ABSTRACT

Title of thesis: INCREMENTAL SENTENCE PRODUCTION IN ADULTS WHO STUTTER: EYE TRACKING WHILE SPEAKING

Kerianna D. Frederick, Master of Arts, 2018

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Previous research investigated whether adults who stutter are affected by the same lexical retrieval factors as typically fluent adults. The findings of these studies indicate that the nature of this impact may (Newman & Ratner, 2007) or may not (Hennessey, Nang, & Beilby, 2008) differ between groups. The current study investigates how lexical retrieval unfolds when words are embedded in sentences across these populations. This work used an eye tracking while speaking paradigm during an "A and B are above C" sentence task. Codability and frequency of objects "A" and "B" were manipulated. Adults who stutter and typically fluent adults showed longer gaze duration with increased B difficulty. Total looking times indicated that effects of pre-planning varied with difficulty of A only in typically fluent adults. This suggests that word-level production interacts with sentence-level production. Pre-planning strategies may be less flexible among adults who do stutter than typically fluent adults.

INCREMENTAL SENTENCE PRODUCTION IN ADULTS WHO STUTTER: EYE TRACKING WHILE SPEAKING

By

Kerianna Frederick

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1. Introduction

Producing fluent, meaningful speech requires coordinating multiple cognitive, speech, and language systems. Interactions between the motor, single-word, and sentence levels impact the fluency and timing of speech signals. Problems across levels can disrupt speech output. Understanding these interactions may shed light on childhood-onset fluency disorder, which is characterized by abnormal breaks in fluency during real-time speech production and occurs in approximately 1% of the adult population (Chang, 2011; Büchel & Sommer, 2004). Models of stuttering indicate that stuttering results from genetic, motor, cognitive, and linguistic variables and is shaped by a person's experience with stuttering (Smith & Weber, 2017). Compared to typically fluent adults, adults who stutter show reduced coordination in speech movements with increased task difficulty (Klinow & Smith, 2000, 2006; Smith, Sadagopan, Walsh & Weber-Fox, 2010). For example, when sentences increase in length, lip-aperture measurements become more erratic in adults who stutter (Klinow & Smith, 2000 see also Klinow & Smith, 2006). At the single-word level, word frequency may impact lexical retrieval in adults who stutter differently than typically fluent adults (Newman & Ratner, 2007; Hennessey, Nang, & Beilby, 2008). Across sentence-production tasks, adults who stutter show longer response times than typically fluent adults (Logan, 2000; Tsiamtsiouris & Cairns, 2009, 2013). Together, research indicates that stuttering impacts multiple levels of the speech production system.

Critically, current research does not address how demands of producing single words and sentences interact in real time for adults who stutter and how this may differ from typically fluent adults. This distinction is critical since sentences are basic units for conveying thought during communication. Since sentences are comprised of words, properties of early-arriving words are likely to impact production of later ones. In the remainder of the Introduction, we will describe past research on the production of single words and sentences in adults who stutter. Next, we will discuss why current measures are insufficient for investigating interactions between producing single words and words in sentences. Finally, we will introduce the current study, which uses an eye-tracking while speaking paradigm to investigate how word production impacts sentence-level production. By comparing real-time production in adults who stutter and typically fluent adults, this work isolates the extent to which distinctions in planning strategies contribute to impairments in producing fluent speech.

1.1 Challenges at the single word level

A common measure of single-word production level is reaction time, which assesses the time between stimulus presentation and speech onset. When a word is more difficult to retrieve, additional processing is required before it can be articulated (Szekely et al., 2005). When asked to read a single word as quickly as possible (e.g., a word like *house*), comparisons of reaction times in adults who stutter and typically fluent adults show inconsistency. Some work shows longer reaction times in adults who stutter, indicating that they experience more difficulty than typically fluent adults (Walla, Mayer, Deecke & Thurner, 2004). However, other studies show no difference between groups (Salmelin, Schnitzlert, Schmitzt & Freund, 2000). Moreover, when response time are measured in a simple picture naming task (e.g., a picture of a *tiger*), no significant differences were found between adults who stutter and typically fluent adults (Hennessey, Nang, & Beilby, 2008). Overall, data from reaction times show inconsistent results across naming and reading tasks and fail to isolate possible sources of variation in single-word production among adults who stutter.

One reason why reaction times may not reliably track single-word performance is that word retrieval can be impacted by several factors, including word frequency and phonological neighborhood density. Frequency refers to how often a person is exposed to a word in their environment, with more frequent words making retrieval easier (Jescheniak & Levelt, 1994). The density of phonological neighborhood refers to the number of phonologically similar terms in the mental lexicon, with greater density leading to longer response times but increased accuracy in naming (Luce & Pisoni, 1988). Early work indicated that frequency may impact speech initiation time in adults who stutter more profoundly than typically fluent adults (Prins, Main & Wampler, 1997). However, recent work shows that changes in frequency lead to similar changes in reaction time during a naming task, suggesting consistent effects between adults who stutter and typically fluent adults (Hennessey, Nang, & Beilby, 2008). However, naming accuracy also provides insight into lexical-retrieval effects on speech output. Unlike response-time measures, naming accuracy takes into account the possibility that quick responses are not always correct. Unlike typically fluent adults, adults who stutter display a significant decrease in naming accuracy on infrequent words (Newman & Ratner, 2007). This suggests that while timing may not be impacted by word frequency, the precision of retrieval is. Adults who stutter may sacrifice producing the correct word in favor of a quick response. Overall, prior patterns indicate that even when response times are unaffected, adults who stutter may engage in lexical retrieval differently than typically fluent adults. Nevertheless, it remains unclear how these effects may unfold when words are embedded in more functional units of communication.

1.2 Challenges at the sentence level

Since communication requires producing sequences of words, investigating sentence-level dynamics is imperative for understanding challenges faced by adults who stutter. However, increasing syntactic demands alone does not appear to increase disfluencies in adults who stutter. When transcripts of conversational tasks were analyzed for utterance length, complexity, and fluency, no correlation was seen among factors (Logan, 2001). This suggests that changes in linguistic load, such as increasing syntactic complexity, do not lead to additional breakdowns in speech fluency in adults who stutter.

However, when performing oral reading of sentences, adults who stutter did reveal longer sentence initiation times than typically fluent adults, both in baseline (e.g., *the hotel was near the train station*) and more complex (e.g., *the hotel that just opened was near the train station*) sentence conditions (Logan, 2003). Moreover, this difference remained steady across baseline and complex sentences rather than increasing with sentence complexity, and effects were only present in speech initiation. However, in tasks that required memorization and repetition of sentences, a significant impact of syntactic complexity was found on response times in adults who stutter (Tsiamtsiouris & Cairns, 2009). Even when only fluent utterances were counted, more complex sentences led to longer speech initiation times compared to less complex sentences and times were slower than those of typically fluent adults (Tsiamtsiouris & Cairns, 2009). Thus, when required to remember and generate a sentence, adults who stutter may experience more difficulty than typically fluent adults. However, it is unclear if this is due to the demands of sentence syntax or if it reflects challenges associated with retrieving multiple words during sentence production.

Investigating speech-motor stability provides additional information regarding effects of sentence demands on sentence-level production. These studies have demonstrated that increased language formulation negatively impacts the motor stability of adults who stutter (Kleinow & Smith, 2000, 2006). In lip-aperture measurements, motor stability decreases when comparing patterns from baseline sentences (*buy Bobby a puppy*) to longer sentences *(They asked us to buy Bobby a puppy this week)* (Klienow & Smith, 2000, 2006). This indicates that the demands of producing a more complex sentence may differentially impact adults who stutter and typically fluent adults. Together, results from single-word and sentence-level tasks indicate that there are differences in how adults who stutter produce language even when there are no clear deficits in the language system. What remains unclear is the extent to which this arises from the motor, syntactic, or lexical demands of producing sentences. Moreover, since most studies rely on speech output (e.g., latency to speak, response time), they are unable to provide information on the types of strategies that may be being utilized during speech planning or be the cause of delays in production.

1.3 Remaining questions

During sentence production, word retrieval may happen incrementally, leading to little pre-planning of late-occurring words. Conversely, larger elements of sentences may be pre-planned, causing early retrieval of late elements (see Griffin, 2001 for information on typically fluent adults). Strategies for planning sentences may also be determined by word properties, with more difficult words causing decreases in planning due to the increased cognitive load needed for retrieval. Measures of response time provide limited insights into these questions since they give information only at one specific time point during speech production rather than assessing how speech production unfolds over time. This leads to a lack of knowledge about the strategies and processes that occur during speech planning. In order to investigate how single-word and sentence-level processes interact, we must adopt measures that give continuous fine-grained data throughout the entirety of the speech production.

One way of isolating incremental sentence formation is eye tracking while speaking. In a typical experiment, visual information is presented on a computer screen, and participants are asked to produce speech accordingly. A camera tracks fixation patterns before, during, and after speech production (Griffin, 2001). Typically fluent speakers fixate on an object long enough to retrieve its name (Meyer, Sleidernick & Levelt, 1998), providing a measure that tracks the ease of retrieving an object label. One factor that impacts lexical retrieval is an object's codability, which refers to the number of competing labels in the mental lexicon. This is related to naming agreement, and more competitors makes retrieval more difficult (Lachman, 1973). Objects that are ambiguous (i.e., a *bug* could be called a *beetle*, *bug*, or *insect*) are less codable than objects with fewer possible labels (i.e., a *clock* is always labeled as a *clock*). Since it takes less time to retrieve more codable objects, speakers will look longer at a less codable object before initiating speech (Griffin, 2001). Similarly, words that are more frequent (e.g.., *house*) will show faster retrieval times and shorter gaze duration than words that are less frequent (e.g., *footman*).

In addition, eye tracking allows for constant gathering of data throughout production of a sentence. In typically fluent adults, Griffin (2001) demonstrated frequency and codability effects when planning a complex sentence frame such "*A and B are above C*." Regardless of object position, lower codability and lower frequency resulted in longer eye gaze prior to naming of the object and longer speech onset times. However, when item B or C is lower frequency and codability, these effects only emerged after item A had already been named. This indicates that typical speakers did not fully plan out late-occurring labels prior to articulation of early-occurring components. Additionally, this study found that typically fluent adults moved their eyes to the next object prior to competing articulation of earlier objects, suggesting that once the motor plan was initiated, processing of the next object begins. Critically, this indicates that while initial retrieval of first word forms (item A) occurred prior to production, subsequent portions of utterances (item B and C) were formulated incrementally as the speaker was articulating earlier-occurring words. This study demonstrated that incremental language formulation leads to parallel language planning and retrieval, requiring precise allocation of cognitive resources in order to facilitate fluent speech.

1.4 Current Study

Previous research in typically fluent adults provides a method for investigating how speech planning and lexical retrieval interact during sentence production in adults who stutter. Specifically, the current study manipulates factors associated with lexical retrieval (codability and frequency) and compares real-time sentence production in adults who stutter and typically fluent adults. This will reveal the extent to which strategies for planning sentences may differ across the two groups. Methodologically, this study differs from traditional measures in fluency research. Unlike speech initiation or response times, eye tracking provides a measure that may be less impacted by stuttering behavior. Silent blocks cannot impact initiation of eye fixation in the same way that they may impact speech initiation time. This provides a way to confirm patterns in speech response time and circumvent inherent confounds in using speech initiation time in adults who stutter. Eye tracking also allows for continuous gathering of data throughout the entire process of sentence production, giving insight into the time course of lexical retrieval and sentence planning.

It is possible that inefficient word-form retrieval leads to differences in the time course of speech production in adults who stutter compared to typically fluent adults. This would lead to an overall larger effect from codability and frequency on speech initiation time and gaze fixation in adults who stutter compared to typically fluent adults. Thus, both groups would take a longer time to retrieve a lower codability infrequent word (e.g., *priest*) than a frequent and codable word (e.g., *car*). However, the magnitude of those effects will be larger in adults who stutter compared to typically fluent adults. Importantly, the time course of these effects may provide additional information about the increments of speech planning. If pre-planning strategies are similar in adults who stutter and typically fluent adults, both groups will fixate on the same objects during the same points in speech production. If pre-planning strategies differ, eye gaze will diverge between the two groups, indicating distinctions in how utterances are being planned prior to speech onset. In short, adults who stutter may plan out a different increment of the sentence prior to initiating speech, leading to looks to more objects prior to beginning sentence production.

2. Methods

2.1 Participants

Nine adults who stutter and nine typically fluent adults were recruited from the University of Maryland's Hearing and Speech Clinic and a private practice Avoidance Reduction Therapy program. Participants had a previous diagnosis of childhood onset fluency disorder from a licensed speech-language pathologist. They were over 18 and identified as native English speakers. Education level ranged from 13 years of education (currently seeking undergraduate degree) to 18 years of education (master's level degree). Age ranged from 18;0 to 68 (mean= 29, SD= 15). Both groups consisted of 3 females and 6 males. All participants were matched according to age, gender, and education level.

Participants were administered both an apprehension survey and an author recognition task during the experimental session. The apprehension survey (AS) was a 7-point scale created by the authors of this project intended to measure apprehension due to the computer-based task. The Author Recognition Test (ART) was used as a measure in order to ascertain if there was any significant difference between the two groups in apprehension or language abilities at baseline (Acheson, Wells, & MacDonald, 2008). No group difference was found, suggesting broadly similar language experiences.

adults who stutter	Age	Sex	Education Level	ART	AS	Therapy History
S1	18; 4	M	B.A (ip*)	16	3.7	Yes
S2	18; 0	M	B.A (ip)	9	4.7	Yes
S3	68; 4	F	B.A	34	2.7	Yes
S4	25; 8	M	B.S (ip)	18	1.7	Yes
S5	26; 7	M	B.S	13	3.4	Yes
S6	22; 4	F	B.A (ip)	19	1.8	Yes
S7	20; 7	F	B.A	26	3.5	Yes
S8	26; 7	M	M.A	13	4.4	Yes
S9	31; 7	M	M.A	15	1.5	Yes

Figure 1: demographic information of adults who stutter (*ip= in progress)

2.2 Materials

Line drawings were obtained for 34 displays. Critical trials varied the codability of objects, which occurred either in position A or B. Codability and frequency of words was based on norms in the MRC Psycholinguistic Database and the International Picture Naming Database. On each trial, pictures had high frequency and high codability (*apple, clock)* or low frequency and low codability (*footman, soldier)*. Across trials, the position of the low frequency and low codability varied in the display (i.e., one-half in position A and one half in position B). This created four critical trial types:

1. Easy A/Easy B: *The <u>circle</u> and the <u>star</u> are above the triangle*
2. Difficult A/Easy B: *The <u>soldier</u> and the <u>star</u> are above the triangle*
3. Easy A/Difficult B: *The <u>circle</u> and the <u>soldier</u> are above the triangle*
4. Difficult A/Difficult B: *The <u>footman</u> and the <u>soldier</u> are above the triangle*

To be considered high codability, words must have two or fewer alternative response listed and a single >90% percent dominant name produced according to the International Picture Naming Project (Szekely, et. al, 2005). To be considered low codability, word must have >5 alternative responses listed and a <70% dominant name produced, according to the IPNP. T-tests were run to compare frequency and naming agreement of easy/hard objects. Across items, mean differences were statistically significant between easy and hard items ($p < .05$). In addition, semantic similarity ratings for paired objects were obtained through an online rating scale. A second set of anonymous participants recruited on line rated, on a 7-point scale, whether object pairs were semantically similar. One object pair (*dresser/bed*) was rated to be semantically similar across responses and was excluded from the final stimuli set. Filler trials consisted of eight high frequency and high codability objects. There were eight single-object filler trials presented randomly with the critical trials.

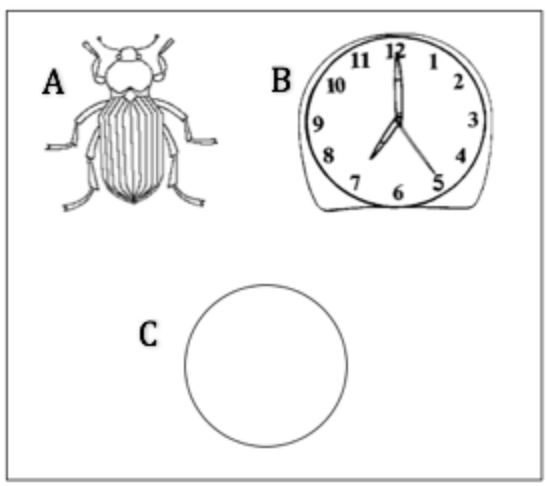

Figure 2: Sample display screen showing position of objects in the A and B are above C task "*the bug" (position A)" and the clock" (position B)" are above the circle" (position C).*

2.3 Procedure

Based on Griffin (2001), participants were instructed to formulate an “A and B are above C” sentence based on line drawings displayed via computer screen. Displays of three objects in the A, B, and C positions (see Figure 2) were shown using the EyeLink eye tracker. Participants were seated approximately 500 mm away from the eye tracker camera. Stimuli were displayed on a 17-inch Windows desktop computer with a resolution of 96 DPI. The task consisted of two phases: familiarization and testing. Familiarization consisted of two familiarization trials. Prior to the study, the task was verbally explained. Participants were told that some pictures may be unclear or difficult to name, but they should simply say their best guess. There was no penalty for incorrect responses. The first familiarization trial consisted of three shapes labeled “A,” “B,” and “C.” Participants were asked to produce the sentence. Any errors were addressed and a check for understanding was conducted. The second familiarization trial, not containing letter labels, was then presented. The sentence frame was written on the screen prior to presentation of objects but was not available while the object display was in place.

After the familiarization phase, the eye tracker was calibrated to track participant’s eye gaze. A microphone was used to record speech output for each trial. During the test phase, each trial began with a drift correct check followed by a display consisting of three objects. The trial ended after the participant had produced the entire sentence frame and the researcher cleared the screen. Audio recordings were linked via eye-link software and an ASIO sound card to visual presentation of objects. Speech initiation time, gaze fixation for all objects, and speech fluency were measured. Eight filler trials consisting of a single high-frequency object were interspersed randomly within the critical trials.

3. Results

3.1 Coding

Participant responses were collected via two channels: vocal coding and eye gaze. Sound files for vocal response were generated by the eye-tracker, with the beginning of each recording linked to the presentation of visual stimuli for each trial. Each trial was coded for the onset and offset of each label in the "A and B are above C" sentence frame. This was used to determine latency to speak as well as vocal duration. All trials were coded for disfluency and discarded if disfluency occurred. Ten percent of all trials were excluded from analysis due to recording error, disfluency, or extraneous distraction. Eye gaze recording tracked when fixations entered and exited interest areas corresponding to each object (A, B, and C) in the visual stimuli. This was used to determine three different measures. *First Fixation Duration* corresponds to how long it took participants to fixate on the first object/only object on the screen. *Gaze Duration* was the amount of time that a participant's eyes remained in each interest area. *Total Time* was the total time where the participant's eye gaze was fixated on the screen during trial presentation.

The remainder of the analysis is organized as follows. We will first examine performance on filler trials to establish any baseline difference between adults who stutter and typically fluent adults. We will then examine codability and frequency effects on eye fixations in critical trials at the point of articulating each object. This will reveal how single-word retrieval issues unfolded during sentence production. Finally, we will examine interactions between objects by looking at total looking times across the critical sentence. This will ascertain if there were any differences in planning strategies based on single-word properties.

3.2 Do groups differ in extraneous dimensions?

To examine if motor abilities impacted completion of the eye-gaze task, we measured how long it took participants to orient to the screen. This was based on the measure of first fixation duration during filler trials to ensure that other objects were not a distraction. Differences in total time and gaze duration were also examined. Data was run through a two-way ANOVA with group as the independent variable and measures of looking time as the dependent variable. No differences in first fixation duration ($F(1,16) = 0.01$, $p = 0.97$), total looking time ($F(1,16) = 1.91$, $p = 0.18$), or gaze duration ($F(1,16)= 0.82$, $p = 0.37$) were found. This indicates that adults who stutter were able to orient to the screen with the same efficiency as typically fluent adults (Figure 3). This suggests that physiological differences are unlikely to affect group-level performance on this eye-tracking while speaking task.

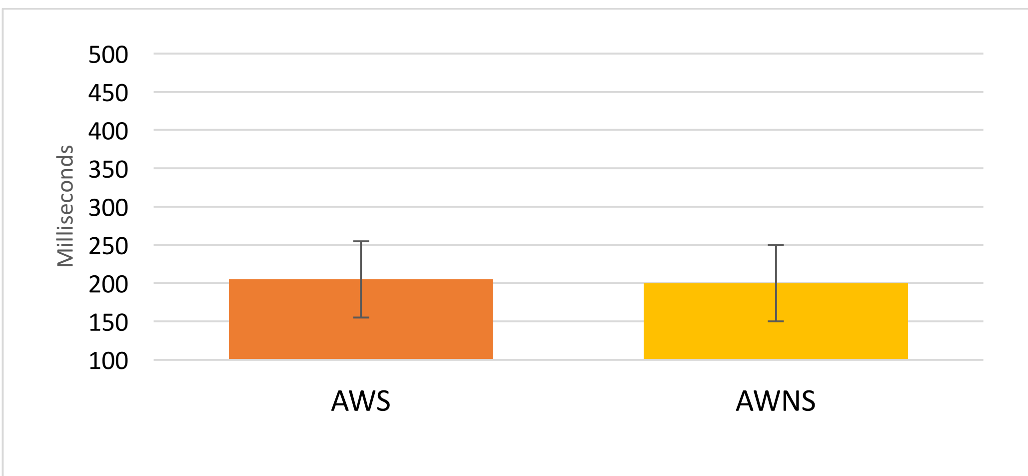

Figure 3: In filler trials, first fixation duration (in ms) for adults who stutter and typically fluent adults

3.3 How do lexical retrieval effects emerge in sentences?

To examine interactions between single word and sentence level production, we turned to gaze duration and total looking time during the first and second object (A and B positions) for critical trials. All analyses were split by object position (first/ item A and second/ Item B). The third object (item C) was disregarded, since items in position C repeated across trials and their codability and frequency were not manipulated.

First, to assess codability/frequency effects for all participants (N=18), we examined overall impacts on gaze duration and total time for each item (A or B). Codability and frequency effects were determined using a 2-way ANOVA with gaze duration and total time as dependent variables and item condition (easy/difficult) and group (stuttering/typically fluent) as independent variables. For the first object (item A), difficulty of A on gaze duration (Figure 4, $F(1,16) = 6.44$, $p = 0.02$) and total time reached significance (Figure 5, $F(1,16) = 4.39$, $p = 0.05$). However, this interaction was opposite of what might have been expected, with easy objects (i.e., *circle*) taking longer than hard objects (i.e., *footman*). In contrast, item B showed codability and frequency effects in the expected direction, with longer gaze duration (Figure 6, $F(1,16) = 25.70$, $p < .01$) and total time (Figure 7, $F(1,16) = 43.70$, $p < .01$) for difficult compared to easy B targets. No interaction of A*B difficulty on B total time or gaze duration emerged ($F(1, 16) = 0.31$, $p = 0.62$). This suggests that, though our task was sensitive to general lexical retrieval effects, these effects were unfolding differently according to object position.

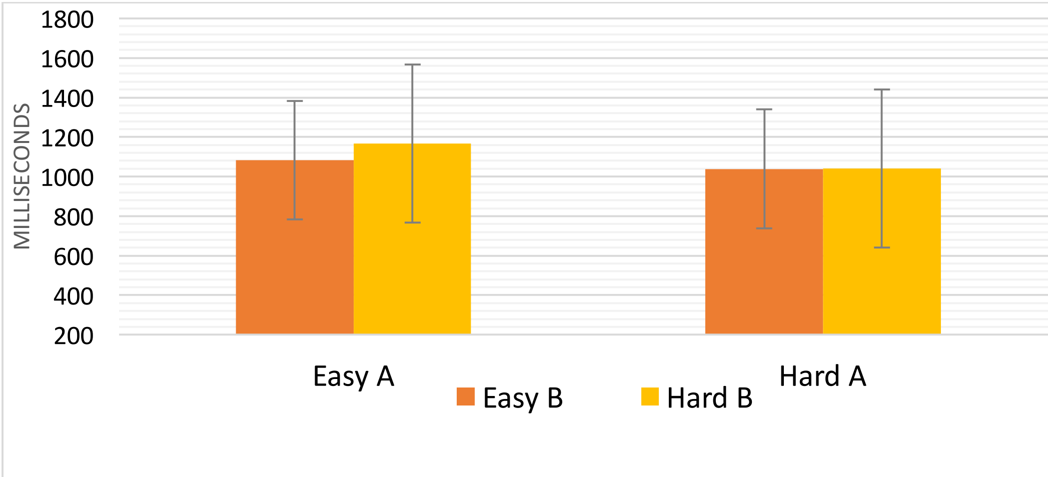

Figure 4: Impact of condition on gaze duration (in ms) on item A

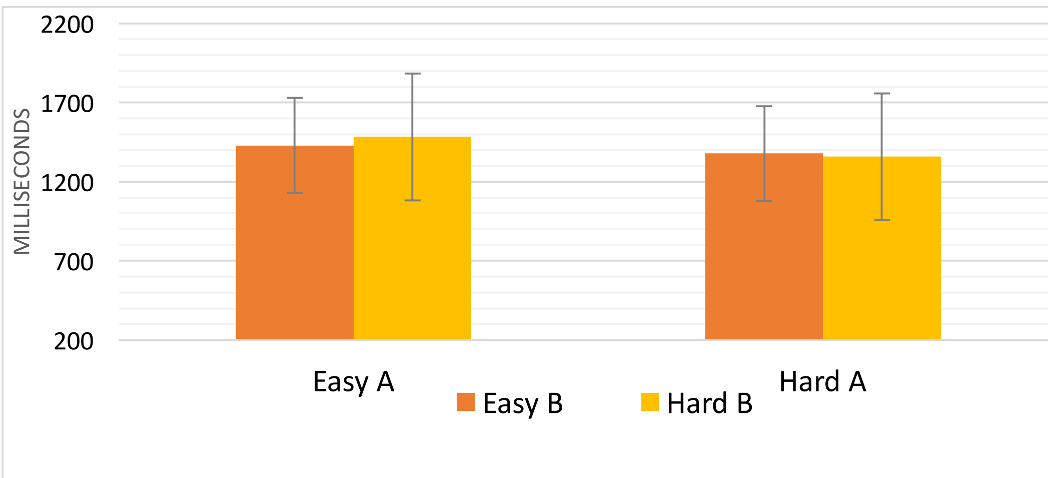

Figure 5: Impact of condition on total time (in ms) on item A

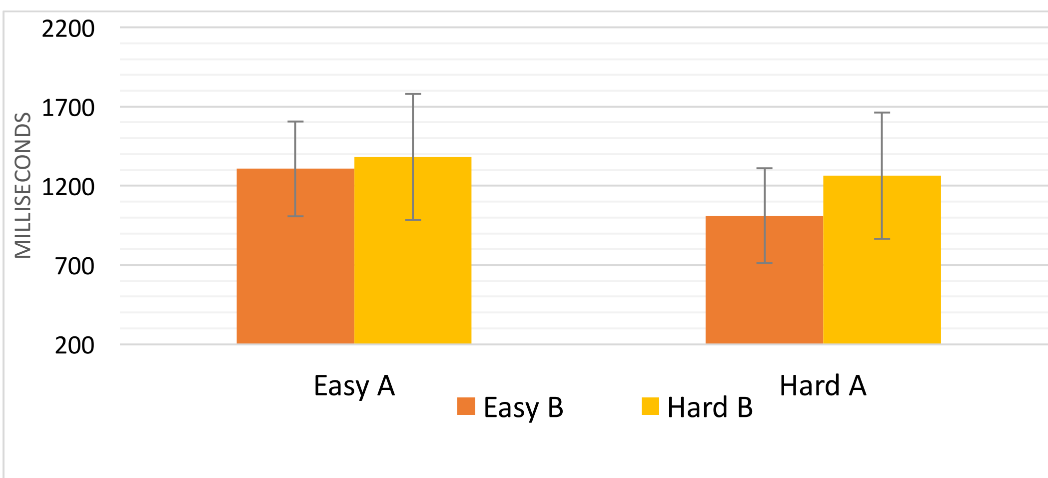

Figure 6: Impact of condition on gaze duration (in ms) on item B

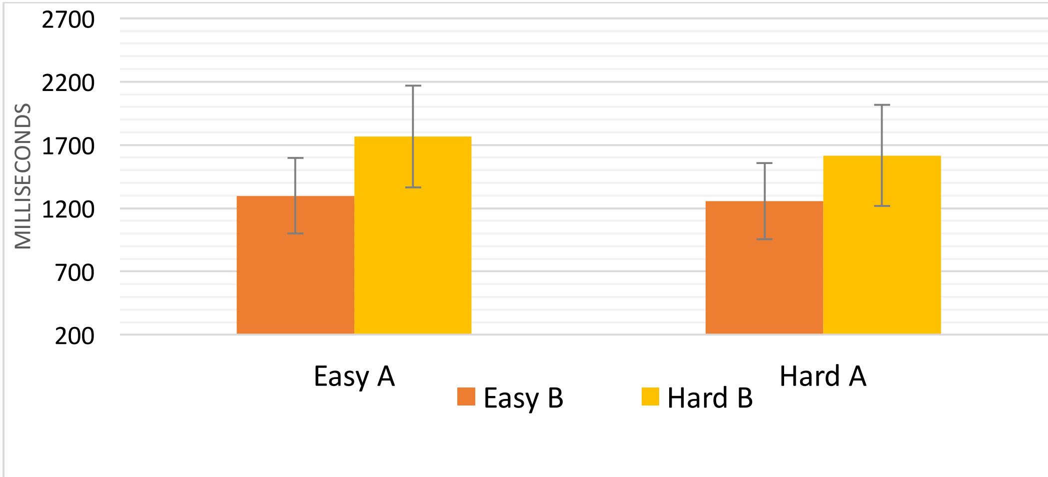

Figure 7: Impact of condition on total time (in ms) on item B

To establish if effects of lexical factors on single-word production differ across adults who stutter and typically fluent adults when words are in sentences, we conducted the same analysis split by groups. First, we inspected eye gaze on item A to see if the counter-intuitive effects that emerged across all participants. On item A, typically fluent adults (*n*=9*)* showed significant effect of difficulty of A on gaze duration (Figure 8, $F(1,8) = 11.60$, $p = 0.01$) and total time (Figure 9, $F(1,8) = 3.62$, $p = 0.09$), with easy objects eliciting significantly longer looks than hard objects. No interactions between A*B difficulty emerged on A gaze duration ($F(1,8) = 2.19$, $p = 0.18$) or total time ($F(1,8) = 3.60$, $p = 0.18$). This indicates that for typically fluent adults, interactions between sentence and single-word production may result in single-word effects that pattern differently from what is expected based on past research.

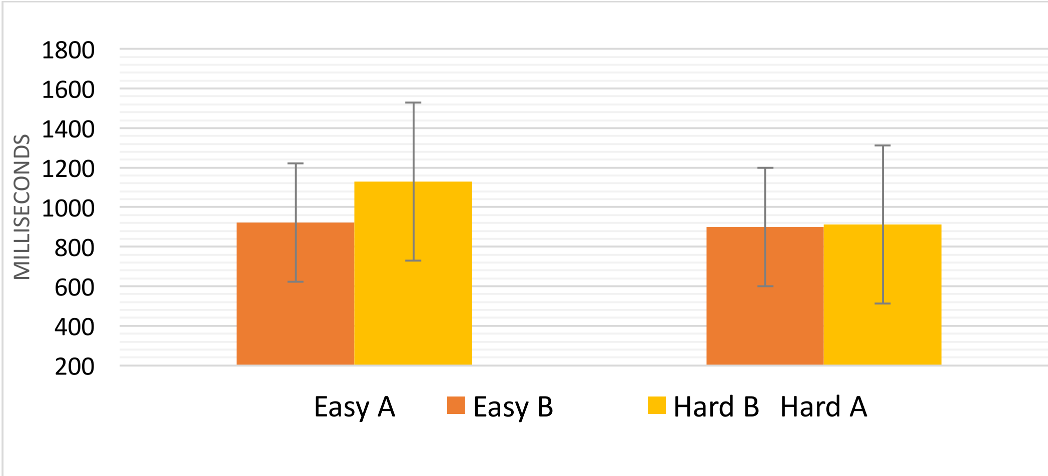

Figure 8: Impact of condition on gaze duration (in ms) on item A in typically fluent adults

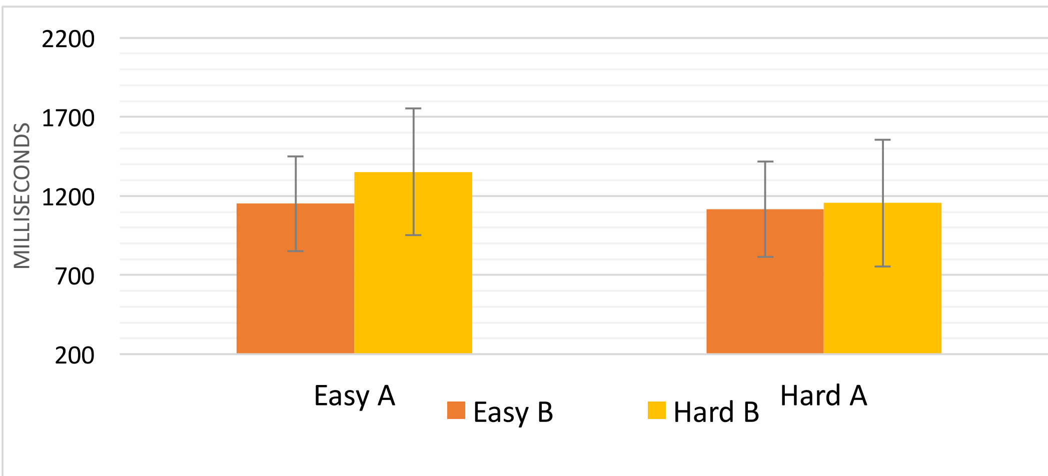

Figure 9: Impact of condition on total time (in ms) on item A in typically fluent adults

The same analyses were carried out on item A for adults who stutter (n=9). Unlike typically fluent adults, these individuals showed no effect of codability/frequency on gaze duration (Figure 10, $F(1,8)= 0.92$, $p = 0.36$) or total time (Figure 11, $F(1,8) = 0.95$, $p = 0.32$) for object A. No significant interaction was observed between A and B difficulty ($F(1,8) = 1.65$ $p = 0.23$). This suggests that word retrieval effects may emerge differently in sentence production by adults who stutter. Moreover, processes underlying lexical retrieval by adults who stutter may differ from those of typically fluent adults.

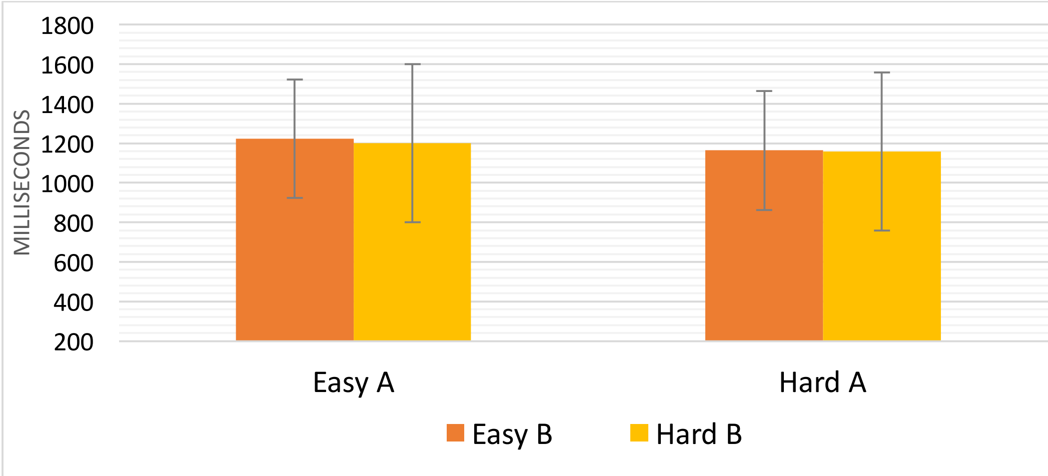

Figure 10: Impact of condition on gaze duration (in ms) on item A in adults who stutter

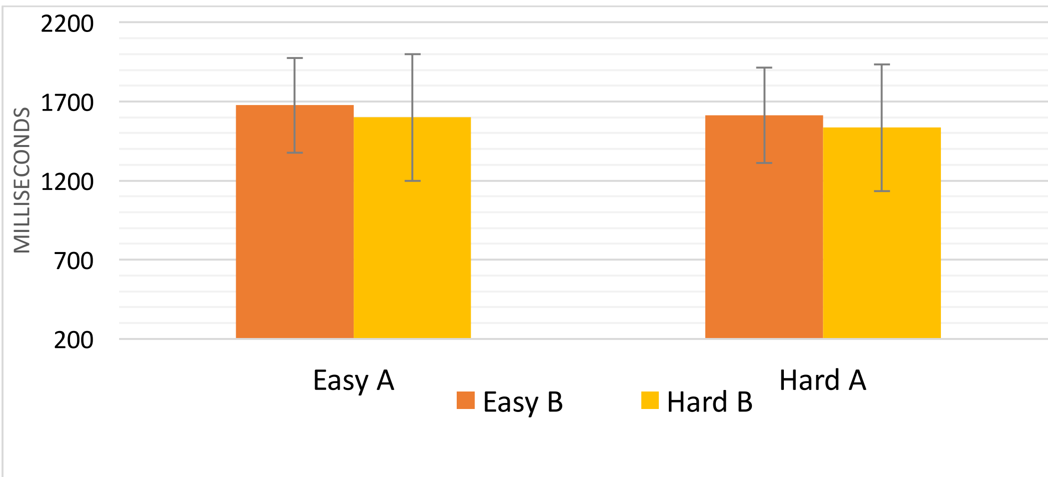

Figure 11: Impact of condition on total time (in ms) on item A in adults who stutter

Next, we repeated analyses on the production of object B (the second object). In typically fluent adults, item B showed pronounced codability/frequency effects on gaze duration (Figure 12, $F(1,8) = 11.50, p < .01$) and total time (Figure 13, $F(1,8) = 21.10, p < .01$). More difficult B's led to longer looking times than easier B's. No interaction emerged between A and B difficulty in total time ($F\ (1, 8) = 1.77, p = 0.22$) or gaze duration ($F\ (1, 8) = 1.05, p = 0.33$).

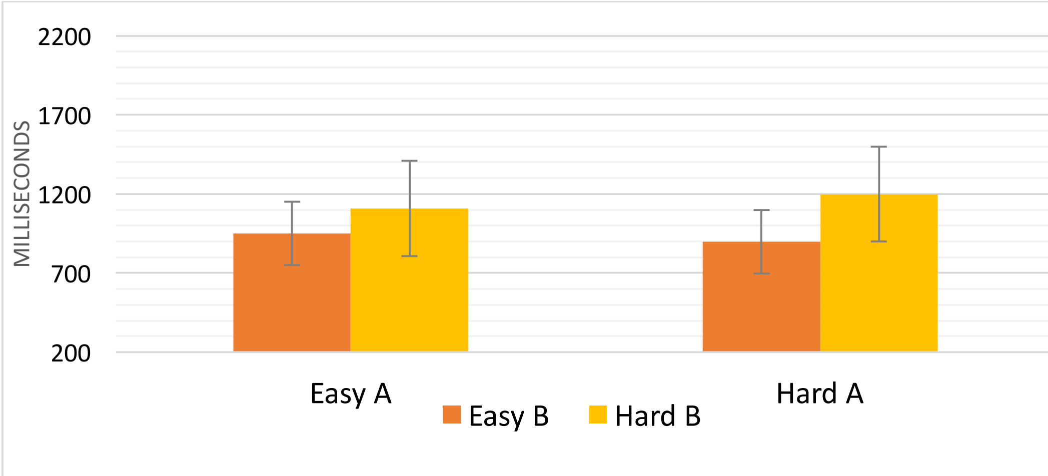

Figure 12: Impact of B difficulty on gaze duration (in ms) on B in typically fluent adults

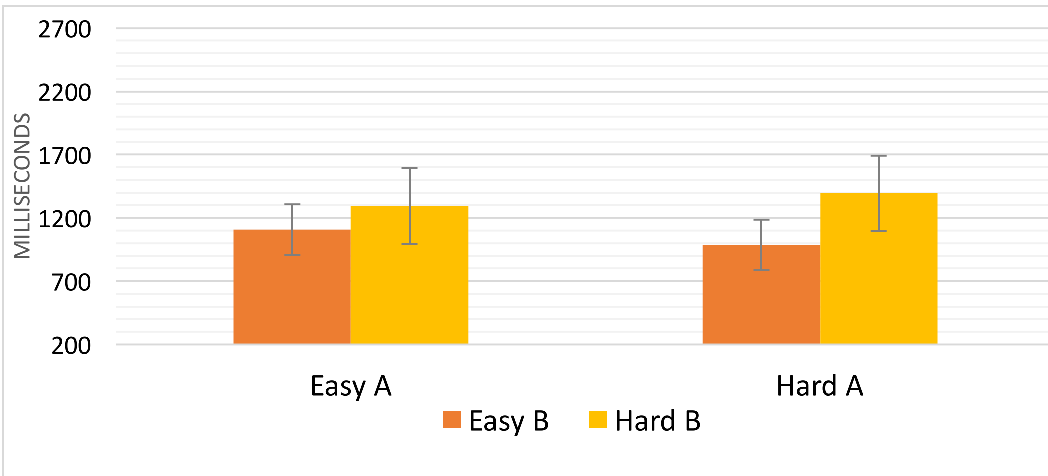

Figure 13: Impact of B difficulty on total looking time (in ms) on B in typically fluent adults

Adults who stutter similarly revealed significant effects of B difficulty on B gaze duration (Figure 14, $F(1,8) = 11.50, p < .01$) and total time (Figure 15, $F(1,8) = 41.60, p < .01$). This demonstrates that, unlike for item A, codability/frequency effects were present for item B. No interactions emerged between A and B difficulty on gaze duration ($F(1,8) = 1.32, p = 0.28$) or total time ($F(1,8) = 1.65, p = 0.23$).

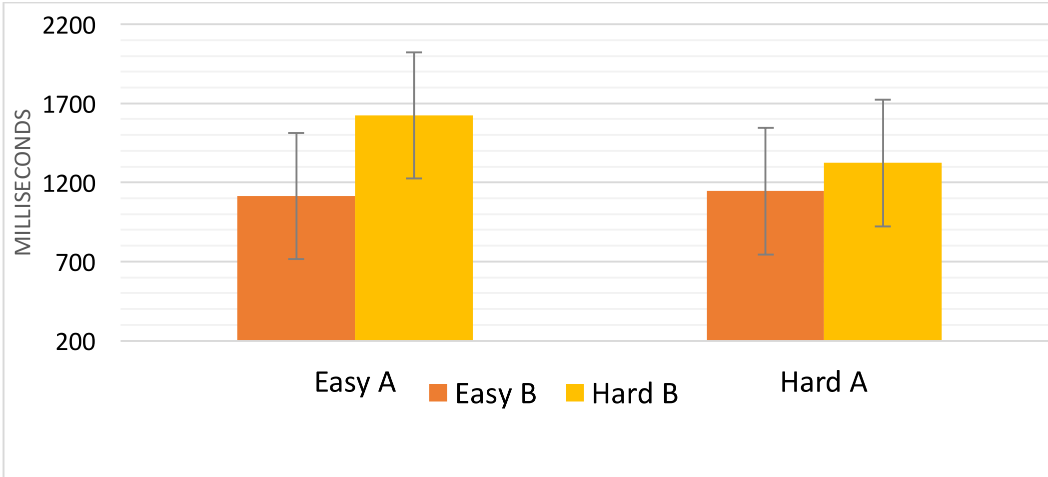

Figure 14: Impact of B difficulty on B gaze duration (in ms) in adults who stutter

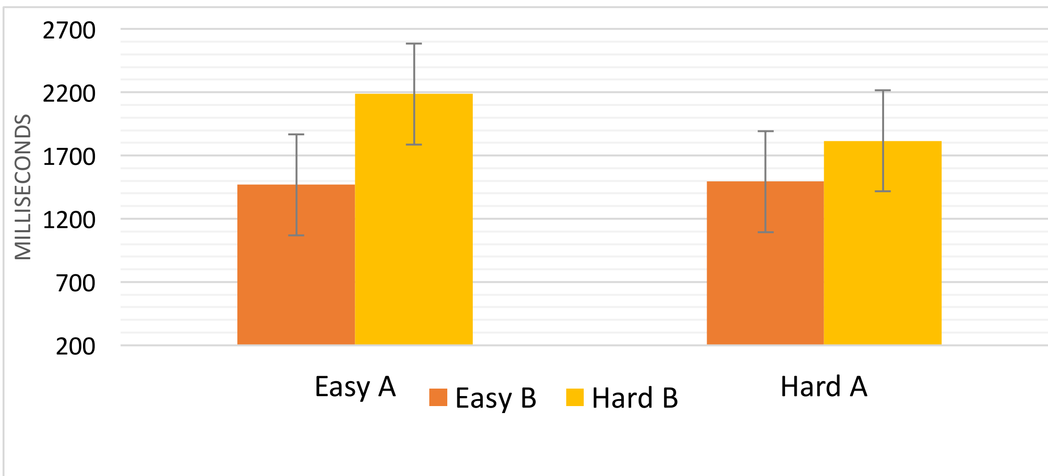

Figure 15: Impact of B difficulty on total looking time (in ms) to B in adults who stutter

3.4 How do word level issues impact sentence planning?

To establish if pre-planning strategies differed between adults who stutter and typically fluent adults, we examined the time course of gaze duration and total looking times across object positions in critical trials. This assessed how the difficulty of the first object impacted the way in which the second object was produced. These analyses held the difficulty of the first object constant, and looked at the impact of the difficulty of the first object on the second. First, we looked only at *easy A easy B* or *easy A hard B* conditions (e.g., *circle*/*star* and *circle*/*footman*).

When the first object was easy, the difference in eye gaze between an easy and hard second object differed significantly between adults who stutter and typically fluent adults (Figure 16, F (1,18) = 5.10, p = .03). Both groups experienced more difficulty on more difficult second objects However, adults who stutter experienced a significantly greater effect of difficulty (F (1,8) =12.03, p < .01) than did typically fluent adults (F (1,8) = 5.32, p = .06).

Next, we inspected conditions where the first object is difficult, *hard A easy B* or *hard A hard B* (e.g., *footman/ circle* and *footman/ eagle)*. There was no significant difference between performance of the two groups (Figure 17, F(1,15) = 5.30, p = 0.65). Thus, when the first object was difficult, adults who stutter and typically fluent adults performed similarly. The difference in the time course of lexical retrieval effects indicates that typically fluent adults may have pre-planned a different increment of the sentence when they encountered an easy first object than a hard first object, showing two different pre-planning strategies. Additionally, adults who stutter only had lexical retrieval effects emerge at the point of articulation, indicating that their increment of pre-planning remained consistent across conditions.

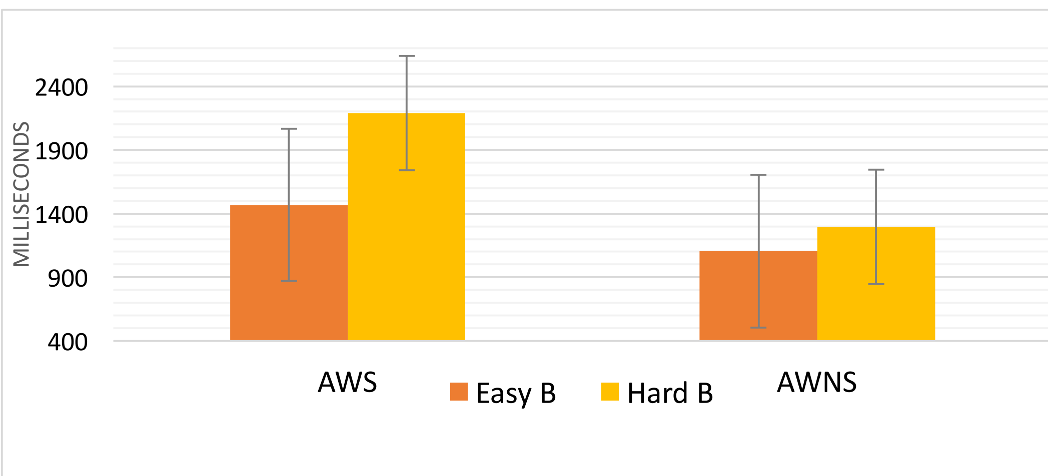

Figure 16: Difference in total times (ms) when first object is easy

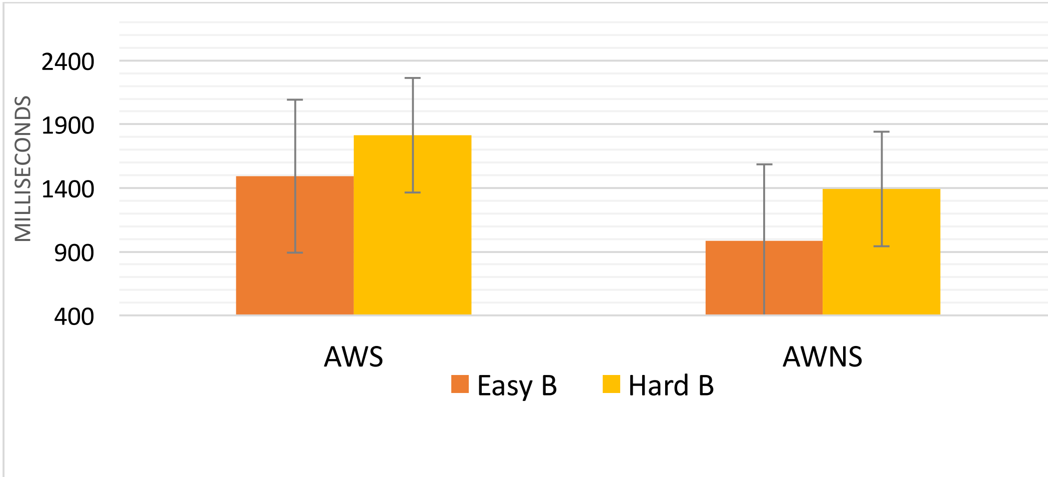

Figure 17: Difference in total times (ms) when first object is difficult

4. Discussion

The current study found that eye tracking while speaking is a valid behavioral measure in this population. The ability to orient to objects on a screen was similar in adults who stutter and typically fluent adults. We also found that lexical retrieval effects emerge differently when unfolding in sentences compared to single-word presentation. Moreover, these effects may differ between adults who stutter and typically fluent adults. Finally, we found that pre-planning strategies differed according to target word properties between the two groups. Typically fluent adults showed lexical retrieval effects (as measured by frequency and codability) of late objects both at the point of articulation (i.e., when faced with a difficult first object) and prior to sentence onset (i.e., when faced with an easy first object), indicating that typically fluent adults changed the amount of a sentence that was pre-planned according to the difficulty of early-occurring elements. Adults who stutter did not showed this difference in the time course of lexical retrieval effects, indicating that they were pre-planning the same increment of the sentence regardless of lexical demands of retrieving its component words.

Note that unlike previous research on typically fluent adults, our results demonstrate pre-planning of the second object can occur prior to production of the first. This contrasts with prior work indicating that words in sentences are planned incrementally (Griffin, 2001). Nevertheless, our experimental design differed from prior work in that we manipulated lexical properties to be either very codable and frequent, or very low codable and infrequent words. Griffin's original study did not follow this strict dichotomy. In addition, we manipulated only the first and second object in the sentence frame, rather than all three. The combination of these manipulations created conditions that were doubly loaded in codability and frequency effects and only had novel first and second objects. This could have significantly decreased cognitive load when compared to Griffin's experimental design, and allowed for greater pre-planning, as only two novel labels needed to be retrieved.

In the remainder of this discussion, we will discuss the implications for our results for the language system of adults who stutter. We will first evaluate our hypotheses about lexical retrieval in sentences and why this unfolded differently in our adults who stutter and typically fluent adults, and how these effects differ from prior studies. We will then discuss sentence pre-planning strategies, how these differ according to sentence properties, and the different strategies demonstrated by adults who stutter and typically fluent adults. Finally, we will discuss the ways in which this work can inform and shape further research.

4.1 Lexical retrieval in sentences

We found that sentence contexts change the ways in which single words are produced. Research has shown that lexical factors impact reaction times for retrieval to the same degree in typically fluent adults and adults who stutter. However, previous work in naming accuracy showed that there may (Newman & Ratner, 2007) or may not be (Hennessey, Nang, & Beilby, 2008) a larger effect of frequency on adults who stutter compared to typically fluent adults. The current study showed no difference in magnitude of lexical retrieval effects between adults who stutter and typically fluent adults. This may arise from the fact that we examined lexical retrieval as it unfolds in the context of sentence production. Thus, differences at the single word level may have been washed out by strategies and processes that occur at the sentence level. When viewed as a whole, these results do not fit with a simple lexical retrieval narrative. Hard objects are not necessarily always harder for adults who stutter than typically fluent adults. Instead, our results suggest that overall lexical-retrieval abilities in adults who stutter may be fairly comparable to typically fluent adults under some and possibly all circumstances.

Since stuttering is a lifelong disorder that may change with a speaker's experience, these findings raise question whether the current patterns arise from stuttering as a disorder or are learned adaptive behaviors. Our findings fit well with the narrative of lexical-retrieval abilities found in previous research on children who stutter. When the effects of frequency were investigated in picture naming, there was no significant difference in response time or accuracy in children who no difference compared to nonstuttering peers (Ratner, Newman, & Strekas, 2009). In contrast, in work that examines the effect of lexical retrieval on disfluencies during connected speech, there is evidence that children are more likely to stutter on infrequent words compared to frequent ones (Anderson, 2007). This indicates that similar to adults, children who stutter experience more difficulty on infrequent words, even when response times remain consistent (see Newman & Ratner, 2007, who found the same interaction of fluency and frequency in adults who stutter).

4.2 Sentence planning and production

One puzzling aspect of our results is the reverse codability and frequency effects that occurred in typically fluent adults on the first object in the sentence frame. This counterintuitive pattern indicates that properties of later-occurring words in sentences may impact how earlier words are retrieved. For typically fluent adults, longer total times when early-occurring objects are easy indicate that more of the sentence is pre-planned. This is corroborated by a decreased impact of the difficulty of later-occurring objects at the point of articulation. Thus, when the cognitive load necessary to retrieve early objects is lower, typically fluent adults demonstrate lexical retrieval effects for late occurring objects early in sentence production. This indicates that under certain circumstances, late-occurring objects are fully planned before articulation of early-occurring objects.

In contrast, adults who stutter did not show pre-planning effects. Across all conditions, codability and frequency effects emerged only at the point of articulation. This distinction is interesting, since it indicates that difficult objects are not necessarily functionally more difficult for adults who stutter than for typically fluent adults (that is, no significant difference in looking times emerged across all conditions). However, adults who stutter were not able to perform the same amount of pre-planning as typically fluent adults, even with presented with an easy first object. Therefore, the flexibility in choosing a pre-planning strategy that was seen in typically fluent adults does not appear available to adults who stutter, at least those in this study. In addition, adults who stutter appeared to experience more difficulty with easier objects, but this difficulty is not cumulative. There seemed to be a larger amount of cognitive resources needed to retrieve any simple object label, but this did not result in larger codability and frequency effects.

Together with previous work, our results show a new aspect of speech planning that may distinguish speakers who do and do not stutter. The different conditions in our own experiment show two different interactions between critical objects in typically fluent adults: one that indicates that pre-planning occurs, one that indicates that the increment of pre-planning is small in this group. Based on this, it seems that typically fluent speakers choose from a variety of sentence pre-planning increments and strategies based on the demands of the task. When early-occurring objects require few cognitive resources, those resources are then devoted to more difficult late-occurring objects. When the beginning of the sentence carries more retrieval demands, late-occurring objects are ignored in favor of devoting cognitive resources to difficult early elements. Critically, adults who stutter seem to be employing the same planning strategies across all conditions, regardless of the demands of late or early occurring elements. This paints a picture of a language system that is less flexible and less able to adapt to different needs based on context, though this difference is subtle.

One possible explanation of this difference in ability to use a variety of strategies may lie in cognitive resource allocation. A review of the interplay between stuttering and cognitive processing load conducted by Bosshardt (2004) indicates that performance in adults who stutter decreases across all tasks when dual-processing is required (also see Bosshardt, 1999, 2000). In fact, there is evidence that multiple types of linguistic processing (i.e., phonological, semantic) are vulnerable to asynchronies due to dual task demands in adults who stutter (Tsai & Ratner, 2016). However, this account alone does not appear to be sufficient for explaining the results of the current study. Adults who stutter show decreased ability to pre-plan when the first object is difficult, but this difficulty is not cumulative. Moreover, they do not always perform worse than typically fluent adults, as would be expected if our results were simply caused by an account suggesting that adults who stutter always experience higher cognitive load. Critically, in conditions where the greatest cognitive load should be experienced, adults who stutter perform similarly to typically fluent adults. This indicates that multiple factors impact the flexibility and performance of the language production system in adults who stutter.

4.3 Future research

The most significant contribution of this work is the establishment of eye tracking while speaking as a valid behavioral measure for people who stutter. The similarity in ability to fixate on the screen between adults who stutter and typically fluent adults is critical. This is notable in light of established differences in fine motor abilities adults who stutter compared to typically fluent adults when the language system is involved (Kleinow & Smith, 2000). Eye tracking while speaking opens up avenues for investigating how production unfolds in real time and provides information on processes that occur throughout speech production. To examine pre-planning strategies in adults who stutter, future work can use eye tracking while speaking in less structured tasks. Our current study relies on a heavily structured sentence frame. However, eye tracking while speaking could be used in a naturalistic setting to see how adults who stutter create sentences based on a scene. This could give insight into trade-offs between lexical difficulty and syntactic complexity. In addition, this paradigm could be used to ascertain effects of lexical retrieval on verbs in sentences rather than simple nouns. Previous work has established that retrieval is slower in verbs when compared to nouns, and that adults who stutter may experience increased lexical retrieval difficulty with verbs when compared to nouns (Prins, Main, & Wampler, 1997; Howell & Ratner, 2018). Eye tracking while speaking could allow for investigation of lexical retrieval in verbs in sentences as well as any possible tradeoffs between lexical retrieval, timing, accuracy, and sentence complexity during more naturalistic speech.

Since stuttering develops during childhood and continues to adulthood, one enduring question is if patterns among adults are related to the cause of stuttering or adaptive change based on stuttering experience. The current study only investigated adults who stutter. As such, these patterns may reflect a strategy developed as the result of stuttering experiences. It could be that building sentences with smaller incremental units of pre-planning arises from increased speaking apprehension and attempts to maintain fluency. This, coupled with the small sample size of this study, highlights the need to apply the eye tracking paradigm to a larger set of both adults and children who stutter in order to ascertain if the differences pre-planning strategies observed in this study carries over to a larger number of both adults who stutter and typically fluent adults.

5. Conclusion

The current study is the first to establish eye tracking while speaking as a plausible method of investigating the language system of adults who stutter. This allows us to gather moment-by-moment data during real-time speech production. This work gives greater insight into differences in the speech production and pre-planning of adults who stutter and typically fluent adults. Our main findings are as follows. First, lexical retrieval effects unfold somewhat differently than expected when placed in the contexts of sentences. Second, the properties of the words in sentences impact the ways in which sentences are produced. Third, typically fluent adults are able to switch between multiple pre-planning methods during sentence production, but the incremental unit of pre-planning in adults who stutter remains constant. Together, these results indicate that adults who stutter may conduct less flexible speech pre-planning than their typically fluent adults in some conditions.

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