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Clinical Focus

An Investigation of Developmental Coordination Disorder Characteristics in Children With Childhood Apraxia of Speech

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ABSTRACT

Purpose: Children with childhood apraxia of speech (CAS) evidence a high rate of co-occurring fine and gross motor deficits. This clinical focus article reports a preliminary investigation of characteristics of developmental coordination disorder (DCD), a neurodevelopmental disorder categorized by poor motor proficiency and functional limitations, in this population.

Method: Children with CAS underwent a comprehensive motor evaluation using the Movement Assessment Battery for Children–Second Edition, the Developmental Coordination Disorder Questionnaire, and a developmental history questionnaire to determine if they met criteria for a DCD diagnosis as specified in the *Diagnostic and Statistical Manual of Mental Disorders, Fifth Edition* (DSM-5).

Results: Six out of seven participants met DCD criteria based on the DSM-5 criteria. Four of these children had a co-occurring diagnosis of developmental language disorder, and all met criteria for DCD.

Conclusions: Consistent with previous research, the majority of participants demonstrated motor deficits and 85% met criteria for DCD. Despite this high rate of motor deficits, only 57% had previously undergone a physical/occupational therapy evaluation and intervention and only one had a previous diagnosis of DCD. These findings suggest that formal movement assessments are essential for children with a CAS diagnosis.

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Childhood apraxia of speech (CAS) is a neurological speech sound disorder characterized by deficits in the planning and programming of speech motor movements in the absence of neuromuscular deficits (American Speech-Language-Hearing Association [ASHA], 2007). A child with CAS will typically know what they want to say but will experience a breakdown in getting that message properly articulated. This is due to difficulties planning and programming the direction, degree, timing, and

sequence of the articulatory movements for speech sound production. These deficits can result in vowel and voicing errors, distortions, groping, inconsistent errors, disrupted transitions between sounds and syllables, increased difficulty with multisyllabic words, and equalized or incorrect stress patterns (ASHA, 2007; Iuzzini-Seigel et al., 2017; Shriberg et al., 2011). CAS often results in a severe communication impairment that can have lasting negative effects on social–emotional, academic, and vocational outcomes (Bird et al., 1995; Cassar et al., 2022; Felsenfeld et al., 1994; Rice et al., 1991; Silverman & Paulus, 1989). In addition, there is a high rate of co-occurring disorders with CAS, such as developmental language disorder (DLD), literacy impairments, phonological processing deficits, and fine and gross motor impairments (Bradford-Heit & Dodd, 1998; Duchow et al., 2019; Iuzzini-Seigel,

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2019, 2021; Iuzzini-Seigel, Delaney, & Kent, 2022; Lewis et al., 2004; McNeill et al., 2009; G. J. Miller et al., 2019; Moriarty & Gillon, 2006; Zuk et al., 2018), resulting in a complex presentation for children in this population.

The extant research reveals fine and gross motor deficits in 50%–80% of individuals with CAS, but these motor deficits tend to go undiagnosed in a high percentage of children in this population (Duchow et al., 2019; Iuzzini-Seigel, 2019; Teverovsky et al., 2009; Tükel et al., 2015). Motor deficits are reflected in slower speed and poorer dexterity on fine motor tasks (Bradford & Dodd, 1996), poorer balance, and challenges with aiming and catching as well (Duchow et al., 2019; Iuzzini-Seigel, 2019). Nevertheless, beyond achievement of basic milestones, systematic assessment for fine and gross motor impairments is not standard practice in the screening and referral process for children with CAS. Pediatricians tend to refer children to speech-language pathologists (SLPs) before other allied health professionals (Michaud & Committee on Children with Disabilities, 2004), and in many cases, an SLP may be the only practitioner that a child with CAS is seeing, even though they have other co-occurring deficits. Prior research suggests that motor deficits in children with CAS may be severe enough to be diagnosed as developmental coordination disorder (DCD), a neurodevelopmental disorder characterized by substantial delays in acquisition and execution of fine and gross motor skills that result in functional limitations (American Psychiatric Association [APA], 2013). This makes it essential for SLPs to fully understand the constellation of deficits that can occur among children with CAS, so that they can make appropriate referrals when appropriate. The current clinical focus article provides an overview of the characteristics of motor deficits associated with DCD and uses a small data set to illustrate the profile of speech, language, and DCD characteristics that are observed in this group.

DCD

The prevalence of DCD in the general population of children is 5%–6%, and males are affected more frequently than females (APA, 2013; Blank et al., 2019), but may occur at a higher rate among children with certain neurodevelopmental disorders such as autism spectrum disorder (ASD; Licari et al., 2020; H. Miller et al., 2021), attention-deficit/hyperactivity disorder (ADHD; Kadesjö & Gillberg, 1998), and DLD (Flapper & Schoemaker, 2013; Visscher et al., 2010). Consequently, it is possible that children with CAS also represent a population with a high rate of co-occurring DCD as well. Children with DCD exhibit slower, less accurate, and more varied motor performance than their peers and score lower on motor assessments than would be expected for their age and intelligence level

(Brown-Lum & Zwicker, 2015). The movement abilities of children with DCD frequently lead to performance difficulties in activities of daily living and physical games that typically developing children easily perform. DCD is considered a significant health problem among school-age children, with consequences that often extend beyond the motor domain to include secondary mental health and behavioral issues as well (Missiuna et al., 2008).

DCD Diagnosis

DCD should be diagnosed by a multidisciplinary team of professionals (i.e., physician, therapist, and psychologist) qualified to assess the *Diagnostic and Statistical Manual of Mental Disorders, Fifth Edition* (DSM-5) criteria for the disorder (Blank et al., 2019). In particular, the team should include a physical or occupational therapist who can administer a standardized motor assessment. It is also important that the motor assessment employed has been validated for use among children with a range of cognitive–linguistic abilities (Henderson & Sugden, 1992; Lam & Henderson, 1987; Spanò et al., 1999; Sugden & Wann, 1987). This is particularly important when assessing children with CAS, as DLD has been reported in up to 80% of children in this population (Iuzzini-Seigel, 2019, 2021; Lewis et al., 2004). A diagnosis of DCD is recommended after age 5 years, although Blank et al. do specify some circumstances when it is possible to diagnose a child younger than 5 years. There are four criteria in the DSM-5 that should be met to warrant a diagnosis of DCD: (a) Acquisition and execution of coordinated motor skills are below what would be expected at a given chronologic age and given the child's exposure and opportunity for skill learning and use; difficulties are manifested as clumsiness (e.g., dropping or bumping into objects) and as slowness and inaccuracy of motor skill performance (e.g., catching an object, using scissors, handwriting, riding a bike, or participating in sports); (b) the motor skill deficit significantly or persistently interferes with activities of daily living appropriate to the chronologic age (e.g., self-care and self-maintenance) and impacts academic/school productivity, prevocational and vocational activities, leisure, and play; (c) the onset of symptoms was in the early developmental period; and (d) the motor skill deficits cannot be better explained by intellectual disability or visual impairment and are not attributable to a neurological condition that affects movement (e.g., cerebral palsy, muscular dystrophy, or a degenerative disorder).

Assessments Used to Make the DCD Diagnosis

The most common assessments used to investigate DCD criteria are the Movement Assessment Battery for

Children—Second Edition (MABC-2; Henderson et al., 2007, Criterion A) and the Developmental Coordination Disorder Questionnaire (DCDQ; Wilson et al., 2009, Criterion B). The MABC-2 is the gold-standard instrument to identify motor difficulties in children and adolescents aged 3–16 years. It is sensitive and specific at detecting even mild motor impairments in children across a range of cognitive–linguistic abilities (Henderson & Sugden, 1992; Lam & Henderson, 1987; Spanò et al., 1999; Sugden & Wann, 1987). The sensitivity of a test is the ability to detect a true positive rate of a condition, and specificity is the ability to designate an individual who does not have a condition as negative. One study reported the predictive validity of the MABC-2 in 96 children born preterm, noting that at age 4 years, the test had high sensitivity (79%) and specificity (93%) for predicting motor impairment at 8 years of age (Griffiths et al., 2017). The assessment consists of three components: Manual Dexterity (3 tasks), Aiming & Catching (2 tasks), and Balance (3 tasks); a total percentile is derived from the result from all three components. Scaled scores of 5 or below (\leq 5th percentile) signal performance in the “red zone” and denote children with significant movement difficulty that requires therapeutic intervention. Scaled scores of 6–7 (6th–15th percentiles) indicate performance in the “amber zone” and that the child is at high risk of movement difficulty and developmental monitoring is necessary (borderline). Scaled scores of 8 and above (above the 15th percentile) indicate that no movement difficulty was observed during testing.

The DCDQ is a 15-item survey that asks a caregiver to report the extent of a child’s functional motor difficulties on a 5-point Likert scale. It is composed of three subscales: Control During Movement, Fine Motor/Handwriting, and General Coordination. The test has high internal consistency (Cronbach’s $\alpha = .89$) and concurrent validity with the MABC-2 ($r = .55$). The DCDQ is traditionally administered to caregivers of children aged 5–15 years old. The classification of “Indication of DCD or Suspect DCD” is assigned for a total score lower than 46 (5;0–7;11 [years; months], 55 (8;0–9;11), or 57 (10;0–15;0). While the DCDQ is typically used for screening and referral of motor difficulties associated with DCD, it can also be used to reveal how the motor difficulties observed may affect activities of daily living in children.

DCD and Co-Occurring Disorders

DCD frequently co-occurs with other neurodevelopmental disorders including ASD (Licari et al., 2020, H. Miller et al., 2021), ADHD (Kadesjö & Gillberg, 1998), and DLD (Flapper & Schoemaker, 2013; Visscher et al., 2010); however, it is often undiagnosed because movement abilities are not typically included within the evaluation process of these disorders. Young children who are in

early intervention programs for speech/language delays may have significant coordination difficulties, but these often remain undiagnosed until kindergarten age when motor deficits begin to impact self-care and academic tasks (Gaines & Missiuna, 2019).

Language impairment and motor deficits commonly co-occur (e.g., Bishop, 2002, 2005; Kent, 1984; Zelaznik & Goffman, 2010), although specific studies of DLD and DCD are limited. Research shows that, relative to typically developing children, those with DLD demonstrate poorer performance in fine and gross motor tasks and specific deficits in balance and manual dexterity (Hill, 2001; Sack et al., 2021; Sanjeevan & Mainela-Arnold, 2017; Vuolo et al., 2017), bimanual coordinated and timed clapping tasks (Vuolo et al., 2017), and those with high sequential complexity (Hill, 2001; Sanjeevan & Mainela-Arnold, 2017; Vuolo et al., 2017). One investigation of DCD in 65 children with specific language impairment (Flapper & Schoemaker, 2013) revealed that 32% of participants with DLD met DSM criteria for a DCD diagnosis and that quality of life was lower for children with this comorbidity than for those with language impairment alone. Co-occurrence of DLD and DCD is particularly relevant to the current investigation because DLD occurs in the majority of children with CAS (e.g., Iuzzini-Seigel, 2019; Lewis et al., 2004).

DCD is first mentioned by name in the CAS literature in 1998, when CAS was still known as developmental apraxia of speech (Hodge, 1998), but there are earlier references to clumsiness, motor coordination issues, and other neurological soft signs that may suggest DCD (Bradford & Dodd, 1996; Darley et al., 1975; Dewey et al., 1988). Hodge (1998) suggested the importance of understanding the parallels between CAS and DCD and reinforced the use of transdisciplinary intervention to treat children with more than one type of motor coordination disorder. Children with DCD will often have difficulty sequencing movements—and two- and three-step motor commands in particular—similar to the way children with CAS have increased difficulty producing multisyllabic words compared to monosyllabic words. Likewise, as with speech among children with CAS (ASHA, 2007; Case & Grigos, 2016; David, 1995; Grigos et al., 2015; Iuzzini-Seigel et al., 2017; Shriberg et al., 2011; Zuk et al., 2018), children with DCD show slow and inconsistent body movements, have poor perception of body movements, and have challenges when sensory feedback is limited (David, 1995; Smits-Engelsman & Wilson, 2013).

While motor deficits have been studied directly among children with CAS, less is known about the extent to which DCD affects children with CAS. Recently, a study explored the prevalence of DCD in children with suspected CAS (Duchow et al., 2019) by having parents of children with suspected CAS and typical development

complete the DCDQ, mentioned earlier as a survey used to screen for motor difficulties. Results showed that 49% of participants with suspected CAS ($n = 35$) were at risk for DCD based on DCDQ responses, compared to 9% of children in the general population of Canada where the study was conducted. One limitation of this study was that participants were not directly assessed for speech or motor abilities. These results support the need for a study that integrates direct fine/gross motor testing along with the parent questionnaire (DCDQ) in children with a confirmed diagnosis of CAS. The goal of this clinical focus article is to explore characteristics of DCD in children with a confirmed diagnosis of CAS.

Framework for Co-occurring DCD, Language, and Speech Deficits

A recent longitudinal study of speech, language, and motor skills in 15 children with DLD showed that fine and gross motor deficits present at preschool age were predictive of persistent language impairment 2 years later compared to preschoolers who demonstrated language deficits alone at the first time point (Sack et al., 2021). Importantly, initial *motor* ability was more predictive of later language ability than initial *language* ability was. Sack et al. suggested that the constellation of motor and language deficits demonstrated by children with persistent DLD highlights the interactivity of these domains and the importance of early identification of motor impairments. Such interactivity also suggests shared neural substrates (e.g., corticocerebellar or corticostriatal loop) underlying these seemingly divergent domains (Jäncke et al., 2007; Kent, 2004; Leiner et al., 1991, 1994; Ullman & Pierpont, 2005).

These neural substrates are also implicated in procedural learning, which is the system by which patterns are learned implicitly. For instance, typical acquisition of morphosyntax, speech sound, and motor skill patterns (e.g., hand games like Miss Mary Mack, riding a bike, typing without looking at the keyboard) happens implicitly. Over time, with repeated practice, these patterns are gradually acquired until they can be performed automatically. If the procedural learning system is impaired, it would be expected that an individual would have multisystem deficits in skills that are reliant on implicit learning.

The Procedural Learning Deficit Hypothesis is a framework that has been used to explain co-occurring motor, language, attention, and literacy deficits observed in children with DLD, dyslexia, and ADHD (Nicolson & Fawcett, 2007) and most recently among children with CAS as well (Iuzzini-Seigel, 2021). Research investigating procedural learning in children with CAS, non-CAS speech disorders, and typical development showed that children with CAS performed differently from peers on

procedural learning tasks such that instead of getting faster throughout a sequence learning task, they initially got slower before increasing speed, or they demonstrated slower performance across the entire task. These patterns were observed less frequently among children with non-CAS speech sound disorders or those with typical development. Interestingly, children with CAS who demonstrated these procedural learning patterns also tended to have co-occurring language and motor deficits as well. These findings are consistent with other research showing that individuals with CAS demonstrate implicit learning deficits (Bombonato et al., 2022) and have more difficulty with tasks that have a higher sequencing load across speech, motor, and cognitive-linguistic domains (Button et al., 2013; Peter et al., 2013). Taken together, these studies provide further support for the Procedural Learning Deficit Hypothesis as a possible explanation for the co-occurring deficits observed in children with CAS including why we might expect a high rate of DCD among children in this complex population as well.

Topic Relevance to SLPs Working in Schools

Because SLPs are often the first type of allied health professional to receive a referral from pediatricians (Michaud & Committee on Children with Disabilities, 2004) and because speech may be the most overt and life-limiting issue for children with CAS, it is unsurprising that children with CAS may initially be referred to an SLP rather than to a physical or occupational therapist. In addition, if a child has previously met early milestones (e.g., walking), it is possible that their motor performance during the early school-age years may not have limited access to the curriculum, even if their motor abilities are not optimal. For instance, a child with poor fine motor coordination may not experience academic difficulties in connection with this impairment until they are required to write quickly to take notes, or to write neatly so that they can line up numbers when working out math problems. Still though, a standardized motor evaluation with a specialized professional may reveal that, for example, fine motor performance is well below the normal range and in need of intervention. Even if DCD diagnosis is not typically made prior to age 5 years (Blank et al., 2019), SLPs can still identify children who may benefit from a standardized motor evaluation, so they refer to colleagues and help achieve much needed care aimed at helping the “whole child” to thrive. By doing this, early identification and intervention can help prevent later impacts on quality of life and limited participation in activities. The high occurrence of motor impairments in individuals with CAS suggests that motor problems should be at the forefront of evaluation and treatment for individuals with CAS. SLPs can help to bridge this gap in services so that children

with CAS receive timely and appropriate referrals to physical and occupational therapists, which should result in appropriate evaluations and treatment. This clinical focus article is intended to help SLPs learn about the motor profile of children with CAS (with and without co-occurring DLD) so that they feel confident in making referrals to physical and occupational therapists when indicated.

Purpose and Research Questions

This study conducted a preliminary investigation of characteristics of DCD in children with a confirmed diagnosis of CAS (with and without DLD) using a standardized motor assessment, parent questionnaire, and medical/developmental history for each participant. Due to the high co-occurrence between CAS and DLD, we also investigated to extent to which DLD co-occurred in the current sample and whether this co-occurring diagnosis was related to occurrence of DCD. Due to the common motor challenges observed in children with CAS and the extant literature on the high rate of DCD in other neurodevelopmental disorders (e.g., ASD; H. Miller et al., 2021), we predicted that a high proportion of children would meet diagnostic criteria for DCD. Such findings should highlight the clinical significance of motor problems in children with CAS and the need for targeted motor evaluations and treatments for children in this population.

Method

Seven children with a diagnosis of CAS participated in the study. Participants were recruited via convenience sampling from the North Texas area via flyers posted through the Apraxia Kids organization. Children ranged in age between 4 and 8 years ($M = 5.62$, $SD = 1.25$). Exclusionary criteria included a diagnosis of Down syndrome, cerebral palsy, muscular dystrophy, degenerative disorder, epilepsy, and uncorrected visual deficit. After completing screening and consent/assent procedures, parents or guardians completed a brief questionnaire and developmental history as well as the DCDQ. All participants completed the Nonverbal scale of the Kaufman Brief Intelligence Test–Second Edition (Kaufman & Kaufman, 2004), speech and language evaluations, and motor ability testing. All participants were reported to have normal hearing based on parent report of a previous hearing assessment. See Table 1 for demographic variables.

All participants underwent a thorough virtual communication assessment to confirm the CAS diagnosis and evaluate language. Procedures were completed in one 2- to 2.5-hr session. Sessions were recorded on Zoom using a cardioid directional external condenser microphone (Blue Snowball iCE) at a sampling rate of 32 kHz. Children

were seated in Dr. Tamplain's lab next to a trained research assistant and communication assessments were administered virtually by research assistants in Dr. Iuzzini-Seigel's lab. Children took as many breaks as needed during the session. After completion, participants were provided with a \$25 gift card as a thank you for their participation. All procedures were approved by the institutional review board at The University of Texas at Arlington. Testing included the Sounds-in-Words subtest of the Goldman-Fristoe Test of Articulation–Third Edition (GFTA-3; Goldman & Fristoe, 2015), the core language components of the Clinical Evaluation of Language Fundamentals–Fifth Edition (CELF-5; Wiig et al., 2013), maximal vowel durations and maximal performance diadochokinesis tasks (i.e., “I want you to take a big breath and say “___” as clearly and as fast you can on one breath” for /pa/ and /pataka/; Thoonen et al., 1999), repeated productions of “Buy Bobby a Puppy” (Iuzzini-Seigel et al., 2017), and a customized speech assessment that required imitation of build upon words (e.g., lay, lady, ladybug), and challenging multisyllabic words (e.g., skeptical; Iuzzini-Seigel, 2021). Finally, all participants completed a story retell task in response to a custom script (Smith et al., 2020) for the book “Goodnight, Gorilla” (Rathmann, 2004). All assessments were transcribed and/or scored from the Zoom recordings.

Prior to transcribing and scoring speech assessments, research assistants are required to pass a rigorous training in which they narrowly transcribe increasingly less intelligible speech samples. The final samples they transcribe are of children with CAS and dysarthria. They are required to pass this training with a minimum of 90% agreement with our expert SLP rater on narrow transcription of GFTA responses of severe-to-profound disordered speech.

Rating of Motor Speech Features

Two licensed speech pathologists with motor speech expertise (J.I.S. and L.M.) independently rated 20 speech features on each of the speech tasks using the Profile of Childhood Apraxia of speech and Dysarthria (ProCAD; Iuzzini-Seigel, Allison, & Stoeckel, 2022). The ProCAD was developed to support the differential diagnosis of CAS and dysarthria (Iuzzini-Seigel, Allison, & Stoeckel, 2022). This tool includes a feature checklist designed to sample all speech subsystems (i.e., phonatory, respiratory, resonatory, prosody, and articulatory) and a decision-making tree to support differential diagnosis of CAS and dysarthria. For a child to be considered “positive” for a feature, they needed to demonstrate the feature across at least two tasks (e.g., story retell of “Goodnight, Gorilla” and extra speech tasks). See Table 1 for diagnosis by individual and Iuzzini-Seigel, Allison, and Stoeckel (2022) in this issue of LSHSS for a tutorial on the ProCAD including the feature rating list and clinical decision-making tree template. Token-to-token inconsistency was also calculated for each

Table 1. Demographic and diagnostic data by participant.

Child	Sex	Age	Parent-reported co-occurring disorders ^a	Nonverbal IQ	GFTA-3 SS	Token-to-token inconsistency	Core Language SS	Current motor speech Dx	Current language Dx
1	M	8	SPD	Above average	53	1	107	CAS	TD
2	M	6	Developmental delay	Below average	58	1	92	CAS	TD
3	M	9	DCD, ASD	Average	44	1	98	CAS	TD
4	M	9	ASD	Average	40	1	61	CAS & Dysarthria	DLD
5	M	7	SPD, ASD	Lower extreme	40	1	40	CAS & Dysarthria	DLD
6	F	7	Articulation disorder, Developmental delay, ID	Lower extreme	40	1	45	CAS	DLD
7	M	5	N/A	Average	40	1	63	CAS	DLD

Note. GFTA-3 SS = standard score for the Sounds in Words subtest on the Goldman-Fristoe Test of Articulation–Third Edition (Goldman & Fristoe, 2015); Token-to-token inconsistency evaluated on multiple productions of the phrase “Buy Bobby a puppy” (Luzzini-Seigel et al., 2017), 1 = inconsistency present; Core Language SS = Core Language standard score on the Clinical Evaluation of Language Fundamentals (Fifth Edition or Preschool–Second Edition, dependent on participant age); Current motor speech Dx = diagnosis resultant from the motor speech auditory-perceptual feature rating protocol for diagnosis of childhood apraxia of speech and dysarthria (Luzzini-Seigel, Allison, & Stoeckel, 2022); Current language Dx: DLD = developmental language disorder based on a Core Language standard score below 80; TD = typically developing language based on a standard score of 85 or above; M = male; F = female. All children with DLD in this study scored below 70, indicating a classification of very low range/severe language disorder (Wiig et al., 2013). SPD = sensory processing disorder; DCD = developmental coordination disorder; ASD = autism spectrum disorder; ID = intellectual disability; N/A = not applicable.

^aIn addition to childhood apraxia of speech, disorders are reported the way they were described by the parent.

participant across multiple repetitions of the phrase “Buy Bobby a puppy.”

CAS. A diagnosis of CAS was made if a child demonstrated “CAS-Only features” in both the articulatory and rate/prosody domains on the ProCAD, across at least two tasks. CAS-only features included (a) lexical stress errors and syllable segregation in the prosody/rate domain and (b) intrusive schwa, groping, increased difficulty with multisyllabic words, and difficulty with initial articulatory configurations/transitory movement gestures in the articulation domain.

ASHA criteria. Because the ProCAD is a new speech rating system, CAS diagnosis was also verified using the ASHA criteria, which helps to differentiate CAS and phonological disorder. To meet the ASHA criteria, participants needed to demonstrate (a) inconsistent errors, (b) lengthened and disrupted coarticulatory transitions, and (c) inappropriate prosody. Inconsistency was based on token-to-token inconsistency across five repeated productions of the phrase “buy Bobby a puppy” (Iuzzini-Seigel et al., 2017), and all other features were assessed across the speech tasks described above. All participants met these three criteria.

Dysarthria. If the child demonstrated imprecise articulatory contacts or if they demonstrated dysarthria-only features across at least two speech domains noted on the ProCAD, they were assigned a diagnosis of dysarthria. Dysarthria-only features included (a) consistent hypernasality reflecting the resonance domain, (b) imprecise articulatory contacts reflecting the articulation domain, and (c) low volume or loudness decay, excessive loudness or loudness variation, audible/effortful inspiration, short breath groups, or atypical voice quality reflecting the respiration/phonation domain.

Remaining features (i.e., fluctuating resonance, slow rate, atypical/reduced stress, consonant distortions, vowel errors, and voicing errors) on this checklist are all associated with both CAS and dysarthria. Consequently, while these features contribute to a speech profile description and treatment planning, they are not meant to enhance diagnostic accuracy when using the ProCAD protocol.

Core Language Assessment

All participants completed the Core Language Assessment from the CELF-5, which included the Word Classes, Formulated Sentences, Recalling Sentences, and Semantic Relationships subtests. Core Language standard scores of below 80 were used to indicate DLD ($n = 4$). The remaining three participants demonstrated Core Language scores within the normal range.

Motor Ability Evaluation and DCD Diagnosis

Participants were systematically evaluated to determine whether they met the DSM-5 (APA, 2013) diagnostic criteria for DCD explained earlier in the clinical focus

article. To address Criterion A, we evaluated participants’ scores on a standardized assessment of motor function (MABC-2). To address Criterion B, we evaluated the impact of motor problems on activities of daily living using a parent-report measure (DCDQ). To address Criteria C and D, we evaluated parent- or guardian-reported delays in early motor milestones (holding head up, crawling, sitting, pulling up to stand, and walking) and medical history to determine onset of motor symptoms and to rule out other neurological impairments, respectively. This approach is in alignment with current practice and recommendations for assessment and diagnosis of DCD (Blank et al., 2019). We also asked parents for the child’s history of occupational and/or physical therapy to determine whether there was previous evaluation and/or treatment of motor difficulties.

Data Analysis

In order to characterize Criterion A (MABC-2) and Criterion B (DCDQ), we conducted descriptive analyses to examine motor problems and frequency analyses to determine the number of cases in each level of concern based on each assessment classification system. We also used descriptive analysis to report milestone achievement (Criterion C) and reports of physical or occupational therapy prior to testing. To meet Criterion C, a child had to walk by 16 months of age (a typical age for referral). Criterion D was evaluated based on the child’s history—by recruitment, no other diagnosis would exclude a potential diagnosis of DCD. When results from Criteria A and B were conflicting (i.e., child scored in the red zone of the MABC-2 but the DCDQ results indicated “probably not DCD”), we used the MABC-2 results as the tie breaker for the “eligibility for a DCD diagnosis” since the MABC-2 is a direct assessment of motor performance.

Results

Descriptive statistics were used to summarize demographic, speech, language, and motor data. See Table 1 for participant demographics by individual. Participants ranged in age between 4 and 8 years ($M = 5.62$, $SD = 1.25$) and included six males and one female. One participant had CAS-only with no co-occurring disorders. All other participants were reported by parents to have at least one co-occurring diagnosis, which included sensory processing disorder ($n = 2$), developmental delay ($n = 2$), ASD ($n = 3$), DCD ($n = 1$), intellectual disability ($n = 1$), and articulation disorder ($n = 1$). Testing revealed that four children demonstrated nonverbal IQ scores within or above the normal range and the remaining three were classified as performing below average ($n = 1$) or in the

Table 2. Individual standard, percentile scores, and mean (standard deviation) on the Movement Assessment Battery for Children–Second Edition results.

Child	MD–SS	MD–Perc	A&C–SS	A&C–Perc	Bal–SS	Bal–Perc	Total–SS	Total–Perc
1	3	1	10	50	8	25	6	9
2	9	37	11	63	9	37	9	37
3	6	9	9	37	6	9	6	9
4	2	0.5	2	0.5	1	0.1	1	0.1
5	1	0.1	2	0.5	1	0.1	1	0.1
6	2	0.5	8	25	1	0.1	1	0.1
7	2	0.5	10	50	4	2	3	1
<i>M (SD)</i>	3.57 (2.87)	6.94 (12.61)	7.42 (3.53)	32.28 (22.88)	4.28 (3.19)	10.47 (13.68)	3.85 (2.94)	8.04 (12.41)

Note. Total standard scores of 5 and below indicate performance in the “red zone,” indicating significant movement difficulty in need of intervention. MD = manual dexterity; SS = standard scores; Perc = percentile; A&C = Aiming and Catching; Bal = Balance.

lower extreme ($n = 2$). The ProCAD protocol classified 2/7 (29%) participants as having dysarthria in addition to CAS. Finally, Core Language scores classified 4/7 (57%) participants as having severe DLD as well.

Co-occurrence of DCD

Based on the DSM-5 diagnostic criteria for DCD, participants were evaluated on performance on the MABC-2 (Criterion A), responses on the DCDQ (Criterion B), age at which walking was achieved (Criterion C), and presence of comorbid diagnoses that could otherwise affect motor development (Criterion D).

Criterion A: MABC-2 performance. Four out of seven (57%) of participants scored in the red zone (DCD is indicated), 2/7 (28%) scored in the amber zone (DCD is indicated), and 1/7 (14%) scored in the green zone (DCD is not indicated). Of these, 6/7 participants who scored in the red or amber zones would be categorized as having “DCD” (86%) and 1/7 would not (14%). The standard scores and percentiles for each component of the MABC-2 and total scores are provided in Table 2, as well as the means and standard deviations. Overall, scores were lower on the Manual Dexterity

component, followed by scores on Balance and Aiming and Catching.

Criterion B: DCDQ. Four out of seven (57%) scored as “probable DCD” on the DCDQ.

Criterion C: Milestone achievement. The mean and standard deviation for when milestones were achieved were reported in months as follows: Holding head up (3.5 ± 1.51), Crawling (9.5 ± 1.0), Sitting (7.21 ± 2.26), Pulling up to stand (12.71 ± 3.88), and Walking (16.28 ± 2.71).

Criterion D: Other conditions. All co-occurring diagnoses are listed in Table 1.

Taken together, 6/7 (85%) children were categorized as potentially having DCD. Table 3 shows DCD classifications for participants based on MABC and DCDQ scores.

History of Physical and/or Occupational Therapy

Four out of seven (57%) children were reported to be involved in physical or occupational therapy, with therapy typically occurring 1 time per week. Table 3 shows therapy history by individual.

Table 3. Developmental coordination disorder (DCD) classification of children according to the Movement Assessment Battery for Children–Second Edition (MABC-2) and Developmental Coordination Disorder Questionnaire (DCDQ) scores and history of physical therapy (PT) or occupational therapy (OT).

Child	Milestone ^a	MABC-2 zone ^b	DCDQ	DCD	Therapy ^c
1	Met	Amber	Suspect of DCD	Yes	No
2	Met	Green	Probably not DCD	No	No
3*	Met	Amber	Suspect of DCD	Yes	Yes (OT)
4	Not met	Red	Suspect of DCD	Yes	Yes (PT, OT)
5	Not met	Red	Suspect of DCD	Yes	Yes
6	Not met	Red	Probably not DCD	Yes	Yes (PT)
7	Met	Red	Probably not DCD	Yes	No

^aMilestone met if walking was achieved by 16 months of age. ^bDCD classification based on the MABC-2 zone (DCD if red/amber). ^cIndication of whether child was undergoing physical or occupational therapy at the time of the study.

*Child had a previous diagnosis of DCD or Dyspraxia based on parent report.

Discussion

This study investigated the co-occurrence of DCD in a small sample of children with CAS (with and without language impairment). Results suggest that the potential for undiagnosed co-occurrence of DCD among children with CAS is high and clinically significant. These results are preliminary but support elevated rates of motor impairments and functional limitations in this population (Duchow et al., 2019; Iuzzini-Seigel, 2019). Findings also add to the emerging research base showing that children with CAS and co-occurring DLD (CAS + DLD) may represent a subgroup that tends to perform differently and more poorly on motor tasks than those with CAS-only (Iuzzini-Seigel, 2019, 2021; Zuk et al., 2018).

DCD Affected the Majority of Children With CAS

Results show that 85% (6/7) of our school-age participants with CAS could be diagnosed with DCD based on the DSM-5 criteria; however, only one child had a previous actual diagnosis of DCD. Co-occurring DLD was also evident in 57% (4/7) of our sample based on Core Language scores on the CELF-5; all of these participants had DCD as well. These findings extend our previous research (Iuzzini-Seigel, 2019) that showed co-occurring motor and language deficits in 7/10 participants with CAS, whereas only 1/3 participants with CAS and normal language in that study demonstrated co-occurring motor impairments. The current work on a small sample is preliminary but important because it integrates direct motor testing along with the DCDQ and health history questionnaire, which had not previously been undertaken for children with CAS. Taken together, these assessments show that children with CAS—and especially those with co-occurring DLD—are at high risk for DCD.

Findings show that parent responses on the DCDQ at times seemed to over- or underestimate their child's motor abilities. There were three parents who indicated on the DCDQ that their child did not have any functional limitations, even though two of these children scored in the red zone of the MABC, indicating poor motor skills and a likely DCD diagnosis. This discrepancy may be due to parents giving their child “credit” for making an effort or due to perceived improvement following therapy, rather than an accurate assessment of their child's present motor ability relative to same age peers. It is also possible that children who have poorer motor skills may be less interested in activities that require running, aiming, and catching and therefore parents may have less of an opportunity to observe and therefore accurately report on these skills. Parents may also not be able to properly gauge whether their child can do things like

“write fast enough to keep up with other children in the class” because they do not directly observe these types of skills in the presence of their child's peers. The discrepancy between results of direct motor testing and parent report on the DCDQ suggests that while this survey instrument may be a helpful supplement to direct motor testing, it should not be used as a proxy for direct evaluation of motor skills for children in this population.

Despite the high rate of motor deficits observed based on MABC-2 testing, only 4/7 had previously undergone physical or occupational therapy prior to participating in the study. This percentage is higher than the 28% of participants in our previous work who had previously seen a physical or occupational therapist even though they demonstrated significant motor impairments when tested by the MABC-2. Despite the small sample sizes in each of these studies, these numbers are critical and should call the attention of pediatricians and SLPs working with children with CAS: Evaluation and treatment for potential motor problems is imperative in this population, and referrals to physical and occupational therapists for standardized assessments are needed in the majority of cases.

Co-occurrence of CAS, DLD, and DCD

The majority of participants in this study had co-occurring DLD (4/7), and all of the children in this subgroup met criteria for DCD as well. Previous research has shown that children with CAS who have co-occurring language and motor deficits tend to have procedural learning deficits as well (Iuzzini-Seigel, 2021). A procedural learning deficit is posited to cause multisystem deficits consistent with the profile we observed for the majority of children in the current study. Previous research (Iuzzini-Seigel, 2021) showed that while children with CAS do learn patterns, they require an increased number of exposures to the pattern to demonstrate this learning. This is consistent with what is observed in treatment as well, wherein children with CAS require a high number of practice trials during each session (e.g., Edeal & Gildersleeve-Neumann, 2011) and frequent sessions (e.g., Murray et al., 2014; Thomas et al., 2014) to make progress. Over time, with appropriately intense and frequent targeted treatment, children with CAS do typically make progress on their speech goals and demonstrate increased intelligibility, accuracy, consistency, prosodic accuracy, and expanded speech sound inventories (Edeal & Gildersleeve-Neumann, 2011; Iuzzini & Forrest, 2010; Maas et al., 2012; Maas & Farinella, 2012; Murray et al., 2015; Namasivayam et al., 2015; Stokes & Griffiths, 2010; Strand et al., 2006; Thomas et al., 2014). It is possible that children in this population may require frequent, targeted types of interventions for physical and occupational therapies as well. Future work should investigate the content and treatment delivery schedule of these interventions

for children with CAS + DCD as a step toward optimizing care for children in this population.

Co-occurrence of CAS, ASD, and DCD

An ASD diagnosis was reported for two participants. These participants scored in the red and amber zone of the MABC-2 and as “suspect of DCD” on the DCDQ. Motor challenges are a clinically significant problem in ASD—previous research has identified that over 90% of cases in the ASD group met criteria for co-occurring DCD (H. Miller et al., 2021). Therefore, a co-occurring diagnosis of ASD should not interfere in the process of referral and evaluation for gross and fine motor skills in children with CAS. Future work in a larger sample should compare motor performance of children with CAS with and without ASD to better understand the contribution of ASD to the overall motor profile of children with this comorbid diagnosis.

When Motor Impairments Do Not Indicate DCD

The current data are consistent with previous studies that showed significant motor deficits in children with CAS (Duchow et al., 2019; Iuzzini-Seigel, 2019). In the current work, 85% of participants met criteria for a diagnosis of DCD. It is important to note, however, that not every motor problem/impairment warrants a diagnosis of DCD. DCD is a neurodevelopmental disorder with a specific set of criteria that must be met for a diagnosis. Specifically, a child should demonstrate poor motor proficiency that affects activities of daily living and other function. Some children may have low motor skills due to a lack of exposure or practice, but that does not qualify as DCD. Currently, there is a downward trend reported in the literature in which children’s motor skill proficiency is increasingly falling below expected levels (Bardid et al., 2015; Hardy et al., 2013). For example, a recent study of 707 school-age children found that 175 (25%) of them scored below or well-below average on a comprehensive test of motor proficiency (Ferreira et al., 2018). While this type of low motor skills alone may not be functionally severe enough to suggest a diagnosis of DCD, it does mean that, at the very least, a referral and potentially an incentive for practice of motor activities should be made.

Other motor impairments can actually preclude a DCD diagnosis. Criterion D excludes other conditions that are more severe than DCD and may explain motor difficulties. The most obvious example of a motor disorder that would otherwise explain motor problems is cerebral palsy, but other disorders such as muscular dystrophy, childhood arthritis, and also drug side effects (e.g., neuroleptics, sedatives, etc.; Blank et al., 2019) can also explain motor impairments. Obviously, the SLP will refer the child for

standardized motor assessments, and a decision of whether the child has DCD or not will be made by other professional. Here, our results simply bring attention to the fact that motor deficits seen in children with CAS and CAS + DLD often warrant a diagnosis of DCD.

Specificity of Motor Deficits

Overall, component scores on the MABC-2 were lowest on Manual Dexterity, followed by scores on Balance and Aiming and Catching. While DCD is a comprehensive disorder of motor proficiency (meaning that there are deficits in both fine and gross motor deficits), it is possible to see a pattern of lower scores on Manual Dexterity, which is an important finding—Manual Dexterity and other fine motor skills are constantly required for school achievement and may therefore disproportionately limit access to curricula compared to other motor deficits.

Previous work in children with DLD (Hill, 2001; Sack et al., 2021; Sanjeevan & Mainela-Arnold, 2019) also showed greater deficits in Manual Dexterity and Balance subtests relative to Aiming and Catching. Sack et al. found that only Manual Dexterity and Balance were correlated with language outcomes and posited that these subtests were particularly challenging due to the sequencing elements required by the Manual Dexterity subtest and the higher-order cognitive processes required for the Balance subtest. In addition, Aiming and Catching may be skills that are prone to greater exposure and direct training outside of the clinical and lab settings, which help children to succeed on this subtest.

Divergent Scores on Tests and Questionnaires

It is important to note that a DCD diagnosis is not solely based on numbers on specific assessments. A child may be diagnosed with DCD even if they score as “probably not DCD” on the DCDQ or in the green zone of the MABC-2. Other tests may be used and assessors may choose to look at an array of symptoms instead of specific scores. This was exemplified in Children 6 and 7, who scored in the red zone of the MABC-2 but scored as “probably not DCD” on the DCDQ. Parents may perceive a child as having better skills than they do if a child has somewhat improved after undergoing extensive fine or gross motor skill intervention, or because the child puts in a great deal of effort, or because the parent has not observed their child perform the targeted tasks in the presence of typically developing peers and therefore the parent is not able to make an accurate comparison. Obviously, several factors may affect testing performance and testing score. Here, we chose to “assign” a DCD diagnosis based on the MABC-2 results since that is a direct measure of

motor performance. However, it is important to note that the diagnosis is typically made by a team and goes beyond the results on specific assessments. While the use of standardized testing is necessary, a diagnosis goes beyond the exact numbers on tests.

The Need for Targeted Treatment

Motor therapy (i.e., physical therapy/occupational therapy) was reportedly delivered 1 time/week to those that received it, which may not be sufficiently frequent for children with procedural learning deficits such as children with CAS. It is essential that treatment occurs at an adequate dosage and frequency to see gains. One study on children with DCD showed that participation in a group motor skill intervention program twice a week for 12 weeks improved overall motor proficiency, whereas children participating in the same group program once a week for 10 weeks did not show any significant improvements (Caçola et al., 2016). It is essential that dosage frequency studies are conducted for children with CAS and co-occurring DCD to determine best treatment schedules and treatment distribution for fine and gross motor therapies that can support children coping with this constellation of impairments.

It is important to note that the functional limitations associated with DCD require interventions that target specific motor problems. Findings from a recent systematic review (Smits-Engelsman et al., 2018) revealed positive gains in activity-based and body function outcomes following activity-oriented interventions (i.e., treatments designed to improve performance in specific activities such as working on handwriting skills). In contrast, varied levels of effectiveness were reported for body function-oriented therapy, which targets capacities that underlie motor tasks (e.g., strength training, aerobic training, selective muscle activation [biofeedback], and visual training; Smits-Engelsman et al., 2018). Some studies revealed positive outcomes for treatments that integrate body function and task-oriented interventions as they increase carryover to functional tasks and contexts. Therefore, motor training that is specific to the motor difficulties experienced by the child can help improve their functional performance on those tasks.

DCD Can Impede Access to the Curriculum

While children with DCD may be able to ambulate and hold a pencil to write their name, their fine and gross motor deficits suggest that they may not have adequate skills to fully access their curricula at school. Poor performance on speeded manual dexterity tasks as demonstrated by the children in this study is a likely indicator that they may have difficulty writing quickly and neatly enough to be an efficient and effective note taker. In addition, difficulty writing neatly is also an indicator that a child might

have challenges properly lining up numbers when solving math problems. Difficulties with balance, for example, may affect posture while seated, which also affects the ability to pay attention, work on activities, and copy/write assignments. Problems with gross motor skills such as aiming and catching affect the ability to perform in physical education and play in recess. In addition, issues with planning and sequencing of motor skills that are frequently seen in DCD can affect a child's overall ability to organize their schoolwork, materials, desk contents, and backpack. Taken together, these deficits will likely limit access to the curriculum for a population of children who are already shown to have academic challenges (Lewis et al., 2000, 2004) and need all the advantages possible to support their success in the classroom.

Physical and Mental Health Consequences of DCD

Most importantly, delayed (or, more commonly, lack of) diagnosis and treatment of motor problems can lead to severe mental and physical health consequences (Caçola & Killian, 2018; Hendrix et al., 2014; Li et al., 2018; Zhu et al., 2014) for a developing child with or without CAS. There is a substantial literature showing increased rates of obesity among children and adolescents with DCD (Hendrix et al., 2014), which thus increases long-term risk of significant health issues including stroke, heart disease, and diabetes for children in this population (American College of Sports Medicine, 2020). Recently, robust evidence has emerged to support the notion that children with DCD have an increased risk for mental health difficulties (Lingam et al., 2012; Missiuna et al., 2014). Teachers report that school-age children with DCD have fewer friends and are more socially isolated than their peers (Piek et al., 2005; Poulsen et al., 2008). Likewise, they tend to report lower self-esteem, possibly due in part to having fewer social contacts and friendships (Cairney et al., 2007; Poulsen et al., 2008). Further research is needed to determine whether severe motor problems could have an additive or even exponential impact on psychological or social health in children with CAS, above and beyond the communication and social-emotional challenges inherent to the disorder.

Interprofessional Practice in Schools/Recommendations

These preliminary data suggest that children with CAS are at high risk for DCD, and consequently, motor evaluations should be part of the diagnostic plan for children with CAS. It may be helpful to have caregivers and teachers complete the DCDQ for children with CAS to better understand the functional limitations that children in

this population are experiencing. Teachers may be an important part of the process of identifying potential motor difficulties and referring for assessment and intervention. SLPs, teachers, and physical/occupational therapists should work together to learn about symptoms and characteristics of DCD for proper referral and evaluation. For example, children with DCD may sometimes seem “inattentive” or “fidgety,” which is usually considered a behavioral issue—but in this population, inattention may result from frustration, fatigue, or overwhelm with motor activities required throughout the day, and fidgeting may result from efforts to control posture. It is important for everyone in the school system to know how these types of behaviors may be related to DCD. SLPs can be at the forefront of the screening and referral process. A brief resource sheet on DCD symptoms, diagnostic criteria, and treating DCD is included in Supplemental Material S1 for your usage.

Limitations

This study has several limitations. First, the families participating in the study may have volunteered for this study due to a concern with motor skills, which may have biased the results. In addition, the data were collected during the COVID-19 pandemic, a time in which many children may have had to stay home and restrict extracurricular activities and in-person therapies, as well as school physical education. Recent studies show an increase in both sedentary and screen leisure time compared to nationally representative pediatric samples before the pandemic (Alves et al., 2021), which may have contributed to declines in motor performance in this population. In addition, two children evidenced “lower extreme” classifications on nonverbal IQ. As per Blank et al.’s (2019) recommendation, there is no cutoff for IQ when diagnosing DCD; instead, an evaluation must be conducted to determine whether the motor deficits may not be better explained by IQ. We were not able to conduct further evaluations in this study, but motor deficits were present in both children. Finally, because the speech-language assessment portion of the study was conducted virtually, we did not conduct hearing screenings during the assessment period, but reportedly, all participants had previously undergone and passed a hearing screening.

We believe that the findings of this study outweigh its limitations. To the best of our knowledge, this study is the first to conduct comprehensive DCD assessments using multiple instruments in children with CAS. Future studies should consider investigating specifics of motor problems in children with CAS, as well as study the effectiveness of motor skill-based interventions in this population. Finally, future work should investigate the pathway to diagnosis and intervention related to DCD in children with CAS.

Conclusions

The results of this study demonstrate that most of our small sample of children with CAS meet diagnostic criteria for DCD, even when already receiving physical or occupational therapy. When DLD was present, every child met criteria for a DCD diagnosis. In the community, however, most individuals with CAS do not carry a co-occurring DCD diagnosis that would facilitate access to or insurance coverage for motor interventions beyond achievement of early gross motor milestones. Our findings suggest that children with CAS should be referred and evaluated for motor problems early on so they can receive proper intervention for motor difficulties that may be associated with DCD. Early identification and treatment of gross and fine motor problems may help to reduce or prevent physical and mental health issues and improve long-term treatment outcomes and overall quality of life in this population.

Data Availability Statement

All data generated or analyzed during this study are included in this published clinical focus article.

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