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Speech in children with cerebral palsy

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ABBREVIATIONS

CAS	Childhood apraxia of speech
PCC	Percentage consonants correct

AIM To examine the frequency, characteristics, and factors associated with speech delay and disorder in a community sample of children with cerebral palsy (CP) aged 5 and 6 years.
METHOD Participants were 84 children (37 females, 47 males; aged between 4y 11mo–6y 6mo) with CP identified through a population-based registry. Speech and oromotor function were systematically evaluated to provide a differential diagnosis of articulation, phonological, and motor speech disorders.
RESULTS In total, 82% (69/84) of participants had delayed or disordered speech production, including minimally verbal presentations (n=20). Verbal participants (n=64) presented with dysarthria (78%), articulation delay or disorder (54%), phonological delay or disorder (43%), features of childhood apraxia of speech (CAS) (17%), or mixed presentations across these conditions. Speech intelligibility was poorest in those with dysarthria and features of CAS. Speech delay or disorder in verbal participants was associated with language impairment (p=0.002) and reduced health-related quality of life (p=0.04) (Fisher's exact test). Poorer speech accuracy (i.e. lower percentage consonants correct) correlated with greater impairments in both language (p<0.001) and oromotor function (p<0.001) (Spearman's test).
INTERPRETATION The speech profile of children with CP is characterized by impairment at multiple levels of speech production (phonetic, cognitive-linguistic, neuromuscular execution, and high-level planning/programming), highlighting the importance of a personalized differential diagnosis informing targeted treatment.

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What this paper adds:

- Most children with cerebral palsy had delayed or disordered speech based on direct assessment.
- Dysarthria was prevalent and other speech diagnoses were common, including childhood apraxia of speech.
- This demonstrates the need for a differential diagnosis to inform treatment planning.
- Speech delay or disorder was strongly associated with language and oromotor impairments.

[main text]

Producing intelligible speech requires fine coordination and precision of oral movements.[1] It follows, therefore, that speech disorders are frequently associated with cerebral palsy (CP), the most common physical disability in childhood. Prevalence figures for speech disorder in CP vary, with estimates suggesting that 33% to 63% of individuals experience some form of speech difficulty, including anarthria (or absence of speech due to severe neuromuscular involvement).[2–5] This wide variation in prevalence figures likely reflects a number of methodological differences across studies, such as the definition of speech and its measurement.

'Speech disorder' is a broad term that encompasses a range of distinct disorders, such as articulation and phonological disorders, dysarthria, and childhood apraxia of speech (CAS).[6]

Each disorder reflects a specific level of impairment of the speech chain, with each disorder type requiring highly targeted management strategies. While it is known that children with CP can experience any and multiple speech disorders,[7] a systematic and comprehensive examination of the prevalence and features of childhood speech disorders associated with CP is needed to support service and treatment planning.

To date, prevalence figures have been based on non-standardized measures of speech intelligilbity,[3] dysarthria,[5] the 'indistinctness of speech',[2] or the presence of speech disorder,[4] with the absence of a differential diagnosis of speech disorders and a lack of detail regarding the diagnostic features of each speech disorder. In most studies, speech data have been collected through registry[2,5] or medical records[4] rather than direct assessment followed by in-depth speech analysis to enable a differential diagnosis. While dysarthria is known to be common in this population,[5] its co-occurrence with other childhood speech disorders (e.g. phonological disorder, CAS) has not been explored using a population-based approach. Speech disorders are known to be highly associated with each other, yet their rate of co-occurrence and the cluster of speech disorders most likely to be seen in children with CP is relatively unknown. In particular, no study has systematically examined the presence and diagnostic features of CAS, a rare and severe motor speech disorder, in children with CP.

Here we provide a systematic and differential assessment of speech delay and disorder in children with CP drawn from a population cohort. Using a range of standardized and perceptual speech measures, we examined the frequency, characteristics, and factors associated with speech delay and disorder (articulation, phonological, dysarthria, and CAS).

METHOD

Participants

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Participants were 84 children recruited through the Victorian Cerebral Palsy Register and who were representative of non-participants.[8] All children known to the Victorian Cerebral Palsy Register born between August 2005 and August 2007 were eligible for study inclusion (see Figure S1, online supporting information, for a recruitment flow chart). Participants were verbal (n=64) or minimally verbal (n=20, i.e. children who were unable to verbally produce meaningful/comprehensible speech). Their demographic characteristics are detailed elsewhere.[8,9] Participants (37 females, 47 males) were aged between 4 years 11 months and 6 years 6 months. CP motor types included spasticity (79%, 66/84), mixed (15%, 13/84),

hypotonia (4%, 3/84), dyskinesia (1%, 1/84), and ataxia (1%, 1/84). The motor impairment was bilateral in 61% (51/84). The range of Gross Motor Function Classification System (GMFCS) levels, with higher levels indicating increased severity, was: I (39%, 33/84), II (18%, 15/84), III (15%, 13/84), IV (19%, 16/84), and V (8%, 7/84). Ethics approval was obtained from Human Research Ethics Committees at The Royal Children's Hospital (#30048) and Southern Health (#11380), Melbourne, Australia.

Speech classification

Speech diagnoses were based on normative data[10,11] (i.e. typical articulation and phonological development) and perceptual speech (dysarthria and CAS) ratings. Verbal participants (n=61) were classified into one or more of the following groups depending on their speech profile: (1) age appropriate speech development, (2) articulation delay or disorder, (3) phonological delay or disorder, (4) dysarthria, and (5) CAS (see Tables S1 and S2, online supporting information, for definitions).

Three of the 64 verbal participants were unable to be assessed for articulation and phonology because of compliance, precluding an overall speech diagnosis. Intelligibility ratings (n=3) and dysarthria ratings (n=1) were completed for these participants and are reported here.

Articulation and phonology

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The Diagnostic Evaluation of Articulation and Phonology,[10] a standardized speech assessment, was used to differentiate between articulation and phonological errors in verbal participants. Three subtests were administered: Articulation (n=61), Phonology (n=60), and Inconsistency (n=58). A phonetic inventory was established using responses from these subtests to identify consonants present/absent from a participant's repertoire. Results from the phonetic and phonological analysis enabled a differential diagnosis of articulation (i.e. difficulty in the motoric aspect of speech) and phonological errors (i.e. a cognitive-linguistic based deficit that affects the use of sounds in a language). For minimally verbal participants, consonant inventories were established using the Communication and Symbolic Behaviour Scales – Developmental Profile Caregiver Questionnaire.[12]

Dysarthria and CAS

A 10-minute conversational speech sample was obtained from verbal participants and analysed for features of dysarthria and CAS. Dysarthria refers to an impairment in the

neuromuscular execution of speech that is associated with disruption of tone and/or incoordination of movements. CAS is a disorder of speech planning and programming that impacts on speech precision and consistency. Perceptual ratings of dysarthria were made using a modified version of the Mayo Clinic dysarthria classification system,[13] previously applied to paediatric populations.[14,15] The overall severity of dysarthria was classified as mild, mild-moderate, moderate, moderate-severe, or severe.[16] Diagnostic criteria for CAS were adapted from previous research[15,17–19] based on the American Speech-Language-Hearing Association consensus criteria.[20]

Severity of speech delay or disorder

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Percentage consonants correct (PCC)[21] was derived from the Phonology Assessment. PCC standard scores between 7 and 13 represented the average range of functioning for typically developing children (mean 10, standard deviation [SD] 3, centile rank 16–84, range 3–15 for the study's age group).[10]

Speech intelligibility was rated by the examiner and parents using the National Technical Institute for the Deaf scale,[22] previously used in paediatric motor speech research.[23] The scale consists of five levels: (1) speech is unintelligible; (2) only isolated words or phrases are intelligible; (3) half of the message is understood; (4) speech is intelligible with some exceptions; and (5) speech is completely intelligible.

Oromotor function

The Verbal Motor Production Assessment for Children[24] was completed by verbal participants to identify oromotor impairments and differentiate between dysarthria and CAS (e.g. presence of altered tone, reduced range and rate of the speech musculature associated with dysarthria vs deficits in transitioning across movements associated with CAS). Subtests administered were: Global Motor Control (assessing neuromotor innervation to the torso, neck, head, and face); Focal Oromotor Control (assessing coordination, excursion, and symmetry of the jaw, lips, face, and tongue); and Sequencing (assessing the ability to perform oral and speech movements in sequential order). As per this standardized test, Global Motor Control and Focal Oromotor Control dysfunction are associated with dysarthria, whereas Sequencing deficits are associated with CAS. Scores for each subtest are expressed as a percentage, which are then converted into a severity rating of within normal limits, mild, moderate, or severe.

Associated factors

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Data related to child and environmental factors were obtained to examine factors associated with speech outcomes for verbal participants. Environmental factors included parental level of education, parental mental health, and socio-economic status. Child-related factors were: CP motor type and distribution, gross and fine motor function, presence or absence of epilepsy, birthweight, gestational age, plurality, health-related quality of life, and the presence of language, hearing, and cognitive impairment. Gross and fine motor function were classified using the GMFCS[25] and Manual Ability Classification System.[26] Language and cognitive outcomes were based on standard scores from the Preschool Language Scale, Fourth Edition (Auditory Comprehension and Expressive Communication scales) and the Columbia Mental Maturity Scale, as described elsewhere.[8] Psychosocial health was measured using the Pediatric Quality of Life Inventory, with scores greater than 1 standard deviation below the mean indicating reduced health-related quality of life (mean 80.2, SD 15.8).[27] The Kessler Psychological Distress Scale (K6) was used as an indicator of a likely parental mental health problem (score of ≥4 out of 24). The Socio-Economic Index for Areas Index of Relative Socio-Economic Disadvantage provided an indicator of socio-economic status.[28] All other data were obtained via parent report or the Victorian Cerebral Palsy Register.

Statistical analysis

Speech was assessed and classified by the first author (CM), with interrater reliability performed by a second rater (ST) using data from 10% of verbal participants, selected at random. Point-to-point agreement for broad transcription was acceptable (93%).[29] Point-to-point agreement between phonetic inventories was 97%. Pearson's correlation between PCC scores was high (0.95). One-hundred percent point-to-point agreement on assignment to the three CAS criteria was achieved. Mean point-to-point agreement for dysarthria ratings was 75%, in line with previous child dysarthria ratings.[23]

Data were analysed within the verbal and minimally verbal subgroups, and within the age limits of ≤5 years 5 months and ≥5 years 6 months for PCC, as significant differences have been found between these ages for PCC.[11] PCC scores across this age boundary were analysed using the Mann–Whitney *U* test. PCC, speech intelligibility, and the Inconsistency Assessment data were compared across speech classification groups. The Fisher's exact test examined the association between speech outcome in verbal participants (presence or absence

of any speech delay or disorder) and the previously described associated factors, including oromotor function. The correlation between PCC and performance on the Preschool Language Scale, Fourth Edition, Columbia Mental Maturity Scale, and Focal Oromotor Control subtest was estimated using the Spearman's rank correlation coefficient.

RESULTS

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Frequency and features of speech delay and disorder

Across the entire sample, speech was delayed or disordered in 82% (69/84), including minimally verbal presentations. Among verbal participants, speech was delayed or disordered in 77% (49/64). Participants commonly met criteria for multiple speech diagnoses (see Table 1 for speech classifications).

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Performance within each speech subdomain is described below. Denominators vary depending on the number of participants who completed each assessment. Where speech or oromotor data were not obtained, this was due to compliance rather than participants' capabilities.

Articulation

For the verbal participants, articulation was age appropriate in 46% (28/61), delayed in 26% (16/61), and disordered in 28% (17/61). Articulation was not assessed in three participants. Over half (59%, 35/59) had acquired all the speech sounds expected for their age (i.e. consonants produced by 90% of peers), although these may have been distorted in some instances (e.g. presence of a lisp). A phonetic inventory was not established for two participants due to partial completion of the Diagnostic Evaluation of Articulation and Phonology. The mean number of consonants elicited was 21.9 (SD 2.4, range 14–24) and was comparable for participants aged ≤5 years 5 months (21.6, SD 2.5) and ≥5 years 6 months (22.1, SD 2.4). Most absent consonants were fricatives (80%, 99/123), followed by affricates (8%, 10/123), approximants (7%, 9/123), nasals (3%, 4/123), and plosives (0.8%, 1/123). Consonant distortions included lateralized fricatives or affricates (18%, 11/61), labiodental production of stops or fricatives (5%, 3/61), and interdentalized (/t, d, n, l/; 2%, 1/61).

Of the minimally verbal participants, 17 had available data regarding consonant inventory. Seven participants produced no consonants. The remaining 10 produced a mean of 2.6

consonants (SD 2.9, range 1–8) each. The most frequently produced consonants were those typically seen earlier in development, namely bilabials (i.e. m, b, w) and alveolars (i.e. n, d).

Phonology

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Phonological development for the verbal participants was classified as age appropriate (57%, 34/60), delayed (17%, 10/60), and disordered (27%, 16/60). Phonology was not assessed in four participants. A range of typical phonological processes were identified (Table S3, online supporting information), with stopping and cluster reduction most commonly used (28% [17/60] and 27% [16/60] respectively). Frequent atypical processes were epenthesis (22%, 13/60), backing (18%, 11/60), and affrication (17%, 10/60). It is possible that some of these error patterns may instead reflect features of CAS.

Dysarthria and CAS

Perceptual ratings of dysarthria were not completed for six verbal participants because of insufficient data or the presence of a respiratory infection (which would have potentially skewed/overestimated results). For the remaining, dysarthria was present in 78% (45/58). Dysarthria severity was mild (53%, 24/45), mild-moderate (27%, 12/45), moderate (16%, 7/45), moderate-severe (2%, 1/45), and severe (2%, 1/45). Dysarthria was characterized by disturbances in pitch, loudness, phonation, resonance, respiration, prosody, and articulation (Table 2 and Video S1, online supporting information).

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Among verbal participants, 17% (10/58) met criteria for CAS, that is, impairment across all three consensus criteria (inconsistency, disrupted coarticulatory transitions, and inappropriate prosody) (Table 3 and Video S2, online supporting information). CAS ratings were not completed for six participants who did not complete the Inconsistency Assessment. A diagnosis of anarthria versus severe CAS for minimally verbal participants was not possible since they were unable to complete the Verbal Motor Production Assessment for Children to facilitate a differential diagnosis.

Severity of speech delay or disorder

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PCC

Speech accuracy was age appropriate for 41% (24/59) of verbal participants, indicated by a PCC standard score ≥7 on the Phonology Assessment. Mean PCC scores were 82.5 (SD 17.8, range 29–100) for participants aged ≤5 years 5 months (*n*=28), and 83.9 (SD 16.2, range 45–

100) for participants aged ≥5 years 6 months (n=31) (Mann–Whitney U test, p=0.64). These scores were within 1 and 2 SDs of the normative mean respectively. Reductions in speech accuracy were greatest in participants with dysarthria who also met criteria for CAS (Table 1).

Speech intelligibility

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Just over half of the sample (57%, 47/83) presented with minor or no reductions in speech intelligibility, indicated by a rating of 5 or 4. Examiner ratings of intelligibility were: level 5 completely intelligible=11% (9/83), level 4 intelligible with some exceptions=46% (38/83), level 3 half of message understood=13% (11/83), level 2 isolated words/phrases intelligible=8% (7/83), and level 1 unintelligible=22% (18/83). Intelligibility was not rated in one participant who was reportedly verbal but did not speak during the assessment. In comparison, parent ratings were: level 5=19% (15/81), level 4=40% (32/81), level 3=19% (15/81), level 2=2% (2/81), and level 1=21% (17/81). There was good agreement between examiner and parent ratings (Kappa coefficient: 0.65). Ratings differed by one level in all but one case. Speech intelligibility was poorest in participants with dysarthria who also met criteria for CAS (Table 1).

Oromotor

All verbal participants who completed one or more subtest of the Verbal Motor Production Assessment for Children (n=59) demonstrated impaired functioning on at least one subtest.

The Global Motor Control scale was completed by 59 participants, with performance severely impaired for all. Impairments were frequently characterized by altered tone (100%), poor tongue strength (88%), and reduced range and symmetry of oral movements (53%) (Table 4).

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The Focal Oromotor Control scale was completed by 59 participants. A total score was not computed for two owing to partial completion. Performance was impaired in 91% (52/57), often reflecting severe deviations (77%) (Table 4). Impaired performance during single non-speech oromotor movements (e.g. smile) was characterized by reduced mandibular, labial-facial, and lingual control (Table 4), reflecting poor jaw stability, asymmetry, reduced lip excursion (rounding, retraction), and reduced tongue excursion (elevation, lateralization).

Double oromotor movements (e.g. blow-smile) were commonly impaired (86%, 50/58), often performed with asymmetry, imprecision, reduced smoothness, and reduced lip excursion.

The Sequencing scale was completed by 57 participants, with impaired performance seen in 84% (48/57). Performance was impaired across non-speech and speech sequences (Table 4). For the 10 participants with inconsistent speech errors who met criteria for CAS, non-speech sequencing errors on the Verbal Motor Production Assessment for Children were often due to repeating a movement or only performing one movement, rather than reversing movements.

Associated factors

The Fisher's exact test revealed that the presence of a speech delay or disorder was significantly associated with language impairment (p=0.002), reduced health-related quality of life (p=0.043), and birthweight, particularly low birthweight (p=0.017) (Table S4, online supporting information). The Spearman's test showed a significant correlation between PCC and Focal Oromotor Control scores (r=0.68, p<0.001), receptive language (r=0.51, p<0.001), and expressive language (r=0.59, p<0.001). That is, poorer speech accuracy was correlated with greater impairment in language and oromotor functioning. No correlation was found between PCC and cognition (r=0.19, p=0.193).

DISCUSSION

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Examining the speech outcomes of children with CP is complex because of the multiple levels of possible disruption, including the development of sounds (articulation), understanding the rules of sound placement (phonology), and the precise execution (dysarthria) and planning/programming of speech movements (CAS). Using a representative sample of children with CP, we conducted the first systematic differential diagnosis of these speech conditions to comprehensively delineate the speech outcomes associated with CP. Findings indicated that 82% of children with CP aged 5 and 6 years had a speech delay or disorder (including minimally verbal presentations), despite being at an age where speech development is considered relatively complete and production should be highly intelligible.[11,30] The presence of speech delay or disorder was found to be independent of cognition. Participants commonly met criteria for multiple speech diagnoses, indicating the importance of differentiating between speech conditions to precisely understand the speech profile and management needs of children with CP.

As anticipated, dysarthria was the most common speech disorder, occurring in 78% of participants. This was followed by articulation delay or disorder (54%), phonological delay or disorder (43%), and features of CAS (17%). Speech intelligibility was rated higher by parents than the examiner, which likely reflects familiarity with their child's speech errors and prosody. While the severity of dysarthria was typically mild to moderate, its presence was associated with the poorest speech intelligibility across the sample, particularly when it co-occurred with features of CAS. The proportion of participants who met criteria for CAS is notable, with all participants who met criteria for CAS also presenting with dysarthria. While meeting the three criteria suggests a potential diagnosis of CAS, some criteria for coarticulatory transitions and prosody are also relevant to dysarthria (e.g. excess-equal stress, voicing, slow speech rate), impacting on the ability to make a definitive differential diagnosis. The field is challenged by a lack of measurements that can definitively differentiate between dysarthria and CAS. There are no validated diagnostic features that can differentiate CAS from dysarthria and other speech disorders. However, some features can be used to dissociate CAS from dysarthria (e.g. transposition errors are as a rule not characteristic of dysarthria). Disentanglement of disruption at an execution and/or planning/programming level is not always clear and here we highlight this challenge in differentiating between dysarthria and CAS for children with CP.

There is consensus that a core feature of CAS is variability in productions of the same word.[20] Although only 19% of verbal participants met the criterion for inconsistent speech, the degree of inconsistency across the entire cohort is noteworthy. By 5 and 6 years of age, the mean percentage of inconsistency for typically developing children is only 3% to 4%.[31] In the present study, the age appropriate and isolated dysarthria subgroups demonstrated mean inconsistency scores of 10% and 18% respectively.[31] The large range of inconsistency scores within these and the other speech classification subgroups may suggest that the underlying cause of inconsistency in children with CP lies not entirely in the phonological planning of speech. For instance, deficits in speech motor execution may have led to inconsistency in the manner and place of articulation, as previously reported in non-CP populations of adults with dysarthria.[32] This may be a plausible factor for children with CP given that one participant with dysarthria who did not meet criteria for CAS presented with inconsistent speech. This participant was diagnosed with a right spastic hemiplegia. Phonological short-term memory deficits have been hypothesized as a factor contributing to the inconsistent speech profiles of children with Down syndrome,[33] which may also be a possible explanation since deficits in

this area have been associated with CP.[34] Research analysing the types of errors made across repeated productions of the same word is needed to clarify the cause of inconsistent speech in children with CP, as well as research examining the association between inconsistency and CP motor disorder type, particularly in larger samples consisting of children with a predominant dyskinesia diagnosis.

With regards to speech-sound development, delayed (26%) and disordered (28%) acquisition of consonants occurred at similar rates and nearly always occurred in the context of dysarthria. In comparison, phonological development was more likely to be disordered (27%) than delayed (17%). Fricatives and affricates were often distorted or absent from participants' phonetic inventories. This is in line with previous findings[35] and is not unexpected given the developmental sequence of speech acquisition.[36] During early development, the coordinative constraints of the jaw and lips are thought to restrict the production fricatives.[1] For children with CP, it is likely that these restrictions are due to the oromotor deficits associated with the motor impairment, resulting in the loss of the fine movements required to accurately produce fricatives and affricates.

Given the high degree of co-occurrence across speech classifications, factors associated with each specific diagnosis was not possible. When all speech diagnoses were combined, the presence of speech delay or disorder among verbal participants was associated with language impairment, reduced health-related quality of life, and birthweight (particularly low birthweight). The association between speech and language was expected and likely reflects a combination of factors, including the nature of the brain pathology, motor function, and comorbidities (e.g. hearing impairment, epilepsy). The reduced health-related quality of life found in participants with speech delay or disorder confirms the broader implications of speech impairment on wellbeing and participation.[37,38] Our finding in relation to birthweight should be interpreted cautiously. The smaller number of participants with very or extremely low birthweight likely underestimates the occurrence of speech delay or disorder in this subgroup. Whilst the other factors explored did not reach significance, possibly due to statistical power, there were prominent trends. Speech delay or disorder was always present in participants with non-spastic motor types, quadriplegia, more severe GMFCS (V) and Manual Ability Classification System levels (III–IV), epilepsy, and hearing impairment.

This is the first study to systematically differentiate between articulation, phonological, and motor speech disorders in children with CP. We adopted accepted criteria and classifications of speech delay and disorder to characterize participants' abilities, an approach that has been lacking in the CP field. Consistent definitions and measures of speech delay and disorder are necessary in the field to improve the interpretation of findings and comparisons across studies. There were limitations to the current study. Phonetic inventories were established using the Diagnostic Evaluation of Articulation and Phonology rather than connected speech samples, potentially leading to an incomplete representation of a participant's consonant repertoire. Speech intelligibility was measured using an equal appearing interval scale. Although these scales are commonly used, they are limited in that intervals may not be equal.[39]

While our findings confirm that speech disorders are highly prevalent in children with CP, we highlight that errors reflect disruption at multiple levels of speech production, including phonetic, cognitive-linguistic, neuromuscular execution, and high-level planning/programming. Our findings suggest that during early childhood the majority of children with CP would benefit from a comprehensive speech and oromotor assessment, in addition to language,[8] to facilitate a differential speech diagnosis and improve the targeting of intervention to support better communication outcomes and potentially improve wellbeing and quality of life.

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SUPPORTING INFORMATION

The following additional material may be found online:

Figure S1: Flowchart of recruitment

Table S1: Speech classification and criteria

Table S2: Definition of phonological processes

Table S3: Phonological outcomes

Table S4: Factors associated with presence of speech delay or disorder in verbal participants

Video S1: Dysarthria

Video S2: Childhood apraxia of speech

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Table 1: Percentage consonants correct (PCC), Inconsistency Assessment, and speech intelligibility results according to speech classification

Speech classification	PCC			Inconsistency Assessment[a]			Speech intelligibility (examiner ratings)					
	n	Mean (SD)	Range	*n*	Mean (SD)	Range	*n*	1	2	3	4	5
Age appropriate speech (*n*=12)	12	95.3 (5.3)	86–100	12	9.7 (8.9)	0–28	12	-	-	-	4 (33)	8 (67)
Articulation delay or disorder (*n*=3)	3	94.7 (1.2)	94–96	3	18.7 (9.2)	8–24	3	-	-	-	3 (100)	-
Phonological delay (*n*=1)	1	74.0 (N/A)	74	1	24.0 (0)	24	1	-	-	1 (100)	-	-
Dysarthria (*n*=9)	9	92.9 (5.6)	84–100	9	17.8 (10.4)	0–36	9	-	-	-	8 (89)	1 (11)
Dysarthria + articulation delay or disorder (*n*=11)	10	89.6 (7.2)	78–100	10	26.8 (10.3)	8–36	11	-	1 (9)	-	10 (91)	-
Dysarthria + phonological delay or disorder (*n*=6)	5	84.4 (6.3)	76–91	5	16.8 (13.4)	0–32	6	-	-	2 (33)	4 (67)	-
Dysarthria + articulation delay or disorder + phonological delay or disorder (*n*=9)	9	74.4 (16.3)	45–90	8	29.0 (7.9)	20–40	9	-	1 (11)	2 (22)	6 (67)	-
Dysarthria + CAS criteria met + articulation delay or disorder + phonological disorder (*n*=10)	10	58.7 (18.3)	29–84	10	59.5 (15.6)	44–84	10	-	3 (30)	6 (60)	1 (10)	-
Minimally verbal (*n*=20)		NA	NA		NA	NA		NA	NA	NA	NA	NA
Unknown (*n*=3)		NA	NA		NA	NA	3	-	-	-	2 (67)	1 (33)[b]

[a]Score ≥40% denotes inconsistent speech. [b]Parent report rating. Speech intelligibility ratings: level 5 completely intelligible; level 4 intelligible with some exceptions; level 3 half of message understood; level 2 isolated words or phrases intelligible; level 1 unintelligible. CAS, childhood apraxia of speech; NA, not assessed.

Table 2: Deviant perceptual speech features of dysarthria (*n*=45)

		Impaired	Severity of deviant speech feature, *n* (%)		
Domain	**Deviant speech feature**	***n* (%)**	**Mild**	**Moderate**	**Severe**
Pitch	Altered	33 (73)	26 (79)	7 (21)	0 (0)
	Increased pitch	23 (51)	17 (74)	6 (26)	0 (0)
	Decreased pitch	10 (22)	9 (90)	1 (10)	0 (0)
	Pitch breaks	4 (9)	4 (100)	0 (0)	0 (0)
	Monopitch	29 (64)	18 (62)	11 (38)	0 (0)
	Voice tremor	4 (9)	4 (100)	0 (0)	0 (0)
Loudness	Monoloudness	25 (56)	14 (56)	11 (44)	0 (0)
	Excess loudness variation	2 (4)	2 (100)	0 (0)	0 (0)
	Loudness decay	15 (33)	13 (87)	2 (13)	0 (0)
	Alternating loudness	1 (2)	1 (100)	0 (0)	0 (0)
	Reduced	15 (33)	10 (67)	5 (33)	0 (0)
	Increased	2 (4)	2 (100)	0 (0)	0 (0)
Voice	Harsh	33 (73)	21 (64)	12 (36)	0 (0)
	Hoarse (wet)	1 (2)	0 (0)	1 (100)	0 (0)
	Breathy	14 (31)	13 (93)	1 (7)	0 (0)
	Strained-strangled	16 (36)	12 (75)	3 (19)	1 (6)
Resonance	Hypernasal	28 (62)	24 (86)	4 (14)	0 (0)
	Hyponasal	31 (69)	24 (77)	7 (23)	0 (0)
Respiration	Forced inspiration-expiration	7 (16)	6 (86)	1 (14)	0 (0)
	Audible inspiration	25 (56)	19 (76)	5 (20)	1 (4)
Prosody	Reduced rate	39 (87)	27 (69)	12 (31)	0 (0)
	Increased rate	4 (9)	3 (75)	1 (25)	0 (0)
	Short phrases	25 (56)	15 (60)	9 (36)	1 (4)
	Reduced stress	31 (69)	17 (55)	14 (45)	0 (0)
	Variable rate	5 (11)	5 (100)	0 (0)	0 (0)
	Prolonged intervals	25 (56)	20 (80)	5 (20)	0 (0)
	Short rushes of speech	13 (29)	12 (92)	1 (8)	0 (0)
	Excess-equal stress	34 (76)	25 (74)	9 (26)	0 (0)
Articulation	Imprecise consonants	43 (96)	31 (72)	10 (23)	2 (5)
	Prolonged phonemes	35 (78)	30 (86)	5 (14)	0 (0)
	Repeated phonemes	11 (24)	9 (82)	2 (18)	0 (0)
	Irregular articulatory breakdowns	7 (16)	6 (86)	1 (14)	0 (0)
	Distorted vowels	32 (71)	27 (84)	4 (13)	1 (3)

Table 3: Features of CAS (*n*=58)

CAS criteria	*n* (%)
Criteria 1: Inconsistent errors	
Inconsistent production of the same word, as indicated by a score of ≥40% on the DEAP Inconsistency Assessment	11 (19)
Criteria 2: Lengthened and disrupted coarticulatory transitions	
Difficulty achieving initial articulatory configurations and transitions (including groping during sound production, hesitations)	7 (12)
Syllable segregation	16 (28)
Difficulty sequencing phonemes and syllables	49 (84)
Difficulty maintaining syllabic integrity	12 (21)
Increased errors in longer or more complex syllable and word shapes	25 (43)
Prolonged sounds and/or pauses	32 (55)
Repetitions of sounds or syllables	14 (24)
Slow speech rate	41 (71)
Slow DDK rate	29 (50)
Disrupted DDK accuracy	34 (59)
High number of errors per word	13 (22)
Errors in the ordering of sounds (migration and metathesis), syllables, morphemes, and words	12 (21)
Addition errors, epenthesis, intrusive schwa	16 (28)
Frequent omissions (>10)	14 (24)
Voicing errors	20 (34)
Vowel distortions	40 (69)
Nonphonemic productions/distorted substitutions	21 (36)
Variable nasal resonance	15 (26)
Criteria 3: Inappropriate prosody	
Excess-equal stress	39 (67)
Inappropriate/altered prosody	38 (66)
Prolonged sounds and/or pauses	34 (59)
Reduced range/variable pitch	31 (53)
Number of CAS criteria met	
3	10 (17)

2	32 (55)
1	16 (28)

CAS, childhood apraxia of speech; DEAP, Diagnostic Evaluation of Articulation and Phonology; DDK, diadochokinesis.

Table 4: Features of oromotor impairment (*n*=59)

VMPAC subtest and items	Impaired	Severity of oromotor impairment, *n* (%)[a]		
	n (%)	Mild	Moderate	Severe
Global Motor Control scale		0 (0)	0 (0)	59 (100)
Tone	59 (100)			
Respiration/phonation	16 (27)			
Chewing coordination	19 (32)			
Swallowing coordination	8 (14)			
Facial asymmetry at rest	6 (10)			
Contraction of oppositional oral-facial muscles	25/58 (43)			
Soft palate contraction	32 (54)			
Tongue strength	52 (88)			
Smoothness of oral movements	25 (42)			
Range and symmetry of oral movements	31 (53)			
Focal Oromotor Control scale		5/57 (9)	3/57 (5)	44/57 (77)
Non-speech oromotor movements				
Mandibular control	24 (41)			
Labial-facial control	35/58 (60)			
Lingual control	55/58 (95)			
Speech-related oromotor movements				
Single movements – vowels	23/57 (40)			
Single movements – consonants	26/57 (46)			
Double movements (e.g. 'a-u')	38/57 (67)			
Triple movements (e.g. 'a-m-u')	45/56 (80)			
Word movements (e.g. 'pea, tea, key')	46/55 (84)			
Sentence movements	36/56 (64)			
Sequencing scale		11/57 (19)	7/57 (12)	30/57 (53)
Non-speech sequences	48/58 (83)			
Speech sequences	56/56 (100)			
Word sequences	47/56 (84)			
Sentence sequences	8/56 (14)			

[a]Severity ratings for individual features of oromotor impairment are not provided in the table as the Verbal Motor Production Assessment for Children (VMPAC) only provides severity ratings for the total subtest score.

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