Inhibitory Control in Childhood Stuttering.

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Abstract

Purpose: The purpose of this study was to investigate whether previously reported parental questionnaire-based differences in inhibitory control (IC; Eggers, De Nil, & Van den Bergh, 2010) would be supported by direct measurement of IC using a computer task.

Method: Participants were 30 children who stutter (CWS; mean age = 7;05 years) and 30 children who not stutter (CWNS; mean age = 7;05 years). Participants were matched on age and gender (± 3 months). IC was assessed by the Go/NoGo task of the Amsterdam Neuropsychological Tasks (De Sonneville, 2009).

Results: Results indicated that CWS, compared to CWNS, a) exhibited more false alarms and premature responses, b) showed lower reaction times for false alarms, and c) were less able to adapt their response style after experiencing response errors.

Conclusions: Our findings provide further support for the hypothesis that CWS and CWNS differ on IC. CWS, as a group, were lower in IC pointing towards a lowered ability to inhibit prepotent response tendencies. The findings were linked to previous IC-related studies and to emerging theoretical frameworks of stuttering development.

Key words: stuttering, children, inhibitory control, temperament, executive control

1. Introduction

Inhibitory control (IC) is the ability to suppress, interrupt or delay an inappropriate response under instructions or in novel or uncertain situations (Clark, 1996; Rothbart, 1989) or to ignore irrelevant information (Dagenbach & Carr, 1994; Dempster & Brainerds, 1995; Rothbart & Posner, 1985). IC is essential for the performance of everyday tasks (Simpson & Riggs, 2009) and has been implicated in cognitive development (Harnishfeger & Bjorklund, 1994), executive functioning (Friedman & Miyake, 2004), and the conscious use of attention or attentional control (Desimone & Duncan, 1995; Kochanska, 1997). It is strongly related to the coordination and integration of mental processes in successful task performance (Dowesett & Livesey, 1999) and plays an important role in the self-regulation of emotional states (Kochanska, Murray, Jacques, Koenig, & Vandegeest, 1996; Kopp, 1982).

Several authors have alluded to a possible role for self-regulatory processes, attentional control processes, and more specifically inhibitory control in the development of stuttering. Evidence for possible reduced self-regulation has come from observations that children who stutter (CWS) are (a) lower in adaptability (Anderson, Pellowski, Conture, & Kelly, 2003), (b) lower in biological rhythmicity (Anderson, et al., 2003) and (c) less efficient in emotional regulation (Karrass et al., 2006), although the latter finding was not confirmed in a recent study from the same research group (Arnold, Conture, Key, & Walden, 2011). With regard to attentional control, studies have reported CWS to be (a) more or less distractible, depending on the measurement method used (Embrechts, Ebben, Franke, & van de Poel, 2000; Schwenk, Conture, & Walden, 2007; Anderson et al., 2003), (b) less efficient in attention regulation (Felsenfeld, van Beijsterveldt, & Boomsma, 2010; Karrass et al., 2006; Schwenk et al., 2007), and (c) less efficient in attentional orienting (Eggers, De Nil, & Van den Bergh, 2010, 2011); also studies in adults who stutter pointed to a lowered efficiency in allocating attentional resources under dual task conditions (Bosshardt, 1999, 2002, 2006; Bosshardt, Ballmer, & De Nil, 2002; Smits-Bandstra & De Nil, 2007; Vasic & Wijnen, 2005). Finally, some studies reported that CWS were lower in inhibitory control (Eggers et al., 2010; Embrechts et al., 2000), while others found no difference (Anderson & Wagovich, 2010).

Further study of IC in stuttering may be particularly interesting because of its role in speech motor planning and production (e.g., Alm, 2004b; Smits-Bandstra & De Nil, 2007; Xue, Aron, & Poldrack, 2008); moreover, imaging studies in stuttering (for an overview: see Watkins, Smith, Davis, & Howell, 2008) have revealed aberrant activity in the underlying cortical and subcortical structures of IC, namely the right prefrontal cortex (e.g., Casey, et al., 1997; Aron, Fletcher, Bullmore, Sahakian, & Robbins, 2003) and the fronto-basal ganglia circuit (Aron et al., 2007; Chambers, Garavan, & Bellgrove, 2009; Congdon et al., 2010).

In a number of recent studies, we have found evidence for a possible role of IC in developmental stuttering (Eggers et al., 2009, 2010). These studies were done using the Children's Behavior Questionnaire (CBQ; Rothbart, Ahadi, Hershey, & Fisher, 2001), a parent-report temperament questionnaire for young children based on Rothbart's temperament model. Rothbart defines temperament as constitutionally based individual differences in reactivity and self-regulation (Rothbart, 1989, 2011; Rothbart & Derryberry, 1981). Reactivity refers to motor, emotional, and attentional responses to internal and external stimuli and is operationalized in CBQ-scales such as Approach and Anger/Frustration. Self-regulation are those processes serving to modulate - i.e., facilitate or inhibit - the aforementioned reactivity, and is measured in the CBQ by scales such as Inhibitory Control and Attentional Focusing/Shifting. In a recent study of 3-to-8 year-old children (Eggers et al., 2010) we found that CWS scored significantly lower on the self-regulation-related scales of IC and Attentional Shifting and their overarching superfactor of Effortful Control, a finding that was consistent with other questionnaire-based studies in CWS (Embrechts et al., 2000;

Karrass, et al., 2006).

In a subsequent study (Eggers, et al., 2011), we examined whether the parent-reported lower self-regulation and inhibitory control in CWS could be corroborated experimentally using measures of attentional processes, which are central to these self-regulatory behaviors (Rothbart, Ellis, Rueda & Posner, 2003). Using the child version of the Attention Network Test (ANT; Fan, McCandliss, Sommer, Raz, & Posner, 2002; Rueda, et al., 2004), a computer task measuring the efficiency of the 3 attentional networks, we found CWS to be significantly lower in the efficiency of their orienting network, which is linked to the Attentional Shifting scale of the CBQ. However, for the executive control network, the network underlying IC, only a non-significant trend (p= .066) towards a lower efficiency for CWS was found. This led us to propose that our earlier reported CBQ-based IC findings were either not associated with a lower efficiency of the executive control network or, that the paradigm used to test the executive attentional network in the previous study lacked the necessary power to detect significant between-group differences. One reason for the need of more specific measures is the fact that executive attention consists of three integrated, measurable mechanisms, namely error detection and correction, conflict resolution, and inhibition of automatic responses (e.g., Norman & Shallice, 1986; Posner & Raichle, 1994; Rothbart & Posner, 2001). As such, attempts to measure a complex network such as executive attention using one global measure may be less likely to be successful. Some indirect support for this comes from the observation that in similar studies with ADHD children, differences in IC emerged by using a stop-signal paradigm (Pliszka, Liotti, Woldorff, 2000), while no differences were found for the broader underlying executive attentional network (Adolfsdottir, Sorensen, Lundervold, 2008; Booth, 2003). Therefore, the current study was designed to examine specifically IC in CWS by using a more targeted experimental measurement.

There is a considerable variability in the paradigms used to measure IC and several experimental measures have been developed to assess IC across different age-ranges, e.g. Go/NoGo or stop-signal tasks, Stroop-like or card sorting paradigms, and Mistaken Gift or Gift Delay Tasks (Baron, 2004; Carlson & Moses, 2001; Christ, White, Mandernach, & Keys, 2001). According to Barkley's model of response inhibition (1997), these measures are directed at evaluating three interrelated processes: a) inhibition of an initial prepotent response, which can be measured using a Go/NoGo task (Casey et al., 1997) or a gift delay task (Kochanska et al., 1996); b) stopping of an ongoing response, as measured for instance using a stop-signal task (Aron & Poldrack, 2005; Pliszka, Borcherding, Spratley, Leon, Irick, 1997); and c) protection of self-initiated responses from disruption by conflicting events or interference, for instance as measured by a Stroop-like task (Gerstadt, Hong, Diamond, 1994).

The purpose of this study was to test experimentally previous findings of parent-reported (CBQ) differences in IC between CWS and children who not stutter (CWNS), in particular the inhibition of prepotent responses, using a Go/Nogo task. Based on these previous findings, we hypothesized that CWS, as a group, would be lower in IC compared to CWNS.

2. Method

2.1. Participants

Participants consisted of 30 children (24 boys and 6 girls) diagnosed with developmental stuttering and 30 typically developing nonstuttering children, matched by age (± 3 months) and gender to the children who stutter. The mean age was 7;05 years (*SD* = 1;05 years; range = 4;10-10;00;) for the CWS and 7;05 years (*SD* = 1;05 years; range = 4;10-9;11) for the CWNS. All children were monolingual Dutch speaking. All participants had normal or corrected to normal vision and normal speech and language development (except for stuttering in the experimental group), based on the criteria described below. Participants had no known or reported neurological, psychological, developmental or hearing problems. CWS were recruited through their speech-language therapists, all specialized in fluency disorders, while the CWNS were recruited through the schools. All participants were paid for their involvement. The study was approved by the Research Ethics committee of Leuven University Hospitals and all parents signed an informed consent form. The Antwerp Screening Instrument for Articulation (ASIA-5, Stes & Elen, 1992), in which children are tested on their ability to produce age-appropriate phonemes in different word positions, was used to screen participants for articulation disorders. Children who did not pass this test were excluded from the study. Hearing function of all participants was evaluated as within normal limits as measured using the Accuscreen (Wood, 2003), a handheld hearing-screening device. To assess their language skills, participants were administered two subtests (Vocabulary Production and Sentence Production) of the Language Test for Children (van Bon & Hoekstra, 1982). In the Vocabulary Production subtest participants needed to complete a sentence with the target-word, based on a presented picture. The Sentence Production subtest provides participants with phrases that have syntactical errors, which they have to correct. Participants had to score above percentile Pc16 (mean - 1SD) on both subtests in order to show normal language function. The mean percentiles on the Vocabulary Production subtest were 62 (range 28 - 99) for CWS and 71 (range 27 - 97) for CWNS. On the Sentence Production subtest, the mean percentiles were 54 (range 28 - 99) for CWS and 62 (range 28 - 94) for the CWNS. The differences between both participant groups on both Vocabulary Production, $t(58) = -1.71, p = .10$, and Sentence Production scores, $t(58) = -1.75, p = .09$, were not statistically different.

Two subtests of the Wechsler Intelligence Scale for Children-Third Edition Dutch (WISC-III; Vander Steene, et al., 1986; Wechsler, 2005), Vocabulary and Block Design, were administered to exclude cognitive group differences. The verbal subtest Vocabulary requires participants to explain the meaning of single words. In the nonverbal Block Design subtest, a visual reconstruction task, participants have to rebuild as quickly as possible a geometrical pattern, by using red and white cubes. Both subtests correlate highly with the WISC-III overall score (Groth-Marnat, 2009). The mean scores for the Vocabulary subtests were 19.20 for the CWS (range 7 - 34) and 19.73 (range 7 - 41) for the CWNS. On the Block Design subtest, the CWS scored on average 23.77 (range 6 - 58) compared to 28.60 for the CWNS (range 4 - 52). No significant between-group differences were found for either Vocabulary, $t(58) = -.26, p = .80$, or Block Design, $t(58) = -1.34, p = .19$.

Parental socio-economic status was determined based on the combined scores of the highest educational level (1=primary education, 2=high school, 3=college degree, 4=university degree) for each parent. The average score for parents of CWS was 5.67 (range 3-8), and for parents of CWNS it was 5.93 (range 4-8). The between-group difference in socio-economic status was not significant, $t(58) = -.68, p = .50$.

In order to get a better and more valid understanding of overall stuttering severity, spontaneous speech samples were obtained from all participants during two free play situations recorded on different days with the first author. A minimum of 300 words per participant was used to calculate scores on the Stuttering Severity Instrument-3 (SSI-3; Riley, 1994). The CWS who participated in the study produced at least three within-word disfluencies (sound/syllable repetitions, including monosyllabic word repetitions, prolongations or blocks) per 100 words of spontaneous speech (Conture, 2001) and scored at least mild on the SSI-3 (Riley, 1994). The average percentage stuttered words was 8.54 (SD = 6.77) for CWS and .98 (SD = .88) for CWNS. Thirteen of the CWS were classified as mild, 15 as moderate, 1 as severe, and 1 was rated very severe.

2.2. Materials

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2.2.1. Baseline Speed Task

To avoid the possible confound of between-group reaction time differences on the experimental Go/NoGo task, all participants were administered the baseline speed subtask of the Amsterdam Neuropsychological Tasks (De Sonneville, 2009) prior to the experimental task (see below). Completing this task first also allowed for greater familiarization with the computer equipment to be used during the experiment. Each trial began with a white fixation cross on a black computer screen background. As soon as a white square in the middle of the screen (the target signal) replaced the fixation cross, participants had to press a response button as quickly as possible. Practice sessions of 10 trials were followed by two experimental blocks of 32 trials each, one for the right index finger and one for the left index finger, as is standard for this task. Target signal duration was variable and lasted until a response was recorded. Valid responses fell between 150 ms and 4000 ms after stimulus onset. Inter-trial intervals varied randomly from 500 ms to 2500 ms.

2.2.2. Experimental Task: Go/NoGo Task

The Go/NoGo task of the Amsterdam Neuropsychological Tasks (De Sonneville, 2009) is a computer task that measures the inhibition of prepotent responses. An overview of the paradigm is shown in Figure 1. The Go/NoGo task consists of a practice session of 8 trials, followed by an experimental block of 48 trials (24 Go- and 24 NoGo-trials). Each trial began with a fixation period during which the child focused on a central white cross on a black computer screen background. This fixation period had a fixed duration of 500 ms and was followed by the presentation of the target stimulus. Two different stimuli were possible: a) the Go-stimulus (a green walking man), and b) the NoGo-stimulus (a red standing man). Both target stimuli were presented randomly but with equal frequency during the experimental block. Prior to the practice session, children were shown pictures of the Go- and

NoGo-stimuli and were explained they respectively had to press the response button or refrain from pressing. When they understood these task requirements, the practice session was started. The goal of this practice session was to get the children acquainted with the task. Children were instructed to press the response button as quickly as possible in response to the Go-stimulus, and to refrain from pressing the response button when the NoGo-stimulus appeared (i.e., the measure for efficiency of IC). They were told to make as few mistakes as possible. The response button was the right or left mouse button below the track pad of the laptop, depending on whether the child responded with the left or right-hand. A target stimulus remained on the screen until either the child responded or the maximum stimulus duration of 800 ms had been reached. No feedback was given after the response. As part of the standard procedure of this Go/NoGo task, valid responses fell between 200 ms and 2300 ms after stimulus onset. The total trial duration was fixed at 2800 ms. The overall duration of the task was about 4 minutes. Normative data are available for children between the ages of 4 and 13 years (De Sonneville, 2009).

INSERT FIGURE 1 ABOUT HERE

For each participant, the frequency of the following variables was automatically recorded and stored: a) 'hits' (when a Go-stimulus was followed by a response falling between 200 and 2300 ms after stimulus onset), b) 'misses' (when a Go-stimulus was not followed by a response), c) 'false alarms' (when a NoGo-stimulus was followed by pressing the response button between 200 and 2300 ms after stimulus onset), and d) 'premature responses' (when the response button was pressed between 0 and 200 ms after stimulus onset). In case a child exhibited a false alarm or premature response on two or more trials out of the 48 trials, this was defined as exhibiting 'multiple false alarms' or 'multiple premature responses'. In addition, for the variables 'hits' and 'false alarms' mean RTs were also recorded.

2.3. Procedure

Tests were conducted in a quiet setting at the home of the participant during two separate visits (test sessions A and B) of approximately 45 minutes each. All test sessions were conducted by the first author, a qualified fluency specialist. During test session A participants were administered the speech and language tests, and the hearing screening. The first spontaneous speech sample during play also was collected. During test session B, participants completed the simple reaction time (RT) task and the Go/NoGo task. In addition, the intelligence subtests, and the second spontaneous speech sample was collected. In order to minimize a possible test order confound, half of the participants completed test session A during the first visit while the other half completed test session B first.

The stimuli were presented on a 15-inch screen of a laptop computer, placed on a table. The distance between participant, seated on a chair, and computer screen was approximately 18 inches. To avoid distracting visual stimuli, a large black pliable cardboard was positioned around the laptop, and participants wore noise-reducing headphones to minimize possible distracting environmental sounds.

3. Results

Differences in baseline speed RT were evaluated using a t-test. The mean RT for CWS (414 ms, *SD* = 91) and CWNS (423 ms, *SD* = 115) was not significantly different: $t\ (58) = -.95, p = .72$.

INSERT TABLE 1 ABOUT HERE

INSERT TABLE 2 ABOUT HERE

Table 1 provides an overview of the mean error percentages of Go/NoGo task variables (misses, false alarms, and premature responses) for both participant groups.

Spearman's rank correlations were calculated to examine the relationships between these variables and chronological age (Table 2). No significant correlations were found between the Go/NoGo task variables, pointing to the independence of these measures; the significant negative correlation between chronological age and misses, for both CWS and CWNS, reveals that less misses occured with increasing age.

Between-group differences in error percentages of Go/NoGo task variables were evaluated using nonparametric Mann-Whitney U tests for 2 samples with participant group as the independent variable and error percentages of misses, false alarms and premature responses as dependent variables respectively. Between-group differences emerged for false alarms, U (58) = 308, Z = -2.17, $p < .05$, and premature responses, U (58) = 296, Z = -3.08, $p < .005$, showing that the mean number of false alarms and premature responses was higher in the stuttering group than in the nonstuttering group (Figure 5.2). No significant differences were found for misses, U (58) = 435, Z = -.385, p = .70.

INSERT FIGURE 2 ABOUT HERE

In order to explore the between group differences in more detail, the data for false alarms and premature responses were analyzed further. The total number of false alarms ranged from 0 to 5 for the CWS and from 0 to 3 for the CWNS. Although the likelihood of having false alarms was the same for the children in the stuttering as for the children in the nonstuttering group (χ^2 = 1.49; df = 1; p = .22), the likelihood of having multiple (≥2) false alarms on the other hand did differ significantly between both groups, χ^2 = 10; df = 1; $p < .005$, suggesting that more CWS (60%) exhibited multiple false alarms compared to CWNS (20%). In other words, the number of children with false alarms was not different between the two groups, but among those children who had false alarms, CWS had a higher frequency than did CWNS (higher mean percentage of false alarms for CWS according to the Mann-

Whitney). This is consistent with the reported finding of more multiple false alarms among the CWS.

A similar analysis was done for premature responses. The total number of premature responses ranged from 0 to 4 for the CWS and from 0 to 1 for the CWNS. More CWS (47%) exhibited premature responses than CWNS (7%), a difference that was statistically significant (χ^2 = 12.27; *df* = 1; *p* < .001). This was also the case for multiple (≥2) premature responses (χ^2 = 9.23; *df* = 1; *p* < .005). Only CWS showed multiple premature responses (27%), while none were seen in the CWNS (Table 3).

Differences in mean RTs for hits and false alarms were analyzed using separate univariate ANCOVAs with participant group as factor and mean RT of hits and mean RT of false alarms as dependent variables, respectively; chronological age was set as a covariate. Mean RT of hits was similar for both participant groups, F (1, 57) = 1.67, p = .20, while mean RT of false alarms was significantly shorter for the CWS, F (1, 43) = 5.65, p < .05. Table 4 gives an overview of the mean RTs for both participant groups.

INSERT TABLE 4 ABOUT HERE

4. Discussion

Previous studies based on parent reports already reported mean group differences in IC between CWS and CWNS, with the CWS scoring lower than the control participants (Eggers et al., 2009, 2010; Embrechts et al., 2000), although this finding was not confirmed in all studies (Anderson & Wagovich, 2010). The present study used a computer-based Go/NoGo-paradigm to investigate experimentally the presence or absence of group differences in IC.

4.1. CWS, as a Group, Exhibited a Less Controlled Response Style

Inhibitory control

The most common error type in both participant groups was false alarms, resulting from a failure to inhibit a response to the NoGo-signal; misses, i.e., a failure to respond to the Go-signal, on the other hand were much less frequent. Classically, false alarms have been called the most important measures in Go/NoGo-tasks (Christ et al., 2001) and have been linked to a less controlled, more impulsive response style. Misses, on the other hand, might reflect attention and concentration factors (Baron, 2001; Trommer, Hoeppner, Lorber, & Armstrong, 1988). Our results showed that CWS, as a group, had a higher mean number of false alarms compared to CWNS, with no significant differences in mean percentage of misses. In other words, CWS were less able to inhibit their responses to non-targets. More in depth analyses revealed that false alarms occurred as often in CWS as in CWNS but of those children who had false alarms, CWS had more false alarms compared to the CWNS. This seems to imply that at least some CWS were less able to adapt their response style, e.g. slowing down their reactions, after experiencing response errors. This also appears to be corroborated by the fact that RTs for false alarms in CWS were significantly faster compared to those in the control group. This latter observation might be explained by a speed-accuracy trade-off (also known as Fitts' law; Förster, Higgins, Bianco, 2003; Magill, 2011) which suggests that CWS, compared to CWNS, do not slow down their RTs (after experiencing response errors) but try to maintain high RTs, resulting in a higher occurrence of false alarms. This interpretation appears to find support in other studies, using paradigms in which attentional shifting/switching processes have been known to play a role (Eggers et al., 2011; Subramanian & Yairi, 2006), that have reported a tendency for shorter RTs among CWS. This observation is remarkable because most previous studies (for an overview see Bloodstein & Ratner, 2008) have shown that persons who stutter (PWS) have longer RTs compared to persons who not stutter (PWS).

Inhibitory control

CWS also made significantly more premature responses compared to CWNS. Compared to false alarms, premature responses were much more infrequent in both participant groups, but especially in the CWNS. Only a few CWNS exhibited a single premature response during the paradigm whereas almost half of the CWS group exhibited these kinds of errors and over a quarter exhibited multiple premature responses. Premature responses, defined as responses falling between 0 and 200 ms after stimulus onset, were not a direct reaction to the presented stimulus but rather could be considered resulting from impulsivity during the experimental task; in other words, this finding points to a more impulsive response style (e.g., Ballanger et al., 2009) and/or to a higher anticipatory load/expectation of the upcoming signal. The observation that more CWS have difficulties with adjusting their response style after experience response errors parallels our finding on false alarms. These results (more false alarms and more premature responses) are consistent with earlier CBQ-based findings of lower IC in CWS (Eggers et al., 2010; Embrechts et al., 2001). They also challenge the finding by Anderson & Wagovich (2010) who reported no between-group differences on IC between CWS and CWNS. It is possible that the nonsignificant finding in the Anderson et al. study was due to the considerably low sample size (9 CWS and 14 CWNS). The fact that CWS were found to be lower in IC although they were not inattentive (i.e., no differences emerged on the frequency of hits/misses) also seems to confirm previous parent-questionnaire based findings of CWS scoring similar to CWNS on the CBQ-scale of Attentional Focusing (i.e., the tendency to maintain attentional focus upon task-related channels; Eggers et al., 2010) and on the Behavioral Style Questionnaire (BSQ; McDevitt &Carey, 1978) scale of Attention Span/Persistence (i.e., the ability to continue the activity in the face of distractions; Anderson et al., 2003). Finally, our finding that CWS seemed less able to adapt their response style after experiencing response errors, as indicated by more multiple false alarms and premature responses, seems to correspond to Anderson et al.'s (2003) finding that CWS scored lower on the BSQ-scale of Adaptability (i.e., the ease or difficulty with which behaviors can be changed in a desired way), compared to CWNS.

In one of our previous studies, examing the underlying attentional network of IC (Eggers et al., 2011), only a non-significant trend towards a lower efficiency of the executive control/attention network emerged. Based on that observation, we already hypothesized that a more specific testing paradigm might be needed to fully evaluate IC. This suggestion seems to be confirmed by our current data and demonstrates that the underlying executive attention network encompasses other components besides the inhibition of automatic responses (e.g., Norman & Shallice, 1986; Posner & Raichle, 1994).

4.2. Theoretical Implications for the Development of Stuttering

While response execution, as measured by response speed and accuracy, generally was found to improve with increased age (Kail, 1991), not all results with regard to the development of IC are consistent. While some have argued for a developmental effect for IC between the age of 4 and 12 years or later (e.g., Bedard et al., 2002; Carver, Livesey, & Charles, 2001; Durston et al., 2002; Williams et al., 1999), others have suggested that IC primarily develops during early childhood with marked improvements between 3 and 6 and only limited development after the age of 7 (Christ et al., 2001; Diamond & Taylor, 1996; Frye et al., 1995; Gerstadt et al., 1994; Johnstone et al., 2007; Kochanska et al., 1996; Schachar & Logan, 1990). Our data seem to support the latter findings since no correlations were found between chronological age and the most relevant measure of IC, namely false alarms. While, descriptively, both CWNS and CWS showed less missed responses as age increased, it is important to note that over 60% of our participants were over the age of 7 while only 10% were younger than 6 years. It is likely, thus, that the children who participated in our study were too old to show the typical developmental pattern for IC.

Inhibitory control

Data from imaging (e.g., Casey, et al., 1997), ERP (e.g., Bokura, Yamaguchi, Kobayashi, 2001; Johnstone et al., 2007), and lesion studies (e.g., Aron, Fletcher, Bullmore, Sahakian, & Robbins, 2003) have provided converging evidence for the right prefrontal cortex (inferior frontal gyrus and medial frontal areas, especially pre-SMA) as one of the core anatomical correlates of inhibitory control. In addition to these frontal areas, the basal ganglia, including the subthalamic nucleus, also play a crucial role in this predominantly right-hemispheric network for motor response inhibition (Boehler, Appelbaum, Krebs, Hopf, & Woldorff, 2010), and this for both manual and spoken responses (Xue, Aron, & Poldrack, 2008). Recently, more support was found for this network of cortical and subcortical regions, typically identified as the fronto-basal ganglia circuit (Aron et al., 2007; Chambers, Garavan, & Bellgrove, 2009; Congdon et al., 2010). The basal ganglia, a conglomerate of subcortical nuclei, are the core components of extensive circuits linking the cortex to the frontal lobe cortex (pre-SMA). There is evidence that this linking takes place via a direct (via the striatum and internal globus pallidus) and an indirect pathway (via the striatum, external globus pallidus, subthalamic nucleus, and internal globus pallidus) (Mink & Thach, 1993; Mink, 1996). More recently, evidence was found also for a so-called ‘hyperdirect’ pathway, which does not pass through the striatum (Ballanger et al., 2009; Nambu, Tokuno, & Takada, 2002). Both indirect and hyperdirect routes are responsible for inhibition of the motor program while the direct route activates the desired motor program. It is suggested that upon presentation of a Go-signal, the response is released via the direct pathway, after all motor programs were suppressed via the hyperdirect pathway; No/Go signals are believed to be mediated by the indirect or hyperdirect routes (Boehler et al., 2010; Chambers et al., 2009). Interestingly, it was shown that in patients with Parkinson’s disease both ventral and dorsal subthalamic nucleus stimulation improved motor symptoms but only ventral stimulation affected the

Go/NoGo performance resulting in decreased hits and increased false alarms (Hershey et al., 2010).

Imaging studies in stuttering have revealed aberrant activity in these cortical and subcortical structures (for an overview: see Watkins, Smith, Davis, & Howell, 2008). The structures that form part of the cortical-basal ganglia network have been implicated in several emerging (theoretical) conceptualizations about underlying processes of developmental stuttering (e.g., Alm, 2004b; Smits-Bandstra & De Nil, 2007). Alm hypothesized that this fronto-basal ganglia network plays an important role in the etiology stuttering. He claims that the core dysfunction of stuttering might lie in the "*impaired ability of the basal ganglia to produce timing cues*" (pp. 359). As described by Alm, at the end of one component in a movement sequence, the globus pallidus generates an internal cue triggering the SMA to switch to the next component of the sequence; failing to generate these cues might explain some of the core features of stuttering, namely disruptions in the speech motor act. Smits-Bandstra and De Nil have proposed that stuttering might be associated with deficits in motor sequence skill learning and automaticity development, processes for which the involvement of the basal ganglia and the fronto-basal ganglia circuit is well established (Saint-Cyr, 2003). The current findings that more CWS are having difficulties with adjusting their response style after experience response errors might provide further evidence for this hypothesis.

Several authors (Bernstein Ratner & Wijnen, 2006; Postma & Kolk, 1993) have suggested stuttering to be the result of aberrant monitoring during linguistic processing. Most of these conceptualizations are based directly or indirectly on Levelt's model (1983) of language production. According to this model, language production is comprised of 3 stages, namely the conceptualization, formulation and articulation phase. This model also assumes the existence of several monitoring loops, checking the output at different stages of the production process. According to some, IC plays an important role in this monitoring process.

That is, reduced IC might affect linguistic processing and have an impact on error-detection or error-processing (Engelhardt, Ferreira, & Nigg, 2009; Meyer, Wheeldon, & Krott, 2007). In our earlier work we already hypothesized a possible link between aberrant monitoring and findings in CWS of lower IC (Eggers et al. 2010) and lower efficiency of attentional orienting (Eggers et al., 2011). Recently, Engelhardt, Corley, Nigg, and Ferreira (2010), studying children with ADHD, found evidence for a relation between IC and the ability to repair speech and language disfluencies. Although speculative, we might therefore link our findings of lower IC to possible difficulties in monitoring of speech production.

Finally, our findings could also be interpreted from a more temperament-oriented point of view. Children with a lowered IC are less able to regulate successfully their emotions (Carlson & Wang, 2007; Kochanska et al., 1996; Walcot & Landau, 2004), which, in turn, may lead to an increased emotional arousal response in stressful situations. Furthermore, it might increase the amount of stress-related situations that CWS encounter because lower IC impedes their ability to withhold their responses long enough to consider the complexities of a specific situation and to engage appropriate social skills. Several studies have shown that emotional arousal and anxiety have the potential to exacerbate stuttering symptoms (Alm, 2004a; Ezrati-Vinacour & Levin, 2004; Menzies, Onslow, & Packman, 1999). Consequently, lower IC might increase the amount of emotional arousal some CWS experience in stressful situations, impacting their stuttering symptoms. This is in line with the questionnaire-based finding by Karrass et al. (2006) of lowered emotion regulation in CWS, providing support for their 'Emotional Reactivity, Regulation and Stuttering (EERS) Model'. In this model, emotion regulation and reactivity are considered exacerbating or maintaining factors for childhood stuttering.

4.3. Possible Clinical Implications

Although clinical implications based on the results from the current study may be considered premature, lowered IC has been found repeatedly in studies of CWS, both using parent-questionnaires and experimental paradigms. This may at least allow us to make some speculative clinical suggestions. CWS, who exhibit a lowered IC, would most likely exhibit difficulties in suppressing prepotent responses across a variety of settings (e.g., school setting, playing with a friend). Therefore it might be important to council parents that these children may have more difficulties dealing with everyday situations requiring response inhibition (e.g., following instructions, waiting for something, ending an activity because he/she is asked to), resulting in increased emotional arousal. Both parental guidance techniques (e.g., "wait time technique", giving the child more time to comply) as well as helping children to acquire more self-regulatory behaviors might be appropriate (Kristal, 2005; Wodka et al., 2007). Working on increasing self-regulatory behaviors also may include identifying difficult situations, discussing expected behaviors, consequences of reacting in a certain way, helping the child to use self-directed speech, and using reminders (Kristal, 2005). The above-mentioned approaches in CWS, similar to the frequently used problem-solving strategies in cognitive-based stuttering treatment programs (see e.g. Shapiro, 1999), are aimed at decreasing the emotional arousal, and thus reducing its possible impact on the exacerbation of stuttering symptoms.

Our findings also seem to imply that some CWS are less efficient in altering their response style, e.g. slowing down, after experiencing response errors. Possibly, this could lead to longer sound prolongations or repetitions, or even the observed tendency to cluster disfluencies (Sawyer & Yairi, 2010). Findings like those reported here might validate stuttering treatment components that allow clients to monitor and conscientiously change their speech patterns such as increased monitoring of one's own speech, providing proprioceptive feedback, altering speech rate, providing positive feedback for fluent rather than disfluent speech (e.g., Guitar & McCauley, 2010).

4.4. Caveats, Limitations and Suggestions for Future Research

While the findings reported here are intriguing, it should be noted that the differences represent group tendencies and do not reflect individual performances. However, compared to the control group, a significantly larger proportion of CWS showed differences on the occurrence of multiple commission errors (60% of the CWS versus only 20% of the CWNS). Observations such as this suggest that problems with IC might impact stuttering development and/or maintenance for at least a considerable subgroup of children who stutter. Seery, Watkins, Mangelsdorf, and Shigeto (2007) already highlighted the need for delineating stuttering subtypes in order to study possible different developmental pathways of early stuttering (see also e.g., Tumanova, Zebrowski, Throneburg, & Kulak Kayikci, 2011). The finding of multiple false alarms in a large proportion of CWS might be used as a potential subtyping feature in future studies.

Moreover, although this study was not designed to evaluate the role of IC in the continuation and/or development of stuttering, given the age distribution of the sample it is possible for the reduced IC to be related to a tendency to develop persistent stuttering. Therefore, it might be interesting for future studies to evaluate if similar findings are also apparent in adults who stutter since this might yield additional insights in a potential role for IC in the persistence or recovery in stuttering.

While the current investigation was motivated by findings from a previous parent questionnaire study (Eggers, et al. 2010), no questionnaire was administered in the present study. Follow-up studies might consider combining multiple independent measures of IC, such as computer tasks and parental questionnaires, within the same design. In studying temperamental components in CWS, such as IC, it is also important to include language testing of the participants because of the possible interaction between temperament and language abilities (e.g., Bird, Reese, & Tripp, 2006). In the current study, there were no significant between-group language differences.

CWS showed more false alarms in combination with significantly faster RTs for false alarms. While we interpreted these findings by stating that CWS were less able to adapt their response style by e.g. slowing down their reactions, we acknowledge that another, although in our view less likely interpretation is possible, namely that CWS are simply less skilled in inhibiting the prepotent response rather than being less able to adapt their response style. Therefore, future research might look into reaction patterns of CWS after receiving performance feedback to evaluate directly possible changes in response style.

A difference between the current study and a number of previous studies is that the overall frequency of Go- and No/Go-signals in our study was held equal. Other investigators (e.g, Casey et al., 1997) used a proportionally higher frequency of the Go-signals, thereby increasing the prepotent tendency towards response execution and thus increasing the inhibitory control demands during NoGo-signals. It would be interesting to examine whether increasing the proportion of Go-signals, and thus increasing inhibitory control demands, would result in larger group differences between CWS and CWNS.

Finally, although Go/NoGo and stop-signal paradigms both assess inhibitory control and thus also share some underlying neural substrates, the inhibition takes place at different stages of the response execution process: in a Go/NoGo paradigm the inhibition occurs when response execution is at preparational or early-activational level while in a stop-signal paradigm execution of the response is already initiated (Johnstone et al., 2007). Therefore, it would be interesting to find out if lower efficiency in IC would also be observed in CWS when executing a stop-signal task.

5. Conclusions

Our results, based on a computer based Go/NoGo paradigm, provide further support for the hypothesis that CWS and CWNS differ in IC. CWS, as a group, were lower in IC, which suggests a lowered ability to inhibit prepotent response tendencies. The findings were linked to previous IC-related studies and to emerging theoretical frameworks of stuttering development.

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Table 1

Mean percentage of misses, false alarms, and premature responses for CWS and CWNS.

	Misses		False alarms		Premature responses	
Group	*M*	*SD*	*M*	*SD*	*M*	*SD*
CWS	.56	1.81	8.47*	6.79	2.80**	4.55
CWNS	.69	1.92	4.72*	4.61	.27**	1.06

*p < .05, **p < .005

Table 2

Correlations between the Go/NoGo measures (misses, false alarms, and premature responses) and chronological age for CWS, CWNS, and both groups combined.

Measures	Group	Misses r_s	Misses p	False alarms r_s	False alarms p	Premature responses r_s	Premature responses p
Age	CWS	-.35*	.05	.15	.41	.00	.99
	CWNS	-.49*	.01	.20	.29	-.28	.14
	Combined	-.43**	.00	.18	.17	-.09	.51
False alarms	CWS	.04	.84	1		-.01	.97
	CWNS	.00	.99	1		-.16	.39
	Combined	-.01	.96	1		.07	.59
Premature responses	CWS	-.01	.96	-.01	.97	1	
	CWNS	.33	.08	-.16	.39	1	
	Combined	.06	.66	.07	.59	1	

*p < .05, **p < .005

Table 3

Number of CWS and CWNS exhibiting false alarms or premature responses.

	False alarms		Premature responses	
Number of responses	***CWS***	***CWNS***	***CWS***	***CWNS***
1	7	15	6	2
2	7	2	7	0
3	4	4	0	0
4	4	0	1	0
5	3	0	0	0

Table 4

Mean reaction times in ms for CWS and CWNS.

	Hits		False alarms	
Group	***M***	***SD***	***M***	***SD***
CWS	509	132	382*	111
CWNS	534	104	457*	145

*p < .05

Figure Captions

Figure 1. Overview of the Go/Nogo task

Figure 2. Error percentages for CWS and CWNS with significant between group differences.

Figure 1

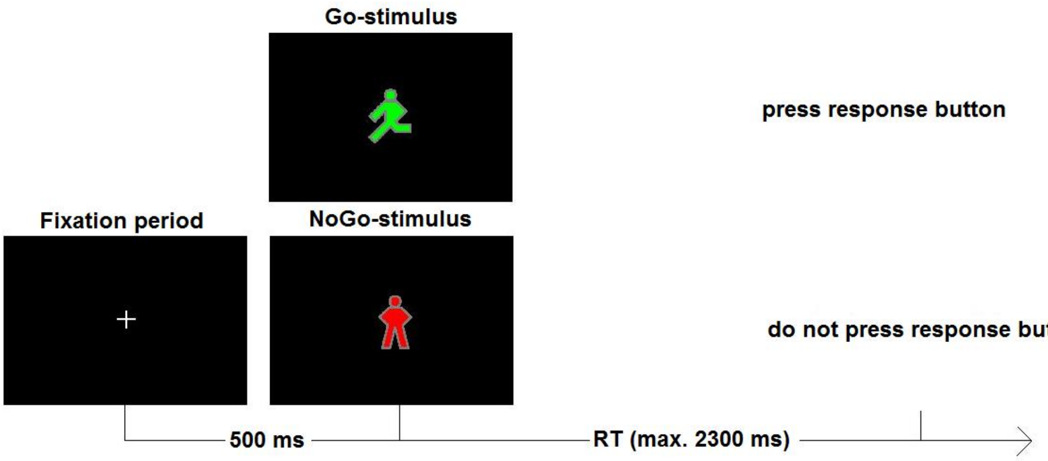
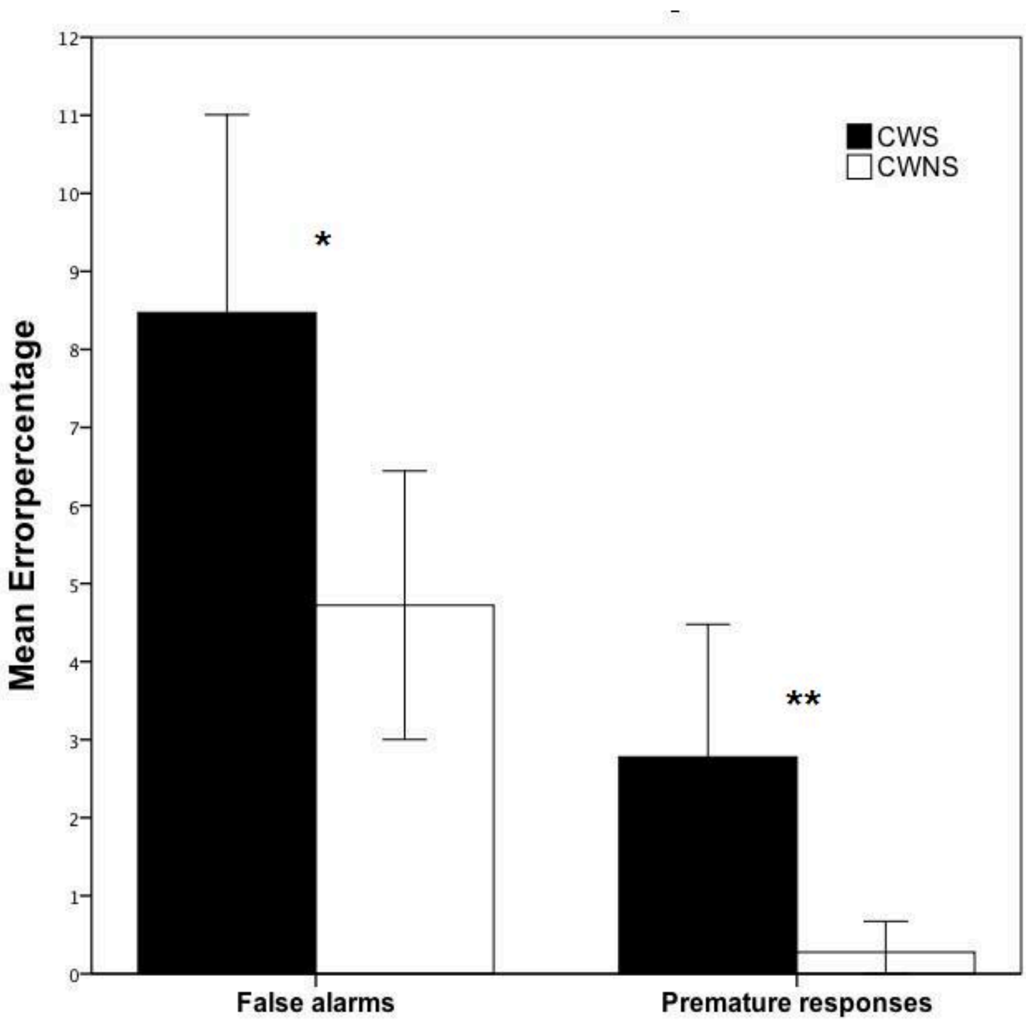

Go-stimulus
press response button
Fixation period
NoGo-stimulus
do not press response button
500 ms
RT (max. 2300 ms)

Figure 2



* p < .05, ** p < .005