RUNNING TITLE: AUDITORY ATTENTIONAL SET-SHIFTING AND INHIBITION

Auditory attentional Set-shifting and Inhibition in Children who Stutter.

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Abstract

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

Method: Participants were 16 Finnish children who stutter (CWS; mean age = 7;06 years) and 16 Finnish children who do not stutter (CWNS; mean age = 7;05 years). Participants were matched on age (± 8 months) and gender. AS and IC were assessed by the Auditory Set-Shifting Task of the Amsterdam Neuropsychological Tasks (De Sonneville, 2009).

Results: No group differences were found for the speed of auditory AS or IC. However, CWS, as a group, scored significantly lower on the accuracy (error percentage) of auditory AS. In addition, CWS, compared to the CWNS, showed a higher increase in error percentages under AS and IC conditions.

Conclusions: The findings on error percentages partly corroborate earlier questionnaire-based findings showing difficulties in CWS on AS and IC. Moreover, it also seems to imply that CWS are less able to slow down their responses in order to achieve higher accuracy rates.

Key words: stuttering, children, attention, auditory set-shifting, flexibility, inhibition

1. Introduction

Sheridan (2007) described attention as the process of focusing sensory, motor, and/or mental resources to environmental aspects in order to acquire knowledge. Posner and Petersen (1990) distinguished three anatomically separate functional networks in the attention system (see also Corbetta & Shulman, 2002; Laberge, 1995; Rothbart & Posner, 2001; Rueda et al., 2004), namely alerting (also named vigilance or sustained attention), which is responsible for achieving and maintaining an alert state, orienting (or selective attention), responsible for the selection of information from sensory input, and executive control (or conflict network).

Executive control processes are responsible for resolving conflict among responses, coordinating and controlling skills and habits, allowing one to choose among tasks, monitoring and adjusting one's performance, and changing tasks if needed (Logan, 2003). Baddeley (1986) described executive control or executive functioning as those mechanisms by which performance is optimized in situations requiring the simultaneous operation of a number of different cognitive processes. Currently, executive functioning has become an umbrella term, encompassing a number of subdomains derived from empirical studies, some more consistently endorsed than others (Baron, 2004), such as attentional control, working memory, attentional flexibility, inhibitory control, verbal fluency (not speech fluency), planning and organization (Jurado & Roselli, 2007). While the exact nature and the relationships between all of these processes are not yet completely understood (Collette, Hogge, & Van der Linden, 2006), working memory, attentional flexibility, and inhibitory control seem to be given central importance in some theoretical models of executive functioning (Barkley, 1997; Garon, Bryson, & Smith, 2008; Miyake, Friedman, Emerson, Witzki, & Howerter, 2000; Roberts & Pennington, 1996).

Some of these key executive functioning processes have already been studied in CWS. There seems to be a growing body of evidence that relates working memory (Anderson & Wagovich, 2010; Bajaj, 2007; Reilly & Donaher, 2005), attentional regulation (Arends, Povel, & Kolk, 1988; Bernstein Ratner & Wijnen, 2006; Bosshardt, 1999, 2002, 2006; Chou, 2014; Felsenfeld, van Beijsterveldt, & Boomsma, 2010; Foundas, Corey, Hurley, & Heilman, 2004; Johnson, Conture, & Walden, 2012; Karrass et al., 2006; Ntourou, Conture, & Walden, 2013; Oomen & Postma, 2001; Schwenk, Conture, & Walden, 2007; Vasic & Wijnen, 2005; Webster, 1990), and inhibitory control (Eggers, 2012; Eggers, De Nil, & Van den Bergh, 2013) to the development and maintenance of stuttering. Moreover, these processes may also play a potential role in the treatment of stuttering because a recent study showed reduced stuttering severity in CWS after receiving attention training, oriented at enhancing executive functioning (Nejati, Pouretemad, & Bahrami, 2013).

Two of these executive functioning processes, i.e. attentional flexibility and inhibitory control, play an important role in emotion regulation. By actively shifting their attention away from stress-evoking situations, children are able to decrease their level of arousal (Harman, Rothbart, & Posner, 1997; Rueda, Posner, & Rothbart, 2004). IC allows children to successfully regulate their emotions by withholding responses long enough to engage appropriate social skills in specific situations (Carlson & Wang, 2007; Kochanska, Murray, Jacques, Koenig, & Vandegeest, 1996; Walcott & Landau, 2004).

Several theoretical models of childhood stuttering have suggested that emotions contribute to the development of stuttering (Brutten & Shoemaker, Conture et al., 2006; Conture & Walden, 2012). This seems to be consistent with research findings indicating that a) the severity of stuttering symptoms is affected by anxiety or emotional reactions resulting from situational stress (Alm, 2004; Ezrati-Vinacour & Levin, 2004; Menzies, Onslow, & Packman, 1999) and b) CWS, as a group, seem to experience more emotional reactivity to their environment (Eggers, De Nil, & Van den Bergh, 2010; Karrass et al., 2006; Schwenk et al., 2007). The Communication-Emotional Model of Stuttering (CE-model; Conture et al., 2006) is a recent model in which emotional reactivity and regulation play a significant role. In this model, moments of stuttering appear as a result of the interaction between distal contributors (i.e., genetic predisposition and environmental triggers) and proximal contributors (i.e., problems with speech planning and production). Conture et al. hypothesized that speech disruptions may be aggravated (e.g., more physically tense or more frequent speech disruptions) or maintained (i.e., persistent stuttering vs. recovery) as a result of the interaction with 'exacerbation factors', i.e. emotional reactivity (arousal) and regulation (coping). The purpose of the present study is to investigate the 'regulation component' of this model by evaluating two of its major contributors, namely attentional flexibility and inhibitory control, in CWS.

Attentional flexibility, also labeled as attentional set-shifting (AS) or attention switching, points to the switching between multiple tasks or mental sets where one has to disengage from the irrelevant task set, shift one's attention and engage to the relevant task set (De Sonneville, 2014), or simply the ability to transfer attentional focus from one activity to another (Rothbart, 1989). Research on the ability to adaptively shift attention started with the 'task switching'-paradigm (Jersild, 1927) and has been ongoing since. Different variations to this paradigm, where one has to switch task or response-set depending on certain cues or information, have been developed (De Sonneville, 2014; Proctor & Vu, 2006), such as the Category Test (Reitan & Wolfson, 1985), the Wisconsin Card Sorting Test (Heaton, 1981), and the Stroop Color-Word Test (Golden, Freshwater, & Golden, 2002). Often, these tests are multifactorial measures, assessing more abilities such as judgment, reasoning, AS, and inhibition (Baron, 2004).

Inhibitory control (IC) is the ability to suppress, interrupt or delay an inappropriate or prepotent response under instructions or in novel or uncertain situations (Rothbart, 1989) or to ignore irrelevant information (Dagenbach & Carr, 1994; Rothbart & Posner, 1985). Specific tests for measuring IC include Go/NoGo or stop-signal tasks, Stroop-like or card sorting paradigms (Baron, 2004; Christ, White, Mandernach, & Keys, 2001).

While previous studies (Eggers et al., 2013; Piispala, Jansson-Verkasalo, & Kallio, 2016) already assessed IC abilities in CWS, no studies have aimed directly at measuring AS in this population. Nevertheless, some of the findings of the studies mentioned above, especially those from the dual-task studies (e.g., Bosshardt, 1999, 2002, 2006), can be interpreted as individuals who stutter having difficulties in AS. In these dual task studies, where participants had to shift their attentional set from one task (e.g., a word repetition task) to another task (e.g., a concurrent calculation task), individuals who stutter seemed to perform less proficient compared to nonstuttering individuals. In some of our own previous work, based on parental questionnaires and neurocognitive computer paradigms, we found support for a decreased ability in AS and IC in CWS. In the first studies (Eggers, De Nil, & Van den Bergh, 2009, 2010) we used the Dutch version of the Children's Behavior Questionnaire (Rothbart, Ahadi, Hershey, & Fisher, 2001; Van den Bergh & Ackx, 2003). This temperament questionnaire is based on Rothbart's model of temperament, which she defines as 'constitutional differences in reactivity and self-regulation' (Rothbart, 2011). Reactivity refers to motor, emotional, and attentional responses to internal and external stimuli. Self-regulation are those processes serving to modulate this reactivity (e.g., Inhibitory Control, Attention

Shifting). Parents of CWS scored their children significantly lower on the AS-scale than parents of nonstuttering children (CWNS), which was in line with an earlier finding by Embrechts, Ebben, Franke, and van de Poel (2000). In a second study we administered the Attention Network Test (Fan, McCandliss, Sommer, Raz, & Posner, 2002), a computer task evaluating the efficiency of the three attentional networks, to a group of CWS and age- and gender-matched CWNS (Eggers, De Nil, & Van den Bergh, 2012). Although no significant between group differences were found on the executive control network, the network under which AS falls, a clear trend was noticeable for a lowered efficiency of this network ($p = .066$); it was suggested there to use more specific tasks for evaluating certain subdomains of executive control.

Therefore, it was the purpose of this study to assess AS and IC in CWS and CWNS during a computer task directly aimed at measuring these two executive functions. Based on the theoretical conceptualizations of the CE-model and previous findings of parent-reported differences, we hypothesized CWS, as a group, to be less efficient in AS and IC compared to CWNS. First, we anticipated that both groups would have a slower response speed and lower response accuracy (i.e., more errors) during task conditions under which AS and IC was required. Our second hypothesis was that CWS, compared to CWNS, would have significantly lower accuracy rates and/or slower speed of responses during task conditions under which AS and IC was required.

2. Methods

2.1. Participants

Auditory attentional set-shifting and inhibition

Participants were 32 monolingual Finnish-speaking children (28 boys and 4 girls) with ages between 6;04 and 9;10 years. Sixteen children were diagnosed with developmental stuttering, and 16 were nonstuttering, typically developing children, matched by age (± 8 months) and gender to the CWS. The mean age was 7;06 years (*SD* = 1;03 years) for the CWS and 7;05 years (*SD* = 1;09 years) for the CWNS, $t\ (30) = .24, p = .81$. Participants had no known or questionnaire-reported neurological, psychological, developmental or hearing problems. All participants had normal or corrected to normal vision and normal speech and language development. The development of all the children was followed-up in the health care system up to school-age. Since there were no standardized tests for school-aged children to assess morphology and syntax in the Finnish language at the time of the data collection, language production was assessed by a qualified speech and language therapist based on the spontaneous speech samples, and was found to be within normal range. In addition, all the children attended the normal pre-school or school system with no known learning problems.

To exclude cognitive group differences, two subtests of the Wechsler Intelligence Scale for Children-Third Edition Finnish (WISC-III; Wechsler, 2005), Vocabulary and Block Design, were administered. The WISC-III consists of 13 subtests, which can be divided in 6 verbal and 7 performal subtests. The verbal subtest Vocabulary and the performal subtest Block Design correlate highly with the WISC-III overall score (Groth-Marnat, 2009). The subtest Vocabulary requires participants to explain the meaning of single words. In the Block Design subtest, a visual reconstruction task, participants have to rebuild as quickly as possible a geometrical pattern, by using red and white cubes. Mean Vocabulary subtest raw scores were 10 for the CWS (range 5 - 19) and 12 (range 7 - 19) for the CWNS. Mean Block Design subtest raw scores were 11 for the CWS (range 5 - 16) and 13 for the CWNS (range 11 - 17).

No significant between-group differences were found for either Vocabulary, *t (30) = -1.40, p = .175*) or for Block Design, *t (30) = 1.11, p = .092*).

Hearing was screened by use of a bilateral screening tone-audiometry at 500, 1000, 2000, and 4000 Hz (SA 50, Entomed, Sweden). All participants had normal hearing.

Spontaneous speech samples were collected from all participants on two different days and a reading task was included for those, who were able to read. Scores on the Stuttering Severity Instrument-3 (SSI-3; Riley, 1994) were calculated based on a sample of minimum 300 words. The participating CWS produced at least three within-word disfluencies (sound/syllable repetition, prolongation or blocks) and/or monosyllabic word repetitions in 100 words of spontaneous speech (Conture, 2001) and scored at least 'mild' on the SSI-3. Eight CWS were classified as mild, 6 as moderate, and 2 were rated severe.

2.2. Materials

2.2.1. Baseline Speed Task

The baseline speed subtask of the Amsterdam Neuropsychological Tasks (De Sonneville, 2009) is a simple computer-based reaction time task. This task was administered to all participants prior to the auditory shifting task in order to evaluate if possible between-group reaction time differences existed, which could confound the results of the auditory shifting task. Moreover, it allowed participants to get familiarized with the computerized experimental setting. Trials began with a white fixation cross on a black background. When the target signal, a white centralized square, appeared, participants had to press as soon as possible the reaction button. Practice sessions of 10 trials, were followed by two experimental blocks of 32 trials, one for the right index finger and one for the left index finger. Signal duration was variable and ended with the response. Valid responses fell between 150 ms and 4000 ms after stimulus onset. Post response intervals varied randomly between 500 ms and 2500 ms.

2.2.2. Experimental Task: Auditory attentional Set-Shifting Task

The Auditory Set-Shifting Task of the Amsterdam Neuropsychological Tasks (De Sonneville, 2009) is a computer-based paradigm that measures AS and IC. De Sonneville (2014) defines AS as the ability to flexibly shift one's auditory attentional set, and IC as the inhibition of prepotent responses (see also Mostert-Kerckhoffs, Staal, Houben, & de Jonghe, 2015; Serlier-van den Bergh & De Sonneville, 2002). Figure 1 provides an overview of the paradigm. The task consisted of 3 different parts: a) Part 1 had compatible stimulus-response (SR) mapping; the stimulus was a single or a double tone with a low pitch (200 Hz); after hearing a single tone the participant had to press the response button once, after hearing a double tone the participant had to press twice; b) Part 2 had incompatible SR-mapping; the stimulus was a single or a double tone with a high pitch (400 Hz) and after a single tone the participant had to press the response key twice, after a double tone the participant had to press once; c) Part 3 had mixed SR-mapping, which consisted of a random combination of low- and high-pitched stimuli. The pitch (low or high) determined the required type of stimulus-response mapping; a low pitch meant compatible SR-mapping (press once when 1 tone is presented and twice when 2 tones are presented) while a high pitch meant incompatible SR-mapping (press twice when 1 tone is presented and once when 2 tones are presented). Single and double tone stimuli were presented randomly in all three task parts. Each part started with a practice session of 10 trials followed by an experimental block of 40 trials for part 1 and 2, and 80 trials for part 3. Prior to the practice session, children were explained what they had to do. When task requirements were clear, the practice session was started. The goal of each practice session was to get the children acquainted with the task. Each trial started with a fixation period during which a central white cross was presented on a black computer screen background. This period had a fixed duration of 500 ms and was followed by the auditory presentation of the stimulus via the headphones and simultaneous presentation of a picture of a musical note on the computer screen. Children were instructed to respond as fast and as accurately as possible. The response button was either the right or left mouse button (below the touchpad of the laptop), depending on whether the child responded with the index finger of the left or right hand (based on hand preference). The auditory stimulus duration was 100 ms and the intertone interval (in case of a double tone stimulus) was 100 ms. As part of the standard procedure of this auditory AS-task, valid responses fell between 200 ms and 6000 ms after stimulus onset. The post response interval was fixed at 1500 ms. The overall duration of the task was about 11 to 15 minutes (part 1: 2-3 min., part 2: 3-4 min., and part 3: 6-8 min.).

INSERT FIGURE 1 ABOUT HERE

For each of the 3 parts of the auditory AS-task, the following variables were automatically recorded and stored for each participant: a) 'mean reaction time (RT)' for both compatible and incompatible SR-coupling (when a stimulus was followed by a correct response falling between 200 and 6000 ms after stimulus onset), and b) 'number of errors' for both compatible and incompatible SR-coupling (when a stimulus was followed by an incorrect response).

This auditory AS-task measures both inhibition and attentional flexibility by measuring and comparing the speed and accuracy of response organization processes. During the compatible SR-coupling of part 1 (see Figure 1), no inhibition of responses is required. Because of the incompatible SR-coupling during part 2, it is necessary to inhibit one's prepotent responses since a single tone here should result in pressing the response button twice and vice versa. Inhibition in this task is evaluated by comparing the results of part 2 with the results of part 1 (De Sonneville, 2014). Also the condition of the SR-coupling differs between different parts of the task: SR-coupling is set during part 1&2, requiring no attentional set-shifting. During part 3 SR-coupling is random (combination of compatible and incompatible SR-coupling) and requires attentional flexibility to continuously shift between response-sets. Therefore, attentional set-shifting in this task is evaluated by contrasting the results of the compatible condition of part 3 with the results of the compatible condition of part 1 (De Sonneville, 2014). It is expected that inhibiting prepotent responses (part 2) will lead to slower RTs and/or higher error percentages. Also the demand to switch flexibly between response sets (part 3) will usually also impact RTs and accuracy.

2.3. Procedure

Participants and parents were all paid volunteers that were recruited after initial contact with their speech and language therapist (for the CWS) or through their schools or daycare centers (for the CWNS). All tests were conducted in a quiet setting during two test sessions by the second author. During test session A, the baseline speed task was administered, followed by the auditory AS-task and collection of a speech sample. During test session B, we administered WISC, followed by the tone audiometry and speech sample collection. Speech samples were always collected during the two test sessions in order to get a better representation of the overall stuttering severity.

Stimuli were presented on a HP Probook 4520s with a 15-inch screen, placed on a table. The distance between child, seated on a chair, and computer screen was approximately 18 inches. Distracting visual stimuli were avoided by placement of the computer to a wall.

Headphones (Sennheiser HD 25 SP) were applied to give the auditory stimuli and to reduce possible distracting auditory stimuli.

2.4. Data analyses

Before the hypotheses were tested, a t-test was used to evaluate possible between-group differences in simple RT (Baseline Speed Task), which could confound the results of the auditory shifting task.

The efficiency of IC was evaluated by comparing differences in mean RTs and error percentages between Part 1 (compatible) and Part 2 (incompatible) for CWS and CWNS, using mixed ANCOVAs. Group classification was the between-subjects variable and mean RT and error percentages for each part were within-subjects variables or factors; chronological age was set as a covariate. Mixed ANCOVAs were also used to evaluate the efficiency of AS. Mean RTs and error percentages for the compatible conditions in Part 3 and Part 1 were compared for CWS and CWNS. Participant group as between-subjects variable and respectively mean RT and error percentages as within-subjects variable or factor; chronological age was set as a covariate. Based on our first hypothesis, we anticipated main effects for Part. Based on our second hypothesis, we anticipated significant Part x Group interactions.

Outliers, i.e. mean RTs and error percentages that deviated more than 3 standard deviations from the mean of all group participants for that specific condition, were excluded (Warner, 2013). From the dataset of 256 values, 8 outliers were removed (CWS: $n = 5$; CWNS: $n = 3$): Part 1 compatible RT (CWS: $n = 1$; CWNS: $n = 1$), Part 1 compatible error percentage (CWS: n = 3), Part 2 incompatible error percentage (CWS: n = 1; CWNS: n = 1), Part 3 incompatible error percentage (CWNS: n = 1).

Normality was checked by Shapiro-Wilk's test of normality and all RTs were normally distributed. This was not the case for the distribution of error percentages; nevertheless we opted for this test since several authors (e.g., Glass, Peckham, & Sanders, 1972; Lix, Keselman, & Keselman, 1996) have demonstrated that the ANOVA procedure is robust enough under lack of normality. Corrections for sphericity are not needed for within-subjects factors with only two levels; in this case SPSS reports a chi-squared of .000 and no p-values.

3. Results

Preliminary analysis employing a t-test showed no significant between-group differences in the baseline speed RT: $t\,(30) = .43,\ p = .67;$ the mean RT was 425 ms (*SD* = 124) for CWS and 408 ms (*SD* = 93) for CWNS. Table 1 and table 2 provide respectively an overview of the mean RT and error percentages for both participant groups in the three parts and specific conditions of the auditory AS-task.

INSERT TABLE 1 ABOUT HERE

INSERT TABLE 2 ABOUT HERE

3.1. Findings on Inhibition

Analyses of RTs showed significant within-subjects effects for Part, $F(1, 27) = 23.10$, $p < .001$, $\eta_p^2 = .46$, observed power = .99, pointing to an increase in RT in Part 2 (M = 1047, *SD* = 355) compared to Part 1 (*M* = 561, *SD* = 103) (Table 1). The Part x Age interaction was also significant, $F(1, 27) = 10.66$, $p < .005$, $\eta_p^2 = .28$, observed power = .88. The Part x Group interaction was not significant, $F(1, 27) = 0.26$, $p = .61$, $\eta_p^2 = .01$, observed power = .08 (Figure 2a). Tests of between-subjects effects showed no significant effect of group classification, $F(1, 27) = 0.19$, $p = .67$, $\eta_p^2 = .01$, observed power = .07.

INSERT FIGURE 2 ABOUT HERE

Analyses of error percentages showed no significant within-subjects effects for Part, $F(1, 24) = 0.273$, $p = .61$, $\eta_p^2 = .01$, observed power = .08, or Part x Age interaction, $F(1, 24) = 0.00$, $p = .99$, $\eta_p^2 = .00$, observed power = .05 (Table 2). The Part x Group interaction however was significant, $F(1, 24) = 5.32$, $p < .05$, $\eta_p^2 = .18$, observed power = .60 (Figure 2b). Tests of between-subjects effects showed no significant effect of group classification, $F(1, 24) = 0.21$, $p = .65$, $\eta_p^2 = .01$, observed power = .07.

3.2. Findings on Auditory Attentional Set-Shifting

For the analysis of RTs, tests of within-subjects effects showed a significant effect for Part, $F(1,27) = 13.93$, $p < .001$, $\eta_p^2 = .34$, observed power = .95, pointing to a significant increase in mean RT in Part 3, with the mean RT for Part 3 (*M* = 1318, *SD* = 434) being significantly higher than the mean RT for Part 1 (*M* = 561, *SD* = 103) (Table 1). A significant effect was also found for Part x Age interaction, $F(1, 27) = 4.32$, $p < .05$, $\eta_p^2 = .14$, observed power = .52. The Part x Group interaction was not significant, $F(1, 27) = 0.22$, $p = .64$, $\eta_p^2 = .01$, observed power = .07 (Figure 3a). Tests of between-subjects effects showed no significant group effect, $F(1, 27) = 0.17$, $p = .68$, $\eta_p^2 = .01$, observed power = .07.

INSERT FIGURE 3 ABOUT HERE

For the analysis of error percentages, tests of within-subjects effects showed no significant effect for Part, $F(1, 26) = 0.03$, $p = .86$, $\eta_p^2 = .00$, observed power = .05, and Part × Age interaction, $F(1, 26) = 0.51$, $p = .48$, $\eta_p^2 = .02$, observed power = .10 (Table 2). In contrast, the Part × Group interaction did show a significant effect, $F(1, 26) = 12.04$, $p < .005$, $\eta_p^2 = .32$, observed power = .92 (Figure 3b). Also the test of between-subjects effects showed a significant group effect, $F(1, 26) = 6.61$, $p < .05$, $\eta_p^2 = .20$, observed power = .70. Pairwise comparisons showed a significant difference in error percentage in Part 1 between CWS (*M* = 0,00, *SD* = 0,00) and CWNS (*M* = 1,16, *SD* = 1,73), $p < .05$, $\eta_p^2 = .16$, observed power = .57; a significant difference in error percentage was also found in Part 3 between CWS (*M* = 10,76, *SD* = 11,65) and CWNS (*M* = 1,06, *SD* = 1,16), $p < .005$, $\eta_p^2 = .27$, observed power = .89.

4. Discussion

Earlier studies revealed a lower efficiency in certain subcomponents of attentional functioning in CWS, more specific, in the subdomain of AS (Eggers et al., 2010 & 2012). Likewise, a lower efficiency was found for IC (Eggers et al., 2010, 2013; Piispala et al., 2016). In the current study the Auditory Set-Shifting Task was used to evaluate whether these earlier parent report-based findings could be corroborated experimentally.

4.1. Attentional set-shifting and inhibition take time

Our first hypothesis was that both groups would have a slower response speed and a higher error percentage during task conditions under which AS and IC (see De Sonneville, 2014) was required. Both CWS and CWNS showed a significant increase in mean RT when they had to inhibit their prepotent responses (incompatible SR-coupling, Part 2) and even more when they had to shift their attentional set (mixed SR-coupling, Part 3). With regard to accuracy we did not find an increase in error percentages in Part 2 and Part 3 when both groups were collapsed but different interaction patters emerged in CWS and CWNS (see below).

The increase in RTs, a consistent finding in attentional flexibility studies (Pashler, 2000) labeled as the ‘switch cost’, was apparent in both CWS and CWNS. This switching cost is caused by task-set reconfiguration. Monsell, (2003) describes it as a sort of mental ‘gear changing’ necessary before appropriate task-specific processes can proceed. Task-set reconfiguration can include shifting attention between stimulus characteristics, retrieving goal states (what to do) and action rules (how to do it) into procedural working memory (or deleting them), enabling a different response set and adjusting response criteria. Moreover, it also involves inhibition of elements of the preceding task-set as well as activation of the required task-set (Vandierendonck, Liefooghe, & Verbruggen, 2010; Verbruggen, Liefooghe, Szmalec, & Vandierendonck, 2005; Schuch & Koch, 2003).

The age effects found for RTs in CWS and CWNS in both inhibition and AS-findings are in line with maturation of response organization processes such as response selection and preparation (Luna et al., 2001; McKay, Halperin, Schwartz, & Sharma, 1994).

4.2. CWS experience general difficulty in responding adaptively to errors

Our second hypothesis was that CWS, compared to CWNS, would react differently, i.e. slower speed of responses and/or lower accuracy rates, during task conditions requiring AS and IC. In other words, we expected interactions between task manipulation and group classification. For speed of responding, similar patterns emerged in CWS and CWNS; both groups had a comparable increase in RTs from Part 1 to Part 2 (IC) and from Part 1 to Part 3 (AS). Also no between-group differences on RTs were found. This was not what we were expecting and clearly shows that, with regards to speed of responding, both groups act alike. For accuracy rates a clearly different pattern emerged for the groups: whereas in CWNS error percentages were rather stable, CWS's error percentages clearly increased and resulted in the AS-condition in as much as than 10 times more errors (error percentage = 11%) than the nonstuttering children (error percentage = 1%).

Parts of our findings seem to be in line with results from previous studies employing parent questionnaires (Eggers et al., 2010; Embrechts et al., 2000) and computer paradigms (Eggers et al., 2012, 2013). A study using the computerized Attention Network Test (Eggers et al., 2012) revealed a lower efficiency in attentional orienting in CWS and, although nonsignificant, a noticeable trend for a lower efficiency of the executive control network. This is the attentional network that is responsible for AS (Posner & Peterson, 1990). Moreover, these findings get support from dual-task experiments that have consistently shown less efficient performances of individuals who stutter (Bajaj, 2007; Bosshardt, 1999, 2002, 2006; Bosshardt et al., 2002; Vasic & Wijnen, 2005) because during these paradigms participants have to shift their attentional resources flexibly between the different simultaneous tasks.

The observation that both groups of children responded more slowly during AS and IC conditions but that only the CWNS benefitted (i.e., were more accurate) as a result is intriguing. Apparently, CWS and CWNS both showed attentional flexibility with different implications for accuracy level. In other words, in the group of CWNS the speed-accuracy trade-off was more successful (for description see Förster, Higgins, & Bianco, 2003; Magill, 2011). Furthermore, one might argue that CWS were less able to adapt their response style, that is, slowing down their responses even more in order to analyze the stimulus, apply the correct rule, and execute the correct response in order to increase the response accuracy. This seems to be in line with recent findings on an ERP study by Piispala et al. (2016) suggesting atypical mechanisms of stimulus evaluation and response selection and execution in CWS.

No significant between group differences in error percentage were found for IC. However, for AS a significant between group difference was encountered which was due to the higher error percentage in Part 3. Moreover, similar interaction patterns emerged under AS & IC conditions: CWS, compared to the CWNS, showed a higher increase in error percentages with increased task complexity. This might be linked to difficulties in motor learning in CWS as shown by several studies (e.g., Smits-Bandstra & De Nil, 2007). Motor learning involves the interaction between the pre-existing capacities and the to-be-learned movement patterns (Kelso, 1995). This means that, with practice, muscle execution becomes increasingly dependent on an internal representations rather than external sensory feedback (Schmidt, 2004). Such learning will result into decreased sensory and attentional demands (Schmidt & Lee, 2005). In case children have difficulties in motor learning, they may need to pay more attention to stimulus evaluation and response selection, as shown by recent studies (Piispala et al. 2016, 2017) which further result into more errors.

Difficulties in auditory-motor integration have also commonly been found in individuals who stutter (e.g., Loucks, Chon, Kraft, & Ambrose, 2013). In addition, Chang and Zhu (2013) showed that CWS aged 3-9 years had attenuated connections between both auditory-motor and cortical-basal ganglia areas on the left side compared to controls. The stimuli used in this study were auditory, and the response motor response. Therefore, there is a possibility that our results are due atypical auditory-motor integration.

4.3. Theoretical and clinical implications

In our study, CWS were not able to slow down their speed of response to such a degree that it resulted in a decrease of errors. This fits well with theoretical accounts that implicate sensorimotor control deficits in developmental stuttering, such as the hypothesis that stuttering results from a speech motor strategy that is biased towards auditory feedback control due to poor feedforward commands (Max, Guenther, Gracco, Ghosh & Wallace, 2004). The DIVA model of speech production (Tourville & Guenther, 2011) integrates both feedforward and feedback control systems and a monitoring system (Bernstein Ratner & Wijnen, 2006; Civier, Tasko, Guenther, 2010; Postma & Kolk, 1993; Vasic & Wijnen, 2005). Speech motor commands are prepared before movement onset and then executed by a feedforward controller. These movements are controlled by a feedback system, comparing auditory and somatosensory information with the expected target position. In case errors are detected, corrective motor velocity commands are generated. When during early childhood (speech) movements become more automatic, CWNS evolve from a feedback-driven motor control strategy to one that is biased more toward feedforward control (Max et al., 2004). It is hypothesized that in CWS, this feedforward control of speech is impaired, possibly because of a dysfunction of the basal ganglia (Alm, 2004) and/or problems with motor sequence skill learning (Smits-Bandstra & De Nil, 2007), making them more dependent on auditory and sensorimotor monitoring (see also under 4.2). This overreliance on auditory afferent feedback (Civier, Tasko, & Guenther, 2010) has its limitations since a time-lag exists between a motor command and its auditory and somatosensory consequences. This may render the system to become unstable, particularly during fast movements, resulting in moments of stuttering. Simulations by Civier et al. (2010) showed that slowing down movement speed reduced the size of the auditory errors and consequently the frequency of the moments of stuttering.

Second, AS and IC are considered a central aspect of the executive control of cognitive processes (Rushworth, Passingham, & Nobre, 2002) and might also play a role in stuttering-triggering situations, both linguistically as well as environmentally determined. Stuttering was found to increase in situations with increased syntactical complexity (Bernstein Ratner & Sih, 1987) and perceived environmental stress (Ezrati-Vinacour & Levin, 2004; Menzies et al., 1999). In both situations, there is a higher demand to flexibly shift one's attentional resources between concurrent tasks, including speech planning and execution. Additionally, earlier studies have shown the speech of people who stutter to be sensitive to interference from concurrent attention-demanding tasks (e.g., Bosshardt, 2006). Also more recent publications seem to pinpoint emotions and temperament - both AS and IC are components of Rothbart's temperament model (Rothbart et al., 2001) as a) causal contributors to developmental stuttering (Conture, Kelly, and Walden, 2013) and b) responsible for influencing the variation of stuttering observed in different speaking situations (Jones, Choi, Conture, & Walden, 2014).

Interestingly, Jones et al (2014) state that children with attentional regulation difficulties may be at risk for both developing stuttering as well as persistence because of less resilience in coping with stuttering over time. Since AS plays a significant role in one's ability to respond flexibly in a changing environment (Miller & Cohen, 2001) and in decreasing levels of arousal by shifting attention away from stress-evoking situations (Harman et al., 1997; Rueda, Posner, & Rothbart, 2004), CWS, as a group, are less able to regulate their emotional reactivity and control their levels of distress. In other words, children with a lowered AS ability, may be more at risk for persistence due to maladaptive responses to their moments of stuttering.

Although speculative, our findings might also shed some light on the reason for the effectiveness of some clinical approaches or used techniques. Earlier we discussed that the ‘switch cost’, i.e. the increase in RT, although apparent in both CWS and CWNS, only resulted in better accuracy in CWNS. Switch cost is linked to task-set reconfiguration and includes retrieving goal states, action rules, inhibition of elements of preceding tasks. Monsel (2003; Monsell, Yeung, & Azuma, 2000) also described that if advance knowledge is given on the upcoming task and time allowed to prepare for it, the average switch cost is usually reduced or results in less errors (preparation effect). During the cancellations of Van Riper’s modification approach (Van Riper, 1982), clients stop immediately after a stuttered word, built in a pause for reposturing, say the word silently in pantomime, and finish with saying the word out loud with the learned modification. These different steps might be considered as ‘inhibiting the preceding task’, preparing for the motor goal that needs to be achieved, and executing the new motor command. The repeated production of the fluent word contributes also to motor memory consolidation, in line with shifting towards a feedforward motor control strategy of the earlier discussed DIVA model. Similarly, in the Lidcombe program (Onslow, Packman, & Harrison, 2003), as part of the parental verbal contingencies, parents acknowledge to the child that a stutter has occurred and can request the child to repeat the same word fluently.

4.4. Additional considerations and future research

Due to the lack of standardized speech and language tests for school-age children in Finnish, language production was assessed based on spontaneous speech samples. Although these were found to be within normal range, this type of assessment did not allow for a between-group comparison. There is evidence that early language skills relate to executive functions (e.g., Ezrine, 2010; Müller, Jacques, Brocki, & Zelazo, 2009) but the exact nature of this relationship is far from clear. Therefore, it may be the case that found differences in executive functions, i.e. AS, were influenced by between-group differences in language skills. However, a recent study by Gooch, Thompson, Nash, Snowling and Hulme (2016) seems to indicate that although there is a strong concurrent relationship between language and executive skills, it is unlikely that language difficulties would cause deficits in executive functioning or that executive functions would provide strong constraints on language development.

While both the administration of the auditory set-shifting task and the measurements of AS and IC were identical to De Sonneville (2014), a procedure also used by others (Mostert-Kerckhoffs, et al., 2015; Serlier-van den Bergh & De Sonnevile, 2002), a possible influence of other response organization processes cannot be fully ruled out. One might argue that the found differences between CWS and CWNS on AS could also reflect possible differences in underlying auditory signal processing. Especially because the existing literature has shown auditory processing differences between stuttering and nonstuttering individuals (Foundas et al., 2004; Hall & Jerger, 1978; Hampton & Weber-Fox, 2008; Jansson-Verkasalo et al., 2014; Kaganovich, Wray, Weber-Fox, 2010; Liotti et al., 2010). In Part 3 one is confronted with a mix of high and low tones and in case of auditory signal processing difficulties, this might become more difficult because one first needs to decide if it is a high or a low tone. This is however not the case for IC since in Part 2 only high tones are presented. Nonetheless, in our view, it is not likely that this aspect had a major impact on the results because previous studies (Corbera, Corral, Escera, & Idiazábal, 2005; Kaganovich, Wray, & Weber-Fox, 2010) showed that CWS did not have any difficulties in processing non-speech sounds, which were also used in this experiment. To clearly rule this out, it might be a good suggestion to compare the results of this task to an AS-paradigm using visual stimuli instead of auditory stimuli.

The current study and various previous studies (Eggers et al., 2010, 2012, 2013; Johnson et al., 2012; Karrass et al., 2006; Ntourou et al., 2013; Schwenk et al., 2007) have focused on finding possible differences between CWS and CWNS in terms of attention, executive functions, and inhibitory control. These studies have contributed to a better understanding of their possible causal or exacerbating role in the development of stuttering. Important questions remain to what extent these processes a) influence specific quantitative and/or qualitative stuttering characteristics, b) can predict or play a role in spontaneous recovery or stuttering chronicity, c) can help tailor stuttering treatments to the individual needs of clients, d) can predict or play a role in treatment outcome.

A noteworthy observation during the test sessions was that many of the CWS, compared to the CWNS, seemed to respond in a somewhat different manner when mistakes were made. The complexity of the task gradually increased resulting in more errors towards the end of the task. While many CWNS verbally responded with statements like ‘Oops, … a mistake.’, ‘High tone … double-click.’, ‘High tone … opposite’, the verbalizations of many of the CWS were more in the range of ‘Wrong again.’ or ‘It’s difficult.’ Research in this area has shown that overt verbalizations can enhance children’s attention to task-relevant features, can help to maintain a positive task outlook and cope with difficulties, and ultimately, improve the learning process (Schunk, 1986). CWS also seemed to have more difficulty coping with their mistakes and became more easily frustrated. From a research perspective, it might be interesting to study whether CWS, as a group, actually do become more easily frustrated or have a lower frustration tolerance, as already referred to by some authors (Amster & Klein, 2008; Hill, 1999; Starkweather, 2002).

5. Conclusions

In conclusion, the results of the current study showed differences in AS and IC between CWS and CWNS, using an auditory AS paradigm. CWS were less accurate in a) flexibly shifting their attention between different response-sets and b) inhibiting their responses when needed. These findings support earlier questionnaire-based findings and were linked to a possible role for AS and IC in developmental stuttering.

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Table 1

Mean reaction times in ms for CWS and CWNS.

	Part 1		Part 2		Part 3			
	Compatible		Incompatible		Compatible		Incompatible	
Group	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
CWS	559	117	1056	398	1273	486	1357	458
CWNS	563	90	1125	378	1364	385	1510	488

Table 2

Error percentages for CWS and CWNS.

	Part 1		Part 2		Part 3			
	Compatible		Incompatible		Compatible		Incompatible	
Group	***M***	***SD***	***M***	***SD***	***M***	***SD***	***M***	***SD***
CWS	0,00	0,00	3,49	4,20	10,76	11,65	12,76	12,78
CWNS	1,16	1,73	2,00	1,94	1,06	1,16	1,88	0,48

Figure Captions

Figure 1. Schematic overview of the Auditory attentional set-shifting test.

Figure 2. Speed (a) and accuracy (b) of inhibition for CWS and CWNS.

Figure 3. Speed (a) and accuracy (b) of attentional set-shifting for CWS and CWNS.

Figure 1

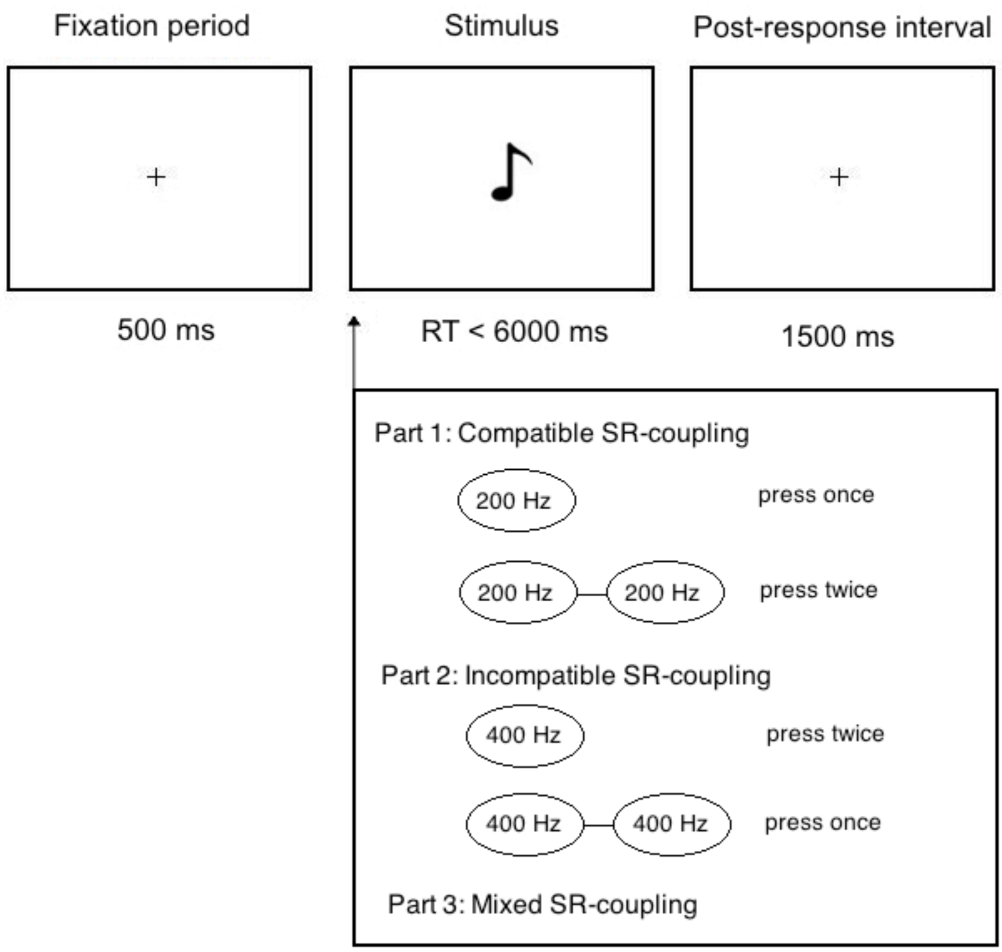

Fixation period
Stimulus
Post-response interval
+
+
500 ms
RT < 6000 ms
1500 ms
Part 1: Compatible SR-coupling
200 Hz
press once
200 Hz
200 Hz
press twice
Part 2: Incompatible SR-coupling
400 Hz
press twice
400 Hz
400 Hz
press once
Part 3: Mixed SR-coupling

Figure 2

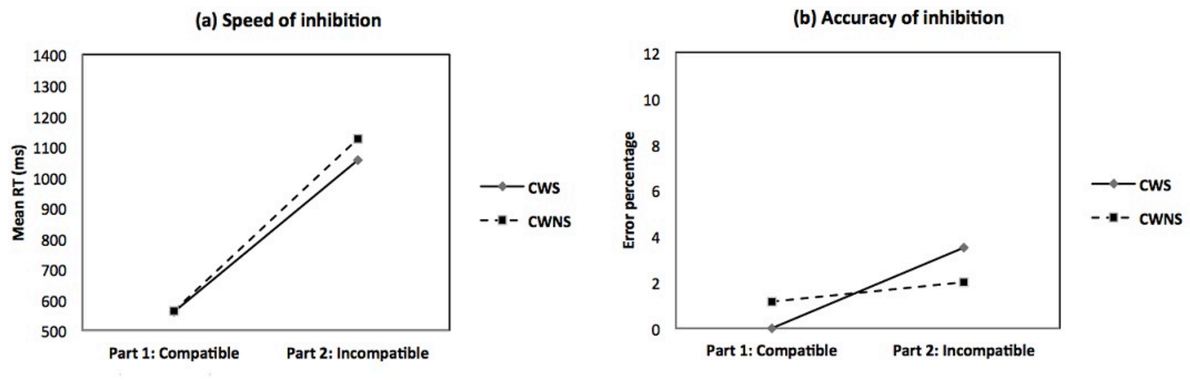
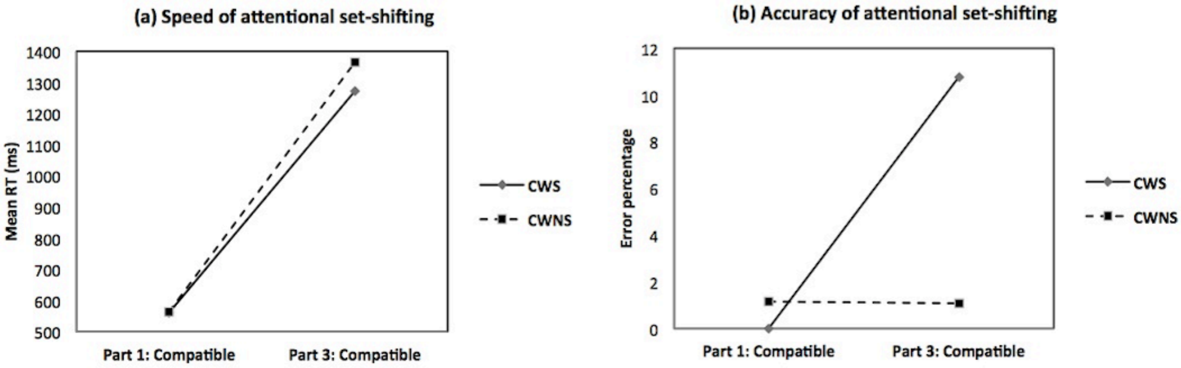

(a) Speed of inhibition
Mean RT (ms)
1400
1300
1200
1100
1000
900
800
700
600
500
Part 1: Compatible
Part 2: Incompatible
CWS
CWNS
(b) Accuracy of inhibition
Error percentage
12
10
8
6
4
2
0
Part 1: Compatible
Part 2: Incompatible
CWS
CWNS

Figure 3


(a) Speed of attentional set-shifting
Mean RT (ms)
1400
1300
1200
1100
1000
900
800
700
600
500
Part 1: Compatible
Part 3: Compatible
CWS
CWNS
(b) Accuracy of attentional set-shifting
Error percentage
12
10
8
6
4
2
0
Part 1: Compatible
Part 3: Compatible
CWS
CWNS