	3	3	3	0	0	0	3	0	0	8	20
P25	1	0	5	3	0	0	3	0	0	12	26
P26	3	1	3	1	4	0	6	0	0	14	24
P27	18	8	3	1	0	1	13	0	0	10	14
P28	4	20	9	0	0	3	10	0	1	6	28
Mean	**6.6**	**8.2**	**6.4**	**2.5**	**1.7**	**0.9**	**9**	*	*	**8.1**	**25.3**

Notes. 1 = present sign; 0 = not present characteristic; *binary 1 or 0 for slow rate and nasality.

Table B2. Observed frequency of occurrence of CAS characteristics for each child in the naming test.

	Observed frequency of CAS characteristics in naming task									
ID	Vowel error	Consonant distortion	Prosody error	Syllable segregation	Groping	Intrusive schwa	Voicing error	Slow rate*	Nasality disturbance*	Deviant articulatory transitions
P1	2	0	3	1	1	0	2	0	0	0
P2	5	2	2	0	0	0	3	0	1	0
P3	13	0	4	3	0	0	9	0	1	2
P4	22	0	5	5	2	0	2	0	1	6
P5	7	5	1	0	0	1	0	0	1	3
P6	6	2	6	0	0	0	4	0	1	2
P7	3	2	0	0	0	0	2	0	1	4
P8	5	0	3	2	0	0	11	0	0	1
P9	1	10	3	0	0	2	3	0	0	0
P10	4	2	3	3	0	0	12	0	1	0
P11	11	5	4	2	0	0	10	0	1	4
P12	7	5	6	7	0	0	6	1	1	8
P13	4	2	3	0	0	0	4	0	1	0
P14	11	2	4	3	0	0	9	1	0	0
P15	7	0	3	0	0	1	8	1	1	2
P16	3	0	2	0	0	0	3	0	0	3
P17	3	21	0	0	0	3	1	0	0	4
P18	15	2	3	0	0	0	6	0	1	0
P19	2	17	0	0	1	0	0	0	0	1
P20	2	2	1	0	0	1	4	1	1	0
P21	3	1	3	0	0	0	6	0	0	0
P22	3	1	0	0	0	0	0	0	0	2
P23	4	5	0	1	0	0	1	0	0	5
P24	4	0	3	0	0	0	2	0	0	0
P25	2	0	0	1	0	1	3	0	0	6
P26	7	2	2	0	0	0	7	0	0	0
P27	7	0	4	0	2	3	9	0	0	0
P28	6	12	3	0	0	0	9	0	1	0
Mean	**6.0**	**3.6**	**2.5**	**1**	**0.2**	**0.4**	**4.9**	*	*	**1.9**

Notes. 1 = present sign; 0 = not present characteristic; *binary 1 or 0 for slow rate and nasality.

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Table B3. Observed frequency of occurrence of CAS characteristics for each child over the two tests.

ID	Observed frequency of CAS characteristics total									
	Vowel error	Consonant distortion	Prosody error	Syllable segregation	Groping	Intrusive schwa	Voicing error	Slow rate*	Nasality disturbance*	Deviant articulatory transitions
P1	5	2	13	4	2	0	12	0	0	5
P2	13	3	6	0	0	1	6	0	1	4
P3	26	9	19	5	1	0	31	0	1	10
P4	43	5	16	7	13	1	2	0	1	23
P5	16	12	4	0	3	1	0	0	1	4
P6	14	20	13	0	0	0	21	0	1	12
P7	5	10	10	9	2	0	5	0	1	18
P8	14	0	9	2	0	3	17	0	0	9
P9	3	29	8	3	3	2	5	0	0	3
P10	6	4	10	6	4	0	32	0	1	6
P11	18	15	22	10	0	0	27	0	1	9
P12	25	19	16	23	2	2	15	1	1	22
P13	7	7	9	0	0	0	7	0	1	4
P14	19	11	12	9	3	0	39	1	0	13
P15	11	8	6	0	5	3	28	1	1	12
P16	8	0	5	1	0	3	12	0	0	10
P17	6	49	3	3	0	7	5	0	0	10
P18	29	16	14	6	1	0	26	0	1	6
P19	4	39	4	3	3	2	2	0	0	5
P20	4	4	7	0	0	4	10	1	1	7
P21	8	4	5	0	3	0	15	0	0	4
P22	7	3	2	3	3	0	1	0	0	8
P23	8	15	3	3	0	0	3	0	0	19
P24	7	3	6	0	0	0	5	0	0	8
P25	3	0	5	4	0	1	6	0	0	18
P26	10	3	5	1	4	0	13	0	0	14
P27	25	8	7	1	2	4	22	0	0	10
P28	10	32	12	0	0	3	19	0	1	6
Mean	**12.6**	**11.8**	**9.0**	**3.7**	**1.9**	**1.3**	**13.8**	*	*	**10.0**

Notes. 1 = present sign; 0 = not present characteristics; *binary 1 or 0 for slow rate and nasality.