The Role of Executive Function in Developmental Stuttering

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ABSTRACT

Developmental stuttering is a complex disorder and children who stutter form a heterogeneous group. Most contemporary researchers would agree that multiple factors, including those associated with linguistic, motor, sensory, and emotional processes, are likely involved in its development and/or maintenance. There is growing evidence, however, that cognitive processes also play a role. In this article, we briefly review behavioral and parent-report studies of executive function in children who stutter, the findings of which have generally suggested that these skills may be challenging for at least some children who stutter. We then consider how deficits in executive function could provide an explanatory account for not only the multifactorial nature of developmental stuttering but also the considerable amount of variability that exists among individuals who stutter.

KEYWORDS: executive function, stuttering, fluency disorders, memory, inhibition, flexibility

Learning Outcomes: As a result of this activity, the reader will be able to (1) identify and describe the major components of executive function; (2) summarize the literature on executive function in developmental stuttering; and (3) describe how executive function could potentially explain the multifactorial nature of developmental stuttering and variability among individuals who stutter.

Executive functions have been likened by some to an "air traffic control system" that manages the flow of aircraft in the airspace, guides pilots during takeoff and landing, and monitors aircraft in flight.[1] To achieve seamless aircraft control from departure to arrival, all components of this system—radar, aircraft, air traffic control towers, controllers, and communication systems—must collaborate. Similarly, executive functions work together to guide,

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Executive Function Skills in Children with Language Differences and Disorders; Guest Editor, Margarita Kaushanskaya, Ph.D.

Semin Speech Lang 2019;40:305–319.
DOI: https://doi.org/10.1055/s-0039-1692965.
ISSN 0734-0478.

monitor, and regulate goal-directed behaviors that are essential for learning and performing everyday tasks.[2] The two systems differ in that the components of an air traffic control system are relatively discrete and easy to identify, whereas those involved in executive function partially overlap and have yet to be fully identified. Indeed, Packwood and colleagues[3] reviewed 60 of the most frequently cited executive function studies across the lifespan and identified 68 different components of executive function. By applying statistical methods to remove semantic and psychometric overlap, they were able to reduce the list to 18; while this represents an improvement, it is still quite large. As the authors note, one consequence of this lack of specificity in defining a small set of executive function components is that it is difficult to compare findings across studies and identify the core structure of executive function.

While the quest to identify and describe the construct of executive function remains ongoing, most researchers generally agree that there are at least three core components involved: inhibition (aka inhibitory control), working memory, and cognitive flexibility/shifting.[2,4,5] Broadly speaking, inhibition refers to the ability to ignore irrelevant information or suppress a dominant or prepotent response (simple response inhibition) with a less dominant, but more appropriate response (complex response inhibition).[6] Those who have strong inhibition skills, for example, can better resist the tendency to act on their first impulse and suppress distracting information to remain focused on a task—that is, they can exercise self-control.[7] Working memory involves temporarily storing information (short-term memory) and then manipulating it in real time.[8,9] For example, during a conversational interaction, people hold in mind information they have already heard and then relate that to what they are hearing now, while also considering their own response.[7] Cognitive flexibility builds on inhibition and working memory to enable flexible switching from one perspective, representation, or rule to another.[6,10] That is, it allows people to switch gears or approaches when something is not working, change their thinking when new information comes along to challenge their current perspective, and shift from one topic to another in conversation.[7,11] Factor analytic studies have indicated that these executive function components not only develop gradually but also may emerge from a single component early in life and become further differentiated over time.[4]

As noted by Baggetta and Alexander,[2] executive function research has exploded during the past few decades and the literature is replete with evidence to support the importance of executive function in a variety of fields. The field of developmental stuttering has not been immune to this trend. In fact, during the past 15 years alone, upwards of 25 behavioral studies have been published on the topic of executive function in children who stutter (CWS). With the inclusion of parent-report studies, this figure easily surpasses 35. Thus, the study of executive function in developmental stuttering is clearly a burgeoning area of exploration.

Interest in the executive function skills of CWS has been fueled by at least two factors. First, studies have revealed that spoken language development and executive function are strongly interrelated.[12–15] This relationship is further substantiated by the fact that children with developmental language disorders have been shown to have deficits in executive function.[16–18] Thus, since depressed language skills have also been reported in some CWS relative to their normally fluent peers (for a meta-analysis, see the study by Ntourou et al[19]), it stands to reason that these children may also have weaknesses in executive function. Second, studies examining temperament in CWS have used parent-report questionnaires that include items that measure aspects of effortful control. Effortful control is similar to executive function but focuses more on self-regulation in emotion-laden contexts.[20] For example, Kraft and colleagues[21,22] reported that parent ratings of effortful control significantly predicted stuttering severity, with low levels of effortful control being associated with higher levels of severity. Studies examining individual components of effortful control have further revealed that the parents of CWS typically rate their children as having weaker inhibition and attention skills in everyday life than the parents of children who do not stutter (CWNS).[23] Thus, in the course of examining temperament, findings of differences in effortful control in CWS have further prompted investigators to consider these components in the emotionally neutral context of executive function.

In this article, we briefly review the extant literature on executive function in CWS, including inhibition, working memory, and cognitive flexibility. We then consider how executive function might play a role in developmental stuttering. Although some aspects of executive function, particularly working memory, have been examined in adults who stutter,[24–29] we limit our review to studies of preschool and school-aged CWS.

THE INHIBITION SKILLS OF CWS

At least eight behavioral studies have been published concerning the role of inhibition in developmental stuttering (see Table 1). Of these eight studies, four studies reported that CWS have weaker inhibition skills than CWNS,[30–33] three studies revealed that CWS and CWNS have similar inhibition skills,[34–36] and one study found that CWS have stronger inhibition skills than CWNS.[37] Thus, the findings from these studies are inconclusive and contradictory as to whether CWS have more difficulty than CWNS suppressing prepotent responses.

Table 1 Summary of behavioral studies that examined inhibition in children who do (CWS) and do not stutter (CWNS)

Study	*N*	Age	Task	Stimuli (S) and response (R)	Results
Anderson and Wagovich[30]	41 CWS 41 CWNS	3;1 to 6;1	Grass-snow and baa-meow tasks	S: Auditory R: Manual	The CWS exhibited significantly slower RTs on both tasks than the CWNS. The CWS were significantly less accurate than the CWNS on the baa-meow task, but not on the grass-snow task. Findings indicate that complex response inhibition is less effective and efficient in CWS
Eggers et al[31]	30 CWS 30 CWNS	4;10 to 10;0	Go/NoGo task	S: Visual R: Manual	The CWS produced significantly more false alarms and premature responses than the CWNS. The CWS also produced significantly faster RTs for false alarms than the CWNS. Findings indicate greater impulsivity in CWS
Eggers et al[34]	18 CWS 18 CWNS	7;4 to 10;11	Stop-signal task	S: Visual R: Manual	No significant difference in the estimated stop-signal RT, suggesting that CWS and CWNS are comparable in exogenous response inhibition
Eggers et al[35]	16 CWS 16 CWNS	6;4 to 9;10	Shifting set task (Part II)	S: Auditory R: Manual	No significant difference between groups in RT or errors in Part II, the response inhibition component of the task
Harrewijn et al[37]	17 CWS 19 CWNS	9;0 to 14;0	Stop-signal task[a]	S: Visual R: Manual	Stop-signal RT was significantly faster for CWS than for CWNS when IQ was controlled, which was interpreted, along with the findings of a self-report questionnaire, to suggest that CWS were more inhibited (i.e., less impulsive)

(*Continued*)

Table 1 (*Continued*)

Study	*N*	Age	Task	Stimuli (S) and response (R)	Results
Piispala et al[36]	11 CWS 19 CWNS	5;8 to 9;6	Go/NoGo task	S: Visual R: Manual	No significant differences in the number of errors, false alarms, or premature responses. The CWS and CWNS did not differ in ERP latencies and N2 and P3 amplitude, measured over 9 electrodes, in the NoGo condition. Findings indicate that CWS and CWNS exhibit similar inhibition skills
Piispala et al[32],b	11 CWS 19 CWNS	5;8 to 9;6	Go/NoGo task	S: Visual R: Manual	The CWS, when compared with the CWNS, exhibited reduced ERP P3 activity using 36 channels, in the NoGo condition, suggesting difficulty with inhibitory control
Piispala et al[33],c	12 CWS 12 CWNS	5;8 to 9;6	Go/NoGo task	S: Visual R: Manual	Compared to the CWNS, the CWS showed reduced occipital α-activity in the NoGo condition, which is suggestive of difficulties with the inhibition of visual attention

Abbreviations: Age, age range (years;months); ERP, event-related potentials; *N*, sample size; RT, reaction time.
[a]The children also completed a rolling marble task,[38] which measures voluntary action control in children using fMRI. Children had to press a button to stop a marble from crashing on some trials and decide whether to execute or inhibit this same response on other trials. Although this task does involve inhibition, whether a child chooses to inhibit the response is entirely voluntarily. The authors reportedly chose this task because they wanted the two groups of children to perform similarly (they did) so that they could examine neural differences that were not induced by performance differences.
[b]The 11 CWS and 19 CWNS who participated in the study of Piispala et al[32] had also been participants in the study of Piispala et al.[36]
[c]11 of the 12 CWS and all 12 CWNS had participated in the studies of Piispala et al.[32,36]

In examining the characteristics of these studies, we observe that all but two studies examined simple response inhibition and that the findings from the two studies that examined complex response inhibition[30,35] were mixed. Findings based on sample sizes also varied; while two of the studies that reported differences had the largest sample sizes (30 or more participants), some studies employing smaller sample sizes also found differences. Response modality did not vary across studies (all required manual responses) and while most studies used visual stimuli, the two studies that used auditory stimuli yielded conflicting results. Thus, differences in the type of inhibition being examined, sample size, and stimulus/response modality do not readily account for the variability in findings across studies.

One important characteristic, however, that may be contributing to the variability in findings across studies is the chronological age of the participants. The four studies reporting that CWS have weaker inhibition skills than CWNS all included preschool children as participants.[a] While one study that failed to find a difference between CWS and CWNS also included preschool children (along with school-aged children), the remaining studies were all based on school-aged children. In fact, the one study in which CWS were found to have stronger inhibition skills than their peers—largely based on participant self-report—also included adolescents, as well as school-aged children. Thus, it appears that the ages of the participants being studied may have

[a] *Age group determinations vary across research reports and government agencies, but typically preschool is from age 3;0 to 5;11 (years;months), school-age is from 6;0 to 12;11, and adolescence is from 13;0 to 17;11.*[39]

accounted for at least some of the variability in findings. It may be that in early childhood, CWS are slower to develop inhibition skills than CWNS, but over time, these differences diminish and CWS eventually "catch up" with their normally fluent peers.

Findings from studies of inhibition based on parent report have also been contradictory, with some reporting that the parents of CWS rate their children lower in inhibition than the parents of CWNS[40,41] and others finding no differences.[42,43] However, when data from these studies are combined in the form of a meta-analysis, the resulting effect size is statistically significant and negative, revealing that the parents of CWS rate their children, on average, almost half a standard deviation below the mean of CWNS.[23] Furthermore, even though Ntourou et al[43] failed to find differences between parent-reported inhibition in 75 CWS and 75 CWNS based on the *Behavioral Rating Inventory of Executive Function–Preschool Version* (BRIEF-P[44]), 17.3% of the CWS exhibited clinically significant difficulties with inhibition compared to 6.7% of the CWNS, a significant difference that represents a two- to threefold increase in risk for CWS.

In sum, despite inconsistencies in the literature, several behavioral studies suggest that CWS, particularly in the preschool years, have weaker inhibition skills than CWNS. Furthermore, while there are many ways in which behavioral studies differ from those of parent-report studies,[23,43] whatever difficulties CWS have with inhibition do not appear to be limited by the context in which it is being measured. That is, as a group, CWS are more likely than CWNS to have difficulty suppressing inappropriate responses, regardless of whether the child is being evaluated in a laboratory-based setting or real-life activities. More research, however, is clearly needed to resolve some of the discrepancies in the literature and, thus, arrive at a better understanding of the potential impact of inhibition on stuttering.

THE SHORT-TERM AND WORKING MEMORY SKILLS OF CWS

As revealed in Table 2, the short-term and working memory abilities of CWS have received the most attention in the literature, with at least 17 studies having been published to date.[b] Hakim and Ratner[45] were among the first to use nonword repetition to examine phonological short-term memory in CWS. Since then, several other researchers have examined the ability of CWS to repeat nonwords. Findings from these studies have largely been contradictory, with some suggesting that CWS are less successful than CWNS in their ability to repeat nonwords[42,45–48] and others finding no differences.[49–52] As indicated by Anderson et al,[53] these inconsistent findings are a likely consequence of the tool being used to measure nonword repetition; different nonword repetition tasks have been shown to tap into different skills, resulting in significantly different effect sizes across studies.[16] For example, some tasks contain nonwords that are longer in length and/or more articulatory complex (i.e., more consonant clusters and/or late-acquired consonants), whereas other tasks contain shorter nonwords, singleton consonants, and/or early acquired consonants, making them less complex.[16]

As also indicated by Anderson et al,[53] one problem with using nonword repetition measures to assess verbal short-term memory skills is that, in addition to phonological memory, the ability to repeat nonwords requires other skills, such as auditory-perceptual processing and phonological encoding.[54] Speech motor skills could also impact performance, although findings from some studies suggest that motor skills do not play an appreciable role in the accuracy with which children repeat words.[55] Thus, while findings from most studies would seem to suggest that CWS have difficulty with nonword repetition, exactly what is it that CWS are having difficulty with is less than clear.

That said, findings from studies employing forward span tasks have also revealed weaknesses in the short-term memory skills of CWS,[47,53,56,57] although not all studies have

[b] *Note that while short-term memory typically does not fall explicitly under the umbrella of executive functions, it is a component of working memory. For that reason, we consider this literature to be relevant, particularly since only a few studies have incorporated measures of working memory, none of which included preschool CWS.*

Table 2 Summary of Behavioral Studies that Examined Short-Term and Working Memory in Children who do (CWS) and do not Stutter (CWNS)a

Study	*N*	Age	Task	Stimuli (S) and response (R)	Results
Anderson and Wagovich[42,b]	9 CWS 14 CWNS	3;6 to 5;2	CNRep	S: Auditory R: Verbal	The CWS produced significantly fewer nonwords correctly overall and at the 2- and 3-syllable lengths compared to the CWNS, suggesting difficulties with phonological working memory
Anderson et al[53]	42 CWS 42 CWNS	3;0 to 5;11	Phonological similarity and semantic category tasks	S: Auditory R: Verbal	The memory spans of the CWS were significantly shorter for phonologically dissimilar words compared with the CWNS. The CWS were less affected by the phonological and semantic qualities of the words than the CWNS. Findings suggest reduced verbal short-term memory capacity in CWS associated with difficulties with phonological and/or semantic processing
Anderson et al[46]	12 CWS 12 CWNS	3;0 to 5;2	CNRep	S: Auditory R: Verbal	The CWS produced significantly fewer 2- and 3-syllable non-words correctly and produced more phoneme errors at the 3-syllable length than the CWNS. Findings suggest that CWS have weaknesses in phonological working memory
Bakhtiar et al[49]	12 CWS 12 CWNS	5;1 to 7;10	Persian nonword repetition and digit span tasks	S: Auditory R: Verbal	No differences in the accuracy and speed with which the CWS repeated nonwords compared with the CWNS. Both groups had similar digit spans
Hakim and Ratner[45]	8 CWS 8 CWNS	4;1 to 8;4	CNRep	S: Auditory R: Verbal	The CWS repeated 3-syllable nonwords less accurately than the CWNS, suggesting difficulty with phonological working memory
Kaganovich et al[58]	18 CWS 18 CWNS	4;0 to 5;11	TAPS digit and word span subtests, nonverbal memory task, and auditory oddball paradigm	S: Auditory/ Visual R: Verbal/ Manual	Both groups exhibited comparable performance on the behavioral tasks. However, deviant tones in the auditory odd-ball paradigm did not elicit P3 in CWS, suggesting weaknesses in attentional allocation and working memory update
Oyoun et al[47]	30 CWS 30 CWNS	5;0 to 13;0	CNRep, memory span, and recall tasks	S: Auditory R: Verbal	The CWS repeated 2- and 3-syllable nonwords significantly more slowly and with more phonological errors than the CWNS. Digit spans were significantly shorter for the CWS compared with the CWNS. Findings suggest that CWS have difficulty with verbal short-term memory

Table 2 (*Continued*)

Study	*N*	Age	Task	Stimuli (S) and response (R)	Results
Pelczarski and Yaruss[48]	11 CWS 11 CWNS	4;9 to 6;8	CTOPP nonword repetition and memory for digits subtest	S: Auditory R: Verbal	The CWS were significantly less successful in accurately repeating nonwords compared with the CWNS, but both groups were similar in digit span
Reilly and Donaher[56]	5 CWS 5 CWNS	7;0 to 10;7	Digit and letter span tasks	S: Auditory R: Verbal/ Written	Recall accuracy was significantly lower for the CWS than the CWNS, regardless of whether responses were verbally produced or written. Findings suggest reduced short-term memory capacity in CWS
Sasisekaran and Basu[59]	12 CWS 12 CWNS	7;0 to 16;0	WMS-III forward and backward digit span subtest	S: Auditory R: Verbal	No significant between-group differences
Sasisekaran et al[60]	9 CWS 9 CWNS	10;0 to 14;0	WMS-III forward and backward digit span subtest	S: Auditory R: Verbal	No significant between-group differences
Sasisekaran and Byrd[50]	14 CWS 14 CWNS	8;0 to 15;0	Nonword repetition task and WMS-III forward and backward span subtest	S: Auditory R: Verbal	No significant between-group differences
Sasisekaran and Byrd[61]	9 CWS 9 CWNS	7;0 to 13;0	WMS-III forward and backward digit span subtest	S: Auditory R: Verbal	No significant between-group differences
Smith et al[51]	16 CWS 22 CWNS	4;0 to 6;0	NRT, TAPS-R digit and word span subtests, and nonverbal memory task	S: Auditory R: Verbal	No significant between-group differences
Stokić et al[57]	35 CWS 35 CWNS	8;9 and 8;11 (means)	Serbian immediate and delayed memory tasks	S: Auditory R: Verbal	The CWS recalled significantly fewer words than the CWNS during all tasks, suggesting reduced memory capacity
Weber-Fox et al[52]	10 CWS 10 CWNS	9;4 to 13;9	NRT	S: Auditory R: Verbal	No significant between-group differences

Abbreviations: Age, age range (years;months); CNRep, Children's Nonword Repetition Test[62]; CTOPP, Comprehensive Test of Phonological Processing[63]; *N*, sample size; NRT, Nonword Repetition Test[64]; TAPS, Test of Auditory-Perceptual Skills[65]; TAPS-R, Test of Auditory Perceptual Skills-Revised;[66] WMS-III, Wechsler Memory Scale-III.[67]
[a]This summary is limited to studies for which children were reportedly within normal limits in their speech (other than stuttering) and language skills.
[b]The 9 CWS and 8 of the 14 CWNS had also participated in the study of Anderson et al.[46]

arrived at the same conclusion.[48–50,58–61] Of note, although Kaganovich et al[58] failed to find differences between CWS and CWNS in their performance on two forward span tasks and a nonverbal memory task, they did find event-related potential differences in the P3 component during a nonlinguistic auditory oddball paradigm. They discovered that the deviant tones elicited the P3 component in CWNS, but not CWS. These results were interpreted to suggest that CWS are less efficient in their ability to allocate attentional resources and update the contents of working memory.

To date, only four studies have reported on the working memory skills of CWS by including backward span tasks in their experimental protocols, the findings of which have indicated no significant difference between school-aged and adolescent CWS and CWNS.[50,59–61] The same task, the Digit Span subtest of the *Wechsler Memory Scale-III* (WMS-III[67]), was used to measure backward (and forward) digit span in all four studies. The WMS-III Digit Span subtest, however, has received some criticism. One of the most significant is that the variance in scores is often large relative to the mean because participants receive different numbers of trials, the consequence of which is that coefficients of variation are high and clinical sensitivity is reduced.[68] For example, as reported by Woods et al,[68] one study found only slight mean z-score differences between individuals with mild Alzheimer's disease and age-matched neurotypical adults (−0.22 for forward digit span vs. −0.44 for backward digit span), suggesting poor discriminative sensitivity. Thus, if the WMS-II Digit Span subtest does not adequately discriminate between adults who have frank memory deficits and those who do not, it is, perhaps, not surprising that no differences have been found between CWS and CWNS, especially considering that variances tend to be even higher in children than in adults. Thus, while these studies provide insights into the working memory skills of CWS, more research using different types of working memory measures is needed to draw firm conclusions about the role of working memory in developmental stuttering.

Taken together, although findings from individual studies are far from consistent, collectively they point toward the conclusion that, when compared with CWNS, some CWS likely have subtle limitations in short-term memory. This conclusion is based on the findings from the meta-analytic study of Ofoe et al,[23] where CWS were found to score more than half a standard deviation below CWNS on nonword repetition measures and more than one-third of a standard deviation below CWNS on forward span measures. While current research does not support the contention that school-aged and adolescent CWS and CWNS differ in their working memory skills, one study reported that the parents of preschool CWS rated their children higher (worse) on the working memory scale of the BRIEF-P than the parents of preschool CWNS.[43]

THE COGNITIVE FLEXIBILITY SKILLS OF CWS

To our knowledge, only three behavioral studies of cognitive flexibility in CWS have been conducted to date (see Table 3). Findings from these studies[35,69,70] revealed significant differences in cognitive flexibility between CWS and CWNS, with CWS performing more poorly (slower and/or less accurately) than CWNS. Of note, between-group differences were observed across all studies even though the children who participated in these studies were exposed to different stimuli (auditory vs. visual; verbal vs. nonverbal) and task requirements. For example, the tasks used by Anderson et al[69] and Eichorn et al[70] required children to shift in response to the categorical and/or perceptual nature of the stimuli (e.g., for a perceptual task, showing the children a target picture and then having them select one of three pictured associates that "match" it based on color, shape, or size), whereas the switch in the task used by Eggers and Jansson-Verkasalo[35] required children to change their motor response (i.e., when children heard a low-frequency tone, they had to respond one way and when they heard a high-frequency tone, they had to respond another way).

Cognitive flexibility has also been examined in CWS using parent-report measures. In the study by Ntourou et al,[43] the parents of CWS rated their children higher (worse) on the

Table 3 Summary of Behavioral Studies that Examined Cognitive Flexibility in Children who do (CWS) and do not Stutter (CWNS)

Study	*N*	Age	Task	Stimuli (S) and Response (R)	Results
Anderson et al[69]	44 CWS 44 CWNS	3;0 to 5;11	Double semantic and perceptual categorization tasks	S: Visual R: Manual	No significant between-group differences in response accuracy, but the CWS responded significantly more slowly than the CWNS on both tasks, suggesting less efficient CF
Eggers and Jansson-Verkasalo[35]	16 CWS 16 CWNS	6;4 to 9;10	Shifting set task (Part III)	S: Auditory R: Manual	No significant difference in RT, but the CWS produced significantly more errors than the CWNS (and Part I, the baseline), suggesting less effective CF
Eichorn et al[70]	16 CWS 30 CWNS	3;0 to 6;6	Dimension Card Change Sort task	S: Visual R: Manual	The CWNS were significantly slower and less accurate in the postswitch phase compared with the preswitch phase. The CWS exhibited similar accuracy rates in both phases and were even slower in the postswitch phase than the CWNS. Findings interpreted to suggest that CWS have difficulty with CF

Abbreviations: Age, age range (years;months); CF, cognitive flexibility; *N*, sample size; RT, reaction time.

BRIEF-P Shift scale than the parents of CWNS, which suggests that CWS have more difficulty flexibly shifting from one situation, activity, or aspect of a problem to another. Similarly, Eggers et al[40] found differences between CWS and CWNS in parent-reported attentional shifting, with CWS again having more difficulty than CWNS. These findings are also consistent with other studies that have reported that CWS have more difficulty adapting to changes in the environment than CWNS.[71,72]

In sum, findings from the studies that have been conducted thus far would seem to suggest that cognitive flexibility is an area of weakness for CWS. However, these findings are not altogether surprising considering that the ability to flexibly switch from one rule or dimension to another also requires inhibition and working memory,[6,7] skills that are at least somewhat weaker for CWS, as indicated in the preceding review.

HOW MIGHT EXECUTIVE FUNCTION PLAY A ROLE IN DEVELOPMENTAL STUTTERING?

Despite an exponential increase in our knowledge of stuttering over the years, in some ways, its causal mechanisms remain as elusive today as they were 100 years ago when the field first emerged. This state of affairs is, perhaps, symptomatic of the fact that stuttering is a complex disorder and individuals who stutter form a heterogeneous group. Indeed, most contemporary researchers would agree that multiple factors, including linguistic, motor, sensory, and emotional factors, are likely involved in the development and/or maintenance of childhood stuttering. The notion that stuttering may be associated with multiple factors is, perhaps, not surprising considering that speech, whether it is fluent or not, is clearly the end-product of a concatenation of sensory, cognitive, linguistic, and motor processing events. When viewed in this way, it may also come as no surprise that children with primary impairments in specific domains, whether it be language or sensory, typically have deficits in other areas. For example, children with developmental language disorders exhibit more articulatory variability during speech production[73] and perform more poorly than their peers on fine and gross motor tasks.[74,75] Similarly, deaf children who have more advanced motor skills tend to perform better on spoken language measures following cochlear implantation compared with those with less advanced motor skills.[15]

Nevertheless, the domain-specific processes associated with speech, language, motor, sensory, and emotional development also depend on shared domain-general cognitive processes, including executive function, attention, and processing speed.[14,15] The link between domain-specific and domain-general processes is evidenced, in part, by the fact that children with impairments in specific domains are often reported to have weaknesses in executive function. For example, children with developmental language disorders have been shown to perform poorly on measures of short-term and working memory,[76] as have deaf children with cochlear implants[12] and children with speech sound disorders.[77,78] As suggested in this review, CWS may also have weaknesses in the storage component of working memory (i.e., short-term memory), as well as inhibition and cognitive flexibility.

There are several specific ways in which deficits in working memory, inhibition, and/or cognitive flexibility could impact developmental stuttering based on the link between these skills and language development. For example, weaknesses in inhibition and/or working memory could result in the development of less stable long-term phonological and/or lexical representations of words in the mental lexicon, making them more susceptible to fluency disruptions.[23,30] On a broader level, however, given that domain-general processes govern many other self-regulatory functions, including language and motor behaviors (also implicated in stuttering), differences in executive function could potentially explain the multifactorial nature of developmental stuttering and the vast amount of variability among individuals who stutter.

In this way, given that domain-general and domain-specific processes are interrelated, it is conceptually possible for a deficit in executive function to have a negative effect on domain-specific processes and vice versa.[14,15] To illustrate, imagine building a two-story house with a concrete slab foundation, critical for the structural integrity of the house. The first floor contains a kitchen and living room, while the second floor contains two bedrooms and a bathroom. Unbeknownst to you, the home builder did not lay the foundation properly, a problem compounded by the fact that the house sits on an uneven ground of clay soil on top of a hill. As a result, horizontal cracks appear in the foundation of your new house. After a few years, these cracks become larger, triggering a cascade of events: cracks surface in the floors and interior walls of the bedrooms and kitchen; the large window in the living room becomes difficult to open and close; and the bathroom door jams and fails to latch. The same builder built your neighbor's house, as well, and although the layout and style are different from yours, the foundation of their home was not laid properly either. While the interior of your neighbor's house will also be affected by the poorly laid foundation, it will experience different symptomatic signs because the style and floor plan are different.

Now imagine that the house is a young CWS, and the four rooms each embody a domain-specific process, such that the kitchen is now speech, the living room is language, and the upstairs bedrooms and bathroom are motor, emotional, and sensory processes, respectively. The foundation represents executive function. Like the cracks in the foundation of your new house, the young CWS has weaknesses in executive function. As the child grows, these weaknesses begin to cause problems with other aspects of his speech, language, motor, sensory, and/or emotional development—in much the same way as the cracks in the foundation led to problems with the home's interior. Thus, what initially started as a weakness in executive function eventually resulted in subtle to not-so-subtle difficulties with other domain-specific processes, as these processes depend on strong working memory, inhibition, and cognitive flexibility skills to function properly. The extent to which various processes are affected would manifest themselves differently in individual CWS, in much the same way that foundation problems impact houses differently. Children are not

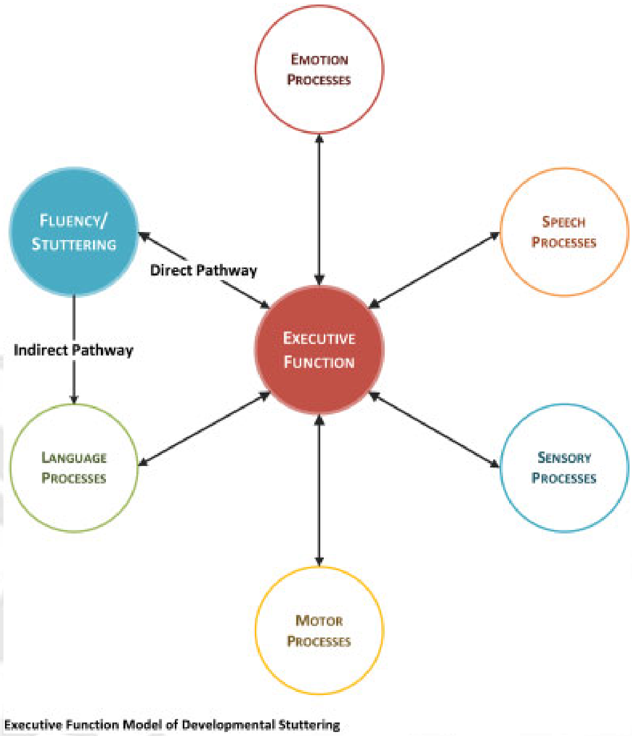

Figure 1 A conceptual model of the relationship between developmental stuttering, executive function, and the domain-specific processes of language, motor, sensory, speech, and emotion. Stuttering directly impacts executive function in the direct pathway, leading to deficits in one or more domain-specific processes. Stuttering is associated with weaknesses in language processes in the indirect pathway, which in turn affects executive function and subsequently other domain-specific processes.

homogeneous by nature, but rather their development is influenced by different genetics, socioeconomic factors, etc., any of which could be linked to the expression of stuttering.

One critical question that has gone unanswered in this illustration is why young CWS would have weaknesses in executive function in the first place. At least two possibilities come to mind, and we illustrate these in our Executive Function Model of Developmental Stuttering (see Fig. 1). First, the frequent fluency breaks that represent the *sine qua non* of developmental stuttering indicate that fluent speech and language production is, by definition, less fluid and automatic in CWS. Thus, from a resource allocation standpoint, as CWS struggle to plan or execute speech/language and/or attempt to manage their fluency breaks, they may overutilize limited executive function resources, including aspects of attention, to compensate for fluency processes that do not come as automatically for them (see the study by Kronenberger and Pisoni[12] for discussion of the compensatory role of executive function in language processing). Consequently, the overall "pool" of available executive function resources may be depleted more rapidly.[c] Furthermore, it seems reasonable to speculate that over time, repeated instances of fluency breakdown might negatively affect executive function development, leading to a bidirectional relationship between domain-specific and domain-general processes. With this possibility, the pathway between fluency and executive function skills is direct: weaknesses in executive function can emerge as a consequence of stuttering or as the antecedent.

Second, and similarly, there is a strong reciprocal relationship between spoken language development and executive function.[12] It is well documented that the language skills of

[c] *Note that findings from Schmeichel[79] indicate that executive function resources can, in fact, be depleted—at least temporarily.*

otherwise typically developing CWS (i.e., CWS without concomitant speech and language disorders) are less robust than those of CWNS.[19] Thus, if CWS also have even subtle weaknesses in language, regardless of whether it is etiologically relevant, then this could theoretically affect their executive function development, and spread to other domain-specific processes. With this possibility, the pathway between fluency and executive function is indirect: concomitant weaknesses in language processing result in limitations in executive function, which subsequently lead to deficits in other domain-specific processes.

Note that this conceptual model of the relationships among developmental stuttering, executive function, and the domain-specific processes of language, motor, sensory, speech, and emotion does not presume that all CWS have weaknesses in executive function. Some CWS, in fact, may have strong executive function skills. Thus, even if they are overutilizing available resources, it might be theorized that these children would have enough resources in reserve to withstand repeated depletions and would, therefore, experience no adverse effects on executive function development. These CWS, however, would not have deficits in any other domain-specific processes.

SUMMARY AND FUTURE DIRECTIONS

In summary, despite the inconsistent findings in the literature, most research would seem to suggest that CWS, as a group, have weaknesses in short-term memory, inhibition, and cognitive flexibility. Because executive function and domain-specific processes, particularly language, are reciprocally linked, it is reasonable to suggest that weaknesses in executive function and other domain-general cognitive processes (e.g., attention) may provide an explanatory account of the multifactorial nature of developmental stuttering and the considerable variability among individuals who stutter.

Future research might address the effect of executive function training on the frequency of stuttering—not for clinical purposes, but rather as a test of the relation between executive function and stuttering. That is, if executive function plays a role in the development and/or maintenance of stuttering, then fluency ought to improve following training. In fact, preliminary findings from Nejati et al[80] support this contention, as inhibition training not only resulted in improved executive functioning in 15 CWS but also reduced stuttering severity. These findings suggest that executive function training may be one of many fruitful avenues of research to pursue.

Research to define what, if any, role executive function plays in developmental stuttering is rapidly growing and evolving. It is hoped that this increased interest will lead to a deeper understanding of the complex forces that shape the emergence of stuttering in young children.

DISCLOSURES

Financial: J.D.A. is a full-time, salaried associate professor in the Department of Speech and Hearing Sciences at Indiana University, whose research is funded by the National Institute on Deafness and Other Communication Disorders, National Institutes of Health (R01DC012517; PI: J. Anderson). L.C.O. is a doctoral student in the Department of Speech and Hearing Sciences at Indiana University who receives funding from the department.

Nonfinancial: No relevant nonfinancial relationships exist for either author.

CONFLICT OF INTEREST

None declared.

ACKNOWLEDGMENTS

This work was supported by a grant to the first author from the National Institute on Deafness and Other Communication Disorders, National Institutes of Health (R01DC012517).

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