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Tutorial

Update on Identification and Treatment of Infants and Toddlers With Suspected Childhood Apraxia of Speech

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ABSTRACT

Purpose: The purpose of this tutorial is to (a) provide an updated review of the literature pertaining to proposed early features of childhood apraxia of speech (CAS), (b) discuss the findings of recent treatment studies of infants and toddlers with suspected CAS (sCAS), and (c) present evidence-based strategies and tools that can be used for the identification of and intervention for infants and toddlers with sCAS or at high risk for the disorder.
Method: Since Davis and Velleman's (2000) seminal work on assessment and intervention in infants and toddlers with sCAS, limited research has guided clinicians in the complex task of identifying and treating early speech motor difficulties prior to a definitive diagnosis of CAS. Following the structure of Davis and Velleman, we explore the proposed early characteristics of CAS with reference to contemporary research. Next, we describe the limited treatment studies that have investigated intervention for infants and toddlers at risk of or suspected of having CAS. Finally, we present practical suggestions for integrating this knowledge into clinical practice.
Conclusions: Many of the originally proposed correlates of CAS in infants and toddlers now have research supporting their presence. However, questions remain about the developmental trajectory of the disorder. Although limited in number and restricted by lack of experimental control, emerging treatment studies can help guide clinicians in providing appropriate intervention to infants and toddlers with sCAS who need not wait for a definitive diagnosis to initiate intervention.

Childhood apraxia of speech (CAS) is considered to be a neurobiological impairment of speech motor movement affecting the precision, consistency, and intelligibility of speech sound production (American Speech-Language-Hearing Association [ASHA], 2007). Because of its presumed neurobiological basis, CAS is believed to be present from birth in most cases. Core symptoms that become evident in childhood include inconsistent consonant and vowel errors during syllable or word repetitions, disrupted coarticulatory inter- and intrasyllabic transitions, and deficits in lexical or phrasal prosody (ASHA, 2007).

Research efforts to describe, diagnose, and treat the disorder have largely focused on older children and adults, with comparatively little research on infants (ages 0–12 months) and toddlers (ages 1–3 years; Overby & Highman, 2021). However, observable early speech motor movement/planning deficits should nevertheless be expected in infants and toddlers with suspected CAS (sCAS) or those considered at high risk due to their family history or genetic profile (Davis & Velleman, 2000; Highman et al., 2012; Maassen, 2002). Recently, atypicalities in early vocal development, such as babbling differences and speech

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sound development delays, have been reported in children with or genetically at risk for sCAS (Abbiati et al., 2022; Aziz et al., 2010; Highman et al., 2008, 2012; Overby & Caspari, 2015; Overby et al., 2019, 2020). These atypicalities have provided clinicians with new perspectives for identifying sCAS in infants and toddlers.

Until now, the seminal work of Davis and Velleman (2000) has been the most comprehensive published resource available for speech-language pathologists (SLPs) assessing and treating infants and toddlers with sCAS. Davis and Velleman outlined characteristics of CAS that had gained consensus in the literature and proposed correlates of these for infants and toddlers. Spanning general, phonetic/phonological, and co-occurring characteristics, the proposed correlates provided clinicians with information to aid clinical decision making. The purpose of this tutorial is to provide clinicians with an updated review of the evidence regarding identification of the disorder in very young children and assist clinicians in interpreting those findings to inform evidence-based goals and measure progress in infants and toddlers with sCAS.

Differential Diagnosis

The etiology of CAS is largely unknown for most reported cases (Murray et al., 2015), and therefore, many children are believed to have an idiopathic form of the disorder (i.e., occurring in the absence of an underlying condition). Although much of the CAS research in the last 2 decades has focused on children with this idiopathic form, there has been increasing acknowledgment that CAS can not only be present in the context of known neurodevelopmental disorders (e.g., autism [Beiting & Maas, 2021], Down syndrome [Wilson et al., 2019], and cerebral palsy [Mei et al., 2020]), but that this comorbidity is not unusual. For example, prevalence estimates of CAS have been reported in children with Down syndrome (11%–15%; Kumin, 2006; Shriberg et al., 2019), autism (0%–63%; E. J. Dawson, 2010; Shriberg et al., 2019; Tierney et al., 2015), galactosemia (6.5%–24%; Shriberg et al., 2011, 2019), and 22q11.2 syndrome (11.8%; Shriberg et al., 2019). High co-occurrence of CAS has been reported in children with 7q11.23 duplication syndrome (Dup7; > 75%; Velleman & Mervis, 2011) and in boys with 49, XXXXY syndrome (91.8%; Samango-Sprouse et al., 2021).

Because CAS may either appear as an idiopathic condition or co-occur with other neurodevelopmental disorders, SLPs face challenges in the differential diagnosis of infants and toddlers with sCAS. A majority (56%) of 147 surveyed SLPs believed that CAS could not be diagnosed in preverbal children (Randazzo, 2019). Nevertheless, converging evidence across retrospective parent reports, retrospective video analyses, and prospective longitudinal studies suggests that SLPs can identify and treat at-risk infants and toddlers within an evidence-based framework, prior to a diagnosis. Recent evidence presented in this tutorial on genetics, general characteristics, phonological/phonetic correlates, and co-occurring characteristics of CAS in very young children can be helpful in this endeavor.

Genetics

In the last decade, there have been multiple reports of specific genes and gene variants (deletions, duplications, or genomic anomalies) as possible etiologies of CAS. Thirty-four or more different genes have already been identified as associated with CAS (Chenausky & Tager-Flusberg, 2022; Kaspi et al., 2022). "Genes of interest" include 2,145 genes from every chromosome except for 10 and Y. Many of these genetic differences are "de novo" (i.e., they were not passed down by the parents; Kaspi et al., 2022). Although it is beyond the scope of this tutorial to summarize such an extensive body of work, we offer a brief overview of the relevance of genetic findings to the early identification of infants and toddlers with sCAS.

Difficulties with early speech motor control in some children with sCAS would be consistent with the likelihood of genetic anomalies (Centanni et al., 2015; Peter et al., 2016; Turner et al., 2013). That is, when impairments in speech motor control appear in early development, evidence now suggests that the source of the problem for some infants and toddlers may be a genetically based expression of CAS.

Many gene candidates (single genes and gene variants) for the disorder have been reported (e.g., Chenausky & Tager-Flusberg, 2022; Kaspi et al., 2022; Laffin et al., 2012; Morgan & Webster, 2018; Worthey et al., 2013). For example, *FOXP2* on the 7th chromosome (e.g., Adegbola et al., 2015; Centanni et al., 2015; Morgan et al., 2017; Rice et al., 2012; Turner et al., 2013) and 16p11.2 on the 16th chromosome (Demopoulos et al., 2018; Mei et al., 2018; Raca et al., 2013) appear to be associated with motor speech control and CAS. In addition, there are neurodevelopmental disorders (such as epilepsy and dysarthria) that can be comorbid with CAS and for which there is evidence of a possible common genetic pathway (i.e., the same genetic difference is responsible for both the neurodevelopmental disorder and the CAS; see Morgan & Webster, 2018, for a review).

Familial aggregation data (Lewis et al., 2004; Peter & Raskind, 2011; Turner, 2017) suggest that speech sound development may be influenced by the interaction of multiple genetic and environmental factors (Peter et al., 2016).

Although far more research is needed into the genetic origins of CAS (Laffin et al., 2012), the findings presented above suggest that the etiology of CAS is likely heterogeneous (i.e., due to one or more of several genetic differences). These genetic differences, which may or may not co-occur with other neurodevelopmental disorders, can influence the acquisition of early speech motor control and planning by infants and toddlers.

Chenausky and Tager-Flusberg (2022) note that "children with disorders of motor planning plus other NDDs [neurodevelopmental disorders] experience more severe communication profiles than children without such comorbidity" (n.p.); Kaspi et al. (2022) indicate that children with CAS for whom a genetic basis can currently be identified are more likely to have motor, language, and/or cognitive impairments as well. Lang et al. (2019) highlight the important role that delayed canonical babbling, in particular, can play as a red flag for later-detected developmental disorders, such as fragile X and Rett syndrome. However, more specific differences in CAS symptoms between children with CAS associated with a neurodevelopmental disorder versus those with no known cause for their motor speech disorder have not yet been identified.

The question of when to make a referral for genetic testing is complex, depending largely on the presence of other potentially genetic symptoms, family history of speech-language or other potentially genetically based disorders, and severity. The tutorial provided by Pletcher et al. (2007) offers a decision framework for health care professionals considering a referral for genetic testing and may be helpful to SLPs in making this decision. Clearly, additional research on causative genes for CAS and the specific role(s) these genes may have in the early expression of the disorder is crucial to furthering our understanding of genetic risk factors for CAS in infants and toddlers.

General Characteristics

In their comprehensive review of CAS in infants and toddlers, Davis and Velleman (2000) described several general characteristics of CAS that clinicians should use to aid in their differential diagnosis of sCAS from other speech sound disorders. One proposed characteristic was that the child's speech difficulties could not be attributed to deficits in peripheral motor or sensory function, cognition, or receptive language. It was suggested that infants and toddlers with sCAS were likely to demonstrate a receptive–expressive gap, with receptive language being more advanced than expressive language. Although the intelligence quotient of these infants and toddlers was suspected to be largely within normal limits, this characteristic could not be reliably assessed by clinicians at that time. Nevertheless, Davis and Velleman reported that many early play skills should be appropriate for the child's chronological age, although a toddler with speech motor planning deficits might demonstrate difficulties in planning sequenced, hierarchical play routines. For example, Davis and Velleman noted that while a toddler with sCAS may be able to pretend to cook, feed a baby, or drive a car, the child may experience difficulty integrating those isolated play schemes together (e.g., driving a car to get food to feed a baby).

Current Evidence

Current thinking on general characteristics of CAS in infants and toddlers concurs with Davis and Velleman (2000) in that the disorder does not directly arise from impairments in peripheral motor or sensory function, cognition, and/or receptive language (although such impairments may be found in infants and toddlers with sCAS co-occurring with other neurodevelopmental disorders). The deficits associated with CAS are now believed to arise from congenital speech motor control impairments that reduce an infant's vocal exploration and babbling (Maassen, 2002) and the tactile, proprioceptive, and auditory feedback required for mapping articulatory movement to auditory consequences (Kuhl & Melzoff, 1996; Maassen, 2002; Tourville & Guenther, 2011). It is this impoverished mapping (not peripheral, cognitive, or receptive language deficits) that is believed to be associated with impaired phone production in infancy and beyond (Guenther, 2006; Howard & Messum, 2011).

The presence of a receptive–expressive gap (Davis & Velleman, 2000) remains a red flag for clinicians and has been documented in at-risk (Highman et al., 2013) and affected (Highman et al., 2012) infants and toddlers; see Table 1. However, such a gap does not always indicate CAS; it may instead foreshadow a language disorder. In addition, due to individual variability, this gap may not be evident in every infant and toddler later diagnosed with CAS. Highman et al. (2012) reported that out of five preschoolers exhibiting clinical symptoms of CAS, all but one presented with a receptive–expressive gap according to retrospective infant data on the Receptive–Expressive Emergent Language Assessment–Second Edition (Bzoch & League, 1991). A study of 32 children with CAS, some of whom were as young as 25 months old, revealed typical receptive language levels on the Preschool Language Scales (PLS; Zimmerman et al., 2002), but overall expressive language performance on the PLS fell 1.5 *SD*s below the mean (Newmeyer et al., 2007). In a longitudinal study tracking the development of infant siblings of children with CAS from ages 9 months to 2 years (Highman et al., 2013), a clear receptive–expressive gap on standardized assessments was observed for the one infant who went on to show evidence of CAS.

Table 1. Assessment evidence, tools, and strategies.

Characteristic	CAS population	Sources	Findings (single source or summarized across multiple sources)	Assessment tools and strategies
Family history of CAS	Children with CAS	Multiple sources	• Multiple gene candidates • Genes and environment interact	Formal or informal caregiver questionnaire
	Siblings	Highman et al. (2013)	• Siblings may be at risk	
Receptive–expressive language gap	LCAS	Highman et al. (2012)	• Some participants show receptive–expressive language gap	CDI parent vocabulary questionnaire or early language test (e.g., PLS-5)
	Siblings	Highman et al. (2013)		
	Dup7	Abbiati et al. (2022)		
Limited phonetic diversity (i.e., few consonants in inventory or reduced number of different consonants/min)	LCAS	Abbiati et al. (2022) Aziz et al. (2010) Beerman (2011) Canault et al. (2021) Highman et al. (2008) Overby et al. (2019) Overby & Caspari (2015)	• Parents report lack of phonemes • Vowel errors may not change with maturation • Group mean number different consonants/min was 1/4 to 1/5 of expected number • Often no consonant at 12 mos. • ≤ 3 consonants at 8–16 mos. • ≤ 5 consonants at 17–24 mos. • Often only 1–2 inventory places and/or manners at 24 mos.	Formal or informal caregiver questionnaire Create phonetic inventory from speech sample or caregiver questionnaire: Minimum 50 utterances total Across ≥ 3 observations Phoneme must appear ≥ twice Age of first consonant acquisition Check variety by: place, manner, voicing Compare to typical normative data
	Siblings	Highman et al. (2013)	• Reduced diversity in some	
	Dup7	Abbiati et al. (2022)	• Group mean number different consonants/min was 1/5 of expected number	
Reduced/delayed canonical babble	LCAS	Aziz et al. (2010) Abbiati et al. (2022) Highman et al. (2008, 2012) Overby et al. (2020) Overby & Caspari (2015)	• Parents report reduced babbling • Few participants had 0.15 CBR by 12 mos. • Most participants had 0.15 CBR by 18 mos.	Determine babbling onset from parent questionnaire Calculate babbling status from speech sample: CBR Canonical babble frequency Compare to typical normative data
	Dup7	Abbiati et al. (2022)	• CBR group mean was 1/2 of expected • Group mean canonical babble frequency was 1/4 to 1/5 of expected	
Limited volubility (i.e., "quiet"; syllables/min)	LCAS	Abbiati et al. (2022) Highman et al. (2008) Overby et al. (2019, 2020) Overby & Caspari (2015)	• Parent recall of less vocalization • Fewer utterances/min • Group mean syllable rate was 1/4 of expected	Determine volubility from speech sample Check with parent about frequency of client's vocalization
	Dup7	Abbiati et al. (2022)	• Group mean syllable rate was 1/4 to 1/5 of expected	
Restricted word shape	LCAS	Abbiati et al. (2022) Overby et al. (2019) Overby & Caspari (2015)	• Often limited to consonant, vowel, or consonant–vowel • Little word shape diversity	Determine word shape diversity Compare to typical normative data
	Dup7	Abbiati et al. (2022)	• Word shape diversity group mean was 1/3 of expected	

Note. CAS = childhood apraxia of speech; Siblings = siblings of children with CAS; LCAS = later diagnosed with childhood apraxia of speech; Dup7 = 7q11.23 duplication syndrome; CDI = Communication Development Inventories; PLS-5 = Preschool Language Scales–Fifth Edition; mos. = months; CBR = canonical babbling ratio (number of canonical syllables/total number of syllables); canonical babble frequency = number of canonical babbles/min.

Although CAS appears to impact expressive language, the exact nature of any relationship remains unclear (Murray et al., 2018), especially in very young children. Despite expressive language difficulties, communicative intent (e.g., use of gestures, pointing, and eye gaze) may be spared. In one investigation, evidence of strong communicative intent (as evidenced by measures of manual gesture use) in the context of weak speech sound production skills was documented in an infant later diagnosed with CAS (Highman et al., 2013). This limited finding, in association with support for augmentative communication for infants and toddlers with sCAS (Apraxia Kids, n.d.; Fish & Skinder-Meredith, 2022), suggests a need for broader research describing the developmental trajectory of communicative intent in this population.

Findings in older children with CAS support a view that speech processing deficits (i.e., processes involved in the perception, storage, and production of speech) may underlie at least some of the speech sound deficits associated with CAS (Groenen et al., 1996; Maassen et al., 2003; Shriberg et al., 2017). This is particularly evident for children with CAS and comorbid language difficulties, rather than those with CAS alone (Spencer et al., 2022). However, no research has addressed speech processing deficits in infants and toddlers later identified with CAS, or whether/how any such deficits might present in early speech sound development.

Phonological/Phonetic Correlates

Davis and Velleman (2000) described phonological/phonetic characteristics of CAS in older children and hypothesized correlates for infants and toddlers. The authors cautioned that these characteristics overlapped with those of other speech sound disorders and that no single correlate was a necessary attribute of CAS in infants and toddlers. Reported infant–toddler correlates included systematic gaps (missing categories of speech sounds) with little variety in the child's consonant or vowel repertoire, immature babbling/lack of babbling, few word shapes with consistent meaning, incomplete syllables and/or reliance on singleton consonants or vowels, restricted or stereotypical intonation patterns, words disappearing from the child's repertoire, minimal combinations of different syllables or movement patterns, and groping of articulators. Thus, speech output in infants and toddlers with sCAS could be limited in a variety of respects, beyond simply reduced volubility (i.e., frequency of speechlike productions). Furthermore, unusual variability during productions of the same word, as well as more difficulty generating novel speech productions (e.g., "Say your new word") than familiar routine words, could be an important early diagnostic indicator of CAS. However, due to the limited output and variable speech sound production in infants and toddlers with sCAS, Davis and Velleman recommended that SLPs working with this population obtain a 6- to 12-month therapy history with the child before designating a CAS diagnosis.

Current Evidence

As detailed in Table 1, research studies focused on infants and toddlers later identified with CAS have provided quantitative support for many of these aforementioned clinical observations. Vocalization measures (described below) are directly or indirectly related to "canonical babbling," a major milestone in early vocal development, and have predominantly been used in these quantitative studies. Canonical babbling is the vocalization of rhythmical units consisting of at least one consonant and one vowel nucleus with a rapid but inaudible transition between the two sounds (Oller, 1986). This vocalization milestone is readily identified by caregivers and is robust across languages (Oller et al., 2001).

Vocalization Measures

Four clinical assessment measures of early vocalizations used most often by researchers and clinicians have been phonetic diversity, canonical babbling ratio (CBR), volubility, and mean babbling level (MBL). Phonetic diversity is the number of different phones in a child's repertoire. A child's CBR is most often calculated by counting the number of canonical syllables and dividing it by the total number of syllables (both canonical and noncanonical). A simplified version of CBR (i.e., the number of utterances containing canonical syllables divided by the total number of utterances) has also been shown to be valid and highly correlated with the more commonly used syllable-based CBR (Nyman et al., 2021). A CBR of at least 0.14–0.15 is considered an indicator of canonical babble onset (Lynch et al., 1995; Nyman et al., 2021). Volubility is typically defined as the number of speechlike syllables produced per minute.

MBL, a measure of phonological maturity and diversity in children in the babbling stage of development, is calculated by first counting the number of babbled vocalizations at three different maturity levels (see Morris, 2010; Stoel-Gammon, 1987a). Following this, the number of Level 1 vocalizations is multiplied by 1, Level 2 vocalizations by 2, and Level 3 vocalizations by 3. These numbers are then summed, and the weighted total is then divided by the overall number of babbles to arrive at the MBL. This measure has not yet been used in published studies of infants or toddlers suspected of or at risk for CAS, though it has been used in studies of other populations (e.g., Morris, 2010; Stoel-Gammon, 1989).

Findings From Vocalization Measures

Systematic gaps in children's consonant repertoires, with little variety, have been reported by parents (Aziz

et al., 2010; Canault et al., 2021) and documented in the literature. Repertoire restrictions, such as three or fewer consonants between 8 and 16 months of age and/or five or fewer consonants between 17 and 24 months of age, overreliance on stops and nasals (e.g., [d], [b], [m]), and/or overreliance on phones with visually salient place features (e.g., bilabials; Highman et al., 2013; Overby & Caspari, 2015; Overby et al., 2019), have been observed. One possible early red flag for CAS is the lack of any consonant before 12 months of age (Overby et al., 2019), though clinicians should bear in mind that other neurodevelopmental disorders (e.g., hearing impairment) may also adversely impact consonant acquisition (Moeller et al., 2007).

Additional evidence of decreased repertoires is reported in toddlers with the genetic syndrome Dup7 (7q11.23 duplication syndrome). Dup7 results from an extra copy of approximately 26 genes in the Williams syndrome region of the 7th chromosome (Mervis et al., 2021). Children with Dup7 most typically demonstrate low-average cognitive abilities, with a relatively even profile across various cognitive skills (Mervis et al., 2015). Over 80% have some type of speech sound disorder, with more than three fourths of children with Dup7 displaying at least some symptoms of CAS (Mervis et al., 2021; Velleman & Mervis, 2011). Toddlers with Dup7 produced significantly fewer different consonants, place features, and manner features per minute ($p < .001$; Cohen's $d = 2.58$ or large effect size) than toddlers with typical development (TD; Abbiati et al., 2022). However, because these various studies of systematic gaps have also highlighted individuality and variability in speech sound development, clinicians should be aware that repertoire restrictions in a particular client could present quite differently than as described here.

Systematic vowel gaps have not been verified in infants and toddlers with sCAS, though it appears that older children with CAS produce vowels with greater variability in vowel length and formant frequencies than children with TD (Blech et al., 2007; Lenoci et al., 2021; Nijland et al., 2002, 2003). Beerman (2011) found no difference between the vowels of seven toddlers (aged 2;6–2;11 [years;months]) with CAS and two older groups (preschoolers [aged 4;0–4;11] and school-age children [aged 5;0–9;9]) with CAS with respect to the number of articulatory production errors, vowel-to-vowel movement errors, or consonant-to-vowel movement errors on the Kaufman Speech Praxis Test (Kaufman, 1995). While this finding implies that neither age nor maturation decreases (nor increases) the number of vowel errors in the speech of children with CAS, additional research is needed. In a parent retrospective study of infants with sCAS (Highman et al., 2008), parental recall of the frequency of infants with TD who produced vowel noises was statistically significantly greater than that of infants with sCAS, suggesting that vowel development of infants with sCAS was less robust than expected.

Evidence of reduced babbling in infants later diagnosed with CAS, as described retrospectively in both parent reports (Aziz et al., 2010; Highman et al., 2008; Overby & Caspari, 2015) and studies directly measuring vocalization types from recordings (Abbiati et al., 2022; Overby et al., 2020), includes fewer and less frequent canonical babbles compared to infants later diagnosed with non–motor speech sound disorders or those with TD. In addition, delayed canonical babbling onset, as measured by CBR, was reported in a study of 10 infants later diagnosed with CAS, only one of whom achieved a CBR of ≥ 0.15 between 7 and 12 months of age (Overby et al., 2020). Abbiati et al. (2022) found the CBR and babbling frequency of infants and toddlers with Dup7 to be statistically significantly lower than those of same-age youngsters with TD ($p < .008$, Cohen's $d = 3.00$, large effect size, and $p < .001$, Cohen's $d = 2.04$, large effect size, respectively). Reduced babbling in infants and toddlers at risk for sCAS is consistent with findings that infants later diagnosed with CAS vocalize less than their peers and produce less mature vocalizations (Overby et al., 2020), perhaps due to difficulties in the motor planning and execution required for vocal exploration.

Reports of reduced volubility have been documented in infants and toddlers later diagnosed with CAS or at risk for the disorder. Toddlers with Dup7 were statistically significantly less voluble than toddlers with TD (Abbiati et al., 2022). Furthermore, Overby et al. (2020) showed that infants and toddlers later diagnosed with CAS were statistically significantly less voluble compared to infants and toddlers later diagnosed with non–motor speech sound disorders or with TD. In two other studies investigating the vocal productivity of infants and toddlers later diagnosed with CAS, the number of phonetically transcribable vocalizations was notably lower in infants later diagnosed with CAS than infants with TD ($p = .005$, Overby & Caspari, 2015; $\Delta = .88$, Overby et al., 2019).

Recent studies have supported the observation that infants and toddlers later diagnosed with CAS (or at high risk for it) typically have restricted syllable and word shapes, which may be limited to singleton consonants or vowels in some children (Abbiati et al., 2022; Overby & Caspari, 2015; Overby et al., 2019). The most common syllable or word structure used by infants and toddlers later diagnosed with CAS was singleton vowel before 24 months of age, with few children using a consonant–vowel–consonant (CVC) word shape (Overby & Caspari, 2015). However, use of CVC by age 24 months is a common milestone for children with TD (Stoel-Gammon, 1987b).

Even though infants and toddlers later diagnosed with CAS have apparent differences from children with TD with respect to canonical babbling onset, CBR, volubility, and consonant variety, so do infants and toddlers with certain other neurodevelopmental disorders, as shown in Table 2. In addition to children later diagnosed with CAS and those with Dup7, several other populations also demonstrate delayed canonical babbling, including those with Down syndrome (Cobo-Lewis et al., 1996), autism (Patten et al., 2014), elevated likelihood of autism including children with Rett syndrome (Marschik et al., 2014), or hearing loss (Eilers & Oller, 1994). All these populations have also been shown to have lower CBRs (Bartl-Pokorny et al., 2022; Lofkvist et al., 2020; Patten et al., 2014; Stoel-Gammon, 1997) and, except those with Down syndrome, lower volubility and smaller consonant inventories (Marschik et al., 2014; Moeller et al., 2007; Schoen et al., 2011; Stoel-Gammon, 1997). Vocalization characteristics in some of these other groups (but not in individuals with CAS/at risk of CAS) include atypical nonspeech-like sounds and/or, for older English-exposed infants and toddlers, atypical non–English-like speech sounds. These are found in those who are autistic (Plumb & Wetherby, 2013) or at elevated likelihood of being autistic (Marschik et al., 2014) and those with Down syndrome (Legerstee et al., 1992). Vocal regression has also been reported in children with autism (Chericoni et al., 2016) and Rett syndrome (Marschik et al., 2012). More research is needed to confirm and elaborate on these findings. As such, clinicians must recognize that differences in babble development are not singular characteristics of CAS. Nevertheless, clinicians do not need a definitive CAS diagnosis in an infant or toddler to initiate appropriate early motor speech treatment protocols (described below).

Co-Occurring Characteristics

Davis and Velleman (2000) described co-occurring characteristics of CAS as symptoms frequently cited or observed by clinicians but "considered corollary and not central to the differential diagnosis" of CAS (p. 182). Possible co-occurring characteristics included idiosyncratic or home-based signs/manual gestures to aid functional communication, gross and fine motor praxis difficulties, uncoordinated feeding patterns, and excessive drooling. They suggested that there may also be a lack of flexibility in motor tasks, such that a motor task (as in eating) can be accomplished in only one way (e.g., with the same food, spoon, and bowl). Oral motor incoordination was also hypothesized to be present in some cases, so that the infant or toddler has difficulty imitating oral motor sequences upon request (e.g., smacking one's lips followed by tongue protrusion).

Current Evidence

There is currently insufficient evidence describing the extent and nature of co-occurring characteristics of CAS in infants and toddlers to draw clear conclusions about their significance. Despite a lack of evidence, we nevertheless suggest that the use of idiosyncratic or home-based signs/manual gestures by infants and toddlers later diagnosed with CAS remains a possible indicator of exceptional difficulty with functional expressive language and still cannot, as noted by Davis and Velleman (2000), be used to differentiate CAS from other disorders.

A small body of evidence implies fine and gross motor skill differences in infants and toddlers with CAS. Further interprofessional study is needed in light of the reported high rates of co-occurrence of fine and gross motor difficulties in older children with CAS (Iuzzini-Seigel et al., 2022). Of relevance to infants and toddlers is a prospective study that identified an association between poor oral–motor imitation skill and poor visual–motor integration in preschoolers with a severe speech sound disorder consistent with CAS (Newmeyer et al., 2007). However, the participant age range (25–72 months old) was

Table 2. Evidence for babble characteristics of various populations.

Population	Delayed onset canonical babble	Lower canonical babble ratio	Reduced volubility	Reduced consonant inventory	Atypical vocalizations	Vocal regression
LCAS	Y	Y	Y	Y	**?**	**?**
Dup7	Y	Y	Y	Y	N	N
Down syndrome	M	Y	N	N	Y	?
Autism	Y	Y	Y	Y	Y	Y
Rett syndrome	Y	Y	Y	Y	Y	Y
Hearing loss	Y	D	Y	Y	N	?

Note. LCAS = later diagnosis of childhood apraxia of speech; Y = published evidence for that characteristic; ? = no published evidence found regarding that characteristic; Dup7 = 7q11.23 duplication syndrome; N = published evidence suggests that that characteristic is not present; M = mixed results in published reports; D = depends on type of hearing loss, use of hearing aids versus cochlear implants, and number of hours/day of usage.

not exclusive to toddlers, and the criteria used for a CAS diagnosis were not reported. Highman et al. (2013) found that at-risk infants (i.e., siblings of children with CAS) demonstrated significantly lower fine motor performance on the Ages and Stages Questionnaire (Bricker et al., 1999) than infant peers with TD. Additionally, a retrospective parent report of speech and motor milestones in children later diagnosed with CAS revealed a statistically significant difference from children with TD in ages of onset of sitting upright and in crawling, but not of first steps (Highman et al., 2008).

Only one study to date has directly addressed the frequency of increased drooling and/or feeding problems in infants and toddlers later diagnosed with CAS. In their retrospective study of children with sCAS (n = 20), specific language impairment (n = 20), or TD (n = 20), Highman et al. (2008) found that more parents of children with sCAS (45%) reported their child had increased drooling as an infant than did parents of children in the TD group (10%). Similarly, 45% of parents of children with sCAS reported that their child experienced feeding problems during infancy compared to only 15% of parents of infants with TD. There was a statistically significant between-groups difference for drooling (p = .013) but not for feeding issues.

Iuzzini-Seigel (2021) proposed deficits in procedural learning to account for the inflexibility and difficulty that older children with CAS have in learning motor tasks, but application to infants and toddlers was not empirically addressed. Typically, children learn procedural motor tasks through repeated practice and automatization, but Iuzzini-Seigel theorizes that impairments in the mapping of articulatory movements to subsequent acoustic output (Guenther, 2006; Tourville & Guenther, 2011) ultimately lead to inconsistent speech sound production. This inconsistency is commonly considered a core feature of CAS (ASHA, 2007).

Another possible co-occurring characteristic of CAS, at least in some individuals, may be pediatric dysarthria (Iuzzini-Seigel et al., 2022), though studies to date have solely focused on older children. In one study of complex neurological disorders and CAS (Shriberg et al., 2019), 4.9% of children with idiopathic CAS had co-occurring dysarthria. However, this study also revealed that the prevalence in children with complex neurological disorders and CAS varied from 0% (in children with 16p11.2 deletion and duplication syndrome, idiopathic intellectual disorder, and fragile X syndrome) to 22% (in children with Down syndrome). Even though data lack descriptions of how dysarthria might present in infants and toddlers with CAS (with/without other neurological disorders), clinicians should be aware of the possibility that it might influence early speech sound development in some young children.

Since the publication of Davis and Velleman's (2000) study, there have been multiple studies about co-occurring language and literacy impairments in older children with CAS (e.g., Gillon & Moriarty, 2007; Iuzzini-Seigel, 2021; Lewis et al., 2004; McNeil et al., 2009; Miller & Lewis, 2022; Miller et al., 2019). Given the relations between early speech sound production and later language and literacy development, clinicians treating infants and toddlers with sCAS should be aware of the potential future deficits that may appear in older children's language and literacy development. However, a review of these findings is beyond the scope of this tutorial.

Factors Related to Intervention

In the treatment of infants and toddlers with sCAS, there are three factors related to intervention that bear particular discussion: the brain's neuroplasticity, principles of motor learning (PML), and a team approach to service delivery. Neuroplasticity addresses "when" treatment should start, PML address "how" intervention should be delivered, and a team approach addresses "who" should deliver the intervention.

Neuroplasticity

Neuroplasticity refers to the long-lasting changes in a brain's structure and function as a result of environmental input (Demarin et al., 2014; Kolb & Gibb, 2008). It is evident in non–speech motor learning (e.g., Doyon, 2008; Doyon et al., 2018) and speech-language learning (for a review, see Whelan et al., 2021). Brain changes related to neuroplasticity can occur throughout life during times of rapid synaptic development (Joja, 2013). They are more related to the stage of neural development than the specific chronological age of the individual (Kolb & Gibb, 2008). Nevertheless, greater therapeutic gains are made with infants and toddlers than neurologically mature individuals (Bruder, 2010; Grafman, 2000; Zwaigenbaum et al., 2013), possibly due to reorganization of existing neuronal networks or the development of novel synaptic networks during rapid neurological growth in young neurological systems (Kolb & Gibb, 2008).

Recent research has demonstrated that early intervention leads to important therapeutic gains in infants and toddlers with known neurodevelopmental disorders, such as hearing impairment (Ertmer et al., 2002), autism (G. Dawson et al., 2012), and Down syndrome (Hines & Bennett, 1996). Moreover, preemptive intervention has been found to be appropriate and successful for very young children with risk factors for neurodevelopmental disorders, prior to a confirmed diagnosis. For example,

early intervention provided to infants aged 9–14 months showing early behaviors associated with later autism significantly reduced the odds of an autism diagnosis at 3 years of age (Whitehouse et al., 2021). Early intervention programs with low–birth weight preterm infants, known to be at risk for later neurodevelopmental difficulties, have shown notable gains in the infants' cognition at ages 3 and 5 years (Nordhov et al., 2010), as well as their behavior (Nordhov et al., 2012).

In the past, SLPs working with infants and toddlers with sCAS may not have been comfortable initiating speech motor–based treatments before a diagnosis of CAS was confirmed, perhaps not until the child was aged 3–4 years and likely capable of participating in a speech motor assessment. However, the current findings on brain neuroplasticity and the emerging evidence summarized below suggest that a prediagnostic course of motor speech treatment for infants and toddlers with sCAS is an appropriate model of care. This prediagnostic approach to treatment is consistent with Davis and Velleman's (2000) suggestion of diagnostic therapy, where the clinician commences therapy, targeting areas of difficulty while continuing to observe the "presence and persistence of differential diagnostic indicators" (p. 183). Importantly, this approach includes addressing the child's broader communication skills. Thus, it supports a specific focus on the development of speech (consonant and vowel inventory, syllabic structure, etc.) in facilitating early communication skills.

PML

PML are variables that can influence the learning of motor skills (for a review, see Maas et al., 2008; definitions provided in the Appendix).

Research on the utility of PML in treating motor speech disorders has largely addressed adults with neurological impairment (e.g., acquired apraxia of speech; e.g., Wambaugh et al., 2013, 2014) or children with CAS (e.g., Edeal & Gildersleeve-Neumann, 2011; Maas et al., 2012, 2019; Maas & Farinella, 2012; Preston et al., 2017; Skelton & Hagopian, 2014). No studies have empirically examined the utility of PML in interventions for infants with sCAS. Although the extent to which they are "active ingredients" of treatment remains largely unclear, PML such as high practice amount, distributed practice sessions, and fading feedback frequency have been incorporated into existing treatments for toddlers with sCAS (e.g., Davis & Velleman, 2000).

In general, intervention studies with infants at risk for CAS have focused on increasing the infant's communication skills, including vocalization and babbling maturity and diversity, through changes in environmental/parental input. Infant interventions that target increased babbling have been successful in treating infants with other speech sound impairment difficulty, such as hearing impairment (Ertmer et al., 2002). They are consistent with the theorized importance of early vocal exploration and babbling for the mapping of articulatory movements to acoustic output (Kuhl & Melzoff, 1996; Maassen, 2002; Tourville & Guenther, 2011).

Team Approach

Children with multiple difficulties require a variety of skilled professionals to provide high-quality treatment and to work collaboratively to solve problems when they arise (Cooper-Duffy & Eaker, 2017). Thorough interprofessional assessment and intervention is critical given that, for example, 50%–80% of children with CAS may also demonstrate fine and/or gross motor deficits and up to 85% may meet criteria for developmental coordination disorder (Iuzzini-Seigel et al., 2022). Current findings on CAS in infants and toddlers suggest that, in addition to the caregiver(s), the pediatrician, and the SLP, the intervention team could include an occupational therapist, a physical therapist, a geneticist, and/or a developmental psychologist. Other relevant individuals could include the child's preschool teacher or day care provider. Each of these individuals can share information about the child's progress and difficulties as well as provide intervention within the provider's domain.

Intervention

Davis and Velleman (2000) described a viable model for diagnostic intervention for sCAS, allowing for differential diagnosis over a period of time, while simultaneously aiming to improve overall communicative competence. Establishing consistent interpersonal communication, followed by establishing consistent use of oral communication, was recommended as overarching sequential goals. Practical ideas were outlined to encourage vocalizations of any type (e.g., sound effects, speech in conjunction with movement, and verbal routines such as singing), followed by systematic sound system goals comprising expanding sounds and syllable structures.

Furthermore, Davis and Velleman (2000) described important components of therapy for this age group, including the importance of movement sequencing goals. They also recommended using short, frequent practice sessions augmented by group activities with verbal routines, high numbers of repetitions, and giving feedback and cues to enhance motor learning, all in play contexts. These recommendations are consistent with, or similar to, many current PML guidelines.

Since 2000, a small number of research studies have started to investigate the efficacy of interventions focusing on the speech motor skills of infants (Peter et al., 2019, 2021) and toddlers (Hodge & Gaines, 2017; Kiesewalter et al., 2017; Namasivayam et al., 2015) at risk for sCAS. These treatment studies are summarized in Table 3.

Infant Intervention

Intervention research focusing specifically on infants at risk of CAS (also shown in Table 3) has largely aimed to improve the quality and quantity of vocalizations. Babble Boot Camp (Peter et al., 2019, 2021) is an intervention program designed for infants with galactosemia, who are at high risk of developing CAS. In both the 2019 and 2021 studies, the entry age for participants was 2–4 months old, and infants were followed until 24 months of age. The 2019 study included five infants (four in treatment, one control); the 2021 study largely reported on the outcomes of 15 infants (12 in treatment, three controls), though limited aggregate data on other infants were also available.

The Babble Boot Camp intervention comprises 17 activities delivered by parents. Activities include intentional eye contact, responding to infant vocalizations, encouraging increasingly complex babble, labeling objects

Table 3. Intervention evidence.

Therapy approach/strategy	Purpose/rationale	Source(s)	Nature of evidence
Babble Boot Camp Parent training 20 min weekly: • Eye contact • Responding to infant vocalizations • Encouraging increasingly complex babble • Labeling objects • Modeling words • Recasting and expanding sentences	• Improve speech and language outcomes for children genetically at risk for CAS	Peter et al. (2019, 2021)	15 infants (12 in treatment, 3 controls) with galactosemia Age: 6–24 months Results (at 2.5 and 3.5 years): • Higher mean babble level at 6–9 months • Language WNL for treated and 2/3 untreated children • Articulation WNL for 11/12 treated and 2/3 untreated children
Wee Words 2 parent training and 6 parent–child sessions: • Understanding of speech development • Model target words in play context • Early, specific feedback • Frequent practice sessions	• Build imitation skills • Increase consonant repertoire • Increase range of syllable shapes • Increase expressive vocabulary	Kiesewalter et al. (2017)	32 children with motor speech symptoms Age: < 3.5 years old Results: • Improvements in all 4 areas • Note: No controls for normal development or untreated participants
Let's Start Talking Direct intervention twice a week for 8 weeks: • Child watches adult face while imitating • Gestural, tactile, and prosodic cues • Progress from simultaneous production to imitation to delayed imitation	Increase: • Consonant and vowel repertoires • Consonant and vowel accuracy • Ranges of syllable shapes • Word accuracy	Hodge and Gaines (2017)	10 children with severe speech delay Age: 34–43 months Results: Significant gains in: • Percent syllable shapes correct • Percent consonants correct But not in: • Percent vowels correct • Whole-word accuracy
Motor Speech Treatment Protocol 10 weeks of direct intervention: • Multisensory cueing • Mass and distributed practice • Multiple practice opportunities • Knowledge of results • Knowledge of performance	Compare high-intensity (2×/week) treatment to lower-intensity (1×/week) treatment in: • Articulation • Functional communication • Intelligibility (word or sentence level)	Namasivayam et al. (2015)	37 children with CAS Age: 32–54 months; unknown how many were toddlers Results: Higher intensity level led to greater gains in: • Articulation • Functional communication No significant difference in: • Speech intelligibility

Note. CAS = childhood apraxia of speech; WNL = within normal limits.

to expand the infant's vocabulary, modeling words to grow the infant's phonetic repertoire, and recasting and expanding sentences to increase syntactic complexity. Increasing complex babble is encouraged by repeating back the infant's most mature babbles and modeling increasingly complex vocalizations in play-based exchanges. A description of the activities is available at the Open Science Framework entry for Babble Boot Camp (https://osf.io/yzht4/). Videos of the infant and of parent–infant interactions are recorded by the parents and reviewed by an SLP. The SLP meets with the parent weekly for 15 min to discuss progress and implementation of the activities.

In the 2019 study by Peter et al., comparison between the control and treated infants revealed that all treated infants had higher performance in babbling speech sounds, three had more meaningful speech sounds, three had better global development scores, two had higher expressive vocabularies, and two had higher vocalization rates. In the later study on Babble Boot Camp (Peter et al., 2021), the MBL was higher at 6–9 months of age for the treated infants than for the control infants. Follow-up at ages 2.5 and 3.5 years revealed typical language scores for all 12 treated participants and typical articulation for 11 of these 12. However, one of the three untreated infants had low expressive language and articulation scores. Thus, the few infant studies available suggest that intervention at very early ages may be helpful for infants at high risk for CAS. Clearly, additional research is needed.

Toddler Intervention

In addition to the emerging intervention studies focused on infants, a small number of studies also have begun to investigate preemptive interventions for toddlers with sCAS. Although limited by methodological constraints, such as lack of experimental control, these studies provide preliminary support for the notion of prediagnostic early intervention for toddlers with sCAS.

Kiesewalter et al. (2017) described a post hoc analysis of their program, Wee Words, designed for toddlers (under age 3;6) with suspected speech motor planning difficulties. The 10-week parent–child program aimed to build imitation skills, increase consonant repertoire, increase range of syllable shapes, and increase expressive vocabulary in the children, via a combination of parent education and parent–child sessions. The program, which incorporated many of the ideas suggested in Davis and Velleman (2000), included PML variables (initial use of immediate, specific feedback; frequent practice sessions). Findings revealed statistically significant improvements in the number of imitation attempts, number of consonants, variety of word shapes, and expressive vocabulary in the participants (all ps < .01, with large effect sizes). The conclusions, however, are limited by the lack of a control group to account for any progress related to maturation or external stimuli.

A related intervention program, Let's Start Talking, was designed by Hodge and Gaines (2017) for young children (older 2-year-olds through to children aged 3;6) with severe speech production difficulties and significant gaps in expressive–receptive skills. This individualized program aims to increase functional communication by increasing speech intelligibility using a modified integral stimulation framework (Strand & Skinder, 1999). Components of integral stimulation include (a) client imitations of a clinician-modeled speech target while the client attends to the clinician's face and auditory model and (b) use of gestural, tactile, and prosodic cues to facilitate speech sound production. The level of multimodal cued support changes based upon the child's needs. The temporal relationship between the stimulus and the client's response is gradually increased (simultaneous production, immediate production, production after a delay, etc.), and multimodal cues are slowly faded so the client ultimately produces accurate and controlled productions upon command. Hodge and Gaines (2017) also incorporated aspects of Hayden and Square's (1994) motor speech hierarchy to assist in the selection of speech sound targets for the participants in the Let's Start Talking Study. Participants specifically needed to be able to start, stop, and sustain phonation for more than 2 s (Stages 1 and 2 in Hayden and Square's motor speech hierarchy) to be included. Goals in the Let's Start Talking Study were to increase consonant and vowel repertoires and ranges of syllable shapes. The program was provided twice weekly over 8 weeks (16 sessions in total). Statistically significant gains in percent syllable shapes correct and percent consonants correct (but not percent vowels correct or whole word accuracy) were reported. The two programs, Wee Words (Kiesewalter et al., 2017) and Let's Start Talking (Hodge & Gaines, 2017), were developed with explicit acknowledgment that some children would move from one intervention program (Wee Words, a less intensive, group intervention) to the other (Let's Start Talking, a more intensive, individual intervention) over time.

Another intervention study that incorporated PML variables was a 10-week intervention comparing lower (once per week) and higher (twice per week) intensity treatment levels among 37 children (aged 32–54 months) with CAS (Namasivayam et al., 2015). Although the number of participants who were toddlers (i.e., younger than age 36 months) was unspecified, cautious interpretation of the findings is still relevant here. The intervention in both the lower and higher intensity treatment groups consisted of PML combined with temporal and multisensory cueing

to aid in the improvement of speech motor control and speech intelligibility. The PML principles included focused use of mass and distributed practice, multiple practice opportunities, knowledge of results, and knowledge of performance. Targets moved from simple single words to more phonologically complex targets. Therapy was consistent with an integral stimulation approach (Strand & Skinder, 1999) in the application of faded cues and increasing the temporal delay between the model and the client's response. Namasivayam et al. (2015) also used treatment goals consistent with the Hayden and Square (1994) subsystem hierarchy. Results revealed that the higher intensity level (twice per week) led to greater gains in articulation and functional communication than the lower intensity level (once per week), but the difference between levels in speech intelligibility was not statistically significantly different at the word or sentence level.

Discussion and Clinical Implications

Assessment

As shown in Table 1, research evidence can now guide clinicians in the assessment of infants and toddlers with sCAS and the developmental surveillance of those at risk (i.e., those with an associated disorder or family history of CAS). Because it is unknown how many of the characteristics in Table 1 are needed to suggest an increased risk of CAS, assessment should proceed with caution given the somewhat limited evidence available. The table also outlines a range of assessment tools and strategies clinicians can use.

In the assessment process, clinicians should be sensitive to families' concerns as they may be unsure about developmental expectations and have a heightened sense of worry. Using either an informal or published questionnaire, clinicians should first acquire an extensive case history from the child's caregiver, inclusive of family history of CAS, other speech-language difficulties, and syndromes. Administration of an early language test (e.g., PLS-5; Zimmerman et al., 2011) or use of parent questionnaires regarding receptive and expressive language skills, as well as overall communication development (e.g., Communication and Symbolic Behavior Scales Caregiver Questionnaire; Wetherby & Prizant, 2002), can be helpful in identifying strengths and weaknesses.

Assessment of the infant or toddler's phonetic inventory and babbling status can be obtained with a caregiver interview and analysis of a speech sample of the infant or toddler. Parents should report how many consonants their infant or toddler regularly produces, if their child vocalizes frequently, and at what age their child started to babble. Oller et al. (1999, 2001) demonstrated that parents recognized the emergence of canonical babbling even with little training from researchers. However, to avoid an "acquiescence response bias" (parents responding to direct questions such as "Does your baby say things like baba, dada?" in such a way as to please the interviewer), clinicians should ask open-ended questions, such as "What kind of sounds does your baby make?"

When an SLP obtains a speech sample of the infant or toddler, a minimum of 50 utterances is recommended, obtained over at least three observation periods. From this, the clinician determines how many consonants the child has, mindful that a consonant must appear at least twice in the sample for it to be counted. Additional information obtained from this speech sample includes the diversity of the place and manner features of the inventory consonants as well as how frequently the child vocalizes (the number of vocalizations per minute).

If the child is babbling, the CBR, canonical babbling frequency, and MBL can be calculated (as described earlier). An efficient method of calculating CBR is identifying how many utterances contain a canonical syllable and dividing that by the total number of utterances (Nyman et al., 2021).

Finally, the SLP should determine the type and diversity of syllable/word shapes in the speech sample. Specifically, clinicians should determine whether the infant or toddler is experimenting with a variety of word shapes (one vs. two syllables, CV vs. CVC, etc.) consistent with age expectations.

For all data collected, the clinician should compare the performance of the infant or toddler to developmental expectations. Table 4 outlines a summary of relevant published information about typical infant and toddler vocalizations (e.g., McLeod, 2009; McLeod & Baker, 2017; Robb & Bleile, 1994; Stoel-Gammon, 1987b; Velleman, 2003, 2016; Vihman, 1996; Vihman & Greenlee, 1987). In interpreting this table, clinicians should consider the highly variable nature of early speech sound development. Nevertheless, evidence reviewed in this tutorial suggests that infants and toddlers later identified with CAS have early speech sound skills that stand out as being markedly different to developmental expectations.

Clinical forms and checklists documenting the infant or toddler's phonetic inventory and word shapes (as well as additional instructions for calculating CBR and MBL) can be found in Velleman (2016). Clinicians should consider both the findings from the parent interview and the speech sample when drawing conclusions from the assessment. They are encouraged to closely monitor changes in these young clients.

Table 4. Early vocalization developmental expectations.

Variable	Age (mos)[a]	Findings	Selected sources
Babbling onset	6–12		Vihman (1996)
	7–10		Oller (1980)
	≤ 10		Eilers et al. (1993)
CBR[b]		0.15 (no. canonical babbles/total no. syllables)	Lynch et al. (1995)
		0.14 (no. canonical babbles/total no. syllables)	Nyman et al. (2021)
MBL[c]	9	1.3	Velleman (2016)
	15	1.58	
	18	1.65	
	23	1.9	
Syllable shape	0–12	Single C[d], single V[e]	Velleman (2003, 2016)
	12	CV	
	18–24	CVC (same consonants)	
	24–30	CVC (different consonants)	
	36	CCV, CCVC, CVCC	
Word shape	0–12	1 syllable, 2 syllables (same Cs and SW stress[f])	Velleman (2003)
	12–18	2 syllables (different Cs, SW stress)	
	36	2 syllables (WS[g] stress), 3 syllables	
Inventory[h]	9–18	4–6 consonants	McLeod & Baker (2017)
	24	10 initial consonants, 4 final consonants	
	12	Mean 4.4 consonants, median 4, range 0–16	McLeod (2009)
	24	9–10 initial phones in 3 places (labial, alveolar and velar), inclusive of stop(s), nasal(s), fricative(s), and glide(s) 5–6 final phones in 3 places, inclusive of nasal(s), fricative(s), and often a liquid	Stoel-Gammon (1987b)

[a]Months. All ages are approximate. [b]Canonical babbling ratio. [c]Mean babbling level. [d]Consonant. [e]Vowel. [f]Strong–weak (i.e., first syllable is stressed). [g]Weak–strong (i.e., first syllable is unstressed). [h]Number of different consonants. Findings should be considered a general (not absolute) guideline.

Intervention

Appropriate intervention relies on evidence-based practice, which requires clinicians to integrate clinical expertise/expert opinion, research evidence, and the needs/preferences of the client and/or caregiver in clinical decision making (ASHA, n.d.). Currently, in the treatment of infants and toddlers with sCAS, clinicians can consider the small body of published evidence reviewed here but must still largely depend on their clinical expertise, other expert opinions, and the perspectives of caregivers to guide intervention decisions.

Overall Communication

Overall communication remains the top priority for children with CAS. This is important because subsequent research has confirmed the presence of a receptive–expressive language gap, with particular weaknesses in speech sound production in the context of often quite strong communicative intent in some children with CAS. This highlights the huge potential for frustration often seen in affected children. It is therefore imperative to work with the child's communicative partners to (a) recognize attempts to communicate and (b) respond to these communication attempts. Facilitating successful communication in toddlers with restricted verbal skills may include encouraging the use of a range of natural gestures, sound effects, and other types of augmentative communication. Identifying the child's strengths, which may include receptive language and communicative intent, can help clinicians and parents alike to capitalize on these skills while building overall communicative capacity.

Oral Communication

Once an infant or toddler considered at risk of CAS has a way of communicating, oral communication should become a more direct focus of intervention (Davis & Velleman, 2000). Of particular importance is the need to identify the child's current level of oral communication and to start therapy at that level of skill development. This may initially mean "increasing vocalizations of any sort" (Davis & Velleman, 2000, p. 184), including sound effects, communicative grunts, and idiosyncratic protowords (speechlike vocalizations with apparent general meanings, such as requesting while reaching). These initial oral vocalizations should become as automatic as possible and, thus, potentially bypass the more difficult act of motor planning thought to be impaired in affected

children. Davis and Velleman (2000) suggested minimizing communication pressure by simultaneously producing with the child the following types of speech: (a) speech in conjunction with movement (e.g., "whee" while sliding down a slide), (b) sound effects (e.g., animal noises), (c) songs and rhymes, and (d) verbal routines (greetings, predictable books, etc.). For toddlers who may be vocalizing, but with limited complexity and variety, consonants and vowels within the child's repertoire can be a starting point for expanding oral communication.

Coaching caregivers to provide focused stimulation to model and encourage vocalizations and babbling may be beneficial for infants at risk of CAS. Appropriate techniques include responding to the infant's vocalizations, modeling babbling, and pairing rhythm and speech through singing (Peter et al., 2019, 2021). These suggestions may be particularly helpful for families who have a family history of speech disorders and wish to be proactive regarding younger infant siblings, for example.

A key component of treatment is the individualization of treatment targets based on what the child already has in their repertoire, using phones within the child's inventory to create target words (Hodge & Gaines, 2017; Kiesewalter et al., 2017). The child's interests and motivations should also be considered in choosing appropriate words to focus on.

Expansion of Speech Sounds

Once the child is consistently using vocalizations to communicate, additional goals of expanding both sounds and structures should be included. Both the number and diversity of consonants are important to expand (Overby & Caspari, 2015; Overby et al., 2019). For example, one can encourage the use of words that include consonants that differ in place, manner, or voicing by using the strategies above: modeling words or sound effects with movement, in songs, and in verbal routines. Several books on CAS treatment (e.g., Fish & Skinder-Meredith, 2022) offer specific suggestions for how to implement these strategies.

Expansion of Structures

Expansion of structures refers to increasing the diversity of the syllable shapes the child is using, given that infants and toddlers later diagnosed with CAS or at risk for the disorder often have syllable shapes restricted to consonants, vowels, and/or CV. New syllabic structures can be created using sounds already in the child's inventory, and new sounds can be introduced within known syllabic structures.

Clinicians should first target early developing syllable structures (e.g., CV and CVCV) if these are not yet acquired, before expanding to more complex structures. The importance of infants and toddlers acquiring early "babbling-like" syllable structures (e.g., CVs such as [bɑ] or CVCVs such as [bɑbɑ]) is highlighted by the fact that reduplicated CV structures often appear not only in infants' earliest babbles but also as first words (e.g., "mama" and "dada").

Movement Sequencing Goals

A key component of therapy is to explicitly work on sound sequences. A suggested hierarchy is to start with the same syllable repeated (e.g., "ba ba ba ba"), then to include one change at the end (e.g., "ba ba ba ba boo"), then to alternate the syllables (e.g., "ba boo ba boo"), and, finally, to target a varied sequence (e.g., "ba bee boo bye"; Davis & Velleman, 2000). Pictures or objects (e.g., a sheep for "baa," a ghost for "boo") can be used to support these syllable sequences. Consistency, not accuracy, is the recommended focus at this stage. There are numerous fun activities that can be used to incorporate such practice in an appropriate way.

Contemporary research supports targeting syllables rather than individual sounds in isolation for children with CAS. Because the disorder is one of speech motor movement, it is important to work on speech movement and not the articulation of isolated consonants and vowels (Hodge & Gaines, 2017; Strand et al., 2006). Although isolated vowels with meaning (e.g., "ow" and "ah") may be a starting point for children with no CV syllables, all other targets should be at the syllable or word level (e.g., CV, "moo," "baa"; CVCV, "puppy," "muddy"; Kiesewalter et al., 2017).

General Intervention Considerations

Several key factors to consider when planning and implementing intervention for infants and toddlers with sCAS include being flexible with goals, using short but frequent play-based sessions, and providing opportunities for multiple repetitions (Davis & Velleman, 2000; Fish & Skinder-Meredith, 2022; Hodge & Gaines, 2017). Providing multiple types of feedback (both knowledge of results and knowledge of performance) and incorporating social feedback ("understanding" the child's attempt after feigning confusion) are also important for this population (Davis & Velleman, 2000).

A common feature of infant and toddler intervention programs is the use of parent/caregiver education and participation as a component of therapy (Carson et al., 2022). Such parent-focused intervention approaches are commonly used for children who are late talkers (e.g., Girolametto et al., 1995), and a similar approach to parental involvement has been noted in the emerging studies focusing on motor speech disorders for this age group (Peter et al., 2019, 2021). Parental input is an important therapeutic component and is consistent in keeping with

the notion that neuroplasticity is responsive to the strength and consistency of environmental input.

Because of the frequent co-occurrence of motor and other developmental issues with CAS, especially in children with neurodevelopmental disorders, a team approach to assessment and treatment in early intervention is vital for this population. Our mission is to support not only the whole infant or toddler with CAS but the whole family, as well, and not only to treat the most pressing current symptoms but also to prevent and/or prepare for those that may occur over time. To achieve these goals, multiple professions must collaborate.

Summary

Despite significant advances in the conceptualization, assessment, and treatment of CAS, relatively few studies have focused on the identification and treatment of the disorder in infants and toddlers (Overby & Highman, 2021). However, recent research building on Davis and Velleman's (2000) review and recommendations has identified a number of potential "red flags" that may be considered in early development. Moreover, a small number of treatment studies have started to evaluate treatments that target early speech, prior to a confirmed diagnosis of CAS. Although preliminary, the research described above represents an important first step in evaluating the efficacy of prediagnostic intervention for infants and toddlers with sCAS and provides clinicians with a basis from which they can begin to approach intervention with this population. Theoretical understandings of the importance of infant vocal development and the value of the early application of appropriate treatment techniques in the toddler population offer support to clinicians engaged in early intervention with infants and toddlers with sCAS. These, combined with clinician expertise, professional collaborations, and the goals of the family, can also be used to underpin intervention.

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Appendix

Glossary

Canonical babbling	Vocalization of rhythmical units consisting of at least one consonant and one vowel nucleus with a rapid but inaudible transition between the two sounds
Distributed practice	Practice in which a given number of trials or sessions occur over a longer period of time
Integral stimulation	A treatment approach whereby the clinician models utterances that the child is encouraged and supported to copy, via the use of various cues that are faded over production attempts
Knowledge of results	Feedback about whether the production was correct or incorrect
Knowledge of performance	Feedback about how the sound was produced (e.g., "I like how you made your lips round")
Massed practice	Practice in which a given number of trials or sessions occur over a short period of time
Praxis	The ability to plan and execute a skilled movement
Principles of motor learning	Variables that can influence the learning of motor skills. See Maas et al. (2008) for a comprehensive list of principles and more detailed explanations
Procedural learning	The learning of skills by repeated exposure and practice (implicitly learned and automatically produced)
Vocal regression	Decrease in vocalization (e.g., as seen in the second half of the first year of life in some infants later diagnosed with autism)