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Research Article

Executive Control in Adults Who Stutter: The Antisaccade Task

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Purpose: The purpose of this study was to investigate executive control in adults who stutter (AWS) and adults who do not stutter (AWNS) via a nonspeech paradigm, wherein eye movements were monitored (i.e., antisaccade task). Processes involved in an antisaccade task include working memory, attention, and voluntary motor control, but the task primarily provides insight into inhibitory control.
Method: Seventeen AWS (14 men, three women; *M* = 23.41 years) and 17 AWNS (*M* = 23.29 years) were presented with a combination of prosaccade (i.e., looking toward a target) and antisaccade (i.e., suppress a reflexive saccade toward the target and look in the opposite direction) trials. The distance of the target from the center of the screen was also manipulated (i.e., 5.5° = short distance and 10.8° = long distance). Data for accuracy and reaction time of the first accurate saccade were collected and analyzed.
Results: No difference was found between AWS and AWNS in accuracy or in reaction time. Both groups were more accurate in the prosaccade than the antisaccade trials and in the long compared to the short distance trials. Furthermore, both groups demonstrated longer saccade latencies for long compared to short distances and for antisaccade compared to prosaccade trials.
Conclusions: Preliminary results do not support deficits in inhibition in AWS during a motorically simple, non–speech-related oculomotor task, but additional research is warranted.

Stuttering is a neurophysiological disorder that is multifactorial in nature (Conture, 2001), with genetic, linguistic, cognitive, emotional, and motor factors contributing to its onset and development (e.g., Bloodstein et al., 2008). Among these factors, executive control warrants further investigation.

Executive control or executive functions or cognitive control—terms that have been used interchangeably—involves a set of top-down mental processes (i.e., working memory, attention, inhibition, cognitive flexibility) that carry out goal-directed behaviors (e.g., Diamond, 2013; Miller & Cohen, 2001) and control the execution of complex activities (e.g., Royal et al., 2002). They also seem to play an important role in the production of disfluent speech.

For example, Dell's spreading activation model of lexical access assumes the connection of distinct semantic, lemma/word, and phonological units (e.g., Dell & O'Seaghdha, 1992). When semantic units of the concept to be conveyed are activated, activation spreads to other semantically related units as well as to their relevant word/lemma and phonological units. Although multiple word entries and their units will be activated, only one word will receive the greatest activation and will be selected for motor execution. Therefore, inhibition is critical in order to suppress the less activated competing units so that the target word is ready for execution (e.g., Bock, 1982; Dell & O'Seaghdha, 1992). Disfluencies could potentially occur as the result of ineffective inhibitory mechanisms during the lexical selection process (Anderson & Byrd, 2008; Anderson & Wagovich, 2017).

Despite its critical role in speech production, only a handful of studies have explored inhibition in adults who stutter (AWS). Thus, the purpose of this study was to assess executive control, using a task that primarily targets inhibition, wherein eye movements are being monitored (i.e., antisaccade task). Although eye-tracking paradigms have been explored in AWS (see Pelczarski et al., 2018), for this study, eye movements were analyzed via the antisaccade task, a novel measure in the stuttering literature. The analysis of eye movements provided an objective, unobstructive, and online measure of the cognitive processing of the participants as they completed the antisaccade task (e.g., Duchowski, 2002).

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Executive Control in People Who Stutter

Executive control (also referred to as "executive functions/processes" or "cognitive control") involves three core processes: (a) inhibition (i.e., inhibitory control, including self-control, and interference control, including selective attention and cognitive inhibition), (b) working memory, and (c) cognitive flexibility (i.e., set shifting or mental flexibility; Diamond, 2013). The role of attention and its interaction with the core executive function processes is fundamental for successful performance in a variety of cognitive tasks (e.g., tasks that require the ability to maintain information in active memory, especially during interference; Engle & Kane, 2004).

Several studies have explored the relationship between working memory and stuttering (see Bajaj, 2007, for a review), with most studies focusing on the phonological loop or central executive components of working memory (e.g., Baddeley, 2003). Regarding the link between phonological loop and stuttering, various tasks have been incorporated, such as nonword repetition and/or phoneme elision (e.g., Byrd, McGill, & Usler, 2015; Byrd et al., 2012; Coalson & Byrd, 2017; Sasisekaran, 2013), phoneme monitoring (e.g., Coalson & Byrd, 2015; Sasisekaran & De Nil, 2006; Sasisekaran et al., 2006), rhyme judgment (e.g., Weber-Fox et al., 2004), or word list recall (Byrd, Sheng, et al., 2015). Results demonstrate deviant performance in people who stutter in terms of accuracy and reaction time. The majority of investigations related to the role of central executive in stuttering have incorporated dual tasks and indicate poorer performance in AWS as the demands for divided attention are increased when both verbal (e.g., silent reading, rhyming) and nonverbal (e.g., finger tapping) tasks are being implemented concurrently (e.g., Bosshardt, 2002; Jones et al., 2012). That is, if a task is not taxing enough, performance differences between people who stutter and people who do not stutter do not emerge. Dual tasks have also been used to investigate attention in people who stutter, with results suggesting less efficient use of attentional resources in both adults (e.g., Bosshardt, 2006; Maxfield et al., 2016) and children who stutter (e.g., Sasisekaran & Basu, 2017).

The aspect of executive control that is most relevant to this study is inhibition. Deviant inhibition-related processes have been observed in various clinical populations, such as attention-deficit/hyperactivity disorder (ADHD), schizophrenia, autism, or obsessive–compulsive disorder to name a few. In healthy adults, inhibition-related processes have been associated with the individual's general cognitive ability, working memory span, reading comprehension, or problem-solving ability (Friedman & Miyake, 2004). Friedman and Miyake (2004) suggest three inhibition-related functions: (a) prepotent response inhibition (the mostly clearly function associated with executive functions), which refers to the ability to suppress dominant, automatic, prepotent responses and can be assessed via tasks such as the antisaccade task, the stop signal task, or the Stroop task; (b) resistance to distractor interference (associated with focused attention), which refers to the ability to resist or resolve interference from irrelevant distracting stimuli and can be assessed with tasks such as the Eriksen flanker task or shape matching tasks; and (c) resistance to proactive interference, which refers to the ability to resolve interference from currently irrelevant stimuli (but those stimuli were previously relevant in the task) and can be assessed through recall tasks that incorporate learning of stimuli, which then need to be ignored.

Even though inhibition and inhibitory control have been the focus of several investigations in children who stutter (e.g., Eggers et al., 2013, 2018; Ntourou et al., 2018; Ofoe et al., 2018), relatively few investigations have been completed with AWS. Results of studies that have explored inhibition in children who stutter are conflicting. Some studies report that children who stutter present with weaknesses in response inhibition compared to children who do not during verbal (e.g., grass–snow and baa–meow task; Anderson & Wagovich, 2017) and nonverbal tasks (e.g., go/no-go task; Eggers et al., 2013). In contrast, other studies failed to find differences in inhibitory control between children who do and do not stutter using stop signal tasks or go/no-go tasks (e.g., Eggers et al., 2018; Piispala et al., 2016). The authors of the latter studies suggest that different types of response inhibition may be involved in different tasks, and children who stutter may have deficits only in some types of response inhibition as opposed to a generalized deficit in inhibition (Eggers et al., 2018).

Only a few studies have investigated inhibition in AWS, and the majority of those studies suggest deficits in AWS. Eggers and Alewaters (2012) investigated inhibitory control in 24 AWS and 24 matched in age and gender typically fluent controls via a go/no-go task. Participants were instructed to press a button as fast as possible during a go stimulus (i.e., green walking figure, 50% of trials) and suppress their tendency of pressing the button during a no-go stimulus (i.e., red figure standing, 50% of trials). AWS produced significantly more false alarms (i.e., failure to inhibit pressing the button) in no-go trials than adults who do not stutter (AWNS).

In a similar study, Markett et al. (2016) employed a stop signal task in 28 AWS and 28 AWNS and asked participants to press one of two possible buttons on a response pad to indicate whether a visually presented word on a screen was an animal or not. Participants were required to withhold their manual response every time a 1000-Hz tone was presented via headphones (25% of trials), immediately after the word appeared on the screen; thus, they had to inhibit a motor response that has already been initiated. In this task, AWS were as accurate as AWNS but significantly slower in the stop signals, suggesting possible deficits in motor inhibition. In a follow-up task in the same study, participants were asked to indicate the direction (i.e., left or right) of an arrow presented on a screen by pressing the left or the right button on a response pad. When a red circle was presented above or under the arrow (10% of trials), participants were required to withhold their response. Results of the second task in the study (i.e., arrows) replicated the results of their first task (i.e., animal/nonanimal word), that is, longer stop signal reaction times in AWS. The authors attributed the atypical inhibitory control demonstrated by the AWS in their study to atypical function of the basal ganglia circuit. This interpretation is plausible given that the basal ganglia and prefrontal cortex are primarily involved in a stop signal task and is also supported by the perspective of stuttering as a speech motor control disorder resulting from poor basal ganglia functioning (e.g., Alm, 2004; Smits-Bandstra & De Nil, 2007).

In contrast, Maxfield (2018) did not find any differences in inhibitory control between 12 AWS and 12 AWNS during a flanker task. For his study, Maxfield asked participants to indicate a left- or right-hand response based on the direction of the middle arrow in a sequence of five arrows. Half of the trials included congruent trials (i.e., all arrows in the sequence pointed to the same direction), and the other half included incongruent trials (i.e., the middle arrow of the sequence pointed to a different direction of that of the rest of the arrows). However, based on preliminary event-related potential results, a larger anterior N2 amplitude was found in AWS compared to AWNS when completing the task. Therefore, even though evidence for less accurate or slower inhibitory control was not supported in the study, Maxfield suggested that AWS may recruit more neurocognitive resources during inhibitory control tasks.

Taken together, there appears to be deficits in executive functions, in particular in inhibitory control, in AWS, but relatively few studies have been completed, and the data are conflicting. Thus, additional research is warranted to elucidate the relationship between executive control and stuttering.

Description of the Antisaccade Task

In this study, we aimed to investigate executive control in AWS via a nonspeech oculomotor task: the antisaccade task. The prosaccade/antisaccade task is a paradigm that has been widely used to investigate executive attention and executive control (e.g., Everling & Fischer, 1998; Unsworth et al., 2004) in a variety of clinical populations, such as ADHD, Parkinson's disease, and schizophrenia (for a review, see Everling & Fischer, 1998).

One benefit of the antisaccade task is that it is a simple and quick task that enables participants to "contrast aspects of willful behavior" (Hutton & Ettinger, 2006, p. 1); thus, it can provide important insights regarding cognitive and neural mechanisms involved in the volitional control of behavior. Another benefit of the task is that minimal language is required to complete the task; thus, linguistic influences when assessing executive control are excluded. Finally, since eye movements are being collected and a verbal response is not required, speech motor influences in participants' performance are also excluded. Therefore, use of the antisaccade task allowed us to better understand executive control, in particular, inhibition, in AWS while addressing the limitations of prior studies (e.g., overt vocal response, linguistic processing).

Processes Involved in an Antisaccade Task

In a standard prosaccade task, participants are required to look at a sudden/flashing onset target (i.e., stimulus) as quickly as possible. In an antisaccade task, participants are instructed to suppress a reflexive prosaccade toward a sudden/flashing onset target and instead look at the opposite direction (Everling & Fischer, 1998).

Processes that are involved in an antisaccade task include active maintenance of instructions and goal in working memory, attention, inhibition, and voluntary motor control (see Hutton & Ettinger, 2006). During antisaccade trials, participants need to suppress a prepotent response (i.e., inhibition) while planning and executing a voluntary saccade in the opposite direction. In addition, task goal needs to be actively maintained (i.e., working memory) for successful task performance.

The association of working memory in the antisaccade task is obvious, as participants need to be able to keep the relevant task instructions in their working memory in order to complete the task (Hutton & Ettinger, 2006). When the working memory load of the task increases, as in the case of dual tasks, participants make more direction errors (e.g., Mitchell et al., 2002; Roberts et al., 1994) and produce longer saccade latencies (e.g., Evens & Ludwig, 2010). Performance in the antisaccade task is also influenced by working memory span ability (e.g., Kane et al., 2001; Unsworth et al., 2004) as well as other measures of working memory ability, such as spatial working memory (see Hutton & Ettinger, 2006).

When prosaccade and antisaccade trials are presented in mixed blocks, higher demands are being placed on task goal maintenance as well as on suppression of the prior trial's task goal, since prior trials do not predict upcoming trials. Therefore, the need for attention control is increased in mixed blocks compared to exclusively prosaccade and/or exclusively antisaccade blocks (e.g., Unsworth et al., 2004; Wang et al., 2013). Due to the increased attentional demands in mixed blocks, saccade latencies of successful saccades (i.e., correct direction) are shorter in mixed blocks compared to exclusively antisaccade blocks (e.g., Wang et al., 2013). Incorporation of only mixed blocks in this study was motivated by those results.

The primary executive process involved in an antisaccade task is inhibition. Recall that participants need to suppress a reflexive prepotent response toward a sudden-onset target and instead generate a saccade in the opposite direction. Therefore, the first step for a correct antisaccade generation is the suppression of a reflexive prosaccade. Uncorrected direction errors in an antisaccade task have been suggested to indicate deficits in inhibition (e.g., Coe & Munoz, 2017; Hutton & Ettinger, 2006). Individuals with various psychiatric and neurological disorders, such as schizophrenia, ADHD, Parkinson's disease, or patients with frontal lobe lesions, demonstrate increased error rates in antisaccade tasks compared to healthy controls. These results suggest deficits in inhibitory control and provide further evidence for the association of inhibition in the antisaccade task (e.g., Crawford et al., 2002; Hutton & Ettinger, 2006).

Factors That Affect Antisaccade Performance

In general, a high number of erroneous prosaccades in antisaccade trials (i.e., looking toward the target during an antisaccade trial; poor performance in antisaccade trials) reflects deficits in the inhibition of reflexive responses or weakness in voluntary control of saccadic movements. In contrast, a high number of erroneous antisaccades in prosaccade trials (i.e., looking in the opposite direction of the target during a prosaccade trial; poor performance in prosaccade trials) reflects deficits in fixation stability (i.e., failure to suppress reflexive prosaccades by proper fixation) or inability to generate voluntary saccadic movements (Everling & Fischer, 1998; Fischer et al., 2000). Variables that are often analyzed in an antisaccade task include latency (i.e., the elapsed time between the onset of the sudden/flashing target and the beginning of the fixation in the correct direction) and direction errors (i.e., number of first saccades that are made in the direction opposite to the area of interest).

Among the factors that affect the error rate of prosaccades and antisaccades is the presence or absence of a gap in the experiment. In a gap condition, a fixation point (i.e., fixation cue) is presented first (e.g., a cross or a cue that provides information whether participants need to perform a prosaccade or an antisaccade, usually presented at the center of the screen), while the target (e.g., a flashing object) appears after a delay (i.e., gap). When a gap is present (i.e., gap condition), participants tend to make more errors in antisaccade trials compared to when the fixation point remains visible until target presentation (i.e., overlap condition; Fischer & Weber, 1996). Furthermore, shorter saccade latencies are observed during prosaccade trials in gap conditions than in overlap conditions. This is known as "the gap effect." The presence of a gap releases attention from the original fixation point so that it can move toward the target more quickly (Fischer & Weber, 1996).

Differences in error rates and saccadic reaction times also depend on the duration of the gap. According to Fischer and Weber (1997), an increased number of errors and decreased saccadic reaction times in antisaccade trials were observed in medium gap durations (e.g., 200 or 250 ms). Decreased error rates and increased saccadic reaction times were observed in short (e.g., 0 or 100 ms) or long (e.g., 600 ms) gap durations during antisaccade trials. For these reasons, a gap of 200 ms separated the fixation and targets on all trials in the current study.

Another factor that affects error rate and saccadic reaction times in an antisaccade task is the distance between the fixation point and the target (Hutton, 2008). In particular, the error rate decreases and the initial correct saccade latencies increase as the stimulus distance from the fixation point increases during antisaccade trials (Smyrnis et al., 2002). One possible reason for this pattern is that short distances between the fixation point and the target experience more interference between fixation and saccade signals, with this ambiguity leading to more errors (e.g., Bell et al., 2000; Weber et al., 1992). That is, after fixation to the fixation point and prior to the initiation of a saccade, saccade and fixation signals are active. In short distance trials, where smaller amplitude saccades are performed, conflicting signals of both fixations and saccades are generated, leading to unresolved interferences, which result in more errors.

Purpose of This Study and Research Hypotheses

The purpose of this study was to investigate the executive control abilities, primarily inhibition, of AWS using a nonspeech oculomotor task: the antisaccade task. First, we anticipated that both AWS and AWNS would demonstrate more errors and longer saccade latencies in the antisaccade compared to prosaccade trials, due to the increased inhibition demands on those trials. Second, we expected to see fewer direction errors and longer saccade latencies in the longer distance condition (i.e., 10.8°) compared to the shorter distance condition (5.5°) by both groups, similar to the patterns reported in neurotypical individuals.

Between-groups differences (as evidenced by increased error rates and longer saccade latencies) were expected to emerge during antisaccade but not during prosaccade trials (i.e., significant interaction) due to the increased inhibition demands in those trials. Furthermore, since errors in antisaccade trials represent either deficits in inhibition or weakness in voluntary control of saccadic movements and AWS demonstrate deficits in both inhibition and motor control (e.g., van Lieshout et al., 2004), between-groups differences were expected in the antisaccade trials and not in the prosaccade trials. Finally, we anticipated longer saccade latencies by AWS compared to AWNS in the longer (i.e., 10.8°) but not the shorter (i.e., 5.5°) target distance trials during the antisaccade tasks for a couple of reasons. First, differences have been observed in neurotypical young adults between short and long distance trials (e.g., Smyrnis et al., 2002). Second, longer reaction time data have been reported for AWS as compared to AWNS across multiple diverse linguistic and motor tasks. Those two reasons coupled with the reported motor control deficits in AWS (e.g., van Lieshout et al., 2004) drove our hypothesis.

Method

Participants

Thirty-four participants, 17 AWS (M = 23.41 years, SD = 4.0, age range: 18–33 years; 14 men, three women) and 17 AWNS (M = 23.29 years, SD = 3.88, range: 18–34 years; 14 men, three women) completed this study. Participants were matched in age (± 2 years), gender, educational level (i.e., highest degree obtained), and handedness. Approval for the completion of this study was provided by the authors' institutional review board. Informed consent was obtained prior to participation in the study, and all participants received monetary compensation.

Each participant completed an extensive case history form. No prior or current neurological, emotional, psychiatric diagnoses (e.g., autism or attention-deficit disorder/ADHD) or treatments and/or medication that would alter performance were reported. All participants were native English speakers, had typical or corrected-to-normal vision, and reported no past or present history of speech or language disorders (with the exception of stuttering for the AWS). All participants were required to pass a hearing screening per American Speech-Language-Hearing Association (1997) guidelines. Handedness was determined by the revised version of the Edinburgh Handedness Inventory (Dragovic, 2004).

Stuttering status was determined by a licensed speech-language pathologist based on the following criteria: (a) self-identification as an individual who stutters by the participant and (b) a score of 11 or higher on the Stuttering Severity Instrument–Third Edition (Riley, 1994), which was based on a 300-word conversation sample between each participant and the first author. Stuttering severity in the study's participants varied from very mild to moderate/severe, with 12 participants presenting with very mild/mild stuttering, three participants with moderate stuttering, and two participants with moderate/severe stuttering.

Apparatus

Eye movements were monitored monocularly using an Eyelink 1000 desktop mounted eye tracker by SR Research Ltd. (n.d.). Only the movements of the right eye were recorded. Sampling rate was 1000 Hz. Stimuli were displayed on a 17-in. monitor and presented via the Experiment Builder application by SR Research. Calibration, validation, and drift correction were also operated via the Experiment Builder application by SR Research. Participants were asked to place their foreheads against a rest in order to prevent movements and to maintain a constant distance of their eyes from the monitor.

Procedure

Participants were seated in a comfortable chair at a 67-cm distance from the remote Eyelink 1000 camera and were required to place their foreheads against a rest. The stimulus distance in degrees was manipulated in this experiment and included two possibilities: 5.5° (i.e., short distance) and 10.8° (i.e., long distance).

Participants were tested one at a time in a quiet room. All participants were presented with a total of 64 trials, four blocks consisting of 18 trials each. An equal number of prosaccade (n = 32) and antisaccade trials (n = 32) was included in the experiment, with half the trials comprising the short distance condition (i.e., 5.5°; n = 16) and the other half comprising the long distance condition (i.e., 10.8°; n = 16) within each task. The location of the target was presented on the left side of the screen in half of the trials (n = 32) and on the right side of the screen in the remaining half (n = 32). The trials for each combination of task, direction, and distance were presented in a random order created for each participant. The first eight trials of each participant were used as practice trials, leaving a total of 56 as experimental trials.

At the beginning of the experiment, participants read the following instructions: "In this experiment, you are going to see series of events happening in each trial. A colored fixation box will be presented at the beginning of the trial, followed by a white box appearing at either side of the screen. If the color of the initial fixation box is green, you should look at the white box. If the color of the initial fixation box is red, you should look in the opposite direction from the white box with the same amount of distance to the center of the screen. Please try to perform the task quickly and as precisely as possible."

Next, a 9-point calibration took place (i.e., tracking nine dots on the screen), and the actual experiment began. For each trial, participants saw a black screen displaying a red (i.e., antisaccade) or a green (i.e., prosaccade) fixation cue at the center of the screen (0°) for varying times between 800 and 1,200 ms, followed by a 200-ms delay (i.e., blank screen, gap). Immediately after the delay, a white box appeared on one side of the black screen at 5.5° (i.e., short distance) or at 10.8° (i.e., long distance). Depending on the color of the initial fixation cue, participants had to either look at the white box (i.e., green initial fixation cue, prosaccade) or in the opposite direction of the white box (i.e., red initial fixation box, antisaccade). The target screen was present for 1,250 ms. Data recording for each trial took an additional 335 ms before advancing to the next trial, which began with the presentation of the red or green fixation cue. Therefore, the interval between trials varied from 2,585 to 2,985 ms, depending on the duration of the fixation cue on the screen.

Data Preparation

Reports generated from the EyeLink Data Viewer by SR Research included information regarding the direction of the first saccade and saccade latencies. Accuracy of the first saccade was determined by the direction of the first saccade in each trial to the correct side of the screen (i.e., toward the target for the prosaccade trials and in the opposite direction of that of the target for the antisaccade trials). Reaction time was defined as the time between the onset of the target (i.e., presentation of the white box either on the left or the right of the screen) until the onset of the first saccade toward one side of the screen. Only reaction times of the accurate first saccades were included in the analyses.

Data Screening

Of the 36 participants initially completing the study (18 participants per group), one AWNS was removed from the analyses after completing the experimental paradigm due to his outlier reaction time performance (2.6 *SD*s from the mean of their group). The outlier's match was also removed from the analyses in order to keep an equal sample size and matched properties across the two groups.

After excluding the first eight trials for each participant (i.e., practice trials), the total number of trials left among all participants was 1,904. Incorrect responses (i.e., first saccades in the wrong direction; n = 254 trials, AWS = 130 trials, AWNS = 124 trials) comprised the 13.3% of all trials and were excluded from the analyses. An additional 7.4% of trials (140 trials) was excluded due to calibration errors or blinking (AWS = 64 trials, AWNS = 76 trials). Finally, trials that were 2 *SD*s below or above the mean of each group in reaction time were excluded (i.e., 3% of trials, AWS = 28 trials, AWNS = 30 trials; Ratcliff, 1993). Thus, 1,452 accurate trials were included in the following analyses of saccade latencies (76.3% of all trials, AWS = 730 trials, AWNS = 722 trials) .

Statistical Analyses

A mixed-effects analysis of variance type model was used to analyze the data in R, Version 3.5.1 (RStudio Team, 2018), using the function "mixed" from the package "afex" (Version 0.27-2; Singmann et al., 2020). A mixed-effects model was selected to analyze the data for a few key reasons (Harel & McAllister, 2019): First, they have an advantage in managing missing data. That is, they access and use any data that are available from each participant, which increases the power of the model. Therefore, mixed-effects models are preferred over more traditional approaches (e.g., repeated measures analysis of variance). Second, instead of averaging all trials and arriving at a single value for each participant to enter in the model, mixed-effects models gather every individual trial; hence, they capture the variability of the data for each participant. Finally, mixed-effects models allow for inclusion of both fixed and random factors in the model compared to more traditional approaches that include only fixed factors for more details on mixed-effects models (see Harel & McAllister, 2019). In this study, fixed factors were group (AWS vs. AWNS), task (prosaccade vs. antisaccade), and distance (long vs. short); participant was used as a random intercept. Incorporation of random intercepts for each participant assumes that participants can differ in their performance, and this variability can be captured by the model with the inclusion of random effects (Harel & McAllister, 2019).

Dependent measures in the analysis included accuracy and reaction time for every participant in every trial. A full factorial design was used to examine all possible interactions. Fractional degrees of freedom are reported due to the Kenward–Roger method used to compute the denominator degrees of freedom in the mixed-effects linear model (i.e., reaction time). A likelihood ratio test method using a binomial family was used in the nonlinear mixed-effects model (i.e., accuracy). The package "emmeans," Version 1.2.3 (aka least-squares means; Lenth et al., 2018) was used to calculate post hoc pairwise comparisons for significant interactions using the Holm adjustment. Since effect sizes are not available for mixed-effects models, standardized betas were calculated via the package "sjstats" (Lüdecke, 2020) and are reported for the significant reaction time results. Generally speaking, a standardized $\beta \geq .02$ indicates a small effect, a standardized $\beta \geq .15$ indicates a medium effect, and a standardized $\beta \geq .35$ reflects a large effect (Cohen, 1988). Odds ratios (*OR*) are reported for all the accuracy significant results.

Results

Accuracy

AWS were no less accurate than AWNS as the main effect of group did not approach significance, $\chi^2(1) = 0.02$, $p = .90$ (AWS: M = 88.60%, SE = 1.94%; AWNS: M = 88.24%, SE = 1.96%). As expected, a significant main effect was found for task, $\chi^2(1) = 76.90$, $p \leq .0001$, $OR = 1.92$ (see Figure 1), with both AWS and AWNS being significantly more accurate in the prosaccade (M = 93.61%, SE = 1.03%; AWS: M = 94.28%, SE = 1.35%; AWNS = 92.87%, SE = 1.56%) than in the antisaccade trials (M = 79.91%, SE = 2.22%; AWS: M = 78.54%, SE = 3.24%; AWNS: M = 81.21%, SE = 3.01%). Furthermore, a significant main effect was found for distance, $\chi^2(1) = 5.36$, $p = .02$, $OR = 0.83$, with all participants being significantly more accurate in the long distance trials (M = 90.16%, SE = 1.43%; AWS: M = 89.83%, SE = 2.08%; AWNS: M = 90.48%, SE = 1.95%) than the short distance trials (M = 86.42%, SE = 1.78%; AWS: M = 87.23%, SE = 2.43%; AWNS: M = 85.56%, SE = 2.58%). No interactions were significant in the model.

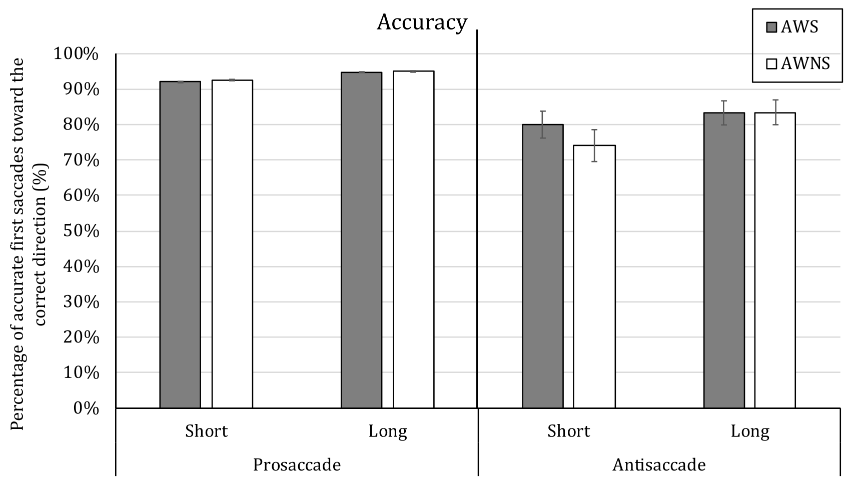
Reaction Time

No differences were found between AWS and AWNS in saccade latency, as the main effect for group did not reach significance, $F(1, 32.04) = 0.53$, $p = .47$ (AWS: M = 239.01 ms, SE = 6.36 ms; AWNS: M = 245.58 ms, SE = 6.36 ms). As expected, a significant main effect was found for task, $F(1, 1414.41) = 274.85$, $p \leq .0001$, standardized $\beta = .36$ (see Figure 2), with both talker groups demonstrating longer saccade latencies in the antisaccade (M = 268.27 ms, SE = 4.82 ms; AWS: M = 262.36 ms, SE = 6.82 ms; AWNS: M = 274.18 ms, SE = 6.82 ms) compared to prosaccade trials (M = 216.32 ms, SE = 4.80 ms; AWS: M = 215.64 ms, SE = 6.64 ms; AWNS: M = 216.99 ms, SE = 6.67 ms). A significant main effect was also found for distance, $F(1, 1413.37) = 18.96$, $p \leq .0001$, standardized $\beta = .13$, with both talker groups demonstrating longer saccade latencies in the long distance trials (i.e., 10.8°; M = 249.11 ms, SE = 4.75 ms; AWS: M = 246.24 ms, SE = 6.70 ms; AWNS: M = 251.98 ms, SE = 6.72 ms) compared to the short distance trials (i.e., 5.5°; M = 235.48 ms, SE = 4.78 ms; AWS: M = 231.77 ms, SE = 6.77 ms; AWNS: M = 239.18 ms, SE = 6.76 ms). No other main effects or interactions were significant in the model.

Discussion

The purpose of this study was to investigate executive control in AWS using the antisaccade task. Apart from being a widely used task of executive control in several other clinical populations (for a review, see Everling & Fischer,

Figure 1. Percentage of accurate first saccades toward the correct direction for adults who stutter (AWS) and adults who do not stutter (AWNS) per task (i.e., prosaccade and antisaccade) and target distance from the center of the screen (i.e., short and long distance). Error bars denote standard error of the mean.



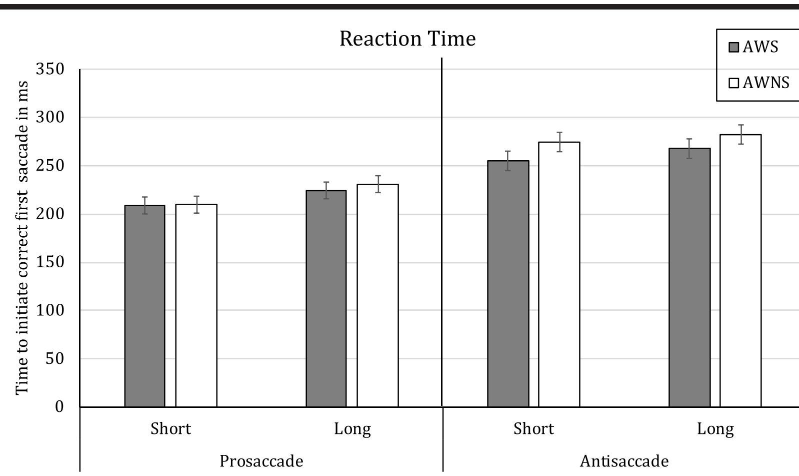
1998), the antisaccade task allowed us to exclude any linguistic and speech motor influences on task performance as participants were only required to move their eyes. In addition, analyzing eye movements provided a more direct and unbiased measure of ongoing mental activity compared to manual behavioral tasks (Hannula et al., 2010).

To review, we assumed that both AWS and AWNS would perform worse, as evidenced by reduced accuracy and longer saccade latencies, in the antisaccade compared to prosaccade trials, as typically found. Decreased accuracy was also expected for the shorter compared to longer target distance trials, and longer saccade latencies were expected in the longer compared to shorter target distance. Our hypothesis was that, due to deficits in executive control, AWS would perform more poorly than the AWNS in the antisaccade task, particularly with respect to latency on long distance trials.

Better Performance in Prosaccade Compared to Antisaccade Trials by Both Groups

As expected, both AWS and AWNS demonstrated more errors and longer saccade latencies in the antisaccade compared to prosaccade trials. Studies performed in neurotypical adults (e.g., Fischer & Weber, 1996; Wang et al., 2013) as well as in other adult clinical populations (e.g., Hutton & Ettinger, 2006) report that antisaccade performance is worse when compared to prosaccade performance.

Figure 2. Saccade latencies of first correct saccades toward the correct direction for adults who stutter (AWS) and adults who do not stutter (AWNS) per task (i.e., prosaccade and antisaccade) and target distance from the center of the screen (i.e., short and long distance). Error bars denote standard error of the mean.



One reason for this pattern is the increased cognitive involvement (i.e., working memory, attention, inhibition) in the antisaccade trials (e.g., Everling & Fischer, 1998; Fischer et al., 2000; Hutton & Ettinger, 2006; Unsworth et al., 2004; Wang et al., 2013).

A considerable body of evidence supports the link between cognitive involvement and performance on the antisaccade task. For example, individuals with lower working memory capacity make more errors and have slower antisaccade latencies compared to individuals with higher working memory capacity (e.g., Unsworth et al., 2004). Patients with schizophrenia (e.g., Barton et al., 2008) and patients with frontal lobe deficits (e.g., Guitton et al., 1985) also demonstrate slower antisaccade latencies compared to neurotypical individuals. The difficulties observed in clinical populations have been attributed to the patients' inability to implement inhibitory control in the saccadic system (e.g., Barton et al., 2008) as well as to difficulties activating goal-directing behaviors (e.g., Barton et al., 2008; Guiton et al., 1985), thus providing further evidence of cognitive involvement in the task.

Better Performance in Longer Compared to Shorter Distance Trials by Both Groups

Our hypothesis regarding increased accuracy in the long compared to short target distance by both talker groups was confirmed. As seen in studies with neurotypical individuals (e.g., Smyrnis et al., 2002) and nonhuman primates (e.g., Bell et al., 2000), the performance error rate in an antisaccade task drops as the target distance from the central fixation point increases (i.e., larger saccade amplitude). This observed pattern has been attributed to the conflicting signals of both fixations and saccades generated from superior colliculus, which lead to an interference that cannot be resolved in small amplitude saccades, resulting in more errors (e.g., Bell et al., 2000; Weber et al., 1992). Saccades of larger amplitude (i.e., longer distance) are not expected to experience this type of interference.

Our hypothesis of longer saccade latencies in the longer compared to shorter target distance by both AWS and AWNS was also confirmed. Even though larger saccade amplitudes do not seem to experience the interference described above, they still have increased saccade latency. Bell et al. (2000) attributed the longer reaction times of larger saccade amplitudes to sensory factors. For example, as the target distance from the central fixation point increases, the location of the target on the retina moves farther away from the fovea. Eventually, the target may enter into an area of reduced visual acuity. Therefore, sensory responses required to initiate a saccade will be decreased, contributing to increased saccade latencies (e.g., Bell et al., 2000).

Between Group Performance and Target Distance From the Center of the Screen

Contrary to our predictions, there were no differences between AWS and AWNS neither in accuracy nor in reaction time in the longer target distance trials in the antisaccade trials. Since neurotypical adults demonstrate differences in their performance between short and long distance trials and AWS have been shown to have motor control deficits and to be slower than AWNS across linguistic and nonlinguistic reaction time tasks, we assumed that AWS would demonstrate more difficulties, as indicated by longer reaction times, than AWNS in the longer distance antisaccade trials. However, no such pattern was observed in our study.

One potential reason for the lack of between-groups differences in the longer target distance trials may lie in the simple motoric nature of our task. The number of movement steps required to complete a motor task define the complexity of the task (Ma & Trombly, 2004). In our study, participants had to only move their eyes to the left or right side of the screen in order to provide their response in the task, which, from a motoric perspective, is considered a simple task. Therefore, the preliminary results from our study confirm prior studies that have also failed to report performance differences between AWS and AWNS during simple motor tasks (e.g., Hulstijn et al., 1992; Max & Yudman, 2003; Webster, 1985, 1986). Furthermore, our results lend further support to the perspective that more complex motor tasks may be required to trigger differences between people who stutter and typically fluent controls.

Between-Groups Performance in the Prosaccade and Antisaccade Trials

Contrary to our predictions, when directly comparing AWS to AWNS, AWS were no less accurate or slower than AWNS on the antisaccade trials. Initially, we anticipated that differences would be found between the two groups in the most cognitively demanding trials: the antisaccade trials. The antisaccade trials required participants to suppress a reflexive prosaccade toward the target (i.e., inhibition), actively maintain task goal and instructions in their working memory (i.e., working memory), while at the same time planning and executing a voluntary saccade in the opposite direction of that of the target (i.e., voluntary motor control; Hutton & Ettinger, 2006). Based on prior evidence reporting deficits in AWS in all of the above processes, we hypothesized that between-groups performance differences would be found in the antisaccade trials. However, results of our study did not support this hypothesis.

Completion of the antisaccade task requires inhibition. The limited number of prior studies that investigated inhibition in AWS employed go/no-go tasks (e.g., Eggers & Alewaters, 2012; Markett et al., 2016) or flanker tasks (e.g., Maxfield, 2018) and reported conflicting results. Recall Eggers and Alewaters (2012) and Markett et al. (2016) reported poorer performance in AWS compared to AWNS during go/no-go tasks. However, Maxfield (2018) did not find any inhibitory processing differences in accuracy or reaction time between AWS and AWNS during a flanker task. Our study, which also failed to find differences between the two groups, involved an antisaccade task. Methodological differences and task variability among studies might have contributed to the mixed results regarding inhibition in stuttering. For example, both go/no-go and flanker tasks require a manual response from participants, whereas our task required only movement of the eyes. Perhaps, the additional movement of the hand that is required for a manual reaction task makes the task motorically more complex compared to only moving the eyes (e.g., Ma & Trombly, 2004).

The counterbalancing of different conditions in the task might have also played a role. Some studies included an equal number of prosaccade/antisaccade, go/no-go, or congruent/incongruent trials (e.g., this study; Eggers & Alewaters, 2012; Maxfield, 2018), whereas others included an unbalanced number of different types of trials (see Markett et al., 2016, for 25% of no-go trials with word stimuli and 10% of no-go trials with arrows). Studies that include a smaller number of an unexpected event (e.g., no-go or antisaccade trials) can lead to more errors due to the infrequent nature of those stimuli compared to studies that include a more balanced number of expected and unexpected events.

Furthermore, the type of the stimuli used in each study could have also influenced each study's results. Maxfield (2018) and Eggers and Alewaters (2012) included nonlinguistic stimuli (i.e., arrows, a green walking figure and a red standing figure), whereas Markett et al. (2016) included linguistic stimuli (i.e., words). Results from prior studies have repeatedly demonstrated that people who stutter have difficulty processing linguistic information but when processing nonlinguistic information results are inconclusive. All these methodological differences hinder our ability to make comparisons among studies and generalize each study's results regarding the role of inhibition in stuttering.

Finally, the lack of differences between AWS and AWNS in the antisaccade task may be explained through the type of inhibition that was involved in our task. As Eggers et al. (2018) stated, there may be different types of inhibitory control, and individuals who stutter may present with deficits only in one type but not in another. The antisaccade and the go/no-go task both assess prepotent response inhibition; however, the flanker task assesses resistance to distractor interference (Friedman & Miyake, 2004). Therefore, different functions of inhibition seem to be involved in the various tasks that have been employed with individuals who stutter and potentially drive the mixed reported results. These conflicting results impose the need for further studies on inhibition and executive functions in order to understand which specific processes are directly linked to stuttering.

Limitations and Future Directions

Executive functions have been linked to IQ (e.g., Arffa, 2007). One limitation of this study was that participants did not complete an IQ test as part of their pretesting battery (however, see Magnusdottir et al., 2019, for lack of a relationship between IQ scores and antisaccade performance). Future studies should incorporate an IQ test as a pretesting measure and further investigate the role of general intelligence and executive functions in individuals who stutter (but see Engle, 2018).

Another limitation of this study was the relatively small number of trials. A total of 56 total trials were analyzed for each participant. Recall that half of those trials were antisaccade and the other half were prosaccade, with an equal number of short and long distance trials among all trials. Even though the significant main effects in our analysis were moderate or high, it is possible that there were not enough trials to detect possible significant interactions. Similarly, the study's sample size of 17 participants per group might have been insufficient to detect a possible significant interaction.

In this study, saccade latency and accuracy (i.e., direction errors) were analyzed as the most commonly used measures in the antisaccade literature. Nevertheless, other measures, such as correction time, can provide valuable information and future studies should consider including that as a measure.

It may also be useful to contrast executive function in eye movements and manual responses in the same sample of participants to determine whether response modality and automaticity may account for differences between studies. In particular, even in the antisaccade task, eye movement responses occur too rapidly to be mediated by language and thus may be relatively immune to deficits associated with stuttering.

Finally, given differences reported between people with anxiety disorders and controls in the antisaccade task when emotional stimuli are used (e.g., faces) coupled with the reported high rates of social anxiety in people who stutter (e.g., Iverach & Rapee, 2014), incorporating emotional stimuli in an antisaccade task may provide useful information regarding attentional biases of people who stutter toward such stimuli (see also Hennessey et al., 2014, who used a modified emotional Stroop task and found that people who stutter responded slower to thread words, as did people with anxiety disorder). Thus, future studies should consider incorporating a modified emotional antisaccade task with individuals who stutter.

Conclusion

This study investigated executive control in AWS and AWNS via an antisaccade task. Even though deficits in executive control, in particular, inhibition, during a motorically simple, non–speech-related oculomotor task were not supported in AWS in this study, these results are preliminary and should be interpreted with caution. Additional studies are needed in order to determine whether deficits in executive control exist for AWS during other motorically simple oculomotor tasks. Furthermore, future investigations should attempt to isolate different functions of inhibition in order to shed more light on the role of inhibition on stuttering.

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