Exogenous Verbal Response Inhibition in Adults Who Do and Do Not Stutter

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Abstract

Introduction: Behavioral and questionnaire-based studies suggest that children who stutter (CWS) exhibit poorer response inhibition than children who stutter (CWNS). However, the behavioral findings in adults who stutter (AWS) are less unequivocal and mainly based on manual response inhibition. Further study is therefore needed, especially given the lack of studies on verbal response inhibition among these groups.

Methods: Thirteen AWS and 14 adults who not stutter (AWNS) participated in a verbal stop signal task (SST) in which they were asked to read aloud six Chinese characters as fast as possible during the go-signal and ignore-signal trials and refrain from naming them during the stop-signal trials.

Results: The two groups showed a comparable response reaction time in the go-signal and ignore-signal trial conditions. Furthermore, there were no significant differences in terms of the stop-signal reaction time (SSRT) and accuracy. However, a significant positive correlation was found between SSRT and the frequency of stuttering in conversation but not in reading.

Conclusion: Current findings seem to provide additional support that exogenously triggered response inhibition among AWS does not differ from AWNS. The association between stuttering frequency and SSRT seems to suggest that individuals with more severe stuttering in conversational speech have reduced exogenous response inhibition. However, this finding needs to be further explored in future studies using different measures of stuttering severity.

Keywords: Stuttering, Verbal Response Inhibition, stop-signal task (SST), adults who stutter (AWS)

Exogenous Verbal Response Inhibition in Adults Who Do and Do Not Stutter

Stuttering is a speech fluency disorder that is manifested by involuntary repeated movements, and fixed postures of the speech organs (Teesson et al., 2003). Some studies suggest a connection between stuttering and impaired response inhibition, which refers to the inability to efficiently suppress the behaviours that are irrelevant, hazardous, inappropriate, and no longer needed (Chambers et al., 2009). Response inhibition is essential for both cognitive and (speech) motor control (Verbruggen & Logan, 2008). One of the speculations for this connection is that the proposed brain regions that account for a response inhibition deficit also happen to be implicated in people who stutter (PWS). These regions include the basal ganglia structures that serve to initiate and withhold the movement behaviors (for a review of the relevant neuroimaging studies see Etchell et al., 2018). Furthermore, it has been argued that weaknesses in inhibitory control and/or other executive function skills, such as working memory, may lead to less stable phonological and lexical representations, resulting in more fluency breakdowns in PWS (Anderson & Ofoe, 2019). Hence, over the last decade, there has been an increasing interest to study the response inhibition of both children who stutter (CWS) and adults who stutter (AWS) using a variety of behavioral and event-related potential (ERP) measures.

Response inhibition in CWS

Parental questionnaire-based studies revealed that CWS, as a group, score lower on inhibitory control compared to children who do not stutter (CWNS) (Eggers et al., 2009, 2010; Ofoe et al., 2018). Findings from these studies have triggered different behavioral and neurophysiological studies examining the prepotent response inhibition (i.e., the ability to supress a dominant or automatic response, Friedman & Miyake, 2004) of preschool and school-age CWS compared to the typically fluent peers (Anderson & Ofoe, 2019; Ofoe et al., 2018). For instance, some studies using Go-No Go tasks, which require the participant to quickly respond to frequently presented items (go-trials) and refrain from responding to less frequently presented items (no-go trials), reported CWS having more difficulties inhibiting their button press reactions during No-Go trials (Eggers et al., 2013), while others did not find any differences (Piispala et al., 2016). Related neurophysiological examinations have also reported atypical response inhibition as demonstrated by a weaker or indistinct P3 component in No-Go condition in CWS, possibly pointing to insufficient deactivation of the relevant motor areas (Piispala et al., 2017). Anderson and Wagovich (2017) used Grass-Snow and Baa-Meow tasks, measuring prepotent complex response inhibition (i.e., inhibiting a dominant response, while executing a subdominant response) in children in a similar manner to Stroop tasks in adults. The Grass-Snow task requires children to press the ‘snow’ button when they hear the word ‘grass’ and vice versa. The Baa-Meow task was also similar to Grass-Snow task, however, nonverbal stimuli (i.e., baa, meow) were used instead of the verbal stimuli. This task requires children to press the “sheep” button when they hear the sound “meow” and press the “cat” button when they hear the sound “baa”. Children who stutter, compared to CWNS, had significantly longer RTs on both tasks and were less accurate on the Baa-Meow task, indicating a lower efficiency in complex response inhibition (Anderson & Wagovich, 2017) .

Another paradigm that has been used for assessment of inhibitory control in CWS is the Stop Signal Task (SST) in which the person needs to stop an already initiated response after the presentation of a stop-signal (Logan & Cowan, 1984). The theoretical basis of a SST can be explained in terms of the ‘horse-race model’ proposed by Logan and Cowan (1984). The race is between the process triggered by the stop-signal and the ongoing process of responding to the primary task. When the stop-signal process finishes before the primary task process begins, the response is successfully inhibited. If not, the response to the primary task will be executed (Logan & Cowan, 1984). Because the inhibition process in a classical SST is triggered by an external signal, this type of inhibition is also categorized as exogenous response inhibition; endogenous (volitional) response inhibition on the other hand, refers to tasks with no external stop signals in which the inhibition process is internally generated (Eggers et al., 2018; Schell et al., 2014). Some have argued that a SST is more suitable for the assessment of motor response inhibition as it requires the inhibition of a motor response that has already been initiated (Etchell et al., 2012). However, the findings from behavioral studies using a SST in children do not report a reduced response inhibition in CWS. For instance, Eggers et al. (2018) compared the manual response inhibition of CWS to CWNS in reaction to an externally-triggered stop signal, and reported comparable performances between both groups in terms of the stop-signal reaction time (SSRT). On the other hand, Harrewijn (2017) reported a shorter SSRT (i.e., enhanced response inhibition) and lower cognitive impulsivity in CWS during the externally-triggered response inhibition task when the groups were controlled in terms of their IQ level. These authors also suggested that in CWS, internally-triggered (also labelled as volitional or endogenous) inhibition might be more impaired than inhibition in reaction to external stimuli. This was reflected by reduced brain activity at rostral cingulate region during the internally-triggered response inhibition (Harrewijn et al., 2017).

Response inhibition in AWS

Also in AWS, different behavioral measures have been used to evaluate prepotent response inhibition. Markett et al. (2016) examined manual response inhibition using two versions of a SST. During the first version, participants were asked to categorize words that appeared on the screen as animal or non-animal by pressing two response buttons. In about 25% of the trials an auditory stop-signal was presented, signalling participants to withhold their manual response. The second task used left and right arrows instead of words, and a visual stop-signal (a red circle presented either above or below the arrows) appeared in 10% of the trials. AWS, compared to AWNS, showed a comparable accuracy but a longer SSRT across both tasks, indicating they had more difficulty to successfully withholding an already initiated manual motor response. A more recent study by Treleaven and Coalson (2020) also found a longer SSRT in AWS than AWNS. They also reported the slower inhibition in AWS to be predicted by negative experiences related to stuttering (as measured by the Overall Assessment of the Speakers' Experience of Stuttering, OASES; Yaruss & Quesal, 2006) but not by stuttering severity (as measure by the Stuttering Severity Instrument-4, SSI-4; Riley, 2009). In contrast, a recent study that used an anti-saccadic task, comparing the oculomotor response inhibition of AWS to AWNS, showed comparable performances in terms of response accuracy and RT when participants had to inhibit a reflexive saccade toward the flashing onset target stimuli and instead look in the opposite direction (Gkalitsiou et al., 2020). It is also notable that different cognitive functions such as working memory and attention (in addition to response inhibition) have been documented to be actively engaged in the antisaccadic task (Gkalitsiou et al., 2020). Furthermore, a behavioral and fMRI study that used SST to study the manual response inhibition in AWS suggests that AWS do not show any decreased response inhibition compared to AWNS by showing a comparable SSRT in stop-signal trials (Whiltshire, et al., 2022). On the other hand, the neuroimaging data from the same study suggests that AWS may suffer from an increased global inhibition by showing an atypical overactivation of the right inferior frontal gyrus (an area that is selectively engaged in inhibitory behaviors in a typical brain) while responding to the go-trials, but not during the stop-trials.

It is notable that previous studies in AWS have mainly focused on manual response inhibition, despite the fact that stuttering is a speech-related problem. Therefore, it is fair to say that, compared to the manual response inhibition, verbal response inhibition is much understudied in this population (Maxfield, 2020; Treleaven & Coalson, 2021). Recently, Maxfield (2020) used a combined behavioral and ERP paradigm to test inhibitory control of the lexical selection in AWS. Participants had to name two sets of pictures with high and low name agreement. Naming low agreement pictures (i.e., pictures that are named more variably, such as the picture of a flute) in comparison to high agreement pictures (i.e., pictures that are named less variably such as the picture of a dog) takes more time as they elicit more competing words and more cognitive resources are required to inhibit the competing non-target words. Behavioral findings revealed that although both AWS and AWNS named the low agreement pictures more slowly than high agreement, the difference was larger in AWS. Furthermore, the ERP findings documented both groups showed a similarly more negative (N2[i]) ERP component in response to low agreement pictures than the high agreement ones, however, AWS showed less scalp distribution than AWNS. However, since other psycholinguistic variables besides name agreement (e.g., age of acquisition, familiarity, word frequency) have shown to play role in picture naming (Bakhtiar et al., 2013), it is not clear whether the effects of those variables have been accounted for in this study. It should also be noted that Maxfield (2020) failed to find any behavioural or neurophysiological differences when a flanker[ii] task was used to examine the domain-general inhibitory control in AWS

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[i] N2 is a negative-going ERP component, which normally appears between 200 to 400 ms following the stimulus onset, and has been associated to the initiation of the response inhibition (Etchell et al., 2012).

[ii] A flanker task is a response inhibition task where the target is flanked by non-target stimuli corresponding to the same directional response as the target (congruent flanker condition), the opposite response (incongruent flanker condition), or neither (neutral flanker condition).

versus AWNS. Treleaven and Coalson (2021) compared verbal response inhibition to manual response inhibition in AWS by using three versions of a SST (i.e., a two-letter naming task, a two-image naming task, and a 12-image naming task). In contrast to Maxfield, they did not find any significant group differences either in verbal nor in manual response inhibitions. However, the verbal inhibition task (but not manual) was predictive of the adverse effects of living with stuttering as measured by OASES (Yaruss & Quesal, 2006). Furthermore, no significant relationship was found in this study between the verbal and manual response inhibition, documenting that manual inhibition may not necessarily be analogous to verbal inhibition. This maps on to findings from numerous neurophysiological studies documenting that inhibitory control in the verbal domain, governed by the corticobulbar system, differs (and is less effective) compared to the manual domain, governed by the corticospinal system (Etchell et al., 2012; Jaberzadeh et al., 2008; Sowman et al., 2008).

As discussed, previous research has used various stop signal tasks to study the manual and (more recently) verbal response inhibition in people who stutter. However, one potentially confounding factor across all these studies is that the experimental design does not allow to control for the effects of saliency/novelty of the stimuli while measuring the reaction to the stop-signal stimuli. Several ERP studies have incorporated ignore-signal trials in addition to stop-signal trials to account for this phenomena in response inhibition task (e.g., Dimoska & Johnstone, 2007; Etchell et al., 2012). Etchell et al. (2012) have found that successful stop-signal trials and ignore-signal trials have similar amplitude at the early ERP components between 150 ms and 300 ms (i.e., N2), and only differentiate in later ERP components (i.e., P3). Given this overlap in processing of the saliency effects of stimuli in a stop signal task, it was recommended to include ignore-signal trials with a similar frequency and visual/auditory stimulation as the stop-signal trials (Etchell, et al., 2012).

Therefore, in light of the potential dissociation between verbal and manual inhibition and the scarcity of the studies looking into the verbal response inhibition in AWS, as well as to control for the effects of saliency of stimuli in the stop-signal task, this study aims to investigate the exogenous verbal response inhibition of AWS compared to AWNS using a verbal version of the SST while controlling for this saliency effect, and to explore the relation between verbal response inhibition and stuttering frequency. We were also interested to see whether the lack of verbal response inhibition found in previous study (Treleaven & Coalson, 2021) can be replicated in this study when a slightly different SST paradigm is being used.

Methods

Participants

Participants in this study were 13 Cantonese-speaking AWS (9 males, 4 females) between 19 and 66 years old (M = 31.00, SD = 13.29) and 14 AWNS (9 males, 5 females) between 19 and 60 years old (M = 28.18, SD = 11.49). Both groups were matched based on age (± 5 years), and education one to one (see Table 1). Education was measured as the number of years of formal education. The non-parametric Mann-Whitney U test showed the two groups are comparable in terms of age (U = 85.5, p = 0.808) and education level (U = 67.5, p = 0.228). Furthermore, the participants did not report any specific medical, psychological or neurological disorders. The AWS self-identified as persons who stuttered, and were also diagnosed with stuttering by qualified speech therapists based on recorded speech samples and client interviews. The AWNS self-identified as persons who do not stutter.

The recorded speech samples of AWS consisted of 214 to 370 syllables of conversational speech and oral reading. For one AWS, only 153 syllables of conversational speech were collected due to the high stuttering severity. The samples were analysed for stuttering-like disfluencies by the first author, a qualified speech-language pathologist with experience in speech disfluency analysis, and a research assistant who was specifically trained (see Table 1). The intraclass correlation coefficient showed high inter-rater reliability both for conversation (agreement = 0.908) and for oral reading samples (agreement = 0.827).

The study was approved by the local Human Subjects Ethics Committee , and written consents were obtained from both groups. Participants were paid for their participation in this study.

Table 1. Demographic information for all participants and stuttering severity in AWS

Subjects	Gender	Age	Education (years)	Conversation (%SS)	Reading (%SS)
AWS1	M	22	14	1.32	2.52
AWS2	M	19	12	4.18	2.16
AWS3	M	33	16	6.85	2.51
AWS4	F	25	16	1.30	1.08
AWS5	M	29	12	8.79	3.26
AWS6	M	22	16	5.65	3.94
AWS7	M	51	16	1.17	0.90
AWS8	F	36	16	2.36	2.38
AWS9	F	25	18	5.11	10.51
AWS10	M	66	13	13.07	5.37
AWS11	F	35	15	7.94	3.60
AWS12	M	19	12	4.42	2.11
AWS13	M	21	14	4.14	3.35
AWNS1	M	20	16	-	-
AWNS2	M	21	16	-	-
AWNS3	F	21	16	-	-
AWNS4	M	23	16	-	-
AWNS5	F	24	16	-	-
AWNS6	M	27	16	-	-
AWNS7	M	30	16	-	-

AWNS8	M	53	16	-	-
AWNS9	F	38	16	-	-
AWNS10	F	28	18	-	-
AWNS11	M	60	13	-	-
AWNS12	F	31	15	-	-
AWNS13	M	19	12	-	-
AWNS14	M	21	14	-	-

Task, stimuli and procedure

The task used in this study was a verbal variant of the SST, which was adopted from Etchell et al.'s study (2012). The task and stimuli are presented in Cantonese, which is a tonal language in which the speech syllables carry different lexical tones. These systematically distinguish lexical meaning using pitch patterns besides the vowels and consonants. There are six lexical tones in Cantonese based on their relative pitch including three level tones (tones 1, 3, 6) and three contour tones (tones 2, 4, 5). Therefore, six Chinese characters representing 6 lexical tones in Cantonese (姨 /ji1/ "auntie", 椅 /ji2/ "chair",意 /ji3/ "idea",兒 /ji4/ "son", 以 /ji5/ "use", 二, /ji6/ "two") were selected. The phonological structure of these words consisted of a semivowel /j/ and a vowel /i/ and only differed in terms of their lexical tones. In the initial task, the participants were familiarised with the characters to make sure they could recognize them correctly. The characters were presented to the participants across three different conditions including the go-signal trials (surrounded by green borders), stop-signal trials and ignore-signal trials (see Figure 1). The stop-signal and ignore-signal trials were similar to go-signal trials except, that after a variable delay the green border changed to a red border (signalling to stop the response) or blue border (signalling to continue the response), respectively.

The participants were asked to read aloud the Chinese characters as fast as possible during the go-signal trials and refrain from naming them during the stop-signal trials. During the ignore-signal trials participants had to ignore the blue signal and read aloud the Chinese characters as fast as possible. The stimuli were presented over 12 blocks with each block consisting of 48 trials including 24 go-signal trials, 12 ignore-signal trials and 12 stop-signal trials that were presented randomly. The stop signal delay (SSD) changed dynamically across different trials depending on the participant's performance. If a participant was able to successfully inhibit the verbal response on a particular stop-signal trial, then the SSD of the subsequent stop-signal trial was increased by 50 ms or 17 ms to reduce the chance of success on that trial. However, when the participant was not able to successfully withhold the verbal response on a particular stop-signal trial, then the SSD of the subsequent stop-signal trial was decreased by 50 ms or 17 ms to increase the chance of success on that trial. Since the speed of the inhibition process , that is the stop-signal reaction time (SSRT), cannot be observed, a horse-race model is used to estimate the SSRT. The delay between the primary task stimulus and the stop signal, that is the stop signal delay (SSD), is varied based on a specific tracking procedure. Following Etchell et al.'s (2012) procedure, we used two step sizes for SSD including 50 ms for six blocks, and 17 ms for another six blocks. The two staircases (i.e., the step-up and step-down algorithms), presented independently, with the order of staircases randomly interleaved, started at six different arbitrarily selected time points (50 ms, 83 ms, 117 ms, 150 ms, 183 ms, and 216 ms). At the beginning, 30 practice trials were randomly presented (i.e., 20 go-signal trials, 5 ignore-signal trials, and 5 stop-signal trials) to familiarize participants with the task. Furthermore, short breaks were given between the blocks to prevent fatigue among participants.

The performance measures used in this study were mean stop-signal accuracy (SSA: the percentage of responses that are successfully withheld in reaction to the stop signals), mean SSRT (calculated by subtracting mean SSD from the value of the n-th response RT for go-signal trials), mean SSD (delay between the go-signals and stop-signals), mean failed stop-signal RT (FSRT: RTs of the failed to withhold responses in reaction to stop-signal trials), mean go-signal RT (GORT: RTs of the responses given to the go-signal trials), and mean ignore-signal RT (IGRT: RTs of the responses given to ignore-signal trials) (cf. Etchell et al., 2012). Higher scores on SSA, SSD and/or lower scores on SSRT point to a better facility with response inhibition. Lower score on FSRT would generally reflect that the individual is faster (or more impulsive) in responding to the stop-signals.

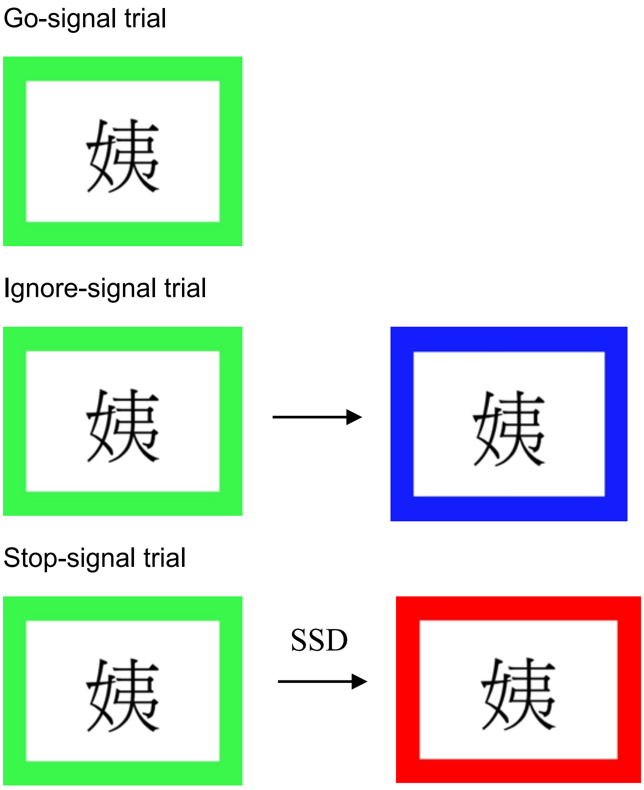

Figure 1. Depiction of presentation of the Chinese characters across go-signal trials (top chart), ignore-signal trials (middle chart) and stop-signal trials (bottom chart), Note: SSD = stop-signal delay

Data analysis

Linear mixed-effect (LME) analysis using lme4 package (Bates et al., 2015) in R software was adopted to analyze the study results across different measures including the RT for go-trials (GORT), ignore-trials (IGRT), stop-trials (SSRT and failed stop RT, FSRT), and also the stop-signal accuracy (SSA). The LME model included the group (AWS vs. AWNS) and lexical tones (tones 1-6) and their two-way interactions (group x tones) as fixed effects and random intercept of the subjects and lexical tones as random effects. The random and fixed effects were removed one by one across different models and each model was compared with the maximal model to reveal the final model.

Furthermore, Spearman correlation analyses were conducted between the different measures of the stop-signal condition (i.e., SSRT, SSA and FSRT) and stuttering frequency across both conversation and reading tasks among AWS. A Bonferroni correction for multiple comparisons was used, resulting in an alpha level of .05/6 = .0083.

Results

Descriptive data for different behavioral measures are provided in Table 2. LME analysis showed significant effects for lexical tones across the different measures including SSA (X^2 = 34.47, $p < 0.001$), SSRT (X^2 = 29.47, $p < 0.01$), GORT (X^2 = 37.38, $p < 0.001$) and IGRT (X^2 = 25.84, $p < 0.01$). Although the SSRT was numerically higher in AWS (M = 358 ms, SD = 91) than AWNS (M = 311 ms, SD = 86), the group difference (X^2 = 2.35, p = 0.12 , d = 0.4) and the interaction with lexical tones were not statistically significant (X^2 = 4.31, p = 0.50) (see also Figure 2). Similarly, the SSA was numerically lower in AWS (*M* = 0.68, *SD* = 0.22) than AWNS (*M* = 0.76, *SD* = 0.17) but the group difference (X^2 = 1.39, *p* = 0.24, *d* = 0.4) and its interaction with lexical tones were not significant (X^2 = 4.57, *p* = 0.47). Furthermore, there were no significant group differences for IGRT (X^2 = 0.0008, *p* = 0.98, *d* = 0004), FSRT (X^2 = 0.95, *p* = 0.33, *d* = 0.001) and GORT (X^2 = 0.00, *p*= 0.99, *d* = 0.00), nor for their interactions with lexical tones.

Table 2. Descriptive statistics for different conditions for AWS and AWNS

AWS	***Mean***	***SD***	***Min***	***Max***
SSA	0.68	0.22	0.17	1.00
SSRT	358	91	173	816
SSD	209	132	0	733
FSRT	576	227	276	1419
GORT	699	265	405	1480
IGRT	697	301	364	1438
AWNS				
SSA	0.76	0.17	0.33	1.00
SSRT	311	86	134	536
SSD	216	133	0	733
FSRT	674	278	207	1417
GORT	699	204	430	1173
IGRT	694	216	398	1197

Note. SSA = stop-signal accuracy; SSRT = stop-signal reaction time; SSD = stop-signal delay; FSRT = failed stop-signal reaction time; GORT = go-signal reaction time; IGRT = ignore-signal reaction time

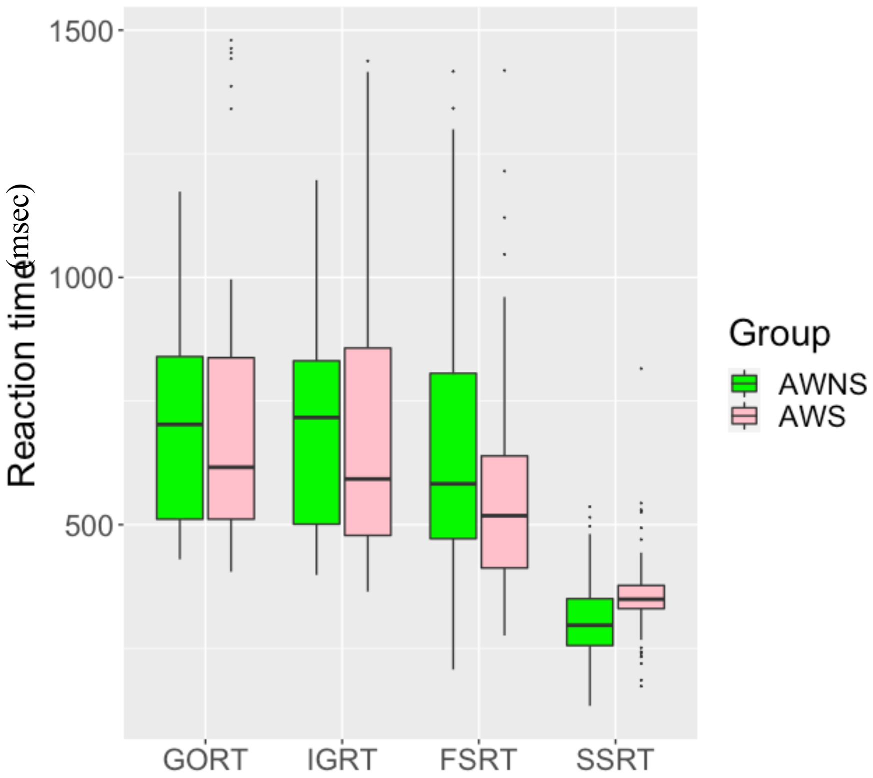

Figure 2. Reaction time measures across different conditions (GORT = go-signal RT, IGRT= ignore-signal RT, FSRT = failed stop-signal RT, SSRT = stop-signal RT

Spearman correlational analyses revealed a significant positive correlation between SSRT and percentage of syllables stuttered (%SS) in the conversation task (r = 0.571, p < 0.05), but not in the reading task (r = 0.19, p = 0.53) or in the averaged percentage of syllables stuttered across the conversation and reading task (r = 0.40, p = 0.18). Other measures of stop-signal condition (i.e., SSA, FSRT) were not significantly correlated with %SS (see Table 3). It is also notable that SSA was significantly correlated with FSRT among

AWS, which indicates that participants who were generally faster (or more impulsive) in responding to the stop-signal trials tend to have lower stop-signal accuracy, or vice versa.

Table 3. Spearman Correlation Matrix between stuttering frequency and different measures of stop signal task

	Conversation	Reading	SSA	SSRT	FSRT
%SS (Conversation)	—				
%SS (Reading)	0.681 *	—	0.190	0.192	-0.149
SSA	0.176	0.190	—		
SSRT	0.571 *	0.192	-0.179	—	
FSRT	0.162	-0.149	0.687 **	-0.058	—

Note. %SS. = % stuttered syllables; SSA = stop-signal accuracy; SSRT = stop-signal reaction time; FSRT = failed stop-signal reaction time (* p < .05, ** p < .01, *** p < .001).

Discussion

Some of the previous experimental studies that examined manual response inhibition showed a lower performance (i.e., slower SSRT) for AWS than AWNS, and found no significant correlation between manual response inhibition and stuttering severity as measured by SSI-4 (Markett et al., 2016; Treleaven & Coalson, 2020a, 2021). One domain that, to our knowledge, has not being sufficiently studied in AWS is verbal response inhibition, despite the fact that stuttering is a speech production problem. Another issue is that the existing research does not account or control for the effect of saliency of stimuli in response inhibition tasks. In this study we aimed to examine the verbal response inhibition of AWS and its relation to stuttering frequency, using a verbal version of the SST that included ignore-signal stimuli to account for the effect of saliency (Etchell et al., 2018).

The results of our study showed a comparable performance in terms of both response inhibition accuracy and RT in the verbal domain among AWS and AWNS. Given that the two groups had comparable performance on response RT for ignore-signal trials, it can be concluded that the lack of group difference in verbal response inhibition cannot be explained by the saliency effects while reacting to the stop-signal stimuli. The findings from our current study resonate with a recent study, which reported comparable verbal response inhibition between AWS and AWNS using the three versions of verbal SSTs (Treleaven & Coalson, 2021). Furthermore, the more recent studies that combined behavioral and neuroimaging methods confirm our results that AWS demonstrated similar exogenous response inhibition to AWNS (Neef et al., 2017; Orpella et al., 2022; Wiltshire et al., 2020). In fact, the accumulating evidence from the recent neuroimaging studies suggests that the response inhibition mechanism in AWS is affected (Neef et al., 2017; Orpella et al., 2022; Wiltshire et al., 2020). For instance, Neef et al., (2017) reported a positive correlation between the strength of connectivity in right inferior frontal gyrus (i.e., the neural pathways suggested to be involved in inhibitory function) and stuttering severity (Neef et al., 2017). The authors indicated that the results would reflect stronger global (non-specific) response inhibition in PWS, which may impede smooth transitions between successive speech motor actions and result in blocks and prolongations. A more recent MEG study (Orpella, et al., 2022) also provided evidence that AWS experience global[iii] motor inhibition prior to the stuttered speech, which was associated with the anticipation of the words being stuttered. This effect was reflected by an increasing beta power in right pre-supplementary motor area, which is considered as a part of the network involved in stopping the actions. Together, these studies indicate that response inhibition (especially the endogenous motor inhibition) is enhanced in people who stutter. This has also been shown across several studies in children that the externally triggered manual response inhibition is either comparable or enhanced in CWS than CWNS (Eggers et al., 2018; Harrewijn et al., 2017) as compared to endogenous/volitional response inhibition (Harrewijn et al., 2017).

[iii] There is evidence for different, partly overlapping types of response inhibition. Besides the earlier discussed endogenous and exogenous response inhibition, global response inhibition refers to a stopping of all actions in contrast to selective inhibition in which only certain actions are stopped (for more detailed information see Jahanshahi et al., 2015).

However, our findings dissociate from the few earlier studies testing manual response inhibition through the SST indicating that AWS are slower or less accurate than AWNS (Markett et al., 2016; Treleaven & Coalson, 2020). Lack of significant group differences in terms of SSRT, in contrast to the previous studies in adults, could be related to several factors. Firstly, we tested the verbal response inhibition whereas those studies tested manual response inhibition. Previous studies that tested both manual and verbal response inhibition have not consistently reported a comparable performance across the modalities among fluent speakers (Castro-Meneses et al., 2015b, 2015a; Wildenberg & Christoffels, 2010). Moreover, a recent study, which has also examined the verbal response inhibition in AWS did not report any significant differences with AWNS (Treleaven & Coalson, 2021). Secondly, the current SST study used visual cues (i.e., changing colored borders) to signal the stop trials, while previous SST studies mainly used auditory cues (e.g., a 1000 Hz tone). Differences in auditory versus visual attention processing might affect response inhibition and impact the different findings. In fact, several studies have reported that AWS have issues in perceptual processing of the auditory stimuli (Bakhtiar et al., 2021; Basu et al., 2018; Sares et al., 2019; Shao et al., 2022). It has been argued that the disadvantages of AWS in using auditory cues as a stop signal may explain their reportedly reduced response inhibition in studies that used auditory cues in SST

(Treleaven & Coalson, 2021). Lastly, previous studies did not seem to control for the effects of saliency/novelty of the stimuli while measuring the reaction to the stop-signal stimuli in AWS.

One of the findings from this study is that SSRT was positively correlated with stuttering frequency in conversation, indicating that people with more stuttering-like disfluencies showed a reduced verbal response inhibition. This seems to be in line with previous survey-based findings in which higher stuttering severity was associated with lower effortful control[iv] (Kraft et al., 2014, 2019). The recent studies that examined the verbal and manual response inhibition using SSTs (Treleaven & Coalson, 2020, 2021) did not find any significant association between response inhibition and stuttering severity as measured by SSI-4 (Riley, 2009). While at first sight this may seem to be contradictory to our finding, a closer examination of the methods shows it is not. In our study, only a positive correlation was found with %SS in conversation, not in reading or combined scores. The %SS used in the Treleaven and Coalson (2021) study was an averaged %SS across conversation and reading. This could mean that the impact of a reduced verbal response inhibition may only surface in more complex speech-language planning and production, as seen in spontaneous speech (see

[iv] Effortful control is an umbrella term for self-regulatory processes including inhibitory control.

e.g., Levelt, 1983), and might be less likely to surface in less complex planning and production, such as reading. Furthermore, Treleaven and Coalson (2021) found that reduced verbal -but not manual- inhibition is more associated to the adverse effects of living with stuttering (as measured by OASES) rather than the severity of stuttering. Further study in this area is needed to get a better insight in the relation between (verbal) response inhibition and the different components of stuttering severity.

Overall, this study reports a comparable verbal response inhibition among AWS and AWNS. While previous studies have suggested that endogenously triggered inhibition (i.e., without external stop signals) is impaired in PWS compared to typically fluent speakers, current findings confirm previous studies documenting that exogenously triggered response inhibition is spared (Eggers et al., 2018; Harrewijn et al., 2017).

Limitations

Currently, there are no norm-referenced tools for the assessment of stuttering severity in Cantonese. Since Cantonese is a distant language from English, with a different topography of stuttering behaviours (Law et al., 2018), any absolute implication from the SSI-4, which is based on the English norms, may not be fully representative of stuttering severity. In the absence of such a norm-referenced tool in Cantonese, %SS was used as a reflection of stuttering frequency for this study. Another of the limitations of this study is that it only reports the behavioral measures of verbal response inhibition, which only provides information about the end product of the relevant cognitive processes involved in response inhibition. Furthermore, it is nearly impossible to obtain a direct measurement of the SSRT in behavioral tasks since a successful response inhibition means withholding the relevant behavioral responses (e.g., button press or naming). Future studies may consider using ERP measures to directly examine the cognitive processes that are involved in response inhibition in children and adults who stutter.

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