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Visual exogenous and endogenous attention and visual memory in preschool children who stutter

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ABSTRACT

Purpose: Attention develops gradually from infancy to the preschool years and beyond. Exogenous attention, consisting of automatic responses to salient stimuli, develops in infancy, whereas endogenous attention, or voluntary attention, begins to develop later, in the preschool years. The purpose of this study was to examine (a) exogenous and endogenous attention in young children who stutter (CWS) and children who do not stutter (CWNS) through two conditions of a visual sustained selective attention task, and (b) visual short-term memory (STM) between groups within the context of this task.
Method: 42 CWS and 42 CWNS, ages 3;0–5;5 (years;months), were pair-matched in age, gender (31 males, 11 females per group), and socioeconomic status. Children completed a visual tracking task (*Track-It Task*; Fisher et al., 2013) requiring sustained selective attention and engaging exogenous and endogenous processes. Following each item, children were asked to recall the item they had tracked, as a memory check.
Results: The CWS group demonstrated significantly less accuracy in overall tracking and visual memory for the tracked stimuli, compared to the CWNS group. Across groups, the children performed better in sustained selective attention when the target stimuli were more salient (the condition tapping both exogenous and endogenous attention) than when stimuli were less so (the condition tapping primarily endogenous processes).
Conclusions: Relative to peers, preschool-age CWS, as a group, display weaknesses in visual sustained selective attention and visual STM.

1. Introduction

Attention develops considerably over the preschool years. Early on, beginning in infancy, exogenous attention develops as an automatic response to highly salient stimuli. Later, children develop endogenous attention, engaging voluntary control over attention (Fisher, Thiessen, Godwin, Kloos, & Dickerson, 2013). These processes are key in the development of speech and language (Jongman, Roelofs, & Meyer, 2015; Kannass & Oakes, 2008). For example, Kannass and Oakes found that attention skills in infants at 9 months of age were positively associated with the children's vocabulary skills as 31 months. Just as adult input is critical to this process, so too is

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children's attention; children attend to the speech and language within their environment as the primary means of acquiring speech and language. In addition, acquisition of speech and language requires the ability to store and process incoming stimuli, engaging short-term memory, to facilitate learning.

Multifactorial accounts of the development of stuttering suggest that stuttering develops through complex interaction among a range of factors, including linguistic and cognitive factors (Conture & Walden, 2012; Smith & Weber, 2017). A recent conceptual model, proposed by Anderson and Ofoe (2019), suggested that cognitive factors, including executive function skills, may be linked to the development of stuttering. Specifically, they argue that, if planning and execution of speech and language represents a challenge for CWS, then this process of planning and executing speech and language may tax cognitive resources such as executive function and attention, particularly if skills in these areas are less robust. These ideas are speculative, of course, but they motivate the present investigation. Moreover, Roelofs and Piai's (2011) WEAVER++ model links attention, in particular, to speech-language production, indicating that speech-language planning requires sustained attention to the phonological form while the planning process, including access of motor programs, is completed. Memory is also engaged; as the phonological form undergoes the planning process, memory of the form must be maintained and continually updated. One potential inference of this model is that, if attentional capacity (or memory) is reduced, the outcome may be disruption in speech-language processing, resulting in disfluent speech. Therefore, characterizing the attention and memory processes of preschool-age CWS enables us to understand more fully the interactions that may exist between the fluency of speech production in early childhood and two key cognitive skills that undergird speech and language production.

Although theoretical accounts of the structure of attention differ, there is broad agreement that attention in both children and adults includes separate but related subsystems (Mahone & Schneider, 2012). Research on attention has often focused on two of these subsystems, *selective* attention and *sustained* attention; selective attention involves focusing on a chosen relevant stimulus while ignoring irrelevant, competing stimuli, and sustained attention involves maintaining alertness toward a chosen stimulus over time (Mirsky, Anthony, Duncan, Ahearn, & Kellam, 1991; Strayer & Drews, 2007). As highlighted above, an additional distinction is drawn between *exogenous* attention, which generally occurs automatically in response to stimuli that are highly salient or inherently interesting, and *endogenous* attention, which calls on voluntary, effortful control to attend to a stimulus (e.g., Fisher et al., 2013). Memory, too, involves multiple components. For example, Baddeley's model describes working memory as relying on separate systems of short-term memory (STM) for phonological and visuospatial sensory information (Baddeley, 1986, 2003).

Several lines of evidence suggest that CWS may have difficulties with attention, working memory in general, and phonological STM in particular (e.g., Anderson, Wagovich, & Brown, 2019; Donaher & Richels, 2012; Eggers, De Nil, & Van den Bergh, 2012; Ntourou, Anderson, & Wagovich, 2018; Pelczarski & Yaruss, 2016), although little is known about the visual STM abilities of CWS. The primary aim of this study was to explore whether young CWS show weaknesses in visual sustained selective attention. Through examination of exogenous and endogenous attention processes, we explored whether CWS have relatively greater difficulty with sustained selective attention than children who do not stutter (CWNS) when more effortful control is required. Our second aim was to explore whether CWS exhibit weaknesses in visual STM. We chose to explore *visual* attention and memory as one means of examining attention processes without directly engaging language skills. It also afforded us the opportunity to examine endogenous versus exogenous attention through manipulation of object salience.

1.1. Attention in children who stutter

Attention undergoes considerable development during the preschool years, with sustained selective attention becoming more integrated over time (Garon, Bryson, & Smith, 2008). Moreover, the ability to focus and maintain attention is fundamental to the development of EF during the preschool period and beyond, as children become more proficient in directing the attention needed for working memory, inhibitory control, and cognitive flexibility (Garon et al., 2008). Early in life, exogenous factors (e.g., contrast or motion) naturally draw children's attention to objects that are more salient. During the preschool years, endogenous attention gradually assumes greater importance as children learn to focus and maintain attention voluntarily (Fisher et al., 2013; Ruff & Rothbart, 2001).

To explore the possible involvement of attentional problems in developmental stuttering, several studies have compared the prevalence of clinically significant attention difficulties (i.e., attention deficit-hyperactivity disorder, ADHD) in CWS to those in the general population. Although findings have been mixed, there is evidence to suggest that ADHD may be more prevalent in CWS than in CWNS (Arndt & Healey, 2001; Donaher & Richels, 2012; Druker, Hennessey, Mazzucchelli, & Beilby, 2019; Riley & Riley, 2000). For example, Druker et al. (2019) found that, in their sample of 185 preschool CWS, approximately half of the children showed elevated levels of ADHD symptoms. Moreover, a pair of relatively recent studies have yielded clues about the genotypic and phenotypic overlap between stuttering and ADHD (Choi et al., 2018; Lee, Sim, Lee, & Choi, 2017). Given that stuttering and ADHD are both heritable, with CWS and children with ADHD often having a positive family history of the disorder (e.g., Brikell, Kuja-Halkola, & Larsson, 2015; Yairi, Ambrose, & Cox, 1996), Choi et al. explored whether young children's family histories of ADHD and stuttering might coincide. When caregivers of both CWS and CWNS were asked about their family history of both disorders, results showed a greater family history of ADHD among CWNS with a positive family history of stuttering than among CWNS with no family history of stuttering. The authors suggested there may be common risk factors for problems of fluency and attention at either a genetic or epigenetic level. CWS and children with ADHD may share phenotypic characteristics as well; Lee et al. (2017) reported that school-age children with ADHD demonstrated more stuttering-like disfluencies on three speaking tasks (reading aloud, story retelling, and picture description) than age-matched peers without ADHD.

To be clear, most CWS do not have a clinical diagnosis of ADHD. However, the findings above are intriguing and perhaps consistent with the idea that attentional problems are best viewed in dimensional rather than categorical terms; many adverse developmental outcomes are associated not only with diagnosed ADHD, but also with subclinical levels of attention problems (Sonuga-Barke, Koerting, Smith, McCann, & Thompson, 2011). Therefore, examination of attention and EF, as important developmental dimensions in CWS, can lead to a fuller understanding of the impact of a range of cognitive factors that may impact stuttering in early childhood.

There is evidence from parent report measures that attentional differences are observed among CWS in daily living activities, relative to peers (e.g., Anderson, Pellowski, Conture, & Kelly, 2003; Clark, Conture, Walden, & Lambert, 2015; Eggers, De Nil, & Van den Bergh, 2010; Embrechts, Ebben, Franke, & van de Poel, 2000; Karrass et al., 2006; cf. Kefalianos, Onslow, Ukoumunne, Block, & Reilly, 2014). Ofoe, Anderson, and Ntourou (2018) conducted a meta-analysis of studies of EF and attention among CWS and CWNS. Across studies, they found that parents of CWS rated their children as having weaker attentional focus and persistence than parents of CWNS.

Related more directly to the present study, the literature on attention skills as measured by behavioral tasks in CWS has been more mixed. The meta-analysis by Ofoe et al. (2018) revealed that, across studies, the CWS and CWNS did not differ in performance on behavioral measures of attention skills. However, it should be noted that these behavioral studies differed in the modality in which attention was measured, which may account for the lack of significant difference in this meta-analytical study.

Attention studies in which the behavioral task modality is auditory have demonstrated significant differences between CWS and CWNS (Anderson & Wagovich, 2016; Eggers & Jansson-Verkasalo, 2017; Kaganovich, Hampton Wray, & Weber-Fox, 2010; Sasisekaran & Basu, 2017). For example, Anderson and Wagovich compared the performance of young CWS and CWNS on tasks of auditory sustained selective attention that included both verbal and nonverbal conditions. (Participants in this study are some of the same children who participated in the present study.) Although no significant group difference in accuracy was found for verbal selective attention, CWS demonstrated poorer overall accuracy than CWNS in nonverbal selective attention and in both verbal and nonverbal sustained attention. Thus, auditory tasks of nonverbal selective attention and verbal and nonverbal sustained attention may be areas of weakness for CWS.

In addition, Eggers and Jansson-Verkasalo (2017) examined attentional shifting in school-age CWS using the auditory set-shifting task of the Amsterdam Neuropsychological Tasks (De Sonneville, 2009). This nonverbal auditory task required children first to produce "compatible" responses to a stimulus (e.g., a single button press in response to a single tone) and then to produce “incompatible” responses to a stimulus (e.g., a double button press in response to a single tone). The third part of the task required attention shifting: when children heard a single or double tone that was low-pitched, they were to give the compatible response, whereas when the tone was high-pitched, they were to give the incompatible response. Findings revealed an interaction with the CWS producing more compatible response errors in the shifting than the non-shifting condition, whereas the CWNS did not show this increase in errors. These findings suggest that CWS have difficulty with nonverbal attentional shifting relative to peers.

Within the research that has focused on visual attention, Johnson, Conture, and Walden (2012) compared the performance of preschool-age CWS and CWNS on a task of visual attention focusing and shifting and found similar patterns of accuracy and response times between groups. Similarly, Blood et al. (Blood, Blood, Maloney, Weaver, & Shaffer, 2007) explored visual attention with school-age CWS and their peers on a visual continuous performance task of sustained attention, finding no significant group differences in either accuracy or response times. However, the CWS demonstrated more risk-taking behavior on the task than CWNS, a result interpreted by the authors as suggesting greater impulsivity on the part of CWS.

In contrast to studies reporting no differences on behavioral tasks of visual attention between groups, two studies have observed performance differences. Heitmann, Asbjørnsen, and Helland (2004) administered a series of attention-demanding experimental tasks to adolescent CWS and CWNS, including visually-based tasks of exogenous and endogenous attention. Although performance did not differ between groups for most of the measures, CWS had significantly slower response times than CWNS on the visual endogenous attention task, suggesting greater difficulty with attention focusing and shifting among CWS. More recently, Eggers et al. (2012) compared CWS and CWNS, ages four to nine years, on a visual task of alerting, orienting, and executive attention. Results showed that CWS performed more poorly than CWNS in orienting (i.e., selective) attention; the authors suggested that weaknesses in orienting attention might hamper the ability of CWS to allocate attention to concurrent tasks such as speech planning and execution, thus leading to greater problems with fluency.

In sum, there is evidence to suggest that attention may be an area of weakness for CWS. Results of parent report measures indicate poorer attention focusing and lower persistence in the course of everyday activities in CWS than in CWNS (Ofoe et al., 2018). However, when assessing problems with attention in young children, it is important not to rely solely on parent and teacher rating scales but also to examine children’s performance on behavioral tasks directly (Stefanatos & Baron, 2007). Despite the equivocal results of behavioral studies of attention in CWS, extant findings suggest that CWS may nevertheless have particular difficulty with sustained or selective attention on nonverbal tasks. Although a previous study found no group differences between school-age CWS and CWNS on a nonverbal task of visual sustained attention (Blood et al., 2007), little is known about visual sustained selective attention among preschool CWS, who are closer in age to the onset of developmental stuttering. Moreover, it is unclear whether CWS are more challenged than CWNS on tasks requiring greater endogenous attention. Thus, the current study examined visual sustained selective attention in CWS using tasks with varying exogenous and endogenous attentional demands.

1.2. Short-term memory in children who stutter

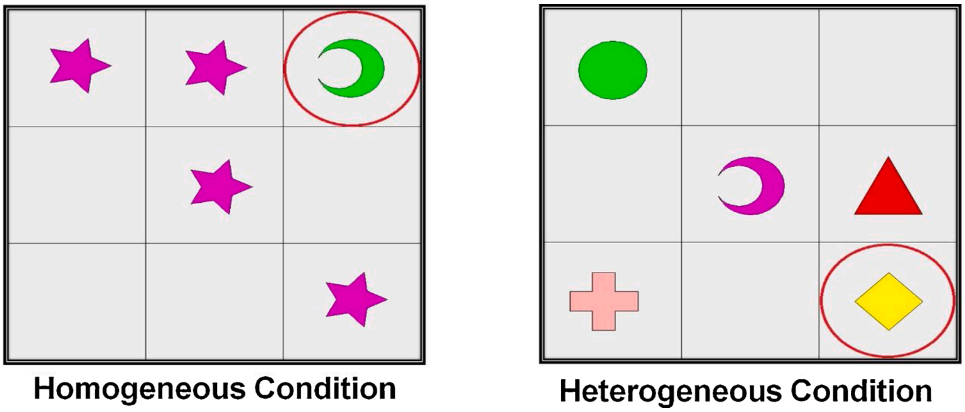
As a component of EF, working memory develops in a linear fashion from early childhood to adolescence (Best & Miller, 2010). Individual differences in working memory are apparent early in the preschool period and appear to remain stable over time (Hughes, 1998). According to Baddeley’s (1986, 2003) model, working memory includes four components: a phonological loop and a visuospatial sketchpad, which allow for short-term storage and manipulation of sensory input; an episodic buffer, which expands short-term memory capacity by linking new information with information already present in long-term storage; and a central executive, which controls the allocation of attention to other components. A key aspect of the model is that there are separate STM components dedicated to the processing of phonological (phonological loop) and visuospatial (visuospatial sketchpad) information. Evidence supports the basic validity of the model for describing the structure of working memory in children. Performance on tasks requiring only STM storage of information, whether phonological or visuospatial, has been shown to mature at an earlier age than performance on more complex tasks requiring extensive manipulation of information held in STM (Best & Miller, 2010).

Most research on STM abilities in CWS has focused on phonological STM using behavioral measures (Bajaj, 2007). In contrast, little attention has centered on the memory abilities of CWS in their everyday functioning, as reflected in the responses of parents on caregiver rating scales. However, findings of a recent study by Ntourou et al. (2018) suggest weaknesses in parent-rated working memory ability among young CWS. Relative to the ratings of parents of CWNS, parents of CWS rated their children as significantly less proficient in working memory, in particular, as well as shifting/flexibility and overall executive function, than parents of CWNS.

Of the studies that have examined STM in CWS using behavioral tasks, most have focused on phonological STM using tasks of nonword repetition (NWR), in which children are asked to repeat lists of nonwords of varying lengths. Although three studies did not find group differences in NWR between school-age CWS and CWNS (Bakhtiar, Ali, & Sadegh, 2007; Sasisekaran & Byrd, 2013; Weber-Fox, Spruill, Spencer, & Smith, 2008), a majority of findings have indicated subtle weaknesses in NWR among CWS, for preschool-age children (Anderson & Wagovich, 2010; Anderson, Wagovich, & Hall, 2006; Pelczarski & Yaruss, 2016) and school-age children and adolescents (Hakim & Bernstein Ratner, 2004; Oyoun, El Dessouky, Shohdi, & Fawzy, 2010). Finally, a pair of studies reported differences between CWS and CWNS, but only for certain subgroups of CWS (Smith, Goffman, Sasisekaran, & Weber-Fox, 2012; Spencer & Weber-Fox, 2014). Smith et al. found that only those CWS with concomitant speech sound or language problems performed more poorly in NWR; scores were similar for CWNS and CWS with typical speech sound and language skills. The second study, by Spencer and Weber-Fox, revealed lower NWR scores only among young CWS who persisted in stuttering at a follow-up assessment; those CWS who had recovered at follow-up did not differ from CWNS.

Span tasks have also been used to investigate STM in CWS (e.g., Anderson et al., 2019; Kaganovich et al., 2010; Oyoun et al., 2010; Pelczarski & Yaruss, 2016; Sasisekaran & Byrd, 2013). A meta-analysis by Ofoe et al. (2018) reported that CWS were weaker overall than CWNS on memory span tasks. For example, Anderson et al. examined verbal STM in preschool CWS and CWNS using two forward word span tasks: one consisting of phonologically similar and dissimilar words and another of semantically homogeneous and heterogeneous words. In both tasks, children repeated lists of two to four words. The CWS displayed shorter memory spans for phonologically dissimilar words than the CWNS, and their performance in repeating the word lists was less impacted by the phonological qualities (similar versus dissimilar) of the words than it was for the CWNS. While the CWS and CWNS exhibited similar memory spans for the semantic items, the CWS produced more omissions and intrusions when repeating homogeneous words and were less sensitive to the semantic qualities (homogeneous versus heterogeneous) of the words than the CWNS. In short, this study documents weaknesses in the verbal STM skills of CWS as they recall word lists. Thus, in addition to NWR differences observed in the extant literature, differences are also observed in verbal STM as measured through word span tasks.

Despite the many studies examining aspects of phonological STM in CWS, little is known about the performance of CWS on tasks requiring visual STM. The only study of which we are aware of visual STM in CWS revealed that the CWS performed more poorly than CWNS (Oyoun et al., 2010). School-age CWS and CWNS took part in a paired-association task in which a series of pictures was presented along with paired digits. After viewing the paired stimuli, children were shown the pictures again, this time without paired digits, and asked to supply the digit that had been paired with each picture. Results indicated that CWS performed more poorly than CWNS in recalling correct digits. This finding is intriguing on a theoretical level, because it suggests that any STM problems in CWS may be domain general rather than limited only to phonological STM.



Homogeneous Condition

Heterogeneous Condition

Fig. 1. A static illustration of the homogeneous and heterogeneous conditions of the Track-It Task (see Fisher et al., 2013). The target object in the homogenous (a green crecent) and heterogeneous (a yellow diamond) conditions were initially circled to indicate to the child which object they were to follow. The circle disappeared once the trial began. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article).

In summary, there is evidence that CWS may have relative weaknesses in STM, with most of that evidence stemming from studies of NWR. Recent studies indicate that children's language skills may relate to their performance on tasks of visual STM, among children with typical language as well as children with language impairment (Kaushanskaya, Park, Gangopadhyay, Davidson, & Ellis Weismer, 2017; Yang & Gray, 2017). Such findings suggest that domain general STM may play a role in children's language development. However, much remains to be understood about the visual STM skills of young CWS, and whether weaknesses might occur in both visual and verbal domains. Therefore, the current study compared the visual STM performance of young CWS and CWNS, as an adjunct to the examination of children's visual sustained selective attention skills.

1.3. *Study aims*

The purposes of this study were to examine (a) exogenous and endogenous visual sustained selective attention in young CWS and CWNS and (b) visual STM between groups and across conditions. We compared the tracking accuracy of CWS and CWNS in two conditions of the Track-It Task, which was designed to be developmentally appropriate for preschool-age children (Fisher et al., 2013). As described in detail below and depicted in Fig. 1, the *heterogeneous* condition required children to engage their attention skills in visually tracking a shape as it moved around a grid while not attending to the other shapes moving around the grid. All shapes moving around the grid, including the target, differed from each other; therefore, the target was not salient relative to the other shapes. This condition primarily measured endogenous attention. In contrast, the *homogeneous* condition required children to attend to a target shape that differed from all the other shapes, which were identical in color and in form to each other. As children tracked the target shape around the grid, they were aided by the fact that the distractor shapes, all identical to each other in shape and color, differed from the target shape. The task of tracking the shape was made easier by the fact that children merely tracked the shape that was different or most salient. Therefore, this task called on both exogenous attention and a degree of endogenous attention, as well. Reduced accuracy in the heterogeneous condition, relative to that in the homogeneous condition, indicates greater difficulty with purposeful sustained selective attention. We hypothesized that CWS would demonstrate poorer overall tracking accuracy than CWNS, with CWS showing a greater decrease in tracking accuracy in the heterogeneous condition, relative to the homogeneous condition, than CWNS. We also hypothesized that CWS would demonstrate poorer visual STM than CWNS, as reflected by lower memory accuracy for tracked stimuli.

2. Method

2.1. *Participants*

Participants were recruited through newspaper and e-newsletter advertisements and through flyers sent to preschools and daycares. The study was approved by the Institutional Review Boards of Indiana University and the University of Missouri. Parental consent was obtained for all children in the study. Participants were 42 CWS and 42 CWNS between the ages of 3;0–5;5 (years;months). Children were recruited from two sites: Indiana University and the University of Missouri. The CWS were pair-matched by chronological age (within 4 months) and gender (31 males, 11 females per group) with a CWNS from the same site. There was no significant difference between the CWS ($M = 48.12$; $SD = 8.49$) and CWNS ($M = 49.00$; $SD = 7.49$) in chronological age, $t(82) = -0.50$, $p = .62$.

Groups were also equated by socioeconomic status (SES) using Hollingshead's Four-Factor Index of Social Position (Hollingshead, 1975). This measure estimates SES by assigning a score ranging from 8 (class V, lower) to 66 (class I, upper) based on parental marital and employment status and education level. A Mann-Whitney *U* test revealed no significant difference in SES between the children in the CWS ($Mdn = 53.75$; M rank = 41.81) and CWNS ($Mdn = 53.50$; M rank = 43.19) groups, $U = 911.00$, $z = 0.26$, $p = .80$. In general, the SES of the participants was, on average, in the upper-middle social class II range, with 79.27 % of the children having social classes of I (upper) or II (upper-middle).

All participants spoke English as their primary language. Parent report revealed no significant developmental or neurological/medical history for any of the children. In addition, parents indicated that children's speech and language skills (other than stuttering for the CWS group) were on-target, impressions consistent with examiner observation during testing. All participants performed within expectations of typical development on four speech and language measures (no lower than 1.0 *SD* below the mean; standard score of 85

Table 1

Means, Standard Deviations, and Univariate Analysis of Variance Tests for Children Who Stutter (CWS) and Children Who Do Not Stutter (CWNS) on Four Standardized Speech and Language Tests.

	CWS		CWNS				
Test	*M*	*SD*	*M*	*SD*	*F*	η^2_p	*p*
PPVT-4	111.36	12.14	115.50	10.63	2.77	.03	.10
EVT-2	112.64	12.05	116.26	13.00	1.75	.02	.19
TELD-3	113.60	12.10	118.38	12.37	3.21	.04	.08
GFTA-2	103.52	9.32	106.02	11.12	1.25	.02	.27

Note. M = mean (standard score); SD = standard deviation; η^2_p = partial eta squared; PPVT-4 = *Peabody Picture Vocabulary Test-4* (Dunn & Dunn, 2007); EVT-2 = *Expressive Vocabulary Test-2* (Williams, 2007); TELD-3 = *Test of Early Language Development-3* (Hresko et al., 1999); GFTA-2 = "Sounds-in-Words" subtest of the *Goldman-Fristoe Test of Articulation-2* (Goldman & Fristoe, 2000).

or higher), and all passed a bilateral pure tone hearing screening of 1000, 2000, and 4000 Hz at 20 dB HL (American Speech-Language-Hearing Association, 1997). Table 1 provides statistics for the speech and language measures (described further below), indicating that the performance of the two groups of children was similar and well within normal limits.

2.1.1. Group classification

To be included in the CWS group, each child displayed an average of 3 or more stuttered words across three 100-word speech/language subsamples, obtained during parent-child play at the beginning of the first session. Stuttered words were defined as part-word repetitions, single-syllable word repetitions, sound prolongations, and blocks (Yairi & Ambrose, 2005). The mean percent stuttered words for the CWS group was 7.13 ($SD = 5.66$). The collective subsamples were used to estimate stuttering severity, using the *Stuttering Severity Instrument – 4th Edition* (SSI-4; Riley, 2009). To be included in the CWS group, a minimum score of 11 (corresponding to a severity of *mild*) on the SSI-4 was required. Of the 42 CWS in the study, 30 had scores in the mild range, 10 moderate, and 2 severe. Average parent-reported time since onset was 14.98 months ($SD = 8.19$).

To be included in the CWNS group, children demonstrated <3.0 % stuttered words across three 100-word speech/language subsamples, obtained during parent-child play at the beginning of the first session. On average, the CWNS group produced 0.91 ($SD = .74$) stuttered disfluencies. A Mann Whitney U test indicated that the frequency of stuttered words produced differed significantly between the two groups of children, $U = 0.00$, $z = -7.90$, $p < .001$ (CWS: $Mdn = 5.50$, M rank = 63.50; CWNS: $Mdn = .67$, M rank = 21.50).

2.2. Procedure

Participation in the study involved two sessions, each approximately 1–1.5 hours. In the first session, following completion of the consent/assent process, children participated with a parent in the 300-word speech and language sample, to enable examination of fluency. Children then were administered two one-word vocabulary measures, the *Expressive Vocabulary Test – 2nd Edition* (EVT-2; Williams, 2007) and the *Peabody Picture Vocabulary Test – 4th Edition* (PPVT-4; Dunn & Dunn, 2007). Next, the children completed one of the two Track-It Task (Fisher et al., 2013) conditions, the homogeneous or the heterogeneous condition; order was counterbalanced across participants. This was followed by several other tasks unrelated to the present study. During this session, parents were asked to complete several questionnaires related to their children's development. As pertains to this study, they completed a case history form and interview, as well as the ADHD Rating Scale-IV Preschool Version (ADHD-RS-IV-P; McGoey, DuPaul, Haley, & Shelton, 2007), described further below.

In the second session, the children completed the *Goldman-Fristoe Test of Articulation – 2nd Edition* (GFTA-2; Goldman & Fristoe, 2000) "Sounds in Words" subtest, a test of speech sound production at the word level; the *Test of Early Language Development – 3rd Edition* (TELD-3, Hresko, Reid, & Hammill, 1999), a measure of overall receptive and expressive language; and the hearing screening. They then completed the other condition of the Track-It Task (Fisher et al., 2013), as well as several additional tasks unrelated to the present study.

2.2.1. ADHD-RS-IV-P

The ADHD-RS-IV-P is an 18-item questionnaire that requires parents to rate the frequency of occurrence of ADHD symptoms, based on the Fourth and Fifth Editions of the *Diagnostic and Statistical Manual of Mental Disorders* (American Psychiatric Association, 2000, 2013), in their children. As a screening instrument, the ADHD-RS-IV-P assesses preschool children's *risk* for ADHD; it is not diagnostic of ADHD (McGoey et al., 2007). Parents rate each item on the ADHD-RS-IV-P using a four-point scale from "rarely or never" true to "very often" true, circling the rating that describes their child's behavior over the last six months. For example, items asked about children's attention to detail, fidgeting or squirming behavior, easily becoming distracted, difficulty with turn-taking, etc. These ratings are subsequently tallied to form two subscale scores for Inattention and Hyperactivity/Impulsivity and one Total score.

As many experts have noted, it can be difficult to diagnose ADHD in preschool children because many of the symptoms, such as hyperactivity, inattention, and disorganization, appear frequently in children of this age range, regardless of whether they have ADHD (e.g., Curchack-Lichtin, Chacko, & Halperin, 2014; McGoey et al., 2006). Thus, preschool children who score at or above the 93rd percentile on one or both subscales of the ADHD-RS-IV-P and/or the Total score are considered to be at-risk for ADHD and may require further evaluation by a child psychologist or pediatrician to determine its presence (McGoey et al., 2007). Given that the ADHD-RS-IV-P is a screening instrument and diagnosing ADHD in preschool children can be challenging, scores on this measure were not used for exclusionary purposes in the present study. Rather, they were used to provide context as to the extent to which the children of either group were at-risk for developing ADHD.

On a descriptive basis, there were more children in the CWS group ($n = 6$, 14.3 %) who scored at or above the 93rd percentile on one or more of the ADHD-RS-IV-P subscales and/or total score than children in the CWNS group ($n = 3$, 7.1 %). A chi-square test of independence was performed to examine the relation between group (CWS, CWNS) and the three ADHD-RS-IV-P scores (inattention, hyperactivity/impulsivity and total). The relation between these variables was not significant, $X^2(2) = 0.66$, $p = .72$. Furthermore, a series of Mann-Whitney U tests revealed no significant differences between the CWS and CWNS on the Inattention, $U = 764.50$, $z = -1.06$, $p = .29$ ($Mdn = 6.00$ and 5.00; M rank = 45.30 and 39.70); Hyperactivity/Impulsivity, $U = 908.50$, $z = 0.24$, $p = .81$ ($Mdn = 7.00$ and 7.50; M rank = 41.87 and 43.13); and Total, $U = 842.50$, $z = -0.35$, $p = .72$ ($Mdn = 13.00$ and 13.00; M rank = 43.44 and 41.56), scales. Thus, although there was a tendency for more CWS to be at risk for ADHD than CWNS, these differences were not significant and, at the group level, there were no significant differences between the two groups of children on any of the ADHD-RS-IV-P scales. This suggests that the two groups of children were comparable in their risk for ADHD.

2.2.2. Experimental stimuli

The experimental measures were the two conditions of the Track-It Task (Fisher et al., 2013), measuring visual sustained selective attention and visual memory. Each condition consisted of 10 trials. Fig. 1 illustrates the task. For both conditions, children were presented with a 3 × 3 grid containing 5 objects (1 target; 4 distractors) with the target object initially circled. Children were instructed that, as the objects began to move around the grid, they were to follow the target object, tracking it as it moved. As illustrated in Fig. 1, in the homogeneous condition, the distractor objects were identical to each other (e.g., all purple stars) and different from the target object (e.g., a green crescent), making the target the salient feature of the array. This condition measures both exogenous and endogenous visual attention. That is, the salience of the target shape compared to the distractor shapes aided tracking, engaging exogenous attention, as well as some degree of endogenous attention (in that they are maintaining focus on the task volitionally).

In the heterogeneous condition, the distractor objects were different from each other (e.g., red triangle, green circle, purple crescent, and pink cross) and the target object (e.g., a yellow diamond). This condition served primarily as a measure of endogenous attention. Because the target shape was no more salient than the distractor shapes, performance was presumed to rely on the children's ability to engage endogenous attention to actively track one shape while ignoring the others.

The target and distractor objects were randomly selected from among nine different objects and colors, and the conditions were randomized across participants. Both the target, whose starting position was randomized, and distractor objects moved at a rate of 800 pixels per second and 30 frames per second. For each item of both conditions, after 10 s of the objects randomly moving around the grid, both the target and distractor objects disappeared from the screen and children were asked to point to the square in the grid where the target object was last seen (tracking accuracy). Children were then presented with a screen depicting nine objects and were asked to point to the target object they had been tracking (memory accuracy).

2.3. Data analyses

Data were analyzed using IBM SPSS Statistics for Windows, Version 25 (Armonk, NY: IBM Corp) and SAS software, Version 9.4 of the SAS System for Windows (Cary, NC: SAS Institute Inc.). Data screening procedures indicated that both the tracking and memory data were non-Gaussian in nature. For this reason, generalized estimating equation (GEE) analyses were conducted using an exchangeable correlation matrix and a binary logistic distribution to model the dichotomous outcome of responding correctly or incorrectly to each trial. The main effects of group (CWS vs. CWNS), condition (homogeneous vs. heterogeneous), and the two-way interaction between group and condition were assessed and reported using Wald Chi-Square statistics (with 1 *df* using the Type III sum of squares approach, two-tailed). Chronological age was also added as a covariate to these analyses as it was moderately to highly correlated with tracking and memory accuracy in both conditions. Planned pairwise comparisons, with Bonferroni corrections applied, were used to further explore differences between means. Finally, correlational analyses between tracking and memory accuracy were conducted using Spearman's rank partial correlation coefficients, with chronological age added as a covariate.

3. Results

3.1. Tracking accuracy

The CWS (adjusted $M = 0.44$, $SE = .03$) were significantly less likely to produce an accurate tracking response across conditions than the CWNS (adjusted $M = 0.53$, $SE = .03$), χ^2 $(1, N = 84) = 5.60$, $p = .02$. The main effect of condition was also significant, χ^2 $(1, N = 84) = 18.87$, $p < .001$ (Homogeneous: adjusted $M = 0.55$, $SE = .03$; Heterogeneous: adjusted $M = .43$, $SE = .03$), as was the covariate, chronological age, χ^2 $(1, N = 84) = 25.85$, $p < .001$. However, the interaction between participant group and condition failed to reach statistical significance, χ^2 $(1, N = 84) = 0.60$, $p = .44$ (see Fig. 2). Pairwise comparisons (Bonferroni corrected) further revealed no significant difference between the CWS and CWNS in the homogeneous (adjusted $M = .51$ and .58; $SE = .03$ and .03; $SD = .19$ and .19, respectively) and heterogeneous (adjusted $M = .37$ and .49; $SE = .03$ and .04; $SD = .19$ and .26, respectively) conditions ($p = .56$ and .11, respectively).[1] These results indicate that the CWS were more likely to have difficulty with sustained selective attention across conditions than the CWNS and both groups of children were more likely to have difficulty maintaining their attention to target objects when predominantly endogenous factors were involved.

3.2. Memory accuracy

The CWS (adjusted $M = 0.61$, $SE = .05$) were significantly less likely than the CWNS (adjusted $M = 0.71$, $SE = .04$) to remember which object they had been tracking across conditions, χ^2 $(1, N = 84) = 6.24$, $p = .01$. While the main effect of condition was not significant, χ^2 $(1, N = 84) = 0.43$, $p = .51$ (Homogeneous: adjusted $M = 0.69$, $SE = .03$; Heterogeneous: adjusted $M = 0.71$, $SE = .04$), the main effect of the covariate, chronological age, was significant, χ^2 $(1, N = 84) = 26.59$, $p < .001$. The interaction between participant group and condition was not statistically significant, χ^2 $(1, N = 84) = 0.01$, $p = .94$ (see Fig. 3). Bonferroni corrected

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[1] Note that with the 6 CWS and 3 CWNS who scored at or above the 93rd percentile on the ADHD-RS-IV-P removed, the results were the same in that the main effects of group, condition, and age were significant ($p \leq .003$), the group x condition interaction was not significant ($p = .39$), and the pairwise comparison was not significant in the homogeneous condition ($p = .15$). However, the pairwise comparison (Bonferroni corrected) between the CWS and CWNS in the heterogeneous condition was significant ($p = .02$), with the CWS performing less accurately than the CWNS.

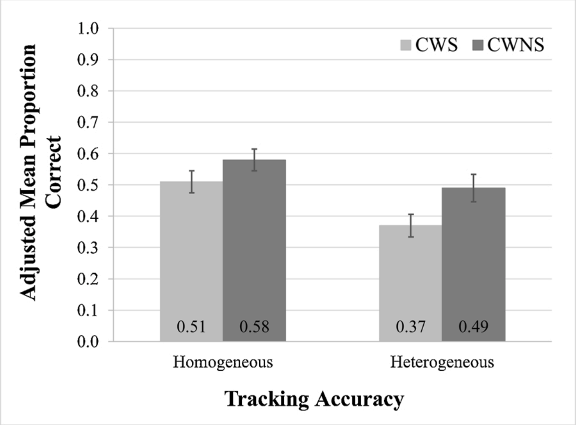

Fig. 2. Adjusted mean proportion correct (with standard error bars) for tracking accuracy in CWS and CWNS.

pairwise comparisons further revealed significant differences between the CWS and CWNS in both the homogeneous (adjusted $M = .61$ and .77; $SE = .05$ and .04; $SD = .32$ and .26, respectively) and heterogeneous (adjusted $M = .62$ and .78; $SE = .05$ and .05; $SD = .32$ and .32, respectively) conditions ($p = .05$).[2] These findings suggest that the CWS were more likely than the CWNS to have difficulty recalling the tracked objects at the end of each trial across both conditions. Furthermore, that there was no difference in memory accuracy between conditions suggests that the difference observed in children's tracking accuracy between the homogeneous and heterogeneous conditions is not likely a consequence of a failure in the encoding of the target object (Fisher et al., 2013).

3.3. *Correspondence between tracking and memory accuracy*

The CWS were less likely than the CWNS to successfully recall the target objects across both conditions. Thus, it is possible that the difficulty they had with tracking was not due to reduced sustained selective attention, but rather to a failure in memory encoding (see Fisher et al., 2013, for further discussion). That is, the CWS may have been able to track the target objects but could not demonstrate that skill because they were unable to remember which target objects they were supposed to track. To test this possibility, we first examined the relationship between tracking and memory accuracy using Spearman's rank partial correlation coefficients, with chronological age as a covariate. For the CWS, the results revealed a significant correlation between tracking and memory accuracy in the homogeneous condition ($r = 0.44$, $p = .005$), but not the heterogeneous ($r = -0.15$, $p = .34$) condition. The CWNS exhibited similar results (Homogeneous: $r = 0.37$, $p = .02$; Heterogeneous: $r = 0.18$, $p = .29$).

Given that the CWS had a significant, positive correlation between tracking and memory accuracy in the homogeneous condition, the tracking data were reanalyzed for only those trials in which both the CWS and CWNS accurately encoded the identity of the target object (i.e., only the trials in which memory accuracy was correct). The results were consistent with the original analyses of the tracking data. The main effects of group, χ^2 (1, $N = 84$) = 6.34, $p = .01$ (CWS: adjusted $M = 0.54$, $SE = .04$; CWNS: adjusted $M = 0.65$, $SE = .03$), condition, χ^2 (1, $N = 84$) = 20.17, $p < .001$ (Homogeneous: adjusted $M = 0.66$, $SE = .03$; Heterogeneous: adjusted $M = .53$, $SE = .03$), and chronological age, χ^2 (1, $N = 84$) = 27.25, $p < .001$, were significant. However, there was no significant group x condition interaction effect, χ^2 (1, $N = 84$) = 1.97, $p = .16$, and the pairwise comparisons (Bonferroni corrected) between the CWS and CWNS in the homogeneous (adjusted $M = .62$ and .69; $SE = .04$ and .04; $SD = .26$ and .26, respectively) and heterogeneous (adjusted $M = .45$ and .61; $SE = .05$ and .04; $SD = .32$ and .26, respectively) conditions also failed to reach statistical significance ($p = .99$ and .06, respectively). These results suggest that the reduced tracking accuracy experienced by the CWS relative to the CWNS was a consequence of difficulty maintaining attention to the target objects, not memory encoding.

Likewise, it is also possible that the CWS performed more poorly than the CWNS on the memory probes simply because they had difficulty maintaining their attention to the target objects. After all, if the children were unable to maintain their attention long enough to track an object over time, then it is reasonable to expect that they would have difficulty remembering which object they had been unsuccessful in tracking. To examine this possibility, the memory data were reanalyzed only for those trials in which the CWS and CWNS tracked successfully. The results were, once again, consistent with the original analyses of the memory data. The main effects of group, χ^2 (1, $N = 84$) = 10.03, $p = .002$ (CWS: adjusted $M = 0.75$, $SE = .04$; CWNS: adjusted $M = 0.91$, $SE = .02$), and chronological age, χ^2 (1, $N = 84$) = 21.03, $p < .001$, were significant. However, the main effect of condition, χ^2 (1, $N = 84$) = 0.82, $p = .37$ (Homogeneous: adjusted $M = 0.84$, $SE = .03$; Heterogeneous: adjusted $M = .86$, $SE = .03$) and the group by condition interaction, χ^2 (1, $N = 84$) = 0.002, $p = .97$, were not significant. The Bonferroni corrected pairwise comparisons between the CWS and CWNS in both the

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[2] Like tracking accuracy, the results were largely the same with the 9 children (6 CWS, 3 CWNS) at risk for ADHD removed: group and age were significant ($p \leq .03$), condition ($p = .17$) and the group x condition interaction effect ($p = .77$) were not significant. The results differed in that the pairwise comparisons between groups were no longer significant in the homogeneous ($p = .17$) and heterogeneous ($p = .15$) conditions.

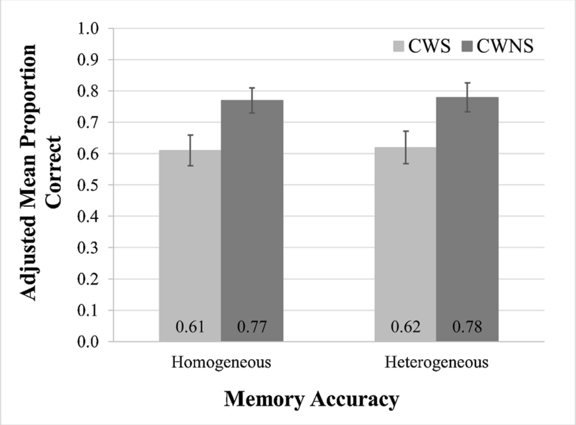

Fig. 3. Adjusted mean proportion correct (with standard error bars) for memory accuracy in CWS and CWNS.

homogeneous (adjusted $M = .73$ and .91; $SE = .05$ and .02; $SD = .32$ and .13, respectively) and heterogeneous (adjusted $M = .76$ and .92; $SE = .05$ and .02; $SD = .32$ and .13, respectively) conditions were also statistically significant ($p < .001$ and .03, respectively). Thus, like the reanalysis of tracking accuracy, these findings indicate that the CWS performed more poorly than the CWNS in memory accuracy not because they had difficulty maintaining their attention to the target objects, but rather because they have weaknesses in visual STM.

4. Discussion

This study explored visual sustained selective attention with focus on exogenous and endogenous attention processes in CWS and their peers. In particular, we evaluated children's ability to track a target shape over a short period of time. We also examined children's visual STM by exploring the extent to which, after tracking a target shape that disappeared, children could identify the target shape from an array.

We chose visual as opposed to auditory stimuli to examine the cognitive processes of sustained selective attention and short-term memory in CWS. This is one means of studying attention processes without (at least directly) engaging language processing skills. The use of visual stimuli also enabled manipulation of the salience of the stimuli. Using the Track-It Task by Fisher et al. (2013), exogenous versus endogenous attention could be compared to explore the extent to which both groups were able to demonstrate sustained selective attention in tracking a shape's movement, even when the shape was not visually set apart from the other shapes moving about the screen. Thus, the homogeneous and heterogeneous conditions provided a less and a more challenging (i.e., developmentally less advanced and more advanced) version of the attention task.

4.1. *Sustained selective visual attention*

We hypothesized that CWS would demonstrate poorer accuracy than CWNS in overall tracking, with CWS showing a greater decrease than CWNS in tracking accuracy in the heterogeneous condition, relative to the homogeneous condition. Results of the study were partially consistent with this hypothesis; CWS experienced greater challenge than their peers in demonstrating sustained selective visual attention across *both* conditions. That is, having attempted to track a target shape in its movement for a period of seconds, the CWS were less likely than the CWNS to respond correctly about the shape's final position upon its disappearance. Together, the groups showed a similar pattern of performing better on the homogeneous than the heterogeneous condition (i.e., revealing no significant interaction between group and condition), thus, in contrast to our hypothesis, the CWS did not demonstrate a greater discrepancy between performance on the two tasks than the CWNS did. It appears these results cannot be accounted for by differences in language, articulation, or SES, as these variables did not differ significantly between groups. In addition, children's memory (or lack of memory) of the shape to be tracked did not account for their performance in tracking the target shape accurately; that is, when tracking data were reanalyzed using only items for which children recalled the correct shape, results did not change for either group. Thus, although it is clearly important to assess children's memory of the target shape, as a validity check for the tracking task, in this case, memory did not appear to impact the tracking results.

The observed difference in visual attention between groups is consistent with previous research conducted with older children. Eggers et al. (2012) found differences in CWS and their peers, ages four to nine years, with CWS performing more poorly on a visual task involving selective attention. Moreover, Heitmann et al. (2004) examined visual attention in older school-age and adolescent CWS, ages 11–16 years. They found that the CWS showed slower response times on their task of endogenous visual attention than the CWNS. Although for the most part, the children in both of these studies were in the school-age years, findings were similar to those of the present study, in that they suggest some weaknesses, even if subtle, in the area of visual attention.

In contrast to these findings are those by Blood et al. (2007), who used a visual continuous performance task, examining sustained attention in school-age CWS. They found that the CWS and the CWNS did not differ in accuracy or response time on this task. Two key differences between the present study and the study by Blood et al. are that, in the latter study, (a) there was no focus on selective attention (or short-term memory), and (b) older children served as participants. Our task required children to demonstrate both sustained attention over a period of seconds and selective attention on a target while ignoring nontargets. This presumably added greater complexity than a task that taps sustained or selective attention alone, which may have accounted for the group differences in our study. Age, too, may have been a reason Blood et al. did not observe differences in their groups. It is possible that, in the school-age years, visual sustained attention differences are more subtle, if they exist at all. Our finding of differences in preschool-age children, much closer to stuttering onset, may suggest that visual attention and STM are important in explaining the *development* of stuttering—and that these skills are less important in explaining continued stuttering into the school-age years. It is in the preschool years, after all, when attention undergoes the most substantial development (Best & Miller, 2010; Ruff & Rothbart, 2001). As suggested by the WEAVER++ model (Roelofs & Piai, 2011), attention and aspects of memory are particularly important for speech-language planning. Therefore, weaknesses in these areas may create a vulnerability in planning processes, ultimately manifesting in disfluency.

4.2. The role of exogenous and endogenous attention in task performance

As described at the outset, exogenous attention is earlier developing (Fisher et al., 2013; Ruff & Rothbart, 2001). A child's ability to selectively attend to a stimulus and to maintain attention over time is aided by the salience of the stimulus. In contrast, endogenous attention develops relatively later and requires volitional control of sustained selective attention. The Track-It Task (Fisher et al.) was employed to explore the advantage conferred by stimuli that are highly salient. Our findings revealed that, across groups, the children performed better on the homogeneous condition than the heterogeneous condition, suggesting that the groups both benefitted from exogenous factors in selectively attending to an object over time. When the target shapes were less salient, in the heterogeneous condition, performance of both groups declined. This overall pattern of performance is consistent with developmental expectations; in the preschool years, endogenous attention skills are developing, making the heterogeneous condition substantially more challenging.

Of importance, the CWS performed significantly less well than the CWNS across both conditions, suggesting greater sustained selective attention difficulties overall, without regard to the role of exogenous or endogenous factors (i.e., there was no significant interaction between group and condition). This finding might be interpreted to suggest that the CWS showed the same pattern as the CWNS, with exogenous factors aiding their performance, but their performance was nonetheless weaker across both conditions.

While there are no studies of preschool-age CWS exploring exogenous versus endogenous attention processes, the study by Heitmann et al. (2004) of school-age CWS examined these processes. (Also see Eggers, De Nil, & Van den Bergh's (2018) study of school-age children, exploring exogenous response inhibition processes.) Consistent with the present study's findings, Heitmann et al. observed differences between CWS and CWNS in attention. However, in contrast to our findings, they observed these differences only in the more challenging of their subtests, measuring endogenous attention. This could signal a developmental shift in which older CWS differ from CWNS only when the stimuli are not aided by exogenous attention (salience of stimuli). The Track-It Task may be more sensitive than other measures of visual attention, resulting in even more subtle differences being identified across both conditions.

4.3. Visual short-term memory

We hypothesized that CWS would demonstrate poorer visual STM than CWNS, as reflected by lower memory accuracy for tracked stimuli. This hypothesis was based, in part, on the findings of Oyoun et al. (2010) indicating that school-age CWS performed more poorly than CWNS on a task of visual STM. Findings of the present study were consistent with this hypothesis; the CWS performed significantly more poorly in recalling the tracked shapes than the CWNS. Results complement prior research that suggests some degree of weakness in phonological working memory on NWR tasks (Anderson & Wagovich, 2010; Anderson et al., 2006; Hakim & Bernstein Ratner, 2004; Oyoun et al., 2010; Pelczarski & Yaruss, 2016; Sasisekaran & Byrd, 2013) and verbal short-term memory on span tasks (e.g., Anderson et al., 2019; Ofoe et al., 2018).

As described at the outset, in Baddeley's working memory model, short-term storage of visual information follows a different path than phonological information, with the visuospatial sketchpad enabling storage and manipulation of the content. (Other than this difference, visual information is processed similarly, with the use of the central executive component to control allocation of attention during this process.) In theory, then, children's performance on phonological short-term memory tasks could reasonably differ from their performance on visual memory tasks, because the model includes separate phonological and visual processing components. Therefore, the study of visual memory is an important step in conceptualizing memory processes more generally in CWS.

Of importance, the visual STM measure and the visual attention measure employed in this study are not independent of each other. Rather, in theory, memory skills could impact the ability to track the target shape. Fisher et al. (2013) emphasized that the memory component of the Track-It Task was intended as a "check" that would allow disambiguation of whether performance difficulty was more directly linked to attention or memory. As noted previously, for the participants of this study, it does not appear that tracking results were impacted by memory, because the results did not change when items for which the target shape was not recalled were excluded from the analysis of tracking.

Similarly, in theory, tracking skills could impact performance on the memory probe. That is, within a particular trial, one's performance in tracking the target shape around the screen could impact performance in identifying the tracked shape at the end of the trial. As described in the results, we explored this possibility by examining whether memory results changed when only accurately tracked items were included in the analysis. Findings showed that memory accuracy was not impacted by tracking accuracy; when tracking accuracy was controlled, the CWS continued to perform less accurately than the CWNS in recalling the tracked object.

4.4. Limitations and conclusions

Findings of this study are consistent with the developmental literature, indicating that even young children in the preschool years can harness exogenous and endogenous attention skills to attend selectively to a visual stimulus over a short period of time. Nonetheless, CWS perform more poorly in this regard. The CWS were also less likely than the CWNS to recall target shapes presented at the ends of each trial, engaging visual STM.

One potential (though unavoidable) limitation relates to the difficulty, in studies of preschool-age children, of making firm diagnostic statements about ADHD. Therefore, it was not possible to know whether a subset of the young children in our study would ultimately be diagnosed later with ADHD in the school-age years. Nonetheless, we attempted to address this issue, in part, by administering the ADHD-RS-IV-P to estimate children's risk of a later diagnosis. Several caveats to parent ratings of ADHD behaviors should be acknowledged. First, parents are not always able to objectively evaluate their children's specific cognitive processes in relation to other children (e.g., see Ofoe et al., 2018, for a discussion of this issue). In fact, following completion of this questionnaire, parents of children in the present study often asked an examiner about whether the attention behaviors of their child were similar to other children. Second, as noted above, diagnosis of ADHD (often performed by a psychologist) generally occurs in the school-age years. Information obtained in the preschool years may be less reliable for diagnostic purposes. For these reasons, the screening measure was used only to glean an idea of the children's risk of a later diagnosis.

Results indicated that there were no significant differences in risk between groups on any of the three ADHD-RS-IV-P domains (inattention, hyperactivity/impulsivity or total), suggesting that statistically, the two groups were comparable in their risk. We also reran the statistical analyses, excluding participants from each group who fell in the "at-risk" category, and the main findings remained unchanged (see Footnotes 1 and 2). Therefore, it seems reasonable to conclude that our findings were not due to the influence of subgroups at risk of ADHD, but rather to inherent group differences in visual sustained selective attention, as a cognitive skill.

Comparisons of subgroups of children, such as groups subdivided by sex, were outside the scope of this work. Future work should be designed to address this as a key variable at the outset, prospectively collecting data to address potential performance differences in sex among CWS. In addition, because we did not follow participants longitudinally, it is not possible to compare the performance of children who ultimately recovered from stuttering to those who persisted. Future study is needed in this area, however, to explore whether those CWS who later recover from stuttering perform differently on tasks such as these from children who continue to stutter.

Taken as a whole, the findings of this study suggest that even preschool-age CWS show experimentally measurable weakness in visual sustained selective attention and visual memory. Thus, the study provides new evidence of broader, domain-general weaknesses that extend to visual attention skills and visual STM among preschool-age CWS. Future studies should tease apart the skills of visual attention and visual memory, using different tasks, to explore the extent to which groups may differ independently on each of these skills. Continued focus in this area will lead to more fine-grained analysis and characterization of the role of attentional and memory processes among children near stuttering onset.

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References

American Psychiatric Association. (2000). *Diagnostic and statistical manual of mental disorders* (4th ed.). Washington, DC: American Psychiatric Association.

American Psychiatric Association. (2013). *Diagnostic and statistical manual of mental disorders* (5th ed.). Arlington: American Psychiatric Association.

American Speech-Language-Hearing Association. (1997). *Guidelines for audiologic screening.* Available from www.asha.org/policy.

Anderson, J. D., & Ofoe, L. C. (2019). The role of executive function in developmental stuttering. *Seminars in Speech and Language, 40*, 305–319.

Anderson, J. D., & Wagovich, S. A. (2010). Relationships among linguistic processing speed, phonological working memory, and attention in children who stutter. *Journal of Fluency Disorders, 35*, 216–234.

Anderson, J. D., & Wagovich, S. A. (2016). *Aspects of attention in developmental stuttering.* November. Philadelphia, Pennsylvania: Seminar presented at the American Speech-Language-Hearing Association.

Anderson, J. D., Pellowski, M. W., Conture, E. G., & Kelly, E. M. (2003). Temperamental characteristics of young children who stutter. *Journal of Speech Language and Hearing Research, 46*, 1221–1233.

Anderson, J. D., Wagovich, S. A., & Brown, B. T. (2019). Phonological and semantic contributions to verbal short-term memory in young children with developmental stuttering. *Journal of Speech Language and Hearing Research, 62*, 644–667.

Anderson, J. D., Wagovich, S. A., & Hall, N. E. (2006). Nonword repetition skills in children who do and do not stutter. *Journal of Fluency Disorders, 31*, 177–199.

Arndt, J., & Healey, E. C. (2001). Concomitant disorders in school-age children who stutter. *Language Speech and Hearing Services in Schools, 32*, 68–78.

Baddeley, A. D. (1986). *Working memory*. Oxford, UK: Oxford University Press.

Baddeley, A. D. (2003). Working memory: Looking back and looking forward. *Nature Reviews Neuroscience, 4*, 829–839.

Bajaj, A. (2007). Working memory involvement in stuttering: Exploring the evidence and research implications. *Journal of Fluency Disorders, 32*, 218–238.

Bakhtiar, M., Ali, D. A. A., & Sadegh, S. P. M. (2007). Nonword repetition ability of children who do and do not stutter and covert repair hypothesis. *Indian Journal of Medical Sciences, 61*, 462–470.

Best, J. R., & Miller, P. H. (2010). A developmental perspective on executive function. *Child Development, 81*, 1641–1660.

Blood, G. W., Blood, I. M., Maloney, K., Weaver, A. V., & Shaffer, B. (2007). Exploratory study of children who stutter and those who do not stutter on a visual attention test. *Communication Disorders Quarterly, 28*, 145–153.

Brikell, I., Kuja-Halkola, R., & Larsson, H. (2015). Heritability of attention-deficit hyperactivity disorder in adults. *American Journal of Medical Genetics Part B Neuropsychiatric Genetics, 168*, 406–413.

Choi, D., Conture, E. G., Tumanova, V., Clark, C. E., Walden, T. A., & Jones, R. M. (2018). Young children's family history of stuttering and their articulation, language and attentional abilities: An exploratory study. *Journal of Communication Disorders, 71*, 22–36.

Clark, C. E., Conture, E. G., Walden, T. A., & Lambert, W. E. (2015). Speech-language dissociations, distractibility, and childhood stuttering. *American Journal of Speech-language Pathology, 24*, 480–503.

Conture, E., & Walden, T. (2012). Dual diathesis-stressor model of stuttering. In L. Bellakova, & Y. Filatova (Eds.), *Theoretical issues of fluency disorders* (pp. 94–127). Moscow, Russia: National Book Centre.

Curchack-Lichtin, J. T., Chacko, A., & Halperin, J. M. (2014). Changes in ADHD symptom endorsement: Preschool to school age. *Journal of Abnormal Child Psychology, 42*, 993–1004.

De Sonneville, L. M. J. (2009). *Amsterdamse neuropsychologische taken [Amsterdam neuropsychological tasks]*. Amsterdam, the Netherlands: Boom Test Publishers.

Donaher, J., & Richels, C. (2012). Traits of attention deficit/hyperactivity disorder in school-age children who stutter. *Journal of Fluency Disorders, 37*, 242–252.

Druker, K., Hennessey, N., Mazzucchelli, T., & Beilby, J. (2019). Elevated attention deficit hyperactivity disorder symptoms in children who stutter. *Journal of Fluency Disorders, 59*, 80–90.

Dunn, L. M., & Dunn, D. M. (2007). *Peabody picture vocabulary test – Fourth edition (PPVT-4)*. San Antonio, TX: Pearson, Inc.

Eggers, K., & Jansson-Verkasalo, E. (2017). Auditory attentional set-shifting and inhibition in children who stutter. *Journal of Speech Language and Hearing Research, 60*, 3159–3170.

Eggers, K., De Nil, L. F., & Van den Bergh, B. R. H. (2010). Temperament dimensions in stuttering and typically developing children. *Journal of Fluency Disorders, 35*, 355–372.

Eggers, K., De Nil, L. F., & Van den Bergh, B. R. H. (2012). The efficiency of attentional networks in children who stutter. *Journal of Speech Language and Hearing Research, 55*, 946–959.

Eggers, K., De Nil, L. F., & Van den Bergh, B. R. H. (2018). Exogenous triggered response inhibition in developmental stuttering. *Journal of Fluency Disorders, 56*, 33–44.

Embrechts, M., Ebben, H., Franke, P., & van de Poel, C. (2000). Temperament: A comparison between children who stutter and children who do not stutter. In H. G. Bosshardt, J. S. Yaruss, & H. F. M. Peters (Eds.), *Proceedings of the third world congress on fluency disorders: Theory, research, treatment, and self-help* (pp. 557–562). Nijmegen, The Netherlands: University of Nijmegen Press.

Fisher, A., Thiessen, E., Godwin, K., Kloos, H., & Dickerson, J. (2013). Assessing selective sustained attention in 3- to 5-year-old children: Evidence from a new paradigm. *Journal of Experimental Child Psychology, 114*, 275–294.

Garon, N., Bryson, S. E., & Smith, I. M. (2008). Executive function in preschoolers: A review using an integrative framework. *Psychological Bulletin, 134*, 31–60.

Goldman, R., & Fristoe, M. (2000). *Goldman-Fristoe test of articulation – Second edition (GFTA-2)*. Minneapolis, MN: Pearson, Inc.

Hakim, H. B., & Bernstein Ratner, N. (2004). Nonword repetition abilities of children who stutter: An exploratory study. *Journal of Fluency Disorders, 29*, 179–199.

Heitmann, R. R., Asbjørnsen, A., & Helland, T. (2004). Attentional functions in speech fluency disorders. *Logopedics Phoniatrics Vocology, 29*, 119–127.

Hollingshead, A. (1975). *Four-factor index of social status*. New Haven, Connecticut: Yale University.

Hresko, W. P., Reid, D. K., & Hammill, D. D. (1999). *Test of early language development – Third edition (TELD-3)*. Austin, TX: PRO-ED.

Hughes, C. (1998). Finding your marbles: Does preschoolers' strategic behavior predict later understanding of mind? *Developmental Psychology, 34*, 1326–1339.

Johnson, K. N., Conture, E. G., & Walden, T. A. (2012). Efficacy of attention regulation in preschool-age children who stutter: A preliminary investigation. *Journal of Communication Disorders, 45*, 263–278.

Jongman, S. R., Roelofs, A., & Meyer, A. S. (2015). Sustained attention in language production: An individual differences investigation. *The Quarterly Journal of Experimental Psychology, 68*, 710–730.

Kaganovich, N., Hampton Wray, A., & Weber-Fox, C. (2010). Non-linguistic auditory processing and working memory update in pre-school children who stutter: An electrophysiological study. *Developmental Neuropsychology, 35*, 712–736.

Kannass, K. N., & Oakes, L. M. (2008). The development of attention and its relations to language in infancy and toddlerhood. *Journal of Cognition and Development, 9*, 222–246.

Karrass, J., Walden, T. A., Conture, E. G., Graham, C. G., Arnold, H. S., Hartfield, K. N., et al. (2006). Relation of emotional reactivity and regulation to childhood stuttering. *Journal of Communication Disorders, 39*, 402–423.

Kaushanskaya, M., Park, J. S., Gangopadhyay, I., Davidson, M. M., & Ellis Weismer, S. (2017). The relationship between executive functions and language abilities in children: A latent variables approach. *Journal of Speech Language and Hearing Research, 60*, 912–923.

Kefalianos, E., Onslow, M., Ukoumunne, O., Block, S., & Reilly, S. (2014). Stuttering, temperament, and anxiety: Data from a community cohort ages 2-4 years. *Journal of Speech Language and Hearing Research, 57*, 1314–1322.

Lee, H., Sim, H., Lee, E., & Choi, D. (2017). Disfluency characteristics of children with attention-deficit/hyperactivity disorder symptoms. *Journal of Communication Disorders, 65*, 54–64.

Mahone, E. M., & Schneider, H. E. (2012). Assessment of attention in preschoolers. *Neuropsychology Review, 22*, 361–383.

McGoey, K. E., DuPaul, G. J., Haley, E., & Shelton, T. L. (2007). Parent and teacher ratings of attention-deficit/hyperactivity disorder in preschool: the ADHD Rating Scale-IV Preschool Version. *Journal of Psychopathology and Behavioral Assessment, 29*, 269–276.

McGoey, K. E., Lender, W. L., Buono, J., Blum, N., Power, T. J., & Radcliffe, J. R. (2006). A model for assessing preschool children with attention and activity problems. *Journal of Infant and Child Psychology, 2*, 117–138.

Mirsky, A. F., Anthony, B. J., Duncan, C. C., Ahearn, M. B., & Kellam, S. G. (1991). Analysis of the elements of attention: A neuropsychological approach. *Neuropsychology Review, 2*, 109–145.

Ntourou, K., Anderson, J. D., & Wagovich, S. A. (2018). Executive function and childhood stuttering: Parent ratings and evidence from a behavioral task. *Journal of Fluency Disorders, 56*, 18–32.

Ofoe, L. C., Anderson, J. D., & Ntourou, K. (2018). Short-term memory, inhibition, and attention in developmental stuttering: A meta-analysis. *Journal of Speech Language and Hearing Research, 61*, 1626–1648.

Oyoun, H. A., El Dessouky, H., Shohdi, S., & Fawzy, A. (2010). Assessment of working memory in normal children and children who stutter. *The Journal of American Science, 6*, 562–569.

Pelczarski, K. M., & Yaruss, J. S. (2016). Phonological memory in young children who stutter. *Journal of Communication Disorders, 62*, 54–66.

Riley, G. D. (2009). *Stuttering severity instrument for children and adults – Fourth edition (SSI-4)*. Austin, TX: Pro-Ed.

Riley, G., & Riley, J. (2000). A revised component model for diagnosing and treating children who stutter. *Contemporary Issues in Communication Science and Disorders, 27*, 188–199.

Roelofs, A., & Piai, V. (2011). Attention demands of spoken word planning: A review. *Frontiers in Psychology, 2*, 1–14.

Ruff, H., & Rothbart, M. K. (2001). *Attention in early development*. New York: Oxford University Press.

Sasisekaran, J., & Basu, S. (2017). The influence of executive functions on phonemic processing in children who do and do not stutter. *Journal of Speech, Language, and Hearing Science, 60*, 2792–2807.

Sasisekaran, J., & Byrd, C. (2013). Nonword repetition and phoneme elision skills in school-age children who do and do not stutter. *International Journal of Language & Communication Disorders, 48*, 625–639.

Smith, A., & Weber, C. (2017). How stuttering develops: The multifactorial dynamic pathways theory. *Journal of Speech Language and Hearing Research, 60*(9), 2483–2505.

Smith, A., Goffman, L., Sasisekaran, J., & Weber-Fox, C. (2012). Language and motor abilities of preschool children who stutter: Evidence from behavioral and kinematic indices of nonword repetition performance. *Journal of Fluency Disorders, 37*, 344–358.

Sonuga-Barke, E. J. S., Koerting, J., Smith, E., McCann, D. C., & Thompson, M. (2011). Early detection and intervention for attention-deficit/hyperactivity disorder. *Expert Review of Neurotherapeutics, 11*, 557–563.

Spencer, C., & Weber-Fox, C. (2014). Preschool speech articulation and nonword repetition abilities may help predict eventual recovery or persistence of stuttering. *Journal of Fluency Disorders, 41*, 32–46.

Stefanatos, G. A., & Baron, I. S. (2007). Attention-deficit/hyperactivity disorder: A neuropsychological perspective towards DSM-V. *Neuropsychology Review, 17*, 5–38.

Strayer, D. L., & Drews, F. A. (2007). Attention. In F. T. Durso (Ed.), *Handbook of applied cognition* (2nd edition). West Sussex UK: John Wiley & Sons, Ltd.

Weber-Fox, C., Spruill, J. E., III, Spencer, R., & Smith, A. (2008). Atypical neural functions underlying phonological processing and silent rehearsal in children who stutter. *Developmental Science, 11*, 321–337.

Williams, K. T. (2007). *Expressive vocabulary test – Second edition (EVT-2)*. Minneapolis, MN: Pearson, Inc.

Yairi, E., & Ambrose, N. G. (2005). *Early childhood stuttering: For clinicians by clinicians*. Austin, TX: Pro-Ed.

Yairi, E., Ambrose, N., & Cox, N. (1996). Genetics of stuttering: A critical review. *Journal of Speech Language and Hearing Research, 39*, 771–784.

Yang, H., & Gray, S. (2017). Executive function in preschoolers with primary language impairment. *Journal of Speech Language and Hearing Research, 60*, 379–392.

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