Attentional Control Systems in Developmental Stuttering

by

Emily Blackburn

Bachelor of Science, Bachelor of Arts, Miami University, 2022

Master of Science, University of Pittsburgh, 2024

Submitted to the Graduate Faculty of the

School of Health and Rehabilitation Sciences in partial fulfillment

of the requirements for the degree of

Master of Science

University of Pittsburgh

2024

UNIVERSITY OF PITTSBURGH

SCHOOL OF HEALTH AND REHABILITATION SCIENCES

This thesis was presented

by

Emily Blackburn

It was defended on

March 18, 2024

and approved by

Dr. Amanda Hampton Wray, CCC-SLP, Associate Professor, Department of Communication Science and Disorders

Dr. Jason Bohland, Assistance Professor, Department of Communication Science and Disorders

Dr. Sarah Wallace, CCC-SLP, Professor, Director of Master's Degree Program in Speech-Language Pathology, Department of Communication Science and Disorders

Thesis Co-Advisor: Dr. Amanda Hampton Wray, CCC-SLP, Associate Professor, Department of Communication Science and Disorders

Thesis Co-Advisor: Dr. Jason Bohland, Assistance Professor, Department of Communication Science and Disorders

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Emily Blackburn, M.S.

University of Pittsburgh, 2024

Stuttering is a neurodevelopmental disorder experienced as a loss of control of one's speech. It is characterized by an involuntary disruption in the forward flow of speech. Theories of stuttering, such as the Multifactorial Dynamic Pathways Theory, suggest that there are several influencing factors that contribute to the development of and persistence in stuttering. Attentional control is one factor theorized to potentially play an influential role in stuttering. The present study examined how different aspects of attentional control factor together in school-age children and whether there were differences in attentional control between children who stutter (CWS) and children who do not stutter (CWNS).

Eighty-two children (40 CWS, 42 CWNS), ages 4-8 years, completed a battery of behavioral tasks that measured speech, language, and attention skills. Parents completed multiple questionnaires assessing their child's attention-related skills in everyday life situations. Exploratory factor analysis (EFA) was used to identify latent structure across the combined group and between and within CWS and CWNS groups individually.

Five factors were extracted for the combined group model. Generally, attentional control skills factored together, separate from measures associated with speech and language. Specifically, factors included: *Parental Reports of Attention Behaviors,* or skills related to attention management in the real world; *Executive Control of Attention,* as measured by behavioral tasks, *Speech Sound Skills,* or articulation and phonology skills; *Language and Verbal Working Memory,* as measured by behavioral tasks; and *Inhibition,* as measured by a Go/No-Go task. There were no group differences across the five factors extracted from the combined group; however, the *Language and Verbal Working Memory* factor trended toward a difference between groups. Factors extracted separately CWS and CWNS were similar to factors for the overall group.

Overall, findings suggest that attentional control between CWS and CWNS is largely comparable for school-age children. Subtle differences in the factor for language and verbal working memory indicate the need for future research in this area. Importantly, different ways of modeling these skills provided stable consistent models of how factors of attentional control group together for school-age children.

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Preface

My mentors, Dr. Amanda Hampton Wray and Dr. Jason Bohland, were paramount contributors when navigating research and composing this thesis. They provided me with invaluable feedback, guidance, and support throughout this master's program. I immensely appreciate their time, energy, and expertise provided throughout and I am grateful they offered me this opportunity. Their help significantly enriched this project and played a pivotal role in the success of this thesis and my professional growth. Additionally, my sincere thanks go to Dr. Sarah Wallace for serving on my thesis committee. Her time, feedback, and guidance were similarly essential in shaping this project. I would also like to extend gratitude to BSL Lab members, Erica Lescht and Brittany Coleman, for providing me with resources and generously giving their time which greatly contributed to this thesis. Furthermore, I want to express my appreciation for Pitt faculty; namely Dr. Erin Lundblom, Dr. William Evans, and Dr. Kendrea Garand for lending a listening ear, offering words of encouragement, and investing time into my overall growth as a student. Thank you to all aforementioned for significantly influencing and contributing to my educational experience as a graduate student at the University of Pittsburgh.

To my friends and family, your love, unending support, consistent encouragement, and confidence in my abilities enabled me to pursue this academic achievement. Thank you for helping me persevere through this journey and offering guidance and motivation when it was needed. I am incredibly grateful for the countless ways you showed up for me. Your contributions to my overall professional and personal growth and this resultant accomplishment cannot be understated. You have made this journey not only achievable, but meaningful.

1.0 Attentional Control Systems in Developmental Stuttering

Fluency is the ability to consistently use the speech mechanism effortlessly and quickly to produce continuous, uninterrupted speech (Yairi & Seery, 2015). A fluent individual forms sentences efficiently and accurately through utterance planning, vocabulary retrieval, and self-correction of mistakes in a natural and automatic fashion (Chang et al., 2015; Yairi & Seery, 2015). Disorders of fluency, such as developmental stuttering, are characterized by disfluent speech patterns resulting in the involuntary disruption of fluent speech (Yairi & Seery, 2015). Disfluencies are categorized into two groups: typical and stuttering-like disfluencies. Typical disfluencies are common across all children and include revisions, interjections, and phrase repetitions. In comparison, stuttering-like disfluencies such as sound/syllable, part word, and whole word repetitions, prolongations, and blocks are not common in children who do not stutter (CWNS). Disfluencies may be accompanied by secondary concomitant behaviors such as tense body movements of the head, neck, and face in people who stutter. However, the experience of stuttering goes beyond the overt speech patterns seen and heard by the listener. It is a complex, dynamic, multidimensional experience that influences physical, emotional, cognitive, and environmental domains (Yairi & Seery, 2015) and is marked by a sense of loss of control of one's speech (Tichenor et al., 2022). Approximately 4-5% of preschool age children develop stuttering (Yairi & Seery, 2015). The majority of children who stutter (CWS) begin between the ages of 2.5-4 years. In most cases, onset of stuttering is rapid, happening within 1-3 days, and is distinguished by heterogenous moderate-severe disfluencies (Yairi & Seery, 2015). Of all children who begin stuttering during early childhood, approximately 75-80% recover without therapy, a phenomenon known as natural recovery. However, around 20-35% of children persist in stuttering, typically stuttering into adulthood (Yairi & Seery, 2015). As a result, approximately 1% of adults stutter.

The exact cause of developmental stuttering is still unknown; however, researchers have determined that stuttering is a disorder with a neurological basis and genetic underpinnings (Yairi & Seery, 2015). It is not a motor muscle problem, as the cranial nerve pathways to the muscles are intact and individuals who stutter are reported to have highly developed fine motor movements (Yairi & Seery, 2015). Additionally, little evidence exists to support clinically meaningful differences in phonological and language systems. Instead, stuttering is a disorder characterized by a sensation of loss of control of speech (Tichenor & Yaruss, 2019) and disfluencies in speech production. It is, however, proposed to be influenced by the development of simultaneous systems in the brain (Chang et al., 2015; Yairi & Seery, 2015).

Foundationally, speech production is a complex motor behavior that requires the coordination and precise timing of hundreds of muscles in the articulatory, laryngeal, and respiratory systems (Chang et al., 2015). These muscles are supported by multiple brain areas and the efficient interactions among them (Chang et al., 2015). Execution of fluent speech is dependent on the simultaneous coordination of overlapping motor speech systems integrated by multiple neural structures (Chang et al., 2015). These speech systems are constantly adapting to individual changes in speech production including speaking rate, coarticulation, and emotional load to support continuous fluent speech production (Chang et al., 2015). As such, there are several proposed factors that influence the production of fluent speech, including both genetic and environmental factors (Yairi & Seery, 2015).

One recognized theory, the Multifactorial Dynamic Pathways Theory (MDPT), states the interactions between a vulnerable speech motor system in combination with other genetic and child factors result in the development and persistence of stuttering (Smith & Weber, 2017). The weight of these influencing factors is dependent on the individual, as stuttering is dynamic, and its emergence and progression varies greatly. Variation exists both between individuals and within individuals (Yairi & Seery, 2015) and small changes in one factor can largely influence an individual's overall speech system (Smith & Weber, 2017). Essentially, the MDPT attributes disfluencies to a disruption of motor signals which influences the generation of normal muscle activation patterns (Smith, 1989). Disfluencies then influence internal behaviors and physiological subsystems which directly interact with the development of the speech system, resulting in the persistence in stuttering (Smith & Weber, 2017). In young children who stutter who eventually recover naturally, brain adaptations "successfully compensate for the atypical neural activity underlying stuttering disfluencies" (p.2495) producing more stable speech connection networks (Smith & Weber, 2017). In comparison, young children who stutter who go on to persist lack adequate neural adaptations and connections to support a developing speech motor system. As a result, "their speech motor systems remain vulnerable to breakdowns in the face of increasingly complex language demands and to psychosocial pressures in the environment" (p.2496). Thus, overlearned abnormal central nervous system patterns are created that underly the speech motor system (Smith & Weber, 2017). The MDPT assists in explaining how different combinations of variables are related with consideration to epigenetics and the development of neural networks for speech, language, cognitive, and emotional functions in the brain. One aspect of cognition that plays an important role in many aspects of development, including speech and language development, is attention. The current study focuses on attentional control, as it is proposed to play a potential influential role when considering the experience of stuttering.

Another recognized theory of stuttering, the Covert-Repair Hypothesis, attributes differences in attentional control as a primary cause of stuttering (Postma & Kolk, 1993). The Covert-Repair Hypothesis suggests that stuttering may result from over-attention or over-monitoring in the speech production or planning process (Yairi & Seery, 2015). Evidence suggests that people self-repair speech errors via two primary monitoring mechanisms including perception of auditory output via external feedback and "internal inspection of the speech program prior to its motoric execution" (Postma & Kolk, 1993, p.472). Internal inspection of errors allows for correction of errors prior to the onset of speech production. Correction of errors, known as the covert repair cycle, is comprised of a series of steps where the speaker detects the error via self-monitoring, halts ongoing speech production, corrects the phonetic plan, and resumes speech production with the revised plan in place. Breakdowns in the covert repair of speech production can cause cessation of the forward flow of speech or repetition of previously produced segments (Postma & Kolk, 1993). The cause of these breakdowns is attributed to the attempt to correct phonetic errors before articulation occurs as "repairing of some part of the articulatory plan makes the complete plan, even the correct parts, temporarily unavailable for articulation, for example, as too many processing resources are consumed" (p.477). The Covert-Repair Hypothesis raises the question of the role of attentional networks in speech production because if attentional resources are being allocated to the process of self-monitoring during the formulation of speech, then there may not be enough attentional resources available during the production of speech to support planning and motor processes for fluid speech.

Stuttering, by nature, is multifaceted. Therefore, while theories attribute the etiology of stuttering to the speech motor system, cognitive factors also play a role in and influence stuttering presentation (Yairi & Seery, 2015). Researchers examining the influencing factors contributing to the development and persistence of stuttering implicate several domains, including linguistic, motor, sensory, emotional, and cognitive processes (Yairi & Seery, 2015). Cognitive domains such as attention, executive functioning, and memory are suggested to factor into stuttering as indicated by existing and ongoing research. A recent meta-analysis reports that while overall findings were inconsistent in the literature, most research suggests that CWS as a group demonstrate weaknesses in executive function (EF), which includes three core components: inhibition, working memory, and cognitive flexibility (Anderson & Ofoe, 2019). Inhibition is the ability of an individual to disregard unimportant information or suppress a dominant reaction. It allows someone to resist their impulse and exercise self-control in directing their attention amidst distractions (Anderson & Ofoe, 2019). Working memory specifically refers to the storage and manipulation of information in real time (Anderson & Ofoe, 2019), a necessary component of speech planning. Cognitive flexibility "builds on inhibition and working memory to enable flexible switching from one representation, or rule, to another" (Anderson & Ofoe, 2019, p.306), therefore, facilitating flexibility in thinking. EF skills rely on other domain-general cognitive processes like attention (Anderson & Ofoe, 2019). Specifically, the three core components "rely on an existing foundation of attentional skills" (Ofoe et al., 2018, p.1628). These foundational attentional skills may contribute to stuttering by influencing the interactions between speech, language, motor sensory, executive function, and emotional development. Underlying difficulties with attention can result in difficulties within or between other interconnected cognitive processes, such as speech production, because these cognitive processes "depend on strong working memory, inhibition, and cognitive flexibility skills to function properly" (Anderson & Ofoe, 2019, p.314).

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1.1 Attention

Attention is a psychological construct broadly defined as the ability to focus on important and meaningful stimuli (Kimbarow & Wallace, 2024). Attention is defined relative to a stimulus, and that stimulus can be internal or external. It has a limited capacity, in that individuals can only process and attend to a set number of stimuli at a time. Attention is also selective in nature, as individuals have the ability to choose which stimuli they want to attend to (Kimbarow & Wallace, 2024). Attention is a whole brain phenomenon, yet certain areas appear to be crucial in the development of attention according to Posner et al. (2006). There are many theoretical models of attention; however, this thesis will focus on Posner's model of attention. In this model, attention is divided into three main networks, including alerting, orienting, and executive control (Fan & Posner, 2004; Peterson & Posner, 2012). The alerting network of attention supports the ability to prepare for and maintain a state of readiness for incoming stimuli (Kimbarow & Wallace, 2024). The associated neural structures involved in alerting include the thalamus, frontal, and parietal regions of the brain which constitute dorsal attention networks (Peterson & Posner, 2012). The alerting network is heavily influenced by the norepinephrine system (Fan & Posner, 2004). The orienting network of attention supports shifting direction and prioritizing attention to specific stimuli, including location and modality (Kimbarow & Wallace, 2024). The associated neural structures involved in orienting attention are posterior parietal, and frontal regions of the brain, which are part of the ventral attention networks (Peterson & Posner, 2012). Acetylcholine is considered an influencing factor in the orienting network (Fan & Posner, 2004). Finally, executive control of attention supports the effortful control of attention and the awareness of a stimulus (Kimbarow & Wallace, 2024; Petersen & Posner, 2012). Executive control is supported by working memory, cognitive flexibility, and inhibition (components of executive function as defined above). The associated neural structures involved in the executive control of attention include the medial frontal cortex and the anterior cingulate cortex (Peterson & Posner, 2012), and it is modulated by the neurotransmitter dopamine (Fan & Posner, 2004). Posner et al. (2006) suggests that, "Attentional networks (alerting, orienting, executive control) are special in that their primary purpose is to influence the operation of other brain networks" (p.1422).

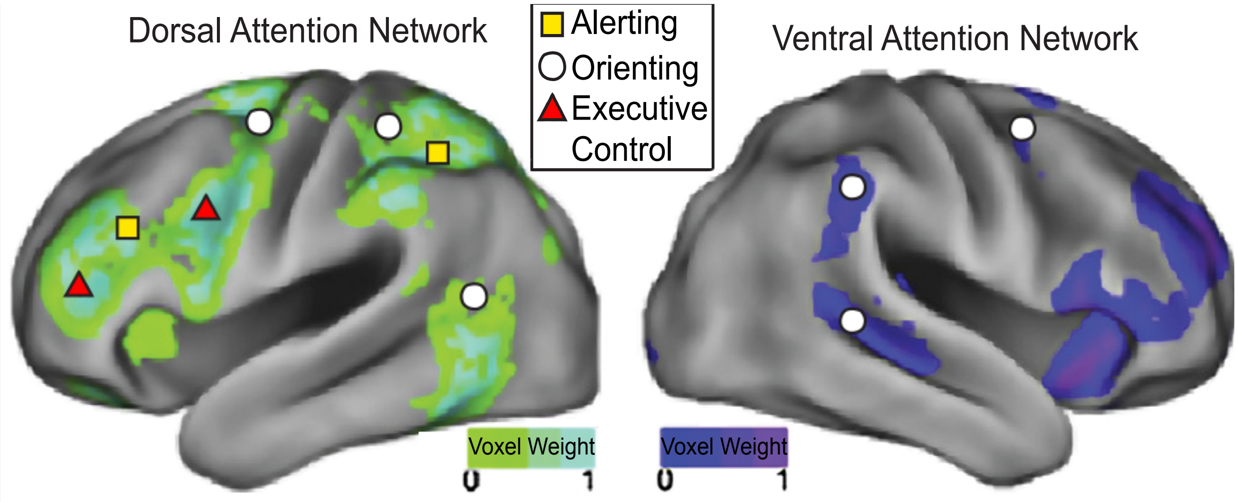


Figure 1. Posner's Model of Attention. Visual representation of the components of Posner's model of attention (alerting, orienting, executive control) mapped onto the two attention networks (Dorsal Attention Network and Ventral Attention Network) in the brain. Adapted from Chang et al. (2017) & Posner & Rothbart (2007).

The role of attention in typical development is defined by the development of the three attention networks: orienting, alerting, and executive control (Posner et al., 2014; Figure 1). Figure 1 illustrates many of the brain areas involved in alerting (yellow squares), orienting (white circles) and executive control (red triangles) attention networks. In general, attention develops during the school years; however, researchers have indicated differences in the development of each attention network (Posner et al., 2014). According to Posner et al. (2014), "brain networks underlying attention are present even during infancy and are critical for the developing ability of children to control their emotions and thoughts" (p.1). These connections between brain regions and associated attention networks change as children mature, which lays the foundation for controlled behavior, including self-regulation (Posner et al., 2014). Researchers have found that the orienting network plays a major role in attentional control for typically developing children during the early years of life. This network "interacts with sensory networks to improve the priority of information relevant to task performance" (Posner et al., 2014, p.2). Pozuelos et al. (2014) suggests "that the function of the orienting network continues developing from middle to late childhood" (p.2412). The alerting network, which plays a role in actively attuning one's attention to receive a response, "is critical to high level performance" (Posner et al., 2014, p.2). Development of the alerting network enables "phasic changes in alertness" (Posner et al., 2014, p.2) where an individual transitions from a resting state to one of enhanced responsiveness to a target (Posner et al., 2014). This network demonstrates "evidence of change up to and beyond the age of 10" (Rueda et al., 2004, p.1029). Additionally, the executive control network heavily influences higher-level thinking and problem-solving, which underlie self-regulation and self-control in children. These systems are controlled by various connections in the frontal and posterior cerebral cortex and continue to develop in efficiency (Posner et al., 2014; Figure 1), "improving significantly between middle and late childhood" (Pozuelos et al., 2014, p.2412). In summary, typical development of attention begins in infancy, relying heavily on the efficiency and control of the orienting network. The orienting network continues to develop into late childhood to account for "processes related to disengagement and reallocation of attention" (Pozuelos et al., 2014, p.2412). Meanwhile, the alerting and executive control network continue to develop as a child matures and brain connectivity changes, with the alerting network stabilizing between the ages of 8-12 years old and executive control continuing to develop into adolescence (Pozuelos et al., 2014).

1.2 Attention and Stuttering

Existing literature suggests a link between stuttering and attention based on observed overlap between areas in the brain associated with both stuttering and attention. According to Chang et al. (2018), there are two major attention networks: dorsolateral attention network (DAN), illustrated in green in Figure 1, and ventrolateral attention network (VAN), illustrated in blue in Figure 1. These attention networks "are associated with different forms of attentional control" (Chang et al., 2018, p.60) where DAN is connected to auditory modalities of attention and goal-oriented behavior and VAN is associated with unexpected events. As can be seen in Figure 1, there is substantial overlap between these attention networks and the brain regions that regulate alerting, orienting, and executive control of attention in the model. In Chang et al. (2018), researchers examined resting-state functional connectivity networks based on functional magnetic resonance imaging (fMRI) in CWS and CWNS. This study found "a disassociation between the DAN and VAN and their interaction with the somatomotor network… suggesting an imbalance in how attention processes regulate speech motor control" in CWS compared to CWNS (Chang et al., 2018, p.60). VAN generally aligns with the orienting network of attention from Posner's model. Therefore, findings of abnormal functioning of VAN in CWS support current research indicating difficulty orienting attention and overall decreased performance on attentional regulation tasks for CWS compared to CWNS (Chang et al., 2018). Ultimately, differences may exist between the dorsal and ventral attention network connectivity in CWS.

Other studies have found differences in basal ganglia thalamocortical (BGTC) loop circuits for CWS as compared to CWNS (Chang & Gunther, 2020). The BGTC loop, which connects the cerebral cortex, thalamus, and basal ganglia, facilitates proper timing and sequencing of speech motor programs that are critical for fluent speech production (Chang & Gunther, 2020). Researchers theorize that the neural differences associated with stuttering may specifically impact the cortical planning stages, with some type of error or discoordination occurring in the way motor speech signals are sent. The three proposed areas of impairment include the basal ganglia, impairment of axonal projections between cerebral cortex, basal ganglia, and thalamus, or broader impairment in cortical processing for speech production (Chang & Gunther, 2020). This means the location of atypical processing could be in either the initiation of the plan from the cortex or in the execution of the plan as guided by the basal ganglia. Ultimately, the BGTC network is responsible for initiating and regulating speech motor programs and includes areas that are implicated in attention regulation, such as the frontal cortex of the brain and the thalamus. Therefore, when CWS are trying to speak in high pressure situations, such as emotionally intense situations or using more complex language, differences in BGTC networks may disrupt the timing and coordination of neural signals to speech muscles, resulting in disfluent speech (Chang & Gunther, 2020). This theory of differences in BGCT loop further supports the idea that attention may play a role in speech production in stuttering. Together, recent findings suggest that attention plays a role in stuttering; however, there is a gap in knowledge in understanding of the ways in which attention may be impacted in CWS and how these differences might influence stuttering behavior.

The relationship between stuttering and attention has previously been measured using group comparisons of parental reports and behavioral data. However, these results often contradict one another; parent reports generally reveal a difference between attention skills in CWS compared to CWNS, while behavioral studies have provided more variable results. A recent meta-analysis revealed that CWS were rated as having weaker attention skills than CWNS by parent report (Anderson & Ofoe, 2019). The differences include more difficulty with attentional focus and inhibition (Felsenfeld et al., 2010; Ofoe et al., 2018), decreased efficiency in allocating attentional resources, and increased challenges in attentional shifting or cognitive flexibility (Anderson & Ofoe, 2019). Additionally, studies examining the prevalence of Attention Deficit Hyperactive Disorder (ADHD) symptoms in CWS using the ADHD Rating Scale: Parent Section have found that CWS are rated as exhibiting elevated ADHD symptoms (Blood et al., 2007; Donaher & Richels, 2012; Druker et al., 2019) and have an increased likelihood of presenting with the co-occurring disorders of stuttering and ADHD (Blood et al., 2003).

The few behavioral studies that exist often have small numbers of participants, examine individual aspects of attention, and often use only visual stimuli. Consistent with studies of parent report, some behavioral studies support that attention, or difficulties with attention, plays a role in stuttering. Across several studies, CWS were found to be less efficient at disengaging and shifting attention in both visual and auditory set shifting tasks than CWNS (Eggers & Jansson-Verkasalo, 2017; Eichorn et al., 2018; Wagovich et al., 2020) and have decreased performance on a sustained attention task compared to CWNS (Costelloe et al., 2019). CWS also performed more poorly on visual selective attention tasks and demonstrated significantly lower orienting network efficiency compared to CWNS (Eggers et al., 2012). As discussed above, the orienting network plays an important role in controlling attention in the early years in life with continued development into late childhood (Posner et al., 2014; Pozuelos et al., 2014), and therefore its efficiency and development can greatly influence attentional control in children. However, even when differences between CWS and CWNS are found, they are often subclinical in nature, which implies that the differences observed in these studies may not be significant enough to interfere with everyday functional tasks (Ofoe et al., 2018).

Other studies of attention in stuttering found no group differences between CWS and CWNS using a variety of methods and tasks. One study examined parent report ratings and found no group differences between CWS and CWNS on any of three attentional scales, including attentional focusing, impulsivity, and inhibitory control (Anderson & Wagovich, 2010). Behavioral studies have also found no group differences in attention between CWS and CWNS. For example, in studies examining visual attention shifting, there were no differences observed between CWS and CWNS (Blood et al., 2007; Johnson et al., 2012). Similar patterns were observed when examining attentional shifting and inhibitory control in auditory set shifting tasks (Eggers & Jansson-Verkasalo, 2017). It is evident that the literature examining attentional control in CWS contains some inconsistencies, likely due to differences in age, sample size, and methodology, and requires further research as to if and how attention may impact CWS. Despite these inconsistent findings, the literature does reveal attentional control as a likely influencing factor in CWS; however, the exact role it plays is unclear.

1.3 Aims of the Present Study

The present study aims to expand on the current research by examining a large battery of parent report forms and behavioral tasks primarily related to attention, as defined in Posner's model of attention, to examine the role of attention in CWS and CWNS. The limitations of the existing research leave gaps in understanding attention in stuttering based on both parent reports and behavioral tasks. However, multiple studies suggest that “CWS, as a group, have weaknesses in short-term memory, inhibition, and cognitive flexibility” (Anderson & Ofoe, 2019, p.313); all of which are skills housed under the domain of the executive control of attention. As such, the present study looks to expand upon the existing research by examining both parent report and behavioral testing data from a battery of tasks in CWS and CWNS. While individual measures may not reliably show differences between groups, researchers use many measurements that likely tap into a common set of underlying skills (i.e., different aspects of attention and executive function). Exploratory factor analysis (EFA) is an analysis method that models covariance across a sample to identify latent structure from a set of measurements (underlying constructs called factors). EFA will be used to identify latent factors in a large existing dataset within and across groups of CWS and CWNS. We will use this approach to develop a larger and more integrative model that explains the role of attention in stuttering and examine the potential underlying differences between CWS and CWNS.

1.4 Research Questions

1.) How do different aspects of attentional control, as measured by the tasks included in the current study, factor together?
2.) Do models of attentional control based on tasks included in the current study differ between CWS and CWNS?

1.5 Hypotheses

The cognitive domain of attention precedes and contributes to the development of several other related cognitive domains that influence speech and language production. Given the multifaceted nature of stuttering and the underlying neurobiological underpinnings, the present study aims to explore the role of attentional control in developmental stuttering. We hypothesized that tasks that tap into the similar aspects of attentional control (i.e., alerting, orienting, and executive control networks) will factor together, and the extracted factors will be similar between CWS and CWNS. Additionally, we hypothesized that CWS and CWNS will score differently on a set of commonly extracted factors. Due to the natural variation that exists for CWNS as compared to CWS, it is possible that there will be differences in the strength of how the measures factor together between groups, with stronger factors indicated in the stuttering group.

2.0 Methods

2.1 Current Thesis Project

The data for this project were previously collected as part of a study on attentional control in CWS. I was not involved in data collection. For this master's thesis project, I developed specific research questions, as noted in the Introduction, completed data processing, data analysis, and interpretation of results. Description of prior data collection steps as well as my direct work are detailed below.

2.2 Participants

Data for this thesis were collected as part of a project examining attentional control in CWS by a licensed speech-language pathologist at Michigan State University and the University of Pittsburgh. Participants include 82 children between the ages of 4-8 years with 39 females and 43 males. Participants were divided into two groups: CWS and CWNS. Inclusion criteria for this project were normal hearing, normal or corrected-to-normal vision, and language and nonverbal intelligence scores within or above the normal range. Exclusion criteria included a history of neurological disease or injury and colorblindness. Participants in the CWNS group reported no personal or family history of stuttering. A total of 40 CWS and 42 CWNS were included in analysis for this thesis project. Of the 40 children in the CWS group, 18 were male and 22 female, with mean age of 6.33 years and a range of of 4.24 to 8.84 years. The CWNS group included 42 children, 25 males and 17 females, with a mean age of 6.13 years and a range of 4.31 to 8.57 years. Additional demographic information collected for each child includes parental education, parental occupation, and household income. Parent education was coded as years of education completed (i.e., 12 = high school degree, 16 = bachelor's degree, 18 = advanced degree). Parental occupation was rated using the Occupational Information Network (O*Net) Job Zone rating (1-5), which rates different jobs based on education, training, and specialized skills needed to complete the job. Caregivers also reported their total household income for all earners. This project was approved by the Institutional Review Boards at Michigan State University and the University of Pittsburgh.

Participants were identified as CWS based on the following criteria: parent report of stuttering, disfluency count derived from a speech and language sample obtained with a certified Speech-Language Pathologist (SLP), and severity rating scores. Severity rating scores were determined using the Stuttering Severity Instrument, Fourth Edition (SSI-4; Riley, 2009). Children who scored a rating of at least very mild were identified as CWS. Speech and language samples were collected via administration of a wordless picture book and during conversational play to determine the percentage of stuttering like disfluencies (SLD) per syllable and per word. Participants with a disfluency count greater than 3% SLD per syllable were identified as a CWS.

Table 1. Demographic information for CWS and CWNS. Comparison of age, sex, parent education, parent occupation, and household income across CWS and CWNS.

	Age	Sex	Parent Education	Parent Occupation	Household Income
CWS	6.33 (4.24-8.84)	18M:22F	15.68	3.72	70,000-85,000
CWS	6.13 (4.31-8.57)	25M:17F	16.225	4	85,000-95,000

2.3 Behavioral Assessments

Participants were administered a large battery of behavioral assessments examining various aspects of speech, language, and attention. Measures examining attention aligned with the attention networks outlined in Posner's model of attention, with a focus on the executive control network. The list of behavioral assessments is provided in Table 2, including a brief description of the measure, the cognitive domain the measure aimed to assess, and whether there were any missing data on that task. Missing data and how they were addressed in data analyses are discussed below.

2.3.1 Measures of Speech and Language

Within the domain of speech and language, several assessments were administered. Articulation and phonology skills were assessed via the Bankson Bernthal Test of Phonology (BBTOP; Table 2). The following scores were derived from BBTOP: number of words correctly produced (Word Inventory; WI), number of misarticulations of individual sounds across word positions (Consonant Inventory; CI), and identification of 10 common phonological processes (Phonological Process Inventory; PPI) (Bankson & Bernthal, 1990). Receptive and expressive language skills were measured via the Clinical Evaluation of Language Fundamentals-Preschool, Second Edition (CELF Preschool-2; Wiig et al., 2004) for participants between the ages of 3-7 years of age and with the Clinical Evaluation of Language Fundamentals Fifth Edition (CELF-5; Wiig et al., 2014) for participants above the age of 7 years (Table 2). A core language score was derived based on the following subtests: sentence structure, word structure, and expressive vocabulary skills. In addition, nonverbal intelligence and abstract reasoning skills, including spatial relationships, visualization, and higher order reasoning were assessed using the Primary Test of Nonverbal Intelligence (PTONI; Ehrler & McGhee, 2008).

2.3.2 Measures of Executive Control of Attention

2.3.2.1 Working Memory

Multiple measures of working memory were also administered. This included three subtests of the Test of Auditory Processing Skills, Third Edition (TAPS-3; Martin & Brownell, 2005), a standardized assessment, to measure short-term verbal working memory (Table 2). On the digit span task, participants repeated strings of numbers that got increasingly longer as the task progressed. Similarly, for the digit span reverse task, participants repeated strings of numbers in the reverse order (i.e., 9-4 repeated as 4-9), which also got increasingly longer as the task progressed. In the word span task, participants repeated lists of simple words, which got longer as the task progressed.

Visual working memory was examined using the Noisy Book task (Hughes et al., 1998; Table 2). This task involved an array of colored boxes with associated animal pictures and noises. Participants were instructed to memorize each colored box to animal association so that when the pictures were removed, children could sequence the animals based on the box color and sound of the box alone. Participants were provided with sequences of animals using the colored boxes starting with 2 stimuli and spanning up to 10 stimuli, and children were instructed to repeat the sequence in the exact order they heard. The task ended when a child was unable to repeat any correct stimuli from a sequence on two consecutive trials. Accuracy and longest sequence span were recorded for each child.

A Nonword Repetition Task (NWR; Dollaghan & Campbell, 1999) was administered to assess phonological working memory (Table 2). Participants repeated a series of one, two, three, and four syllable speakable nonwords. Accuracy was determined based on the total number of correct phonemes produced.

2.3.2.2 Inhibition

The behavioral assessment battery included a measure of inhibitory control using a Go/No-Go task, the "Zoo Game" (Grammer et al., 2014; Table 2). In this task, children were given a scenario in which they were told all the zoo animals had escaped their cages and their job was to help the zookeeper catch all animals and put them back in their cages. However, orangutans were helping the zookeeper, so they should not catch the orangutans. To catch the animals, children were instructed to press a button on a keypad as fast as they could when an animal (except orangutans) appeared on the screen (Go Trials). When an orangutan appeared on screen, children were told to not press any button, or to inhibit their response (No-Go Trials). Accuracy (Go and No-Go Trials) and reaction time (Go Trials) were recorded for this nonverbal inhibition task.

2.3.2.3 Inhibition and Cognitive Flexibility

Two tasks in the assessment battery examined multiple aspects of executive control. The Head Toes Knees Shoulders-Revised (HTKS-R; Gonzales et al., 2021; McClelland et al., 2014) task, (Table 2) was a nonverbal, assessment of verbal working memory, inhibition, and cognitive flexibility. In HTKS-R, participants performed a series of opposing actions based on a given rule. For example, when the instructor told the children to touch their head, the adapted rule required participants to touch their toes instead, and vice versa. Similarly, when instructed to touch their knees, participants touched their shoulders. Subsequent blocks changed the rules again, reordering the association between spoken instruction and which body part was to be touched (i.e., Head-Knees, Shoulder-Toes). HTKS-R consists of 3 sections, each beginning with a set of practice trials to ensure understanding by the participants. If children were unable to successfully complete the practice trials, the task was discontinued.

In addition to HTKS-R, Shape School (SS; Espy, 1997) examined working memory inhibition, and cognitive flexibility in a single task (Table 2). SS has a narrative context in which all the “children" (figures that were either a square or a circle and were either red or blue) are at school and going through their school day. There are five different conditions, each which correspond to a different part of their school day (classroom, lunch, recess, art, etc.). In the first condition (color), children labeled (said their “name”) the figures by their color (red or blue). In the second condition (inhibit), children labeled the colors of the figures with happy faces only and inhibited responses of shapes with sad faces. The third condition (shape) required children to label the shape of the figures wearing hats (square, circle), as opposed to their color. In the fourth condition (switch), children labeled the color of the figures without hats and the shape of the figures wearing hats. In the final condition (switch & inhibit), children labeled the color of the figures without hats and the shape of the figures wearing hats, but only if they have happy faces. No labels were to be said if figures had sad faces. Accuracy and reaction time were calculated for each of the five conditions and trials were discontinued after the fourth condition if fewer than two correct responses were given in each category, based on increased difficulty of the task.

Table 2. Battery of Behavioral Assessments. Summary of the behavioral assessments administered to all participants including the measure name, description, cognitive domain the measure intends to assess, and number of participants with missing data related to each measure.

Measure	Description	Domain	Participants Missing Data
Bankson-Bernthal Test of Phonology (BBTOP) Word Inventory (WI)	Measure of the percentage of words correctly produced	Articulation and phonology	0
BBTOP Consonant Inventory (CI)	Measure of the number of misarticulations of individual sounds across word positions	Articulation and phonology	0
BBTOP Phonological Process Inventory (PPI)	Identifies the presence of 10 common phonological processes	Articulation and phonology	0
Clinical Evaluation of Language Fundamentals Core Language Score (CELF-5; CELF Preschool-2)	Measure of receptive and expressive language abilities. Assessment evaluates sentence structure, word structure, and expressive vocabulary skills	Receptive and expressive language	0
Primary Test of Nonverbal Intelligence (PTONI)	Measure of nonverbal intelligence including spatial relationships, visualization, and higher order reasoning	Nonverbal and abstract reasoning	0
Test of Auditory Processing Skills (TAPS-3) Digit Span	Measure of verbal working memory by repeating strings of numbers in order	Verbal working memory	0

Table 2 (continued).

TAPS-3 Reverse Digit Span	Measure of verbal working memory by repeating strings of numbers in the reverse order	Verbal working memory	11
TAPS-3 Word Recall	Measure of verbal working memory by repeating a list of simple words	Verbal working memory	0
Noisy Book Total	Measure of visual working memory by repeating a sequence of highlighted colored boxes that are associated with animals	Visual working memory	0
Nonword Repetition Sum	Measure of phonological working memory based on total number of phonemes recalled across 1-4 syllable nonwords	Phonological working memory	0
Go Accuracy (Zoo Task)	Measure of accuracy of inhibitory control based on pressing a button when a zoo animal appears (except orangutans)	Inhibitory control	5
Go Reaction Time	Measure of response time for inhibitory control based on speed of pressing a button when a zoo animal appears (except orangutans)	Inhibitory control	5
No Go Accuracy	Measure of accuracy of inhibitory control when inhibiting (not pressing) a response when an orangutan appears	Inhibitory control	5

Table 2 (continued).

Head Toes Knees Shoulders (HTKS) Total	Measure of cognitive flexibility and inhibitory control by learning one set then adapting to new sets of verbal rules for touching head, toes, knees, or shoulders	Cognitive flexibility, inhibition	11
Total Shape School	Measure of accuracy of cognitive flexibility and inhibitory control when responding to changes in rules structures across five different conditions	Cognitive flexibility, inhibition	1
Total Reaction Time	Measure of response time of cognitive flexibility and inhibitory control when responding to changes in rules structures across five different conditions	Cognitive flexibility, inhibition	5

2.4 Parent Reports

In addition to the behavioral measures noted above, parents or legal guardians (hereafter referred to as parents) of participants were given a variety of questionnaires assessing their child's attention-related skills in everyday life. Parent reports allow for collection of information regarding their child's attention-related skills across various contexts within their natural, everyday environments. The list of parent reports acquired are provided in Table 3, including a brief description of the measure, the general domain the measure aimed to assess, and whether there were any missing data on that task. Missing data and how they were addressed in data analyses are discussed below.

This battery of parent reports included rating scales measuring signs and symptoms of attention deficit disorder (ADD) and attention deficit hyperactivity disorder (ADHD) via the Brown Attention Deficit Disorder Scale (BADDS; Brown, 2001), Revised Connors' Parent Rating Scale (CPRS; Connors, 1997), and ADHD Rating Scale-IV (DuPaul et al., 1998). Executive functioning skills were also measured with the Child Behavior Checklist (CBCL; Achenbach & Rescorla, 2000). These tasks provide measures of attentional control in real world settings that cannot be directly measured in the lab. Additional parent reports examined child temperament, via the Child Behavior Questionnaire (CBQ; Rothbart, 1996) for children 3-7 years or Temperament in Middle Childhood Questionnaire (TCMQ; Simonds & Rothbart, 2004) for children ages 8+ years. Individual scores from the CBQ and TMCQ were reduced and combined into the Big-3 Factors: Surgency, Negative Affectivity, and Effortful Control (Rothbart et al., 1994). Parent education, which was obtained during initial collection of demographic information, was also included within this battery as a proxy measure of socioeconomic status (SES).

Table 3. Parent Report Measures. Summary of the parent report forms administered to parents of all participants including the report name, description, general domain the report intends to assess, and number of participants with missing data related to each report form.

Measure	Description	Domain	Participants Missing Data
Brown's Attention Deficit Disorder Scales (BADDS) Total Score	Assesses hyperactivity and executive function impairments associated with attention deficit disorder (ADD)/attention deficit hyperactivity disorder (ADHD) and related problems	Executive function skills	4
Child Behavior Checklist (CBCL) Total	Assesses a range of childhood emotional and behavioral problems	Emotional, self-regulation, and social behaviors	8
Connor's Parent Rating Scale (CPRS) Total Score	Assesses behavioral, social, academic issues associated with hyperactivity & inattention (ADD/ADHD)	Emotional, self-regulation, and social behaviors	3
ADHD: ADHD Rating Scale IV Total	Assesses frequency & severity of ADHD symptoms	Emotional, self-regulation, and social behaviors	12
Child Behavior Questionnaire (CBQ) Surgency	Higher order composite factor of temperament is associated with sustained attention and reflects extraversion-related behaviors. Factor is comprised of the average of scaled scores for the following factors: activity level, high intensity pleasure, impulsivity, and reverse shyness	Temperament characteristics	6

Table 3 (continued).

CBQ Negative Affectivity	Higher order composite factor of temperament associated with negative emotions and reactivity. Factor is comprised of the average of scaled scores for the following factors: anger, discomfort, fear, sadness, and reverse soothability	Temperament characteristics	6
CBQ Effortful Control	Higher order composite factor of temperament is associated with executive attention and reflects the ability to inhibit a dominant response to perform a non-dominant response, plan, and detect errors. Factor is comprised of the average of scaled scores for the following factors: attention focusing, inhibitory control, low intensity pleasure, and perceptual sensitivity	Temperament characteristics	6
Parent Education	One determiner of socioeconomic status (SES) based on average educational level between maternal and paternal caregivers	Demographics, household SES	2

2.5 Procedure

Data for this project were collected in a laboratory setting. Upon arrival, parents and children were shown lab spaces and all experimental tasks were explained by a certified speech-language pathologist. After parental consent and child assent, parents were seated in a separate room where they could view their child on a monitor. The child, together with the speech-language pathologist, then completed the above behavioral tasks, while the parent completed a series of parent report surveys, listed above. All sessions were video- and audio-recorded for scoring and transcribing off-line. Following each session, the child received payment and a small toy for participating.

2.6 Data Processing

For the current study, previously collected data in CWS and CWNS were compiled and prepared for exploratory factor analysis (EFA). The decision steps taken for completion of EFA are illustrated in Figure 2. Data were gathered, curated, and formatted in a machine-readable way in order to select measures of interest, eliminate any inconsistencies, and perform quality control. Specifically, across participants, data measurements within the assessment battery were condensed to exclude hierarchically related scores (to reduce the total number of variables for EFA). This process required the creation of guidelines for inclusion of reasonable measures and exclusion of redundant values. For example, when one score was simply a sum of its sub-scores, we included only the composite score as a variable to be analyzed in EFA and removed subscores. This was observed in the NWR task as separate scores were calculated for one, two, three, and four syllable speakable nonwords and these scores were totaled in a NWR Sum.

Additionally, individual values for participants were replaced if the given score for a measurement was not quantitative and compatible with the data analysis program. For example, some standardized scores for the BBTOP were initially coded as "<65" indicating poor performance on the task. However, this non-numerical score cannot be included in data analysis.

In these instances, scores were replaced with a value one less than the given value to represent that scores were below 65, however, the exact score for these participants were not known. Therefore, "<65" was replaced with a numerical value of 64. Similar methods of data substitution were used throughout the dataset when values were not quantitative. Curation of data ultimately produced a master spreadsheet reporting related measures of speech, language, and attention which was then processed using the statistical data analysis software, R and R-Studio.

Pairwise linear correlations between all measurements (across all participants and within each of the two groups) were calculated to evaluate the strength of the relationships across the assessment battery. The nature of EFA requires a balance of correlated variables with some variance to detect underlying factors; all variables cannot be highly correlated (which would suggest they all measure the same factor), nor can variables be completely unrelated (in which case there would be no latent factors). As such, we systematically considered each variable and removed individual variables that were highly correlated with others. For instance, we compared all scores from the BBTOP (WI, CI, PPI) to determine if they were highly correlated because they were derived from the same test administration. In this case, all three scores were included as variables to be analyzed in EFA because enough variance was detected between scores.

2.7 Missing Data

Across 82 participants and 25 chosen assessment variables, there were 90 missing individual data points. Missing data occurred for a variety of reasons. For parent reports specifically, missing data were often the result of parents not completing or returning the forms. Of note, the highest concentration of data were missing for the HTKS-R task and the ADHD Rating

Scale IV due to a delay in administering these assessments in the project. While data collection began in Fall 2017, inclusion of these tests did not begin until August 2018; therefore, participants tested prior to this date (*n* = 11) were missing these data.

Missing values were accounted for using one of two different imputation methods. In situations where participants were unable to complete tasks due to task difficulty, missing data were substituted with a value of zero. This was especially prevalent for the digit span reverse task because the younger participants, specifically the 4-year-olds, were unable to perform this task and instead continued to repeat the digits in forward order. Other missing values were replaced with plausible values using the multivariate imputation with chained equations (MICE) approach implemented in R (Van Buuren et al., 2011). MICE uses existing data to make multiple predictions about missing values, leading to multiple complete datasets. The MICE approach was wrapped in the multiple imputation factor analysis (MIFA) package (Nassiri et al., 2018). Essentially, MICE created multiple plausible imputations and MIFA combined them using Rubin's Rules (Rubin, 2004) into a single covariance matrix. The covariance matrix was then converted into a correlation matrix to be used in factor analysis using the psych package (Revelle, 2024) in R. MICE was the chosen imputation method for this data set because it makes few assumptions about missing data and accounts for uncertainty in predictions by making multiple complete datasets. The exclusion of participants with missing data was not feasible in this study due to small sample size, which would lead to reduced power to detect latent factors and potential bias.

2.8 Data Analysis

The exploratory data analysis methods described in this thesis are similar to the methods utilized in a previously published paper that examines cognitive functions in two groups of preschool children – those who are typically developing and those with a diagnosis of developmental language disorder (Plym et al., 2021). This paper provided guidance in the creation of the analysis plan for this project because of the parallels that exist across the two studies. For example, both projects included a variety of behavioral assessment data, examine communication disorders in the pediatric population, compare two groups of children, including typically developing children and children with a communication disorder, and utilize correlation matrices and exploratory factor analysis to examine the relationships between measured variables and differences between groups.

Following imputation to account for missing data, three correlation matrices were calculated: (1) across all participants in the complete (CWS and CWNS) dataset; (2) for the CWS group only; and (3) for the CWNS group only. Correlation matrices encode the pairwise Pearson Correlation Coefficients of each measure with another, across all participants in a group. The correlation matrices created for this data set revealed the degree to which different measures within the battery were related within and across the CWS and CWNS groups. Determining this baseline relation of measurements acted as a precursor to further evaluating the given data with EFA. It is common to use these correlations to determine the suitability of data for the EFA (Figure 2). For example, one such suitability calculation we employed is the Kaiser-Meyer-Olkin (KMO) Test (Kaiser, 1970). This value measures the proportion of variance among variables that might have common variance, which is necessary for EFA, and is determined, in part, by the strength of correlation that exists between measurements. High values of the KMO criterion indicate suitability for EFA, with values less than 0.5 considered inadequate. A value of greater than 0.6 has become a commonly suggested threshold for factor analysis involving relatively small samples. Further visual inspection of the correlation matrices was also used to identify potential differences across groups.

The chosen method of analysis for this set of data was EFA. EFA is a data-driven technique adopted to identify underlying factors related to combinations of correlated measurements across individuals to explain the variability that exists within groups. The tasks included in this study's assessment battery examined skills across domains of speech/language and attention, specific to executive control, as opposed to examination of these skills independently. The wide range of related tasks available that likely, in part, provide unique but related measures of common cognitive abilities indicated use of EFA. For this study, EFA was completed on three data sets: (1) for the combined (CWS and CWNS) data set; (2) for the CWS group only; and (3) for the CWNS group only (Figure 2). An additional EFA was also conducted on the combined dataset with a reduced number of variables to aid in interpretation of results from the CWS and CWNS subgroups and the combined group model. EFA was used to identify non-random structure in the observed data and identify "factors" (also called latent variables) that influence sets of correlated measures. Additionally, EFA was a useful technique because there is a general lack of knowledge and comprehensive model hypothesizing the functional role that attention plays in stuttering in young children, as noted in the Introduction (Garson, 2023). In EFA, eigenvalues extracted from the bivariate correlation matrix across variables measured are used to quantify the percent of variance explained by each extracted factor. Larger eigenvalues are associated with more salient factors that best explain the variability that exists within the data (Garson, 2023). As such, application of EFA across these measures enabled examination of latent variables within attentional control tasks to evaluate working hypotheses and define constructs that I hope will ultimately lead to a better mechanistic understanding the role attention has in stuttering.

Scree plots were adopted to examine how many meaningful factors could be extracted from the data and to determine the saliency of the factors (Figure 2). Eigenvalues of the correlation matrix (see above) were graphed in a scree plot to help separate signal (meaningful factors) from noise (random, unreliable relationships). The higher the eigenvalue, the more meaningful (amount of variance explained) the factor (Garson, 2023). Because even "random" factors will explain some variance, these plots have a characteristic "elbow" shape, typically with a few high values and then a flatter plateau. In this way, the number of factors to extract can be determined visually by counting the values that lie above the plateau of the plot. Scree plots were created and examined for the whole group (CWS and CWNS combined) and the CWS and the CWNS groups separately. In these scree plots, we also included eigenvalues obtained using parallel analysis, which is referred to as the "simulated data". Parallel analysis builds a random correlation matrix from normally structured random variables and compares the eigenvalues from the random matrix to the eigenvalues from the data set. We conducted 100 replications using parallel analysis and plotted the 95th percentile eigenvalue distribution. When comparing the two scree plots, scores above the simulated data plot are considered signal and scores below the parallel analysis plot are considered noise. We used this approach to guide the number of factors requested from EFA.

EFA was then conducted using the R package "psych" (Revelle, 2024). EFA requires the specification of a number of parameters (Figure 2). We estimated the factor model using maximum likelihood estimation and performed a varimax axis rotation. Varimax is an orthogonal rotation method that maximizes the variance present within a factor across all participants resulting in easily differentiated presentations of high and low loadings. It is a simplification process to aid in the identification of variables (Garson, 2023). Rotation of axes in EFA serves as a method to increase understanding of the factors for interpretation (Garson, 2023) by increasing factor loadings (weights for each measure on a given factor) for a subset of variables. Variables that heavily load upon a factor allow the researcher to interpret the meaning of a factor. Following identification of factors and factor loadings, we interpreted these factors by considering loadings with absolute value greater than or equal to 0.30.

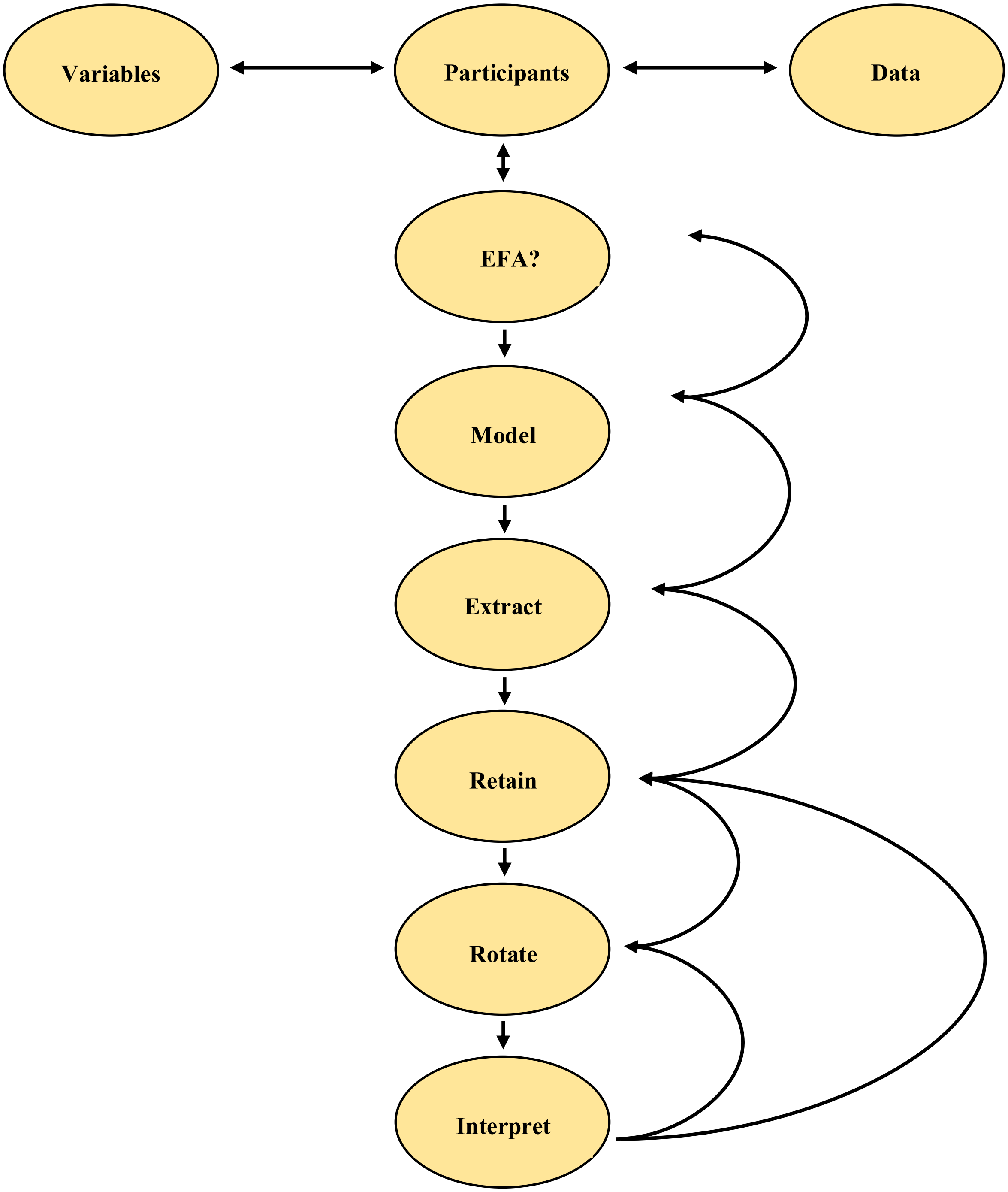


Figure 2. Flowchart of the Decision Steps in EFA. Visual representation of the decision steps taken when performing EFA including consideration of the variables and participants to include, evaluating whether the data and EFA are appropriate, completion of the factor model and extraction of factors, determination of how many factors to retain, rotation of factors, and interpretation of the extracted, retained, and rotated factors. Adpated from Watkins, (2020).

2.9 Data Interpretation

Evaluation of the EFA models were conducted on the combined group (CWS and CWNS), CWS subgroup, and CWNS subgroup. Factor loadings resulting from EFA were thresholded at an absolute value of greater than or equal to 0.30 in order to emphasize loadings with high coefficients, both in the negative and positive direction. The remaining loadings offered possible interpretations of each factor extracted for each group (complete dataset, CWS, CWNS). For each extracted factor, we also determined the proportion of overall variance explained. Next, we qualitatively compared the individual factors that were extracted from each group to determine if similar tasks load on individual factors for each group to interpret possible group differences. Interpretation was conducted using prior knowledge of factor measurements and domain relevant information. Each factor was examined individually in each group to determine what they represent.

For the complete group model, we computed factor scores for each individual participant using Thurstone’s regression method (Thurstone, 1935). These factor scores represent a combined score, based on the individual’s measured data, on each extracted factor. For each factor, we then tested if the factor scores differ, on average, between CWS and CWNS groups using Welch's 2-sample t-tests. Such differences could indicate that groups tend to separate based on the underlying latent variable.

3.0 Results

This research project was designed to examine how different aspects of attentional control, as measured by the tasks included in this current study, factor together. It also examined how models of attention control differ between CWS and CWNS.

3.1 Attentional Control Systems in School Age Children

The full dataset analyzed using EFA consisted of 82 participants (40 CWS and 42 CWNS) and 25 variables. After using multiple imputation methods to account for missing data within this dataset, a combined correlation matrix was derived and is shown in Figure 3. Factors derived from EFA are dependent upon these linear correlations. Results from the correlation matrix demonstrate how different pairs of variables relate to one another across all participants. Accordingly, large red circles in this matrix denote high positive correlations between measures while large blue circles denote high negative correlations between values. Notably, different parent report forms were highly positively correlated with one another (BADDS Total, CBCL Total, CPRS Total, and ADHD IV Total) as were the three scores derived from the BBTOP (CI, WI, PPI). Behavioral testing age was relatively strongly positively correlated with several behavioral tasks – NWR Sum, HTKS Total, Go Accuracy, and NB Total – and negatively correlated with Go RT. None of these are standardized tasks, meaning child scores on these tasks do not already account for age. Additionally, both NWR and HTKS Total were positively correlated with Digit Span Forward, Digit Span Reverse, and Word Recall (all three TAPS-3 scores), NB Total, and Go Accuracy.

Effortful Control was negatively correlated with the following parent report forms: BADDS Total, CBCL Total, CPRS Total, and ADHD IV Total. Scores on the PTONI also negatively correlated with parent reports, including BADDS Total, CBCL Total, and CPRS Total.

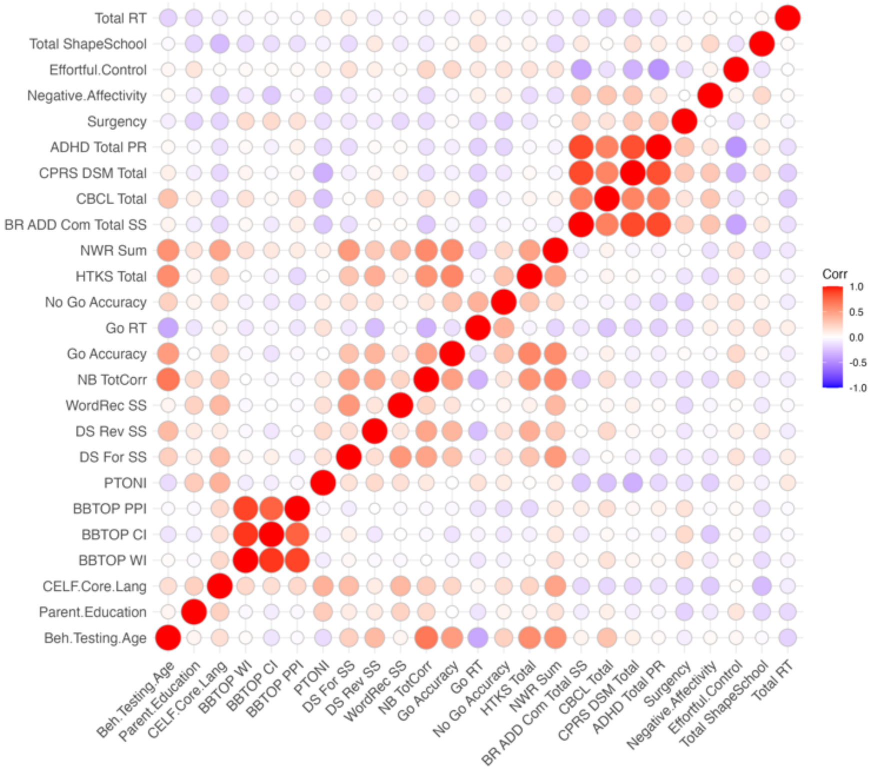


Figure 3. Correlation matrix representing all participants across behavioral tasks and parent report measures. Red circles represent high positive correlations between tasks and blue circles represent high negative correlation between tasks.

From the correlation matrix, a KMO criterion value (Kaiser, 1970) was computed to determine suitability for EFA (Figure 4). According to Kaiser and Rice (1974), this value should be at least >0.5; however, a value of greater than 0.6 has become a commonly suggested threshold for factor analysis involving relatively small samples. The overall KMO criterion value from this data set was 0.69, revealing suitability for EFA. A scree plot was then created using the eigenvalues of the correlation matrix to determine how many factors to include in EFA. Based on the intersection of the observed data with the simulated data derived from parallel analysis, the EFA model was estimated to extract five factors (Table 4).

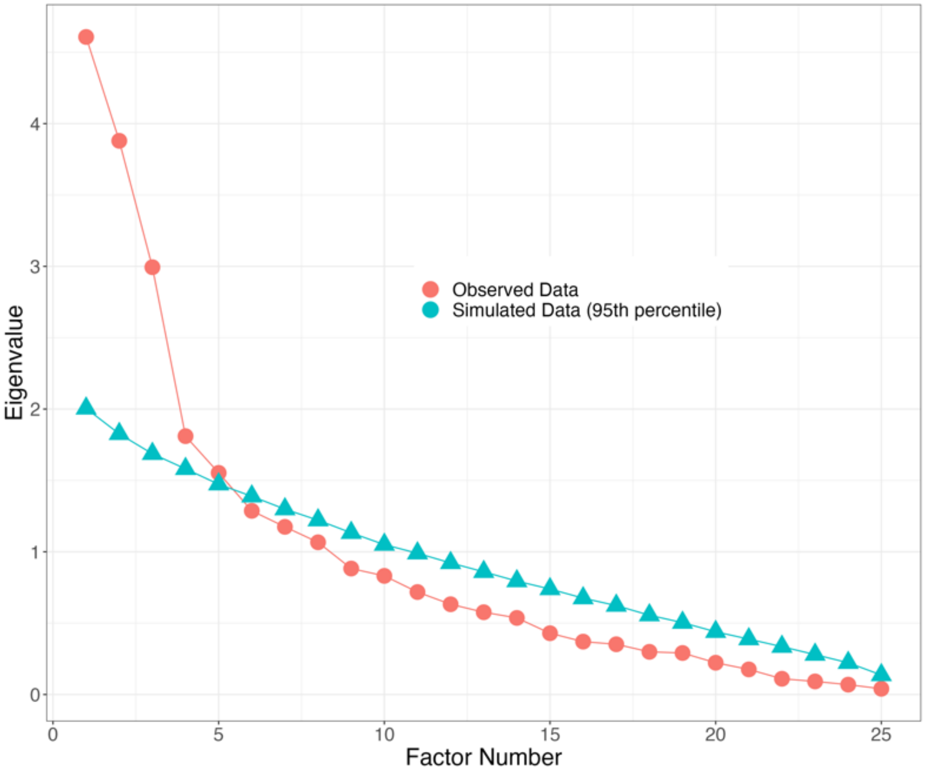


Figure 4. Scree plot illustrating the number of factors (x-axis) and eigenvalues (y-axis) of the observed data set for all participants (red) as compared to the simulated random data from parallel analysis (blue). This was used to determine the number of factors to extract for analysis in EFA.

The factors in Tables 4 and 5 as well as Figure 5 are ordered by weighting, or the amount of variance the factor accounts for, and are therefore not presented in numerical order. Factor 2 and Factor 3 explained the most variance, each accounting for ~14% of the variability within this data set (Table 5). We have labeled Factor 2 as *Parental Reports of Attention Behaviors* since it was composed of five of the parent report forms (BADDS Total, CBCL Total, CPRS Total, ADHD IV Total, and Effortful Control). We labeled Factor 3 *Executive Control of Attention* as it included eight behavioral tasks that measured multiple aspects of executive control, including working memory, inhibition, and cognitive flexibility, as well as child age (Behavioral testing age, Digit Span Forward, Digit Span Reverse, NB total, Go Accuracy, Go RT, No-Go Accuracy, HTKS Total and NWR Sum). The next factor (F1 in Table 4) explained 11% of the variance and we labeled this factor *Speech Sound Skills*. The three tasks loading onto this factor were derived from the BBTOP (CI, WI, PPI). Factor F5, which accounted for 7.8% of variance, we labeled as *Language and Verbal Working Memory*. It was comprised of six measurements including Parent Education, CELF Core Language score, PTONI, Digit Span Forward, Word Recall, and NWR sum. Notably, parent education reliably predicts language scores in other studies (Farah et al., 2006; Fernald et al., 2013; Hackman & Farah, 2009; Hackman et al., 2010). The final factor, Factor F4, explained the least variance (4.8%). It was labeled *Inhibition* and the two tasks loading onto this factor were Go RT and No-Go Accuracy.

Table 4. Factor loadings for each of the five extracted factors and factor loadings across behavioral tasks and parent report measures for all participants following EFA and varimax rotation with loading cutoff of 0.30.

Task Loadings	F2	F3	F1	F5	F4
Behavioral Testing Age		0.872			
Parent Education				0.305	
CELF Core Language Score				0.619	
BBTOP Word Inventory (WI)			0.995		
BBTOP Consonant Inventory (CI)			0.992		
BBTOP Phonological Process Inventory (PPI)			0.876		
Primary Test of Nonverbal Intelligence (PTONI)				0.426	
Digit Span Forward (DS For SS)		0.357		0.571	
Digit Span Reverse (DS Rev SS)		0.492			

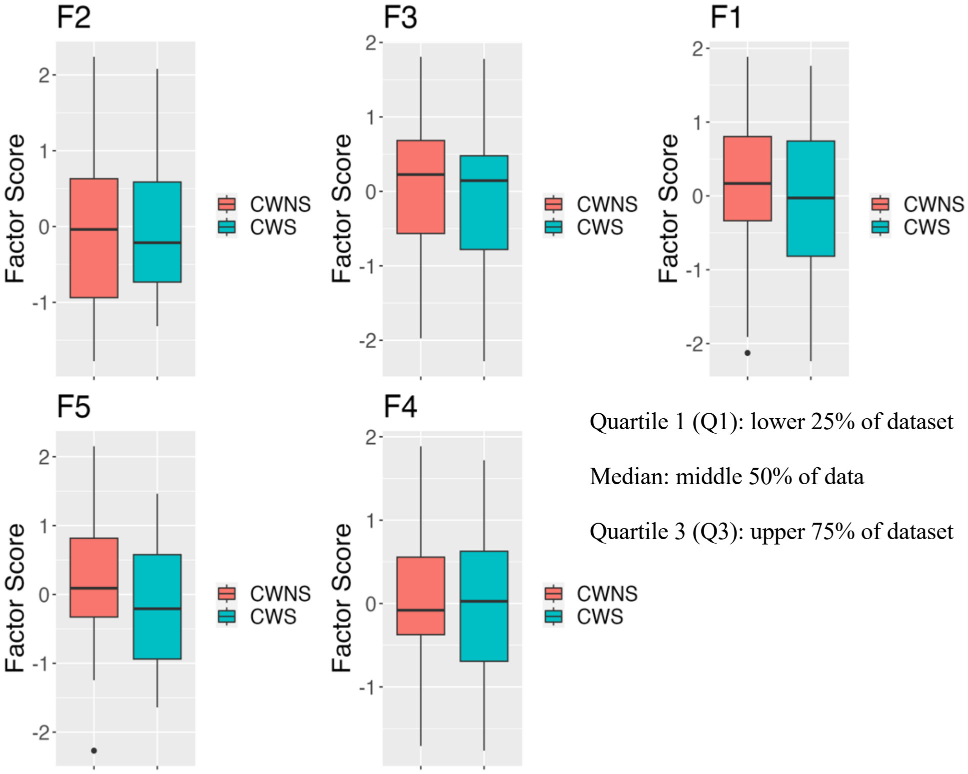
Table 4 (continued).

Word Recall (WorRec SS)				0.642	
Noisy Book Total (NB TotCorr)		0.773			
Go Accuracy		0.671			
Go Reaction Time (Go RT)		-0.323			0.670
No Go Accuracy		0.317			0.664
Head Toes Knees Shoulders (HTKS Total)		0.698			
Nonword Repetition (NWR Sum)		0.641		0.473	
BADDS Total (BR ADD Com Total SS)	0.950				
CBCL Total	0.670				
CPRS DSM Total	0.903				
ADHD Scale IV Total (ADHD Total PR)	0.913				
Surgency					
Negative Affectivity					
Effortful Control	-0.412				
Total Shape School					
Total Reaction Time (Total RT)					

Table 5. Proportion of variance explained by each of the five extracted factors from EFA across all participants.

	F2	**F3**	**F1**	**F5**	**F4**
Proportional Variance	0.140	0.140	0.110	0.078	0.048

Factor scores for each participant were extracted and graphed using box plots (Figure 5) to illustrate potential group differences (CWS vs. CWNS) within the whole data set. Welch's two-sample t-tests were performed to test if scores differed on average between groups for any of the five factors derived from EFA. None of the five factors showed statistically significant group differences; however, factor F5, *Language and Verbal Working Memory*, demonstrated the largest differences between CWS and CWNS groups and resulted in a marginal p-value of 0.0772 (Table 6).



Quartile 1 (Q1): lower 25% of dataset

Median: middle 50% of data

Quartile 3 (Q3): upper 75% of dataset

Figure 5. Box plots comparing CWNS (red) and CWS (blue) factor scores including Q1, median, Q3 (box), and full range of data (whisker) with outlier values (points) across five factors.

Table 6. Welch two sample t-test statistics for the five factors from EFA compared between the CWS and CWNS in the full data model. $^{+} < 0.10$

	F2	F3	F1	F5	F4
t-value	0.2106	-0.6586	-0.8494	-1.7901	0.4727
d(f)	79.980	79.025	78.367	79.051	79.961
p-value	0.8337	0.512	0.3982	0.0772^{+}	0.6377

3.2 Attentional Control Systems in CWS

Similar analyses were performed separately for the CWS and CWNS groups as were completed for all of the children combined. In separating the groups, the sample size decreased. To account for the smaller sample size, we decreased the number of variables analyzed and removed the same variables for each subgroup. When performing EFA, the sample size needs to be greater than the number of variables being analyzed, and reducing the number of variables increased the sampling adequacy and potential to extract meaningful factors. Therefore, to ensure suitability for EFA, we removed the following eight variables: BBTOP WI, BBTOP PPI, Digit Span Reverse, Word Recall, Go Accuracy, Go RT, Total Shape School, Total Shape School RT, resulting in a set of 17 variables that were used for EFA in each subgroup. These tasks were selected for removal based on higher correlation values to other tasks.

The CWS dataset analyzed comprised 40 CWS and 17 assessment variables. Replicating analyses performed for the combined dataset (CWS and CWNS), a correlation matrix was derived following multiple imputation methods to account for the missing data within each group (Figure 6). From the correlation matrix, it was noted Behavioral Testing Age strongly positively correlated with NWR Sum, HTKS Total, and NB Total. Parent forms were also highly positively correlated with one another, including BADDS Total, CBCL Total, CPRS Total, and ADHD IV Total. NWR Sum was positively correlated with Digit Span Forward, NB Total, and HTKS Total. Effortful Control was negatively correlated with several parent form scores, including BADDS Total, CBCL Total, CPRS Total, and ADHD IV Total. Scores on the PTONI were also negatively correlated with behavioral testing age and parent report forms, including BADDS Total, CBCL Total, and CPRS Total.

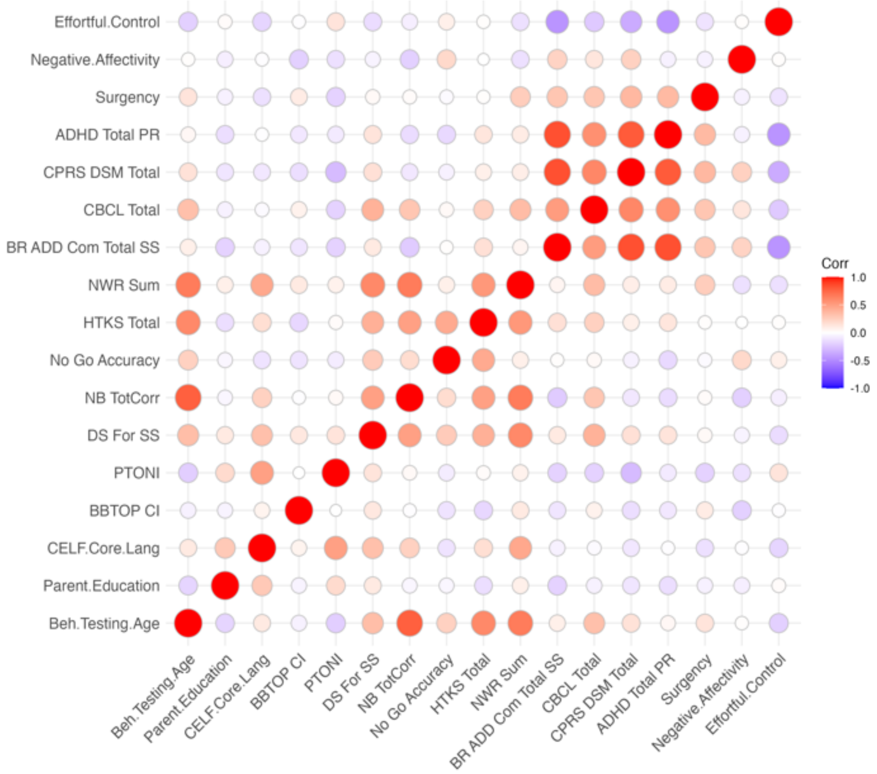


Figure 6. Correlation matrix across behavioral tasks and parent report measures for CWS. Red circles represent higher positive correlations between tasks and blue circles represent higher negative correlation between tasks.

The resulting KMO value based on the correlation matrix for the CWS group was 0.65, revealing suitability for EFA. A scree plot was then created using the eigenvalues of the correlation matrix to determine how many factors to keep following EFA. The intersection of the observed data with the simulated data derived from parallel analysis (Figure 7) indicated three factors could be suitably extracted. These factors were extracted using identical methods as described above and factor loadings were obtained (Table 7).

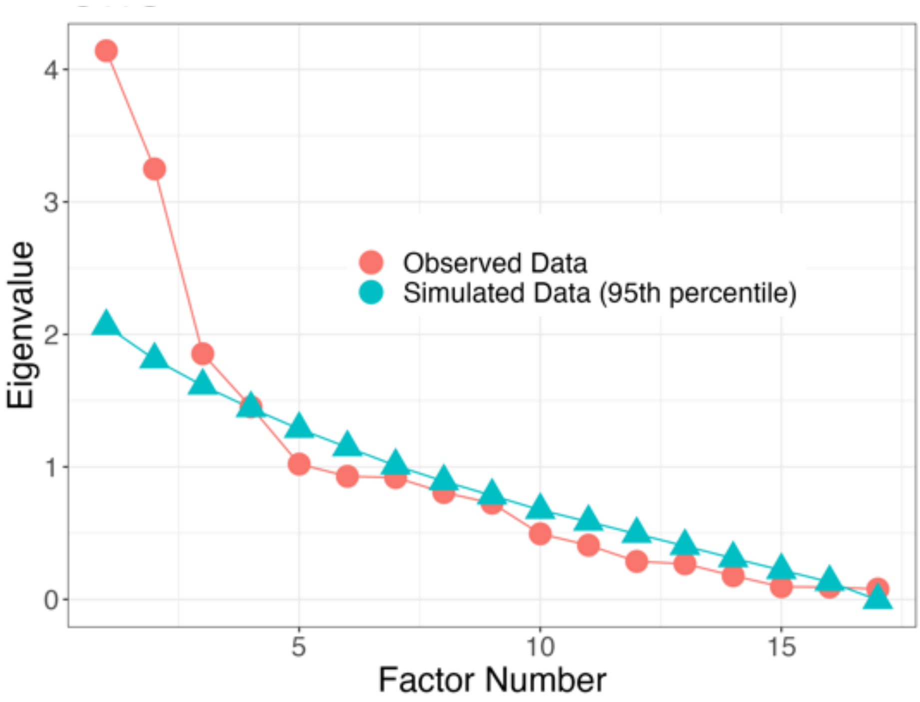


Figure 7. Scree plot illustrating the number of factors (x-axis) and eigenvalues (y-axis) of the observed data set for CWS (red) as compared to the simulated random data from parallel analysis (blue) to determine factors to extract for analysis in EFA.

In Table 7, variable weights highlighted in red indicate tasks that load on to factors extracted for the CWS group that do not load onto factors extracted for the CWNS group. In Table 9, variable weights highlighted in red indicate tasks that load on to factors extracted for the CWNS group that do not load onto factors extracted for the CWS group. Factor F1 explained the largest proportion of the variance (19.9%) (Table 8). The six tasks loading onto Factor 1 were parent report forms including BADDS Total, CBCL Total, CPRS Total, ADHD IV Total, Surgency, and Effortful Control. Factor F2 accounted for 18.2% of the total variance and was comprised of the following six measures: Behavioral Testing Age, Digit Span Forward, NB Total, HTKS Total, NWR Sum, and CPRS Total. Factor F3 included five tasks (CELF Core Language, BBTOP CI, PTONI, Digit Span Forward, and HTKS Total) and explained the least degree of variance (9%).

Table 7. Factor loadings for each of the three extracted factors across behavioral tasks and parent report measures for CWS following EFA and varimax rotation with loading cut off of 0.30. Red values represent tasks that load onto factors extracted from CWS group that do not load onto factors extracted from CWNS group.

Task Loadings	F1	F2	F3
Behavioral Testing Age		0.916	
Parent Education			0.381
CELF Core Language Score			0.656
BBTOP Consonant Inventory (CI)			
Primary Test of Nonverbal Intelligence (PTONI)			0.609
Digit Span Forward (DS For SS)		0.481	0.399
Noisy Book Total (NB TotCorr)		0.885	
No Go Accuracy			
Head Toes Knees Shoulders (HTKS Total)		0.618	0.350
Nonword Repetition (NWR Sum)		0.763	
BADDS Total (BR ADD Com Total SS)	0.904		
CBCL Total	0.628	0.311	
CPRS DSM Total	0.870		

Table 7 (continued).

ADHD Scale IV Total (ADHD Total PR)	0.941		
Surgency	0.369		
Negative Affectivity			
Effortful Control	-0.474		

Table 8. Proportion of variance explained by each of the three extracted factors from EFA in the CWS subgroup.

	F1	F2	F3
Proportional Variance	0.199	0.182	0.090

3.3 Attentional Control Systems in CWNS

The CWNS data set analyzed included 42 CWNS and the same 17 assessment variables analyzed for the CWS group alone. Replicating analyses performed for the CWS group and combined group, a correlation matrix for the CWNS group was created following multiple imputation methods (Figure 8). Notably, parent forms were strongly positively correlated with one another, including BADDS Total, CBCL Total, CPRS Total, and ADHD IV Total. Behavioral Testing Age was positively correlated with NWR Sum, HTKS Total, and NB Total. Additionally, NWR Sum was positively correlated with Digit Span Forward, NB Total Score, No Go Accuracy, and HTKS Total. Negative Affectivity was positively correlated with parent report forms of BADDS Total, CBCL Total, CPRS Total, and ADHD IV Total while Effortful Control was strongly negatively correlated with the same forms. Several other measures were negatively correlated with those parent report forms, including CELF Core Language, PTONI, Digit Span Forward, and NWR Sum. Additionally, Surgency was negatively correlated with the following measures: Behavioral Testing Age, Parent Education, CELF Core Language, Digit Span Forward, NB Total, No Go Accuracy, HTKS Total, and NWR Sum.

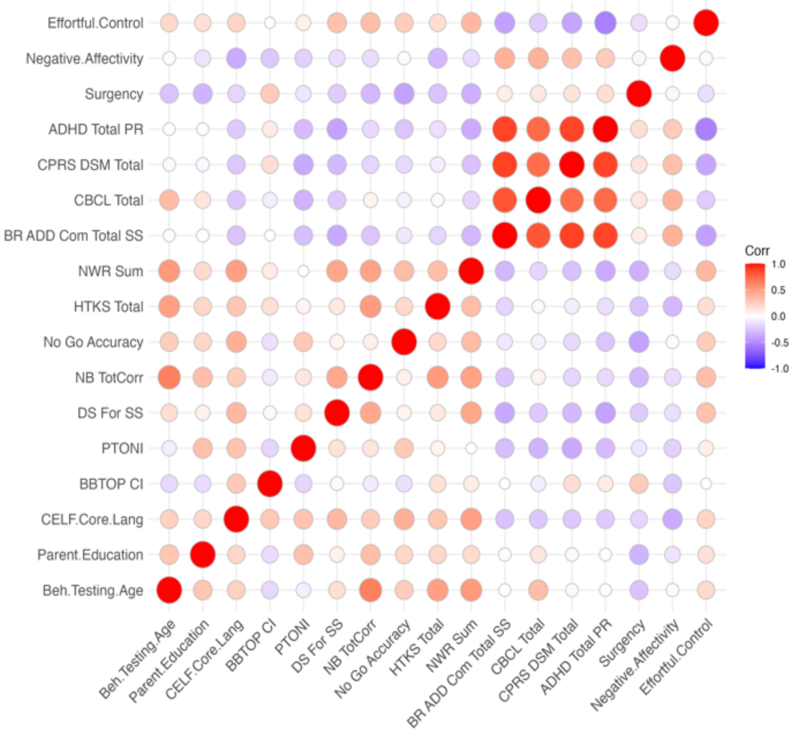


Figure 8. Correlation matrix for CWNS across behavioral tasks and parent report measures with red circles representing higher positive correlations between tasks and blue circles representing higher negative correlation between tasks.

The resulting KMO value based on the correlation matrix for the CWNS group was 0.71, revealing suitability for EFA. Similarly, a scree plot was created using the eigenvalues of the correlation matrix to determine how many factors to keep following EFA. The intersection point of the observed data with the simulated data derived from parallel analysis (Figure 9) indicated three factors could be suitably extracted. These factors were extracted using identical methods as described above and factor loadings were obtained for additional examination for the CWNS group (Table 9).

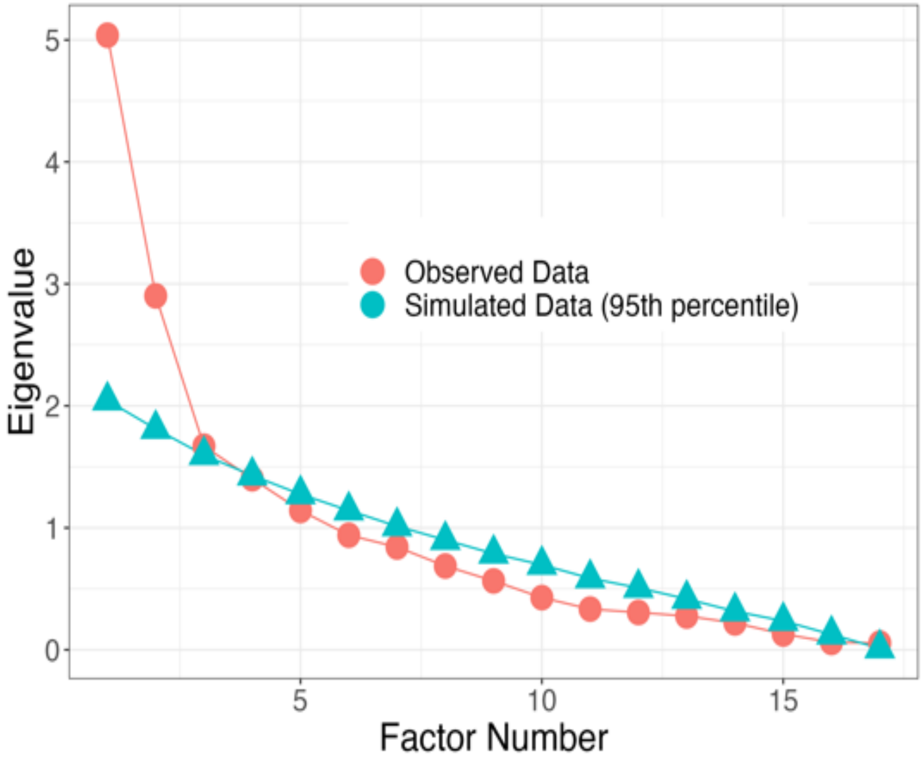


Figure 9. Scree plot illustrating the number of factors (x-axis) and eigenvalues (y-axis) of the observed data set for CWNS (red) as compared to the simulated random data from parallel analysis (blue) to determine factors to extract for analysis in EFA.

Factor 1 was comprised of eight tasks: PTONI, Digit Span Forward, BADDS Total, CBCL Total, CPRS Total, ADHD IV Total, Negative Affectivity, and Effortful Control. It explained 23.3% of variance (Table 9). Factor 2 accounted for 17.7% of the total variance and the following ten measures loaded onto it: Behavioral Testing Age, Parent Education, CELF Core Language, Digit Span Forward, NB Total, No Go Accuracy, HTKS Total, NWR Sum, Surgency and Effortful

Control. Factor 3 explained the least variance (6.8%) and included four tasks (CELF Core Language, BBTOP CI, CBCL Total, and Negative Affectivity).

Table 9. Factor loadings for each of the three extracted factors across behavioral tasks and parent report measures for CWNS following EFA and varimax rotation with loading cut off of 0.30. Red values represent tasks that load onto factors extracted from CWNS.

Task Loadings	F1	F2	F3
Behavioral Testing Age		0.868	
Parent Education		0.390	
CELF Core Language Score		0.391	0.480
BBTOP Consonant Inventory (CI)			0.630
Primary Test of Nonverbal Intelligence (PTONI)	-0.341		
Digit Span Forward (DS For SS)	-0.322	0.362	
Noisy Book Total (NB TotCorr)		0.762	
No Go Accuracy		0.336	
Head Toes Knees Shoulders (HTKS Total)		0.573	
Nonword Repetition (NWR Sum)		0.644	
BADDS Total (BR ADD Com Total SS)	0.937		
CBCL Total	0.845		-0.312
CPRS DSM Total	0.927		
ADHD Scale IV Total (ADHD Total PR)	0.924		
Surgency		-0.368	
Negative Affectivity	0.329		-0.457
Effortful Control	-0.413	0.355	

Table 10. Proportion of variance explained by each of the three extracted factors from EFA in the CWNS subgroup.

	F1	F2	F3
Proportional Variance	0.233	0.177	0.068

3.4 Comparison of Attentional Control Systems Between CWS and CWNS

Next, subgroup correlation matrices for the CWS and CWNS were subtracted from one another to produce a visual representation of group differences (Figure 10). Red circles represent higher correlation values of measures in CWS while blue circles represent higher correlation values of measures in CWNS. For CWS, Digit Span Forward and NWR Sum were more correlated with parent forms, including BADDS Total, CBCL Total, CPRS Total, and ADHD IV Total, as compared to CWNS. Surgency also was more correlated across measures of Behavioral Testing Age, Digit Span Forward, NB Total, No Go Accuracy, HTKS Total, and NWR Sum for CWS. Conversely, Effortful Control was more correlated with several behavioral measures (Behavioral Testing Age, CELF Core Language, Digit Span Forward, NB Total, and NWR Sum) in CWNS compared to CWS. Parent Education was also more highly correlated with measures of Behavioral Testing Age, NB Total, No Go Accuracy, and HTKS Total for CWNS. Additionally, CWNS had higher correlations for No Go Accuracy scores and CELF Core Language and PTONI, compared to CWS.

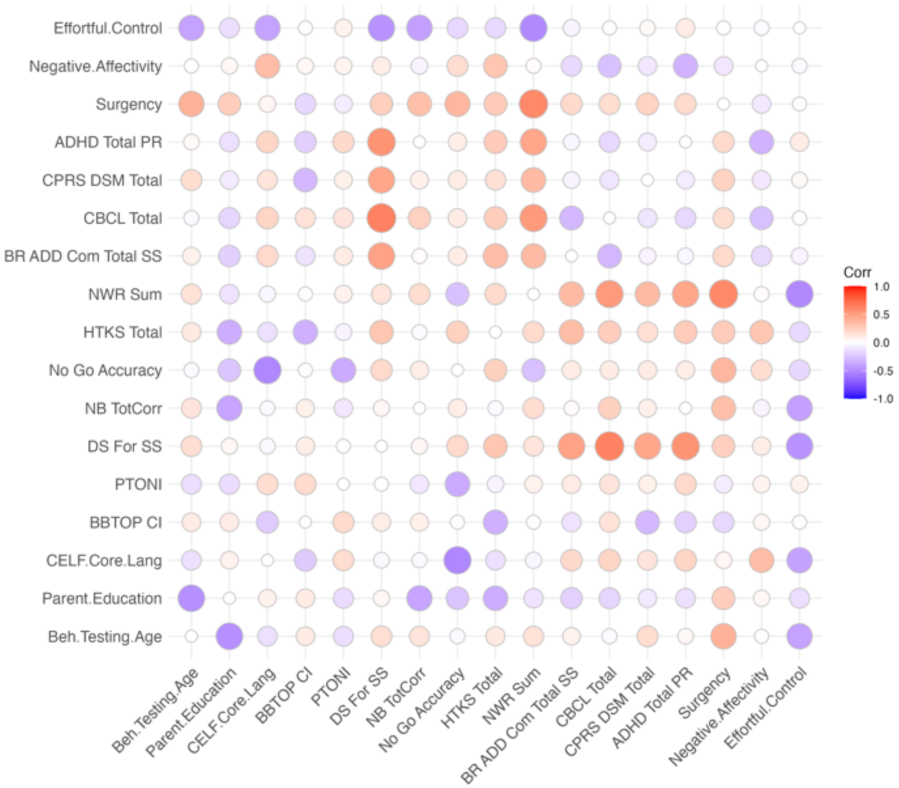


Figure 10. Correlation matrix representing differences between CWS and CWNS across behavioral and parent report measures where red circles denote higher correlations for CWS and blue circles represent higher correlations for CWNS.

To assist in overall understanding of these models, data from all children were again combined and individual participant factor scores in EFA were derived using the reduced number of variables (*N*=17) from CWS and CWNS subgroup models; the same variables were included in this reduced all-participant model as in the individual CWS and CWNS models. A scree plot was created from the whole group correlation matrix with reduced variables, and EFA was conducted to extract 4 factors.

Analysis included 82 participants (40 CWS and 42 CWNS) and the same 17 variables as the CWS and CWNS models. Four factors emerged from the scree plot of the reduced variables data set following parallel analysis (Figure 11).

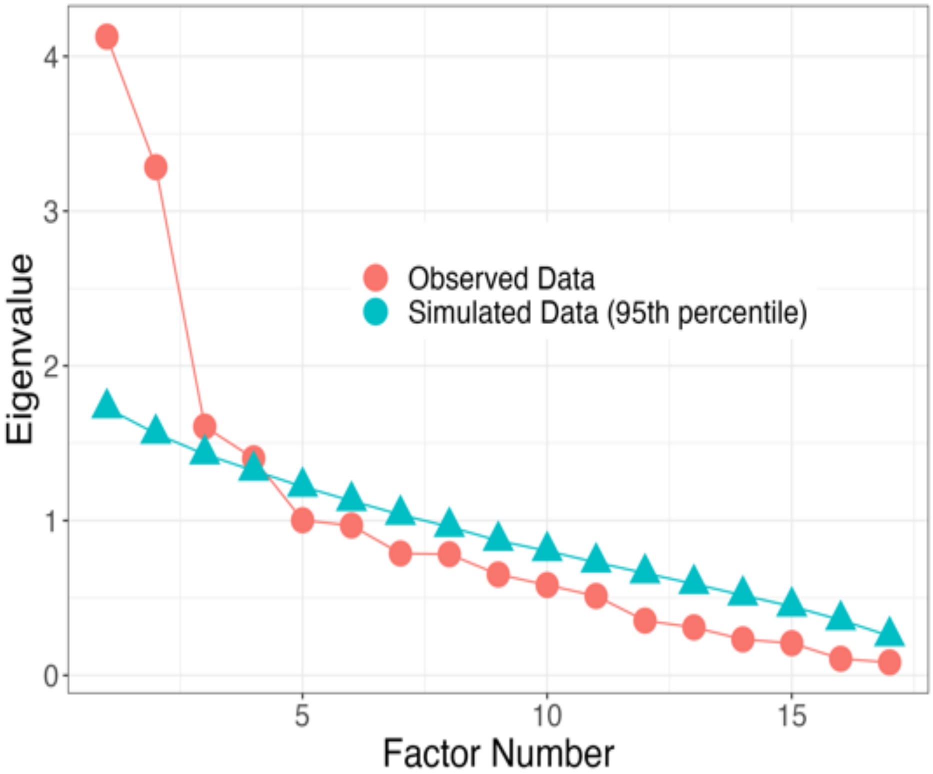


Figure 11. Scree plot illustrating the number of factors (x-axis) and eigenvalues (y-axis) of the observed data set for all participants with a reduced set of variables (red) as compared to the simulated random data from parallel analysis (blue) to compare factors extracted.

Factor 1 explained 20% of the total variance (Table 12) and was comprised of five parent report forms (BADDS Total, CBCL Total, CPRS Total, ADHD IV Total, and Effortful Control) (Table 11). Factor 2 accounted for 16.8% of variance and six measures loaded onto it: Behavioral Testing Age, Digit Span Forward, NB Total, HTKS Total, NWR Sum and CBCL Total. Factor 3 was comprised of five tasks (CELF Core Language, PTONI, NWR Sum, CBCL Total, and Negative Affectivity) and explained 8.5% of the variance. Factor 4 accounted for the least variance (3.8%) and included two tasks: No Go Accuracy and Negative Affectivity.

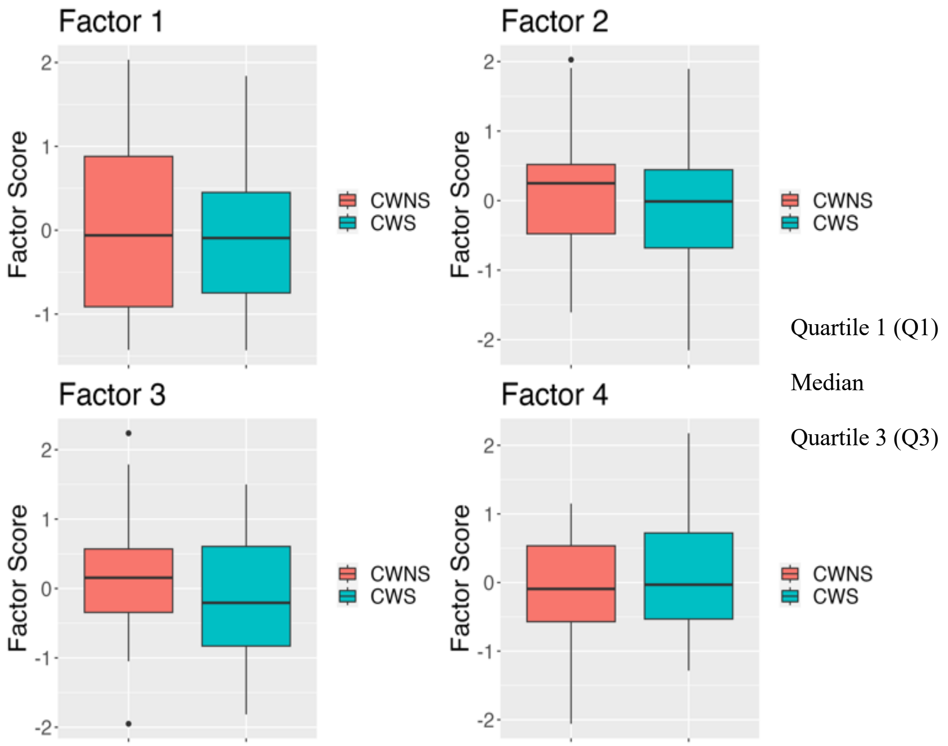
Table 11. Factor loadings for the four extracted factors across behavioral tasks and parent report measures across all children for the reduced variables model following EFA and varimax rotation with loading cut off of 0.30.

Task Loadings	F1	F2	F3	F4
Behavioral Testing Age		0.808		
Parent Education				
CELF Core Language Score			0.731	
BBTOP Consonant Inventory (CI)				
Primary Test of Nonverbal Intelligence (PTONI)			0.512	
Digit Span Forward (DS For SS)		0.446		
Noisy Book Total (NB TotCorr)		0.885		
No Go Accuracy				0.477
Head Toes Knees Shoulders (HTKS Total)		0.664		
Nonword Repetition (NWR Sum)		0.684	0.306	
BADDS Total (BR ADD Com Total SS)	0.928			
CBCL Total	0.671	0.318	-0.309	
CPRS DSM Total	0.883			
ADHD Scale IV Total (ADHD Total PR)	0.961			
Surgency				
Negative Affectivity			-0.397	0.300
Effortful Control	-0.444			

Table 12. Proportion of variance explained by the four extracted factors from EFA across all children in the reduced variables model.

	F1	F2	F3	F4
Proportional Variance	0.200	0.168	0.085	0.038

As was completed for the whole data set with larger number of variables, factor scores for each group were plotted using box plots (Figure 12). Welch's two-sample t-tests were performed to test if factor scores differed on average between groups for any of the four factors derived from EFA. Similarly, no factors showed statistically significant differences (Table 12). However, Factor 3 demonstrated the largest difference between CWS and CWNS groups and had a marginal p-value of 0.0888 (see Table 12).



Quartile 1 (Q1)

Median

Quartile 3 (Q3)

Figure 12. Box plots comparing CWNS (red) and CWS (blue) factor scores including Q1, median, Q3 (box), and full range of data (whisker) with outlier values (points) across four factors with reduced variables.

Table 13. Welch two sample t-test values for weight of each of the four factors from EFA compared between CWS and CWNS in the reduced variables model. + < 0.10.

	F1	F2	F3	F4
t-value	0.03598	-1.3165	-1.723	1.2276
d(f)	79.80	79.705	78.796	79.063
p-value	0.9714	0.1918	0.0888^{+}	0.2233

4.0 Discussion

This study examined the ways in which different measures of attentional control factor together in school-age children. It further explored whether there are differences in how children score on individual factors or how attentional tasks factor together between CWS and CWNS. Previous research reveals gaps in knowledge regarding the role attention plays in stuttering. Specifically, inconsistent results have been reported for measures of parent report of child attention behaviors as well as for performance on behavioral tasks that measure attention. The current study, therefore, aimed to increase understanding of attention control in CWS compared to CWNS. Attentional control was examined using a large battery of behavioral tasks and parent report data, which were examined for underlying latent structure using EFA. We hypothesized that tasks that tap into the three attention networks (alerting, orienting, and executive control) would factor together. Analysis was completed for the combined data set across all children as well as individually for CWS and CWNS. Our findings are largely consistent with our hypothesis as demonstrated by factors that grouped tasks that measured aspects of attentional control. Overall, there were minimal differences found between school-age CWS and CWNS. Factors that emerged from the model with all children and within individual group models revealed consistent overall structure with some subtle differences in factor loadings. We also found no statistically significant differences in factor scores between CWS and CWNS from the factors extracted from combined model including all children.

4.1 Attentional Control Systems in School Age Children

Five meaningful factors were extracted from EFA for the dataset across all children (Table 4). Factor 2, *Parental Reports of Attention Behaviors*, had high loadings (weights) for a combination of parent report measurements that attempt to assess the presence of ADD/ADHD symptomology. This factor accounted for about 14% of total variance. Generally, higher scores on these report forms indicate that participants demonstrate more behaviors consistent with ADD/ADHD. Effortful control, a sub-score from the CBQ, specifically evaluates management of oneself in real world contexts. Lower scores in Effortful Control are also related to behaviors characteristics of ADD/ADHD. As such, parent report measures load in the positive direction while Effortful Control loads in the negative direction for this factor. This suggests that more behavioral patterns associated with ADD/ADHD, indicated by parent reports, are associated with reduced self-regulation in the real world, indicated by lower Effortful Control scores. This factor indicates that multiple parent reports of ADD/ADHD type behaviors are strongly associated with one another and relatively distinct from (less correlated with) behavioral tasks designed to tap into attentional control skills.

Factor 3, *Executive Control of Attention*, includes supra-threshold loadings for age and eight behavioral tasks that evaluate skills that tap into working memory, inhibition, and cognitive flexibility. It also accounted for about 14% of total variance. Overall, higher scores on the behavioral tasks represent better attention, with the exception of Go RT. For Go RT, lower (faster) reaction times on the Zoo Task are related to faster processing speed and better attention. Therefore, age and behavioral measures of executive control of attention load positively while Go RT loads negatively for this factor. None of these tasks are standardized, so the score on these tasks reflects raw performance, not an age-adjusted score. This is likely why age is a variable in this factor – older children generally perform better than younger children on behavioral tasks. Generally, this factor suggests that increased age factors together with improved performance on tasks that are designed to tap into executive control of attention. This study examined school-age children in the age range of 4-8 years. This factor reflects the variability observed in performance on executive control tasks and changes in executive control skills with increasing age.

Factor 1, *Speech Sound Skills*, accounted for about 11% of total variance and includes the measures from BBTOP. BBTOP examines articulation and phonological skills of children. All three sub-scores are derived from one assessment task, with each individual score focusing on a specific domain of speech (word accuracy, consonant production accuracy, presence of phonological processes). These skills, all based on this single task, factor together, revealing speech sound skills as a distinct factor across all children in our dataset.

Factor 5, *Language and Verbal Working Memory*, includes parent education, language (CELF Core Language Score), nonverbal reasoning (PTONI), and behavioral tasks that examine verbal working memory. This factor accounted for about 7.8% of total variance. The tasks we administered, which load highly on this factor, have a shared property of language and verbal working memory. Multiple subtests of the CELF, especially following directions and sentence repetition tasks, rely heavily on verbal working memory skills in addition to language skills to complete accurately. For example, in order to repeat long and complex sentences correctly, as on the sentence structure subtest, a participant must remember what was said, understand the language – semantics and especially syntax – used, and produce the correct syntactic structure in response. This relationship between language and verbal working memory skills has previously been established (Adams & Gathercole, 2000). It is also noteworthy that two variables (digit span forward and nonword repetition) are included in this factor and also Factor 3 (*Executive Control of Attention*). This reflects the fact there is shared covariance between these tasks and tasks designed to measure executive control of attention and language skill. Notably, tasks examining working memory in the visual modality did not group with this factor.

Previous research has identified strong relationships between language skills, attention skills, and parent education level (Farah et al., 2006; Fernald et al., 2013; Hackman & Farah, 2009; Hackman et al., 2010), with stronger language and executive function skills associated with higher parental education levels (a proxy for socioeconomic status). This established relationship may provide insights into why parent education also groups into this factor. Children who live in a household with higher parent education may also have stronger language and attention skills. Parent education has also been associated with general world knowledge and a higher IQ (Farah et al., 2006; Hackman & Farah, 2009). Children who live in a household with higher parent education may be afforded more experiences and, therefore, have a greater knowledge of relationships that exist in the world. These skills support performance on nonverbal IQ tasks, such as the PTONI. This relationship provides additional insight into why PTONI may group in this factor.

The other variable that loads onto this factor, NWR Sum, reflects phonological working memory. NWR was developed as a screening tool for children with developmental language disorder or specific language impairment (Dollaghan & Campbell, 1999). Therefore, the fact that it groups with other tasks that measure verbal working memory skills is not surprising. NWR has an established connection with language and verbal working memory abilities.

This factor, *Language and Verbal Working Memory*, also was the closest to having different factor scores between CWS and CWNS, although the differences did not reach statistical significance (p = 0.077). This indicates that performance on measures that tap into language and verbal working memory skills in school-age children are more different than groups of variables that load onto other factors that emerged in our model (i.e., *Parent Reports of Attention Behaviors, Executive Control of Attention, Speech Sound Skills*, or *Inhibition*). This finding may suggest potential differences between CWS and CWNS in language and verbal working memory skills. This would be consistent with previous studies in CWS that suggest subtle differences in complex language skills (Hampton Wray & Spray, 2021; Weber-Fox et al., 2013). However, given the exploratory nature and the smaller sample size in our study, more research is needed to know if this pattern will hold or may go away with more participants.

Factor 4, *Inhibition*, combines two of the three Zoo Task, or Go/No-Go Task, measures. The Zoo Task is designed to assess inhibition, specifically during No-Go trials. Increased (slower) reaction times on Go trials indicate that a child needed longer processing times in order to click the button and catch the animals. In this factor, increased reaction times for Go trials were associated with higher accuracy on No-Go trials, or better inhibition skills. When children are doing the task more slowly, they may be able to more accurately detect, and therefore not respond to, the No-Go trials. This is consistent with the speed-accuracy tradeoff – slower response times are associated with higher accuracy and vice versa. The factor that includes only these tasks accounts for a small portion of variance (4.8%) in this data set, suggesting it plays a limited role in the overall model of attentional control in school-age children.

Of note, across all participants, measures from the Shape School task were the only variables that did not load onto any of the factors. Shape School was designed for preschool-age children; therefore, we attribute its lack of influence in this exploratory factor analysis to the higher performance and decreased variability of scores in our school-age participants. It is likely that participants scores approached ceiling because the task was easier for older children.

Analysis on the combined data set alone revealed five meaningful factors. Grouping of measurements were interpreted to represent the following 5 constructs: *Parental Reports of Attention Behaviors*, *Executive Control of Attention*, *Speech Sound Skills*, *Language and Verbal Working Memory*, and *Inhibition*. No significant differences in factor scores for any factors were observed between CWS and CWNS. However, the *Language and Verbal Working Memory* factor stands out as a potential influencing factor because the p-value was relatively close to the alpha threshold (0.05). Generally, there was high overlap observed between individual groups.

4.2 Attentional Control Systems in CWS

Next, we conducted EFA on subgroups of participants (CWS and CWNS) with a reduced number of variables (see *Methods*). Three meaningful factors were extracted from EFA for CWS (Table 7). The first factor was comparable to the *Parental Reports of Attention Behaviors* factor from the combined data set. It was comprised of the same combination of parent report forms with BADDS, CBCL, CPRS, and ADHD IV Scores loading positively on this factor dimension and Effortful Control loading negatively. Additionally, another sub-score derived from the CBQ, Surgency, loaded onto F1 for CWS. In the full model, surgency also had a positive weight for *Parental Reports of Attention Behaviors* factor, but this was below our threshold of 0.30. Surgency maps onto selective attention and engagement and corresponds to how one responds to positive environmental situations (Rothbart et al., 1994). One possible reason for the increased weight associated with surgency in this factor for CWS can be seen in the CWS-CWNS correlation difference matrix (see Figure 10). Here, we see that surgency was more highly correlated across several behavioral measures for CWS than for CWNS. Factor 1 for the CWS model also explained slightly more variance (19.9%) as compared to the *Parental Reports of Attention Behaviors* factor from the combined total model (14%). However, there is a larger sample size and more variability present in the combined group as compared to the individual subgroup of CWS, which may explain this difference.

Factor 2 from the CWS model was also similar to the *Executive Control of Attention* factor from the combined data set. It included behavioral testing age and the majority of tasks that tap into different aspects of executive control of attention. Subtle differences include the exclusion of No-Go Accuracy for the CWS model and the inclusion of the parent self-report form CBCL Total. In accordance with Figure 10, all parent self-report forms were highly correlated with executive control tasks of Digit Span Forward and NWR Sum in CWS; however, the CBCL Total measure specifically stands out (large red circle), representing a higher correlation value (larger correlation in CWS vs. CWNS). Additionally, No Go Accuracy was found to correlate more highly with four different measures in CWNS vs. CWS; therefore, its exclusion in the CWS model is supported. Factor 2 in the CWS model also accounted for a similarly high proportion of variance (18.2%) as the *Executive Control of Attention* factor did for the combined data (14%). Notably, Factor 1 and Factor 2 in the CWS model accounted for the most variance in the group in the same way the *Parental Reports of Attention Behaviors* factor and *Executive Control of Attention* factor explained the most variance for the combined groups model.

The final factor in the CWS model, F3, demonstrated homogenous factor loadings to the *Language and Verbal Working Memory* factor in the combined group. Every measure that loaded onto the verbal working memory factor loaded onto F3 as well, with the exception of Word Recall.

However, Word Recall was one of the eight variables removed during data processing for the individual subgroups (due to a low measure of sampling adequacy likely reflecting low within-group variation), and therefore it was not examined in the CWS group factor analysis. It is possible that if Word Recall was included in subgroup EFA analysis, it would also load onto F3 based on the homogeneity present between these two factors. Furthermore, both F3 and the verbal working memory factor explained comparable variance across their respective groups at 7.8% and 9%.

As a whole, the CWS subgroup model was largely comparable to the combined data model following EFA. There were a decreased number of factors extracted from EFA, based on the scree plot (see Figure 7). However, this was to be expected due to the decreased sample size (reduced overall dimensionality) in the individual groups. Measurements that loaded onto factors that were extracted from EFA on the CWS groups were also similar across all three factors and further accounted for similar variance as the factors extracted from the combined group. Some differences were observed within individual factors with respect to the tasks that loaded onto them, but these differences were relatively minor.

4.3 Attentional Control Systems in CWNS

Similar to CWS, three meaningful factors were extracted from EFA for CWNS (Table 9). The first factor was also comparable to the *Parental Reports of Attention Behaviors* factor from the combined data set. All tasks that loaded onto the *Parental Reports of Attention Behaviors* factor also loaded onto F1 in the CWNS group. However, three additional tasks also loaded onto this factor including PTONI, Digit Span Forward, and Negative Affectivity, a sub-score of the CBQ. This differed from both the combined data set and the CWS subgroup, suggesting stronger relationships between these measures and parent reports of ADD/ADHD behaviors in controls. CWNS had tighter coupling between Negative Affectivity and parent self-report forms while CWS had tighter coupling between Surgency and parent self-report forms. Negative Affectivity examines reactions when things are unpleasant or unfavorable (Rothbart et al., 1994). According to Figure 10, Negative Affectivity more strongly correlated to two of the four parent self-report forms (CBCL and ADHD IV) in CWNS vs. CWS, which helps explain why it loaded onto F1 in the CWNS subgroup. However, it is noted that the inclusion of PTONI and Digit Span Forward as task loadings onto this factor for CWNS are somewhat unclear. No strong correlations are present for either factor in the CWS-CWNS Correlation Matrix (Figure 10). Additionally, F1 from the CWNS model explained slightly more, but comparable, total variance (23%) than both the combined model (14%) and the CWS subgroup model (19.9%). Across all three models, the factor extracted that grouped parent self-reports together accounted for the most inter-subject variance for each population (combined, CWS, and CWNS).

As was observed for Factor 2 in the CWS model, Factor 2 from the CWNS model was similar to the *Executive Control of Attention* factor from the combined model. F2 included all tasks loaded onto the *Executive Control of Attention* factor, with exception of the three variables removed during variable selection / pruning for the individual models (Digit Span Reverse, Go Accuracy, and Go RT). Notably, No Go Accuracy loaded onto this factor for the CWNS group, whereas it did not load onto F2 for the CWS model. However, F2 differed from both the *Executive Control of Attention* factor from the combined model and Factor 2 from the CWS model in that several additional tasks were grouped onto this factor including Parent Education, CELF Core Language, Surgency, and Effortful Control. One possible reason for these additional groupings is observed in Figure 10. For CWNS, Effortful Control is more strongly correlated across all executive control measures, Behavioral Testing Age, and CELF Core Language Score, which also loaded onto this factor, as compared to CWS. Parent Education and Behavioral Testing Age were very highly correlated for CWNS as well. Surgency was the only measurement that loaded negatively onto F2 for CWNS model. Loading of surgency onto F2 for the CWNS model could be attributed to the negative correlations present between Surgency and other measures for the CWNS subgroup (see Figure 8), which differed from correlations in the CWS group (see Figures 6 and 10). Despite these differences, F2 from the CWNS model explained comparable variance (18.2%) to the CWS model (17.7%) and the combined group model (14%). Moreover, across all three models, the factors that largely measured aspects of executive control of attention accounted for the second most variance for each population.

The final factor extracted from EFA for the CWNS group, F3, was the least similar to factor 3 from the CWS subgroup and the *Language and Verbal Working Memory* factor from the combined model. CELF Core Language was the only task that loaded onto all three factors across groups. While F3 for the CWS group and the *Language and Verbal Working Memory* factor were largely comparable, Factor 3 for the CWNS group combined CELF Core Language with BBTOP CI, CBCL Total, and Negative Affectivity. BBTOP CI loaded positively onto F3 while CBCL Total and Negative Affectivity loaded negatively. As such, high scores on CELF Core Language and BBTOP CI pulled participants in one direction on this factor dimension while high scores in CBCL Total and Negative Affectivity pulled participants in the opposite direction. Notably, BBTOP CI did not load onto any factors from the CWS subgroup model and was only present in the combined model when grouped with other tasks from BBTOP. It is unclear why these different measures in addition to language grouped together for this factor in the CWNS subgroup model. Figure 10 does not reveal any strong differences in correlations across these measures for CWNS vs. CWS. It may be the case that some of the observed differences depended on the threshold of 0.30 that was used for interpretation, but they, at minimum, reflect quantitative differences between the extracted factors in the different groups. The CWNS Scree Plot (Figure 9) reveals that the third highest eigenvalue is close to the threshold for noise obtained from the simulated data (parallel analysis), so it may have limited overall value in this group. This factor explained 9% of the total variance, which was comparable to the third factor from CWS (7.8%) and the *Language and Verbal Working Memory* factor from the combined data set (9%).

Overall, the CWNS subgroup model was relatively similar to the CWS subgroup model and the combined group model following EFA. Fewer factors were extracted for the CWNS model than for the combined model. However, as noted for the CWS group, this was expected due to decreased sample size. Measurements that loaded onto the factors that were extracted were largely similar across the CWS model and the combined model, although more differences were observed in the CWNS model. Specifically, there were an increased number of additional tasks / measurements that loaded onto the three factors in addition to the tasks that were similar across factors. The third factor stood out as the most dissimilar factor across all three models. Despite increased differences observed in the CWNS model, these differences were still generally modest and did not reveal a clear indication of differences in attentional skills between CWS and CWNS.

4.4 Comparison of Attentional Control Systems

We hypothesized that CWS and CWNS will score differently on a set of commonly extracted factors. Our results do not support our hypothesis, as factor scores for individual participants did not significantly differ across any of the extracted factors between CWS and

CWNS in the full data model. Further analysis of individual groups demonstrated that factors that were extracted for the CWS and CWNS individual group models also had comparable loadings between each other and the full data model. Therefore, while a common set of factors was extracted across CWS and CWNS, factor loadings did not differ between groups.

The differences between variables that loaded onto factors in the CWS group as compared to the CWNS group were not clinically significant. More differences in factor loadings were observed when comparing the CWNS with the other two models (CWS and combined dataset). Specifically, there were an increased number of additional tasks / measurements that loaded onto the three factors in addition to the tasks that were similar across factors, especially in Factor 3. However, the structure of the factors was similar and reflected consistency in the underlying constructs identified from interpretation of the factor loadings. Overall, these three factors are comparable across both groups and with the full group model.

To assist with overall interpretation, we also conducted EFA on the full set of participants again using only the 17 variables selected for the individual group (CWS, CWNS) models. In this analysis, only four factors were determined to be meaningful (compare to three for each subgroup and five for the full cohort including a larger set of variables). The first factor, F1, was identical to the *Parental Reports of Attention Behaviors* factor extracted from the original combined model. It also explained the most variance across the data set (20%) as was observed across all other models. Factor 2 from the reduced recombined model was mostly similar to the *Executive Control of Attention* factor in the original combined model and identical to Factor 2 from the CWS subgroup model. Factor 2 accounted for 16.8% of variance, which was comparable across other factor models as well.

Interestingly, the third factor in this new combined model, F3, appears to represent a combination of the *Language and Verbal Working Memory* factor derived from the original combined model and factor 3 from CWNS model. While the *Language and Verbal Working Memory* factor and Factor 3 from the CWS model were comparable, Factor 3 from the CWNS group was most dissimilar across all models. The third factor from this final combined model had similar loadings across both models. CELF, PTONI, and NWR Sum were shared loadings on F3 from the CWS model and the *Language and Verbal Working Memory* factor from the original combined group. Meanwhile, CBCL and Negative Affectivity were shared negative loadings on F3 from the final combined model and the CWNS model. Excluded measurements include Parent Report and Digit Span Forward (which loaded onto the *Language and Verbal Working Memory* factor from the original combined group) and BBTOP CI (which was grouped into F3 from the CWNS model). Similar to other models, Factor 3 explained 8.5% of the total variance. Notably, this factor also demonstrated the largest difference in individual factor scores between CWS and CWNS groups, despite the difference not reaching statistical significance. This was observed in the original combined model as well and further supports the potential differences in verbal working memory performance between CWS and CWNS, which warrant further investigation.

The final factor, F4, accounted for only 3.8% of the total variance, which was comparable to the variance explained in the *Inhibition* factor from the original combined model (4.8%). As such, it plays a limited role in the overall model of attentional control across school-aged children. This factor was comprised of No-Go Accuracy and Negative Affectivity. Connecting back to the original combined model, No-Go Accuracy was separated as a factor loading. However, Go RT was one of the eight variables removed in data processing, therefore, it could not load onto factors in the reduced model. It is unclear why Negative Affectivity loads positively in combination with No-Go Accuracy for this factor across all school-aged children with reduced variables.

Analysis of the final, reduced dataset combining both groups revealed similarities across all models and aided in interpretation of the extracted factors. When all participants (CWS and CWNS) were recombined with the reduced number of factors (*n*=17), the general nature of the factors remained consistent with the full model. The factors that were extracted were comparable across both models, as were the tasks that loaded onto the respective factors. The recombined model similarly resulted in factors that represented the original *Parental Reports of Attention Behaviors*, *Executive Control of Attention,* and *Language and Verbal Working Memory* factors from the full model. Differences that were observed across individual subgroups models and the original combined model were supported by the factors present in this model. These factors also explained comparable variance. This suggests that the full model is relatively reliable.

4.5 Limitations and Future Directions

Limitations of this study include the relatively small sample size. Despite the sample size being comparatively large for research with the stuttering population, it is still relatively small for EFA. Recommendations about sample size and other minimal characteristics of the dataset studied with EFA have changed over time, but most recommendations call for minimum sample sizes of ~50, depending on the overall correlation structure (MacCallum et al., 1999; de Winter et al., 200). Increased sample size increases the statistical power for factor analysis, resulting in more precise estimates of factor loadings and robustness to sampling error. The interpretation of factors from EFA is exploratory and somewhat subjective in nature, and thus it is important to note that this study is preliminary and aimed at discovering patterns that can be later tested further in additional datasets. It is unclear whether or not the same results would be found if the same study was performed on a different group of participants. As such, future studies could focus on the stability of the latent factors observed within this data set across CWS and CWNS. This is achieved via continued investigation of attentional control across both behavioral measures and parent report forms for CWS and CWNS with larger sample size. Further, it may prove useful to include additional measures that assay the same psychological constructs and underlying developmental skills to be certain that the specific measures included here lead to unbiased results. Ideally, a confirmatory approach (i.e., confirmatory factor analysis and/or structural equation modeling) could ultimately be applied to validate findings across several studies examining attentional control and stuttering.

The current study uses one specific set of methods for employing exploratory factor analysis to evaluate how these measured tasks factor together to reveal latent factors. However, there are other methods for addressing missing data, estimating and evaluating factor models, and testing potential group differences. Future studies could employ other methods for EFA to determine if specific statistical approach might result in similar or different models or patterns in the data.

Another potential limitation is that some of the tasks included, such as Shape School, were relatively easy for school-age children, which resulted in less variability across all children. Future studies could include more difficult tasks that tap into attention to see if they might result in increased variation that helps to separate CWS from CWNS or factor differently with other tasks. For example, future studies could incorporate simultaneous speech and noise tasks, trail making tasks, or the Attention Network Task (ANT), which is designed by Posner to examine all three networks of attention.

Future investigations could prioritize a focus on differences in verbal working memory between CWS and CWNS with similar measures assessed in this study. Current findings were not statistically significant between groups; however, with a larger sample size and increased statistical power, differences in CWS and CWNS may become more defined for the *Language and Verbal Working Memory* factor.

Results from this study are not able to determine whether there were differences in processing or approach to completing a task between CWS and CWNS for behavioral tasks that tap into attentional control. Even when two participants achieve the same results, it does not mean that they processed the information or approached the task in the same way. Future studies may examine the underlying processes used to complete these behavioral tasks by also measuring electrical activity of the brain via electroencephalogram (EEG) or other neuroimaging measures and comparing results between CWS and CWNS. It is feasible that such neural measurements could be summarized and also included in a factor analysis.

The analysis conducted in this study sought to identify how different components of attentional control factor together in children ages 4-8 years and examine if models of attention differ between CWS and CWNS. This was an exploratory study, as is the nature of EFA. High variability is observed within the current study, as has also been reported in previous research across the stuttering population. Individual variability exists within groups as well; not all CWS are the same, nor are all CWNS the same. Generally, overlap is common across these groups with only minor differences observed, likely due to individual as well as potential group variability. As such, large group differences are not expected between CWS and CWNS, furthering the need for studies and/or meta-analyses employing larger samples. These overall patterns of high variability and small effect sizes are consistent across research examining the relationship between stuttering and attention. Addressing some of the limitations of the current study could help further increase our understanding of attention in stuttering.

5.0 Conclusions

This study aimed to examine how different measures of attentional control factor together and whether these patterns differ between CWS and CWNS. Eighty-two school-age children completed a battery of behavioral tasks that are designed to tap into different aspects of speech, language, and attention, and their parents completed multiple questionnaires that are designed to measure attention skills in real world settings. The current results suggest that there are not large-scale differences in attentional control between CWS and CWNS. Our findings reveal that measures of attentional control factor together and separate more from measures of speech and language. Five distinct factors were identified in our most comprehensive model (including all 82 participants and 25 variables), four of which included a subset of attentional control measures. Specifically, factors clustered skills related to attention management in the real world, a combination of visual working memory, inhibition, and cognitive flexibility, language and verbal working memory, and inhibition skills. This was largely consistent with our first hypothesis, that factors would group measures tapping into similar aspects of attentional control together, and that these factors would be similar across CWS and CWNS. Our second hypothesis was that CWS and CWNS would score differently on the extracted factors. This was not supported by our results, though one factor (*Language and Verbal Working Memory*) showed the largest group differences but did not reach the threshold for statistical significance. Factors derived from the overall model were generally similar to individual models for CWS and CWNS. Overall, these findings suggest, that attentional control between CWS and CWNS is largely comparable in school-aged children and different ways of modeling these skills provided stable, consistent models.

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