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Novel Word Recognition in Childhood Stuttering

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Language skills have long been posited to be a factor contributing to developmental stuttering. The current study aimed to evaluate whether novel word recognition, a critical skill for language development, differentiated children who stutter from children who do not stutter. Twenty children who stutter and 18 children who do not stutter, aged 3–8 years, completed a novel word recognition task. Real-time eye gaze was used to evaluate online learning. Retention was measured immediately and after a 1-hr delay. Children who stutter and children who do not stutter exhibited similar patterns of online novel word recognition. Both groups also had comparable retention accuracy. Together, these results revealed that novel word recognition and retention were similar in children who stutter and children who do not stutter. These patterns suggest that differences observed in previous studies of language in stuttering may not be driven by novel word recognition abilities in children who stutter. **Key words:** *children*, *declarative memory*, *eye gaze*, *language*, *learning*, *nonwords*, *stuttering*, *word learning*

STUTTERING is a neurodevelopmental disorder characterized by disruptions in the forward flow of speech, marked by sound, part-word, and monosyllabic whole-word repetitions, sound prolongations, and blocks of sound. Approximately 5% of preschool children stutter, with stuttering onset between 2 and 5 years of age in most children (Bloodstein et al., 2021; Yairi & Ambrose, 2013). Stuttering is posited to result from interactions between a vulnerable speech motor system and a child's language, cognitive, emotional, and environmental factors (Smith & Weber, 2017). Approximately 80% of children recover naturally from stuttering, with or without treatment, whereas approximately 20% persist into adulthood (Bloodstein et al., 2021). Persistence of stuttering is associated with negative impact on quality of life (e.g., Tichenor & Yaruss, 2019; Yaruss, 2007).

Atypical language abilities, including phonological processing, semantics, and syntax, are posited to play a role in stuttering (e.g., Anderson & Conture, 2004; Gerwin et al., 2019; Luckman et al., 2020). Theories of stuttering (Smith & Weber, 2017), supported by behavioral and neurophysiological

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evidence (e.g., Hakim & Bernstein Ratner, 2004; Weber-Fox et al., 2013), suggest that language abilities play an important role in stuttering development as well as persistence or recovery from stuttering (e.g., Gerwin & Weber, 2020; Hampton Wray & Spray, 2020). Children who stutter with stronger or more mature language abilities may be better able to compensate for unstable speech motor networks, supporting the development of more stable speech motor control over time and eventual recovery from stuttering (Smith & Weber, 2017).

However, empirical studies of language skills in children who stutter have yielded inconsistent results. Despite inconsistencies, many studies have identified differences in language abilities in children who stutter (for review, see Bloodstein et al., 2021, and Brundage & Bernstein Ratner, 2022). It is currently unclear whether language differences in children who stutter may result from ineffective language processes, which could arise from ineffective language learning, ineffective access to acquired linguistic information, such as semantic content, syntactic structures, or phonological representation, inefficient translation from linguistic plan to motor plan, or potentially from atypical function in language-related cognitive processes, such as attention or working memory (e.g., Levelt et al., 1999; Roelofs, 2008; Roelofs & Piai, 2011). One way to differentiate these skills is to evaluate specific aspects of language acquisition, such as novel word recognition.

The declarative/procedural model, a prominent theory of language learning, proposes a two-part system for language learning (Ullman, 2001, 2004; Ullman et al., 1997). Declarative memory is important for the learning and maintenance of lexical items, facts, and events, and relies primarily on the medial temporal lobe. To date, brain regions associated with declarative memory in children who stutter have received limited attention in the literature. Procedural memory is important for the learning and maintenance of sequences, morphosyntactic information, categories, motor skills, cognitive skills, and habits, and engages the basal ganglia and frontal cortex. Brain regions associated with procedural memory have been shown to differ between children who stutter and children who do not stutter, including reduced structural and functional connectivity in cortico-basal ganglia–thalamocortical loop (e.g., Chang & Guenther, 2020; Chang & Zhu, 2013).

DECLARATIVE MEMORY IN STUTTERING

The declarative/procedural model was previously applied to stuttering in a study of the production of regular and irregular past tense verbs by children who stutter in spontaneous language samples (Bauman et al., 2012). Verb use did not differ between children who stutter and fluent peers. However, children who stutter tended to produce atypical irregular verb patterns, specifically double-marking irregular past tense verbs (e.g., ranned) and increased use of irregular past tense verbs, compared to children who do not stutter, although these were low frequency patterns in each group. These findings may suggest overreliance on declarative memory in children who stutter and/or inefficient selection or use of both systems. However, more direct evaluations of declarative memory are needed to understand these systems in children who stutter.

Inefficient use of declarative memory systems in developmental stuttering may also be indicated by differences in neural processes for unfamiliar, novel, or nonword stimuli in children who eventually persist in stuttering compared to children who eventually recover and children who do not stutter. This is supported by a series of studies that performed retrospective analyses of data from 5-years-olds, when all children who stutter were stuttering (Gerwin & Weber, 2020; Hampton Wray & Spray, 2020). Findings revealed that children who eventually persisted in stuttering exhibited less mature nonword rhyme processing compared to children who eventually recovered and children who do not stutter (Hampton Wray & Spray, 2020). Importantly, when semantic context was available to support the declarative memory system, children who eventually persisted in stuttering exhibited comparable rhyme processing to children who eventually recovered and children who do not stutter (Gerwin & Weber, 2020).

Studies of word learning allow for evaluation of declarative memory systems. Vocabulary size increases with age (e.g., Uccelli & Rowe, 2016), and larger vocabulary size is associated with stronger language skills and greater academic achievement (e.g., Bleses et al., 2016; Marchman & Fernald, 2008; Morgan et al., 2015). Further, children who stutter have been found to have weaker receptive and expressive vocabulary compared to children who do not stutter (e.g., Choo et al., 2016; Luckman et al., 2020; cf. Millager et al., 2014; Singer et al., 2020), which may have implications for language formulation and fluent speech production (e.g., Smith & Weber, 2017). One common experimental approach to studying word learning is to teach novel words through fast mapping (e.g., Bion et al., 2013; Carey, 1978; Kucker et al., 2015). Fast mapping involves teaching and learning novel word and object pairs through minimal exposures and can provide a measure of real-time novel word recognition, one aspect of word learning.

The looking-while-listening procedure (visual world paradigm; Fernald et al., 2008; also see Huettig et al., 2011; McMurray et al., 2010) uses eye-gaze measures to assess language processing, including fast mapping and real-time novel word recognition. Typical looking-while-listening tasks involve children completing a series of teaching trials where they are presented with unfamiliar objects paired with corresponding novel word labels (e.g., Bion et al., 2013; Venker, 2019). On the subsequent test trials, two of the previously named trained objects are presented, and the child is asked to find one of the objects. Looking toward the correct (named) versus incorrect (unnamed) object provides an indication of the child's novel word recognition. Eye-gaze patterns acquired online, during the task, provide real-time measures of accuracy and speed of recognition, an indication of cognitive–linguistic processes (Key et al., 2020; Venker & Kover, 2015).

Given the ongoing theoretical discussions of whether speech disfluencies in stuttering arise from difficulties in language processing and/or speech motor control (e.g., Bernstein Ratner, 1997; Smith & Weber, 2017; Walden et al., 2012), acquiring information about language processing in the absence of overt speech is an important step toward differentiating these skills. Eye-gaze methods allow for the evaluation of real-time learning without requiring overt speech (Key et al., 2020; Venker & Kover, 2015), making eye gaze a strong methodology for investigating language processing, and specific to this study, novel word recognition, in individuals who stutter. Novel word recognition and retention can also be assessed by immediate and delayed recall of novel words (e.g., Adlof & Patten, 2017; Gordon et al., 2016; Walker & McGregor, 2013).

Although novel word recognition has received minimal attention in stuttering, many studies have evaluated the immediate repetition of nonwords, a task that relies on phonological working memory (e.g., Baddeley, 2003), in children who stutter (e.g., Hakim & Bernstein Ratner, 2004; Ofoe et al., 2018). Multiple studies have revealed that children who stutter perform less accurately on nonword repetition tasks than children who do not stutter (e.g., Hakim & Bernstein Ratner, 2004; Ofoe et al., 2018). However, studies with different age groups, especially older children, or with variations in the repetition task reported no group differences (e.g., Sasisekaran & Byrd, 2013; Weber-Fox et al., 2008). Despite some differences in results, these overall patterns may suggest that children who stutter are less accurate on nonword repetition tasks than children who do not stutter. Importantly, nonword repetition skills have been associated with novel word recognition performance; both tasks require encoding and retention of novel phonological segments (e.g., Gathercole, 2006; Metsala, 1999), skills that have been posited to be weaker in children who stutter compared to children who do not stutter. Together, theories of stuttering with previous studies suggest that children who stutter may have less effective novel word recognition than children who do not stutter, which could have cascading effects for language processing and speech production.

THE CURRENT STUDY

Grounded in the declarative/procedural model of learning, the current study aims to evaluate whether aspects of declarative memory, as measured by novel word recognition, differ in children who stutter compared to children who do not stutter (aged 3–8 years). Novel word recognition was evaluated using real-time measures of eye gaze as well as immediate and delayed retention during a novel word recognition task. Based on previous findings (e.g., Hakim & Bernstein Ratner, 2004; Luckman et al., 2020), we hypothesized that children who stutter would demonstrate slower real-time novel word recognition and reduced accuracy and retention of novel words compared to children who do not stutter.

METHODS

Participants

Participants included 38 children aged 3–8 years: 20 children who stutter (mean age (*SD*) = 5.84 (1.2); 10 females) and 18 children who do not stutter (mean age (*SD*) = 5.77 (1.37); 6 females). Groups were matched for age, $t_{(36)} = 0.17$, $p = .87$. Family characteristics were evaluated using consensus measures (Pollak & Wolfe, 2020) of parent education and occupation levels, household income, and marital status. Maternal and paternal education were coded as years of education completed, adapted from a consensus measure (Pollak & Wolfe, 2020) as follows: some high school = 10; completed high school = 12; partial college = 13; 2-year degree = 14; standard college/bachelor's degree = 16; and graduate school or professional degree = 18. Parent occupation scores were calculated based on the Occupation Information Network (O*NET) Job Zones (1–5; National Center for O*NET Development, 2021). Household income was coded in bins based on total annual income for all earners.[1] All families reported marital status of married except one family of a child who stutters reported divorced status. Group means are included in Table 1. There were no differences between groups in maternal education, $t_{(31.96)} = -1.06$, $p = .30$, maternal occupation, $t_{(28)} = -1.66$, $p = .11$, or household income, $t_{(36)} = -1.06$, $p = .3$. Paternal education, $t_{(32.78)} = -3.24$, $p = .003$, and paternal occupation, $t_{(35)} = -2.63$, $p = .01$, were higher in children who do not stutter than in children who stutter.

Per parent/caregiver report, all participants were monolingual native English speakers with normal hearing, normal or corrected-to-normal vision, and no history of developmental or acquired disorders, except stuttering for children who stutter. Caregivers reported 19 children who stutter as White and one as more than one race, 17 children who do not stutter as White, and one as more than one race. One child who stutters and two children who do not stutter reported as Hispanic/Latino, with 16 children who stutter and 16 children who do not stutter reported as not Hispanic/Latino. Ethnicity was not reported for three children who stutter. Caregivers reported a family history of stuttering for 14 children who stutter and one child who does not stutter. One child who stutters and three children who do not stutter were reported to have mild language delay in early childhood. Importantly, all children performed within the normal range on language

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[1] 1 = $0–$10,000; 2 = $10,000–$25,000; 3 = $25,000–$40,000; 4 = $40,000–$55,000; 5 = $55,000–$70,000; 6 = $70,000–$85,000; 7 = $85,000–$95,000; 8 = $95,000–$105,000; 9 = $105,000–$150,000; 10 = $150,000–$250,000; 11 = over $250,000; 12 = prefer not to answer; and 13 = unknown

Table 1. Mean and standard deviations from speech–language testing[a]

	Children who stutter	Children who do not stutter
Age	5.84 (1.2)	5.77 (1.37)
Maternal education	16 (2.18)	16.61 (1.34)
Maternal occupation	3.71 (0.99)	4.25 (0.78)
Paternal education	14.3 (2.45)	16.44 (1.58)
Paternal occupation	3.05 (0.91)	3.89 (1.02)
Household income	6.25 (2.22)	7 (2.11)
CELF-Core Language	111.15 (13.16)	112.39 (15.07)
BBTOP-WI	92.85 (13.36)	92.17 (15.47)
BBTOP-CI	93.2 (10.33)	93.89 (13.69)
BBTOP-PPI	95.40 (12.95)	93.11 (15.22)
One-syllable NWR	0.88 (0.11)	0.9 (0.1)
Two-syllable NWR*	0.91 (0.07)	0.96 (0.06)
Three-syllable NWR	0.81 (0.17)	0.87 (0.18)
Four-syllable NWR	0.69 (0.17)	0.72 (0.2)
Total NWR	0.79 (0.12)	0.84 (0.13)

Note. BBTOP-CI = Bankson Bernthal Test of Phonology Consonant Inventory; BBTOP-PPI = Bankson Bernthal Test of Phonology Phonological Processes Inventory; BBTOP-WI = Bankson Bernthal Test of Phonology Word Inventory; CELF = Clinical Evaluation of Language Fundamentals, Fifth Edition, or Clinical Evaluation of Language Fundamentals—Preschool, Second Edition; NWR = Nonword Repetition Task from Dollaghan and Campbell (1985).

[a] No group differences were observed for any measure except for accuracy on the two-syllable nonwords on the nonword repetition task, paternal education, and paternal occupation.

*$p < .05$.

assessments at the time of testing (see below). Children completed an abbreviated version of the Edinburgh Handedness Inventory (Oldfield, 1971) and all children were right-handed except one left-handed child who does not stutter, three ambidextrous children who stutter, and one ambidextrous child who does not stutter. Children who stutter were classified as such based on parent report of stuttering and a stuttering severity rating score of at least very mild on the Stuttering Severity Instrument, Fourth Edition (SSI-4; Riley, 2009). Participants were recruited from the local community, speech–language clinics, and physicians' offices. This study was approved by the Michigan State University Institutional Review Board, and parents/caregivers provided written consent for their child's participation. Families were compensated for their participation and children also received a small toy.

A battery of behavioral assessments was administered to ensure speech and language abilities within the normal range. See Table 1 for descriptive information. Receptive and expressive language abilities were assessed via the Core Language Index of the Clinical Evaluation of Language Fundamentals—Preschool, Second Edition (Wiig et al., 2004) or the Clinical Evaluation of Language Fundamentals, Fifth Edition (Wiig et al., 2013), depending on child age at time of testing. The Bankson Bernthal Test of Phonology (BBTOP; Bankson & Bernthal, 1990) was administered to assess articulation and phonology skills. Children who stutter and children who do not stutter exhibited comparable receptive and expressive language abilities ($t_{(36)} = -0.27, p = .79$) as well as comparable performance on the Word Inventory ($t_{(36)} = 0.15, p = .89$), Consonant Inventory ($t_{(36)} = -0.18, p = .86$), and Phonological Processes Inventory ($t_{(36)} = 0.5$, $p = .62$) on the BBTOP.

Children also completed a nonword repetition test during which they heard a nonword and were asked to immediately repeat each word (Dollaghan & Campbell, 1998). Four words were presented at each syllable level: one-, two-, three-, and four-syllable nonwords. Responses were scored offline, and accuracy (%) was based on total phonemes produced correctly. Scores were not included for one child who does not stutter because the child's speech was unclear during the task. Due to violations of normality in outcome variables, Mann–Whitney U tests were conducted to evaluate accuracy. For two-syllable nonwords, children who do not stutter performed significantly more accurately than children who stutter ($U = 98.5$, $p = .02$). No significant group differences were found for one-syllable ($U = 152, p = .59$), three-syllable ($U = 121, p = .14$), or four-syllable nonwords ($U = 147.5$, $p = .5$), or for the total accuracy score ($U = 124, p = .17$).

Procedure

After introductions and consent, children were seated in a soundproof booth in front of a 55-inch television screen to complete the novel word recognition task. A video camera located under the screen was used to record children's eye movements during teaching and testing trials of the novel word recognition task. The walls of the booth were draped with black cloth. Children could sit either on their parent's lap or on a booster seat. If a child sat on their parent's lap, parents were asked to wear glasses with darkened lenses to help ensure they would not influence their children's performance in the task. Immediately after completing the novel word recognition task, children completed the immediate retention measures. The expressive task was administered first. Next, children completed the recognition task. After the novel word recognition task and immediate retention testing, children completed a battery of language and executive function tasks. One hour after children completed the novel word recognition task, all children repeated the expressive and recognition retention testing (the same tasks as the immediate retention testing). The immediate and delayed expressive and recognition retention testing measures were added to the protocol shortly after data acquisition began. Therefore, retention task responses were not collected from five children who stutter and two children who do not stutter. Retention task analyses include 15 children who stutter and 16 children who do not stutter.

Novel word recognition paradigm and retention measures

Stimuli

The novel word recognition task included six novel words: two two-syllable, two three-syllable, and two four-syllable nonwords. The two-syllable novel words—"blicket" and "gazzer"—were chosen from the Novel Object and Unusual Name (NOUN) Database (Horst & Hout, 2016). The three-syllable and four-syllable novel words—"barrazon," "skiticult," "fenneriser," and "perplisteronk"—were selected from the Children's Test of Nonword Repetition (Gathercole et al., 1994). In the teaching trials, each novel word was paired with the image of an unfamiliar object (Figure 1), derived from the NOUN Database (Horst & Hout, 2016). Auditory stimuli were recorded by a female native English speaker with a neutral American accent. Each teaching trial presented the novel word label three times ("Look, it's a [novel word]. A [same novel word]. What a cool [same novel word])." In the test trials, children saw two of the previously labeled objects, one of which was named ("Where's the [target novel word]? Can you find the [same target novel word]?"). An example of the stimuli for teaching and testing is illustrated in Figure 1. Thus, accurate identification of the named object during the eye-gaze task required that children differentiate the target object from a distracter object that had been previously labeled during the teaching phase. Retention measures of the novel word–object pairs were administered offline immediately after the novel word recognition task (immediate) and 1 hr after completion of the novel word recognition task (delayed).

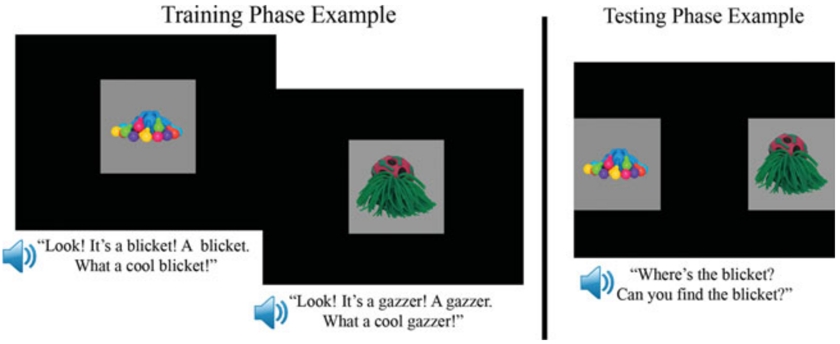

Figure 1. Example of training (left) and test conditions (right) for the eye-gaze novel word learning task. This figure is available in color online (www.topicsinlanguagedisorders.com).

Task design

For the novel word recognition task, children were instructed to sit and watch the video. They were told that the video would ask them questions and to answer the questions with their eyes by looking at the answer, and not to point or say the answer out loud. The novel word recognition task was presented using the E-Prime 3.0 software (Psychology Software Tools, Inc., 2016). Auditory stimuli were presented via a central free field speaker at ~62 dB HL (± 3 dB). Aligned with standard procedures for this task, brief, attention-grabbing, musical video clips were played intermittently (i.e., every three teaching trials and after each testing phase) to reduce repetitiveness and maximize child engagement in and attention to the task (Fernald et al., 2008; Venker & Kover, 2015).

The teaching phase was presented first, with all six novel words taught during the teaching phase. Each teaching trial was ~6600 ms and consisted of simultaneous presentation of the novel image and the teaching carrier phrase (Figure 1, left), during which children heard the target word three times (see above). The complete teaching phase included six teaching trials. Each of the six novel words was taught one time during the teaching phase and was pseudo-randomly presented, such that novel words of the same syllable length were not immediately repeated after each other.

Following teaching trials, children completed the testing phase, consisting of six testing trials. Each testing trial was 7300 ms and began with ~850 ms during which images of two of the trained novel objects were presented on the left and right sides of the screen (Figure 1, right). The target object was displayed on one side, with a distracter object displayed on the other. The distracter was always a previously labeled object, with the same syllable length label as the target word. At 850 ms into the trial, the testing trial audio began, with the onset of the first target novel word at 1889 ms post-trial onset. All six target words were tested in a pseudo-random order, such that no novel objects of the same syllable length were presented in consecutive trials. Children then repeated the entire task (i.e., a second complete set of the teaching and testing phases). Only data from the initial testing phase are included in this study.

The aim of this study was to evaluate novel word recognition in a way that is aligned with nonword repetition tasks. Therefore, we analyzed eye gaze during the first testing phase only. The second set of novel word recognition teaching and testing phases was included to increase the likelihood that children would learn the words well enough to produce them on the expressive retention tasks. However, even with additional exposures to each novel word during the second set of teaching and testing trials, expressive performance was low.

Two task presentation orders were created that counterbalanced the order and visual layout of novel words during the teaching, testing, and retention phases. For example, if the target image was on the left side of the screen for version A, it was on the right side for version B. The novel objects and corresponding novel word pairs were also different for version A and version B. Ten children who stutter completed version A and 10 completed version B. Six children who do not stutter completed version A and 12 completed version B. There were no significant differences between versions for performance in the eye-gaze testing task ($t_{(27.78)} = -0.32, p = .75$), the immediate expressive or recognition retention tasks ($t_{(29)} = 0.2$, $p = .84$; $t_{(29)} = -0.78$, $p = .44$), or the delayed expressive or recognition retention tasks ($t_{(29)} = -0.48, p = 64$; $t_{(29)} = 0.09$, $p = .93$). Thus, data from the two versions were combined.

For both the immediate and delayed expressive retention measures, children saw pictures of each novel object and were asked to name it. For both the immediate and delayed recognition retention tasks, children saw two images of novel objects and were asked to point to the target object. The two images always included the target novel object and the other novel object with the same syllable length, similar to the testing trials during the novel word recognition task.

Eye-gaze coding

Eye movements during the testing trials of the video task were coded offline by trained research assistants. Research assistants were blind to participant group and received no information regarding correct target trial during coding (Fernald et al., 2008). Eye movements were coded every 33 ms using custom coding software, consistent with the sampling rate of the video file. Each frame was coded as "left" if the child looked at the image on the left side of the screen, "right" if the child looked at the image on the right side of the screen, "off" if the child was switching or shifting between fixations, or "away" if the child was looking away from the screen, such as at the floor or ceiling. Ten videos, five from children who stutter and five from children who do not stutter, were randomly selected and recoded by a second trained research assistant. The average frame accuracy agreement (i.e., the proportion of frames that the two research assistants coded similarly) was 99%, and the average shift agreement (i.e., the proportion of shifts in the frames that the two research assistants coded similarly) was 98%, indicating high intercoder reliability. Time frames in which children were not fixating on either image were classified as missing data. Trials were then averaged across each subject and used for data analysis.

Statistical analyses

Eye-gaze task

The proportion of time looking to the target image from 300 to 1800 ms after the onset of the first novel word for each testing trial was analyzed using growth curve analysis (Barr, 2008; Fernald et al., 2008; Mirman, 2014; Oleson et al., 2017). Growth curve analysis uses orthogonal polynomial time terms to capture distinct functional forms of the proportion looking to target over time. The intercept term measures the overall proportion of time looking at the target (Mirman, 2014). The linear term (ot1) reflects the steepness (slope) of the change in eye gaze over time (Kuchinsky et al., 2014) and indicates the speed of learning. The quadratic term (ot2) measures the rate of change of eye gaze over time around a central inflection point (Kuchinsky et al., 2014). To examine differences in learning between children who stutter and children who do not stutter, a growth curve analysis model was fit to model interactions between the intercept, first- (ot1) and second-order (ot2) orthogonal polynomials with group (children who stutter vs. children who do not stutter), which provided a better model fit by the analysis of variance function and lower Akaike information criterion (AIC) and Bayesian information criterion (BIC) than including only the first-order

Table 2. Full growth curve analysis model results

Fixed effects	**Estimate**	***SE***	***t***	***p***
Intercept	0.64	0.04	16.64	<.001
Linear time	0.41	0.13	3.06	<.01
Quadratic time	– 0.04	0.11	– 0.34	.74
Intercept × group (children who do not stutter)	– 0.05	0.05	– 0.96	.34
Linear time × group (children who do not stutter)	0.18	0.18	0.98	.33
Quadratic time × group (children who do not stutter)	0.05	0.16	0.32	.75

Note. The reference group was children who do not stutter.

polynomial ($X^2(5) = 707.72, p < .001$; $\mathrm{AIC}_{\mathrm{M1}} = -2295.8$; $\mathrm{AIC}_{\mathrm{M2}} = -2993.5$; $\mathrm{BIC}_{\mathrm{M1}} = -2252.0$; $\mathrm{BIC}_{\mathrm{M2}} = -2922.4$; McHaney et al., 2021; Morett et al., 2020). The best fitting model included fixed effects of group (reference = children who do not stutter) on the linear and quadratic terms with random slopes of participants on the linear and quadratic terms.[2] Growth curve analysis was implemented using the lme4 package (Bates et al., 2015) in R (version 3.5.3; R Core Team, 2019) with log-likelihood maximization using the BOBYQA optimizer to promote convergence (Mirman, 2014), and *p* values were estimated using the lmerTest package (Kuznetsova et al., 2017).

Retention tasks

Accuracy on the immediate and delayed expressive retention tasks was calculated as the total number of phonemes produced correctly over the total number of possible phonemes. For both the immediate and delayed recognition retention tasks, accuracy was calculated as the number of target objects correctly identified divided by the total number of items. Accuracy was calculated separately for immediate and delayed tasks. Mann–Whitney *U* tests were used to evaluate recognition retention accuracy due to violations of normality.

RESULTS

Online learning measured by eye gaze

The full growth curve analysis model results are shown in Table 2. The linear slope estimates of 0.406 for children who do not stutter and 0.585 for children who stutter (Table 2) indicate clear increases in proportion of looking to the target over time and suggest that both groups demonstrated learning. This is also apparent in Figure 2, which shows the proportion of looking to the target during the 300- to 1800-ms analysis time window.

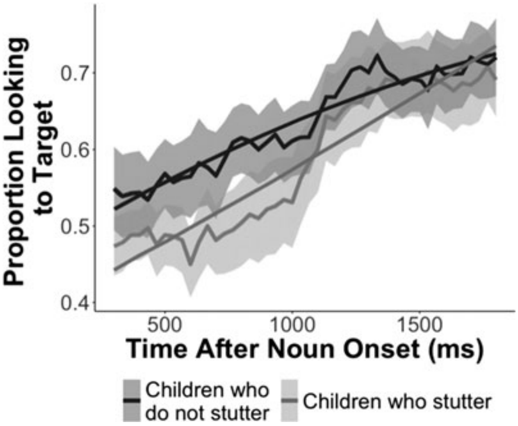

Figure 2. Proportion of looking to the correct target image during the first test phase of the eyegaze task for children who do not stutter and children who stutter. Bold line indicates mean proportion of looking at each time point, with shading indicating standard error from the mean. The proportion of looking to the target image did not significantly differ between groups.

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[2] Model = (Proportion ~ (ot1 + ot2)×Group + (ot1 + ot2|Subject), control = lmerControl (optimizer = "bobyqa"), REML = FALSE).

The growth curve analysis revealed no significant main effects of group on the intercept ($\beta = -.05$, $p = .34$), linear term ($\beta = .18$, $p = .33$), or quadratic term ($\beta = .05$, $p = .75$). These results indicate that children who stutter and children who do not stutter had a similar overall proportion of time looking toward the target word, similar rates of learning over time, and similar changes in rate of learning over time. Overall, the growth curve analysis results suggest there were no group differences for novel word recognition between children who stutter and children who do not stutter.

Novel word retention tasks

Expressive

Accuracy on the expressive retention measures was low (near floor) for both the immediate (children who stutter mean accuracy (*SD*): 24% (0.14); children who do not stutter mean accuracy (*SD*): 24% (0.17)) and 1-hr delayed retention measures (children who stutter mean accuracy (*SD*): 19% (0.12); children who do not stutter mean accuracy (*SD*): 19% (0.17)). There were no significant group differences on immediate ($t_{(29)} = 0.007, p = .99$) or delayed expressive retention testing ($t_{(29)} = 0.03, p = .97$).[3]

Recognition

Both groups of children demonstrated learning on this task, evidenced by high levels of accuracy on the immediate and delayed recognition tasks. Children who stutter (mean accuracy (*SD*) = 83% (0.21); mean rank = 14.13) and children who do not stutter (mean accuracy (*SD*) = 92% (0.15); mean rank = 17.75) performed similarly on the immediate recognition task ($U = 92$, $p = .18$) and on the delayed recognition task ($U = 107.5$, $p = .61$; children who stutter: mean accuracy (*SD*) = 82% (0.24); mean rank = 15.17; children who do not stutter: mean accuracy (*SD*) = 89% (0.17); mean rank = 16.78). Overall, no significant differences in novel word retention were observed between children who stutter and children who do not stutter.

DISCUSSION

The purpose of the current study was to evaluate novel word recognition, an aspect of declarative memory (Ullman, 2001, 2004; Ullman et al., 1997), in children who stutter compared to children who do not stutter. Novel word recognition was assessed via an online eye-gaze task as well as immediate and delayed (1-hr) retention testing. Children who stutter and children who do not stutter performed comparably on all tasks, suggesting that the aspects of the declarative memory system measured by novel word recognition are comparable in children who stutter and children who do not stutter. Despite the lack of significant group differences, children in both groups demonstrated clear evidence of novel word recognition, as evidenced by their performance on the eye-gaze task and on the immediate and delayed recognition retention measures. However, both groups of children performed poorly on the immediate and delayed expressive retention measures.

This study was the first to use a looking-while-listening task (visual world paradigm; Fernald et al., 2008; also see Huettig et al., 2011; McMurray et al., 2010) with children who stutter. Both children who stutter and children who do not stutter demonstrated learning on the task, indicated by the positive eye-gaze slope, with no differences observed between groups. During the online eye-gaze

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[3] Four children in the group of children who stutter went on to recover and stuttering status is unknown for one child. All analyses were re-run with the 15 children who eventually persisted in stuttering. All result patterns remained the same (eye-gaze measures: no main effects of group on the intercept—($\beta = -.04$, $p = .51$), linear term—($\beta = .08$, $p = .68$), or quadratic term—($\beta = -.01$, $p = .94$); expressive retention task: immediate—$t_{(24)} = 0.1, p = .92$, delayed—$t_{(24)} = -0.18, p = .86$; recognition retention task: immediate—($U = 68$, $p = .51$), delayed—($U = 78$, $p = .94$). Therefore, all children who stuttered at the time of testing were included in the analyses.

task, groups were comparable in their overall time looking at the target novel word, speed of learning, and change in rate of learning over the course of the trial. Overall, the trajectory of novel word recognition in children who stutter appears to be on par with children who do not stutter. Findings from the current study also demonstrate the feasibility of using eye-gaze tasks to measure real-time novel word recognition in children who stutter and support their use in future studies. Eye-gaze tasks are likely to be beneficial in future studies of children who stutter because they measure novel (and familiar) word recognition within a fraction of a second without the demands of overt speech (Key et al., 2020; Venker & Kover, 2015). In addition, careful design of the auditory stimuli and competitors has been fruitful in understanding the underlying factors that contribute to other neurodevelopmental disorders, including language impairment and autism spectrum disorder (e.g., Haebig et al., 2017; McMurray et al., 2019; Venker, 2019). This may also be the case in stuttering, with eye-gaze tasks having the potential to provide insights into factors that underlie stuttering, such as effects of subtle differences in task difficulty or learning behaviors under various conditions.

The current findings indicate comparable eye-gaze performance as well as similar performance on immediate and delayed measures of expressive and recognition retention in children who stutter and children who do not stutter. Although expressive retention performance was low despite efforts to increase expressive retention (i.e., repeating the teaching and testing phases), this is similar to previous studies of novel word learning in children (e.g., Adlof & Patten, 2017; Dollaghan, 1985). Importantly, both children who stutter and children who do not stutter exhibited similar performance across all measures. These patterns are consistent with previous findings that demonstrate comparable performance between children who stutter and children who do not stutter on other tasks that tap into semantic skills in a variety of ways, including standardized vocabulary assessments (e.g., Millager et al., 2014; Singer et al., 2020), picture naming (Bernstein Ratner et al., 2009), and lexical diversity in spontaneous speech (e.g., Luckman et al., 2020; Watkins et al., 1999). These findings are also aligned with electrophysiology studies that revealed generally intact neural processes for semantics in children who stutter (Kreidler et al., 2017; Usler & Weber-Fox, 2015; Weber-Fox et al., 2013). Overall, novel word recognition and retention skills appear to be intact in preschool and early school-age children who stutter and on par with their peers who do not stutter, which coincide with null findings between children who do and do not stutter in studies that investigated semantic or lexical language processes.

We hypothesized that children who stutter would perform worse on the novel word recognition task than children who do not stutter based on previous findings of reduced accuracy on nonword repetition tasks in children who stutter (e.g., Hakim & Bernstein Ratner, 2004; Ofoe et al., 2018). These tasks, which are not designed to assess learning, but instead phonological working memory, generally involve children hearing an auditory stimulus one time, then immediately repeating the nonword. However, in the current task designed to assess novel word recognition, participants heard the novel word multiple times in a row. The repetitions, along with the word–object pairing (discussed below), appear to have facilitated novel word recognition in both groups, as repeated exposure has been found to enhance learning and retention (e.g., Dye et al., 2013). The current findings suggest that the retention processes required to complete nonword repetition tasks and novel word recognition tasks may differ, and importantly, that the processes required for nonword repetition may function differently in children who stutter compared to children who do not stutter whereas those supporting novel word recognition appear comparable between groups.

An alternative explanation for the current findings may be that the current study, in which an image of the novel object was paired with the auditory novel word, created more semantic context than traditional nonword repetition tasks, where participants hear a novel word one time without a paired visual image. This may have engaged intact sematic systems in children who stutter, thereby supporting recognition and retention of the novel words. Previous studies demonstrated that children who eventually persist in stuttering exhibit brain responses comparable to peers who recover and children who do not stutter on real word rhyme tasks (Gerwin & Weber, 2020), but exhibit different neural patterns for nonword rhyme tasks (Hampton Wray & Spray, 2020). These studies suggest that stronger semantic context supports neural processing in children who stutter. Together with the current findings, these studies may suggest that when semantic systems are engaged (either by using real words or by providing visual objects for novel words), children who stutter are able to perform these language tasks in a similar way to children who do not stutter. Future studies are necessary to further differentiate the nature of semantic and phonological abilities related to novel words in children who stutter (e.g., Apfelbaum et al., 2011; McMurray et al., 2010).

Results from the current study also suggest that declarative memory is intact in children who stutter. Previous findings of similar past tense verb use in children who stutter and children who do not stutter also indicated intact declarative memory systems in children who stutter (Bauman et al., 2012). The task in the current study focused on novel word recognition, which engages different aspects of declarative memory, and found no significant differences between children who stutter and children who do not stutter. Comparable performance between children who stutter and children who do not stutter on tasks that engage the declarative memory system in various ways may indicate that this system is intact in children who stutter.

Limitations and future directions

One limitation of the current study is the wide age range in the current sample. Although all children who stutter were stuttering at the time of testing, four (out of 20) children eventually recovered from stuttering. Removing these children from analyses (see Footnote 3) did not change the results. However, future studies would benefit from extending the current findings in several ways. The novel word stimuli used in the current study were from the NOUN Database (Horst & Hout, 2016) and Children's Test of Nonword Repetition (Gathercole et al., 1994), and the current stimuli were not explicitly controlled for phonetic difficulty or complexity between words (e.g., Hakim & Bernstein Ratner, 2004; Spencer & Weber-Fox, 2014). Future studies could focus on novel words that are more closely related to one another, harder to distinguish, and/or words that are more phonologically distinct from real words (less phonotactic probability). Phonetic and phonological manipulations, resulting in increased novel word difficulty, might reveal subtle, fine-grained differences in novel word recognition, access, or processes in children who stutter. Applying these extensions to a larger group of children will further extend the current findings. Additionally, children in both groups performed poorly on the expressive retention tasks despite multiple exposures to the novel words and objects. Although this pattern of better recognition retention performance and relatively poor expressive retention performance has been observed in previous studies (e.g., Adlof & Patten, 2017; Dollaghan, 1985), future studies that include different teaching methods may improve expressive retention and provide additional insights into novel word recognition and learning in children who stutter as well as children who do not stutter.

CONCLUSION

This study evaluated novel word recognition in children who stutter compared to children who do not stutter. Using eye-gaze and behavioral retention measures, we observed that children who stutter and children who do not stutter did not differ in novel word recognition. These findings may suggest that declarative memory for language, at least as measured by novel word recognition, is intact in children who stutter.

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