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Inhibitory Control, Cognitive Flexibility, and the Production of Disfluencies in Children Who Do and Do Not Stutter

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Abstract

Purpose: Differences in inhibitory control and cognitive flexibility between children who stutter (CWS) and children who do not stutter (CWNS) have been previously demonstrated. The aim of the current study was to investigate whether the previously reported inhibitory control- and cognitive flexibility-related performance costs for CWS are associated with the number of speech disfluencies that they produce.

Methods: Participants were 19 CWS ($M_{\text{age}} = 7.58$ years, range 6.08–9.17) and 19 CWNS matched on age and gender ($M_{\text{age}} = 7.58$ years, range 6.08–9.33). Gamma regression models were used to investigate possible associations between performance costs in speed and accuracy measured during a computer task evaluating inhibitory control and cognitive flexibility and the number of speech disfluencies during video-recorded speech samples (story retelling and casual conversation).

Results: Two significant interactions were observed. For both inhibitory control and cognitive flexibility, we identified a significant group and inhibitory control/cognitive flexibility performance-cost interaction in stuttering-like disfluencies (SLDs) indicating that the performance-cost effects on SLD production were significantly higher in the CWS group, compared to the CWNS group.

Conclusions: CWS with reduced inhibitory control or cognitive flexibility produce more SLDs, but not other disfluencies. These results are partly in line with some previous findings in non-stuttering and stuttering populations linking inhibitory control and cognitive flexibility weaknesses to the production of speech disfluencies.

Key words: inhibitory control, cognitive flexibility, disfluencies

39 **Inhibitory Control, Cognitive Flexibility, and the Production of Disfluencies in Children**
40 **who Do and Do Not Stutter**

41 Disfluencies occur during spoken communication (Aylward, 2020; Bortfeld et al., 2001).
42 Although many classification systems exist, most researchers agree that they fall into two broad
43 categories: *stuttering-like disfluencies* (SLDs: sound, syllable, or monosyllabic word repetitions,
44 prolongations, blocks, or broken words) and *other disfluencies* (ODs: interjections, revisions, or
45 multisyllable word/phrase repetitions; Ambrose & Yairi, 1999). The frequency of an individual's
46 speech disfluencies reportedly increases when they have lexical access problems (e.g., Hartsuiker
47 & Notebaert, 2010; Pellowski, 2011), with the use of more complex or less frequent lexical items
48 or utterances (e.g., Anderson, 2007; Bosker et al., 2019; Buhr & Zebrowski, 2009; Hartsuiker &
49 Notebaert, 2010; Jong, 2016) and with increases in cognitive load (Lindström et al., 2008).
50 Compared to other children, speech disfluency frequency is higher among children with speech
51 planning difficulties (Bortfeld et al., 2001; Engelhardt et al., 2010), low language efficiency
52 (Engelhardt et al., 2011), and increased attentional demands (Lee et al., 2017). Moreover, both
53 SLDs and ODs occur more frequently among children with executive functioning weaknesses
54 (Engelhardt et al., 2013), such as those with attention deficit hyperactivity disorder (ADHD) and
55 autism; hence, some researchers have speculated that executive functioning weaknesses have a
56 salient role in increasing disfluencies (Engelhardt et al., 2011; Lee et al., 2017; MacFarlane et al.,
57 2017). Some researchers have also speculated that language, speech fluency, and executive
58 functioning might be interrelated (Anderson & Ofoe, 2019) and that executive functioning
59 weaknesses, such as in inhibitory control and/or cognitive flexibility, might contribute to the
60 onset, development, and/or persistence of stuttering (Anderson & Ofoe, 2019; Paphiti et al.,
61 2022; Rocha et al., 2019; Usler, 2022).

62 Inhibitory control and cognitive flexibility have been established as core components of
63 executive functioning (Diamond, 2013). Inhibitory control is an umbrella term that encompasses
64 interference control (i.e., inhibition of thoughts and selective attention) and response inhibition
65 (i.e., inhibition of behaviors that are no longer appropriate; Diamond, 2013). Response inhibition
66 is considered complex when the requirement is not only to inhibit a motoric response but also to
67 execute a conflicting one. Cognitive flexibility has been conceptualized as the ability of the
68 cognitive system to set-shift, to have cognitive control, and to have divergent thinking (Ionescu,
69 2012). It builds upon inhibitory control and working memory (Garon et al., 2008) and allows
70 people to adapt to environmental changes by flexibly shifting their attention to newly introduced
71 rules (Moriguchi & Hiraki, 2009). Both inhibitory control and cognitive flexibility are associated
72 with speech-language development, formulation, and production (e.g., Crosbie et al., 2009;
73 Deák, 2004; Engelhardt et al., 2009; Tonér & Nilsson Gerholm, 2021).

74 Various studies have evaluated the role of inhibitory control and cognitive flexibility in
75 speech production in non-stuttering populations of variable age groups (Aylward, 2020; Dayalu
76 et al., 2022; Engelhardt et al., 2010, 2013; Hart, 2008; Lee et al., 2017), with mixed findings.
77 Although weaknesses in inhibitory control have been associated with increased disfluencies
78 compared to age-appropriate control groups in school-age children, adolescents, and adults with
79 ADHD (Engelhardt et al., 2010, 2013; Lee et al., 2017), other studies (e.g., Aylward, 2020) have
80 not found associations between inhibitory control or cognitive flexibility and speech disfluencies
81 in a similar population. On the other hand, lower cognitive flexibility scores have been
82 associated with increased disfluency in preschoolers (Hart, 2008) and other clinical populations,
83 such as adults with Parkinson's disease (Dayalu et al., 2022).

84 The current literature includes several questionnaire-based and experimental paradigm-
85 based studies investigating inhibitory control and cognitive flexibility in children who stutter
86 (CWS) and adults who stutter (AWS). Among them, the questionnaire-based studies have
87 reported lower inhibitory control (Eggers et al., 2009, 2010; Ofoe et al., 2018) and cognitive
88 flexibility for CWS (Eggers et al., 2010; Ntourou et al., 2018), despite some inconsistencies (e.g.,
89 Kefalianos et al., 2014). Simultaneously, experimental paradigm studies investigating motor or
90 verbal response inhibition in children and AWS have produced mixed findings. Some
91 researchers have reported that participants who stutter do not perform as well as controls, while
92 others have reported comparable performances between the groups (Bakhtiar & Eggers, 2023;
93 Eggers et al., 2018; Harrewijn et al., 2017; Piispala et al., 2016; Treleaven & Coalson, 2021).
94 The results have been less equivocal in studies of complex response inhibition (i.e., not only
95 withholding a response but also executing a conflicting, subdominant response; Anderson &
96 Wagovich, 2017; Eggers & Jansson-Verkasalo, 2017; Paphiti et al., 2022) and cognitive
97 flexibility (Anderson et al., 2020; Eggers & Jansson-Verkasalo, 2017; Eichorn et al., 2018;
98 Eichorn & Pirutinsky, 2021; Ntourou et al., 2018; Paphiti & Eggers, 2022; Paphiti et al., 2022;
99 Rocha et al., 2019), with most studies reporting that CWS do not perform as well as children
100 who do no stutter (CWNS).

101 Recent theoretical models of the etiology of stuttering have suggested an interaction
102 between inhibitory control, cognitive flexibility, and speech fluency. In their proposed model,
103 Anderson and Ofoe (2019) theorize that deficiencies in the domain-general processes of
104 inhibitory control and cognitive flexibility may affect domain-specific processes (i.e., emotion,
105 sensory, motor, and language), resulting in disfluencies in speech production. Meanwhile, Usler
106 (2022) has speculated that the onset and persistence of developmental stuttering could be

107 associated with cognitive processes, such as inhibitory control and cognitive flexibility, and that
108 disfluencies may occur due to “heightened cognitive conflict and control during speech” (Uslar,
109 2022, p. 25).

110 In summary, (a) increasing evidence from studies in nonstuttering populations supports a
111 link between inhibitory control/cognitive flexibility weaknesses and speech disfluencies, (b) past
112 empirical findings suggest lower inhibitory control and cognitive flexibility performance in CWS
113 when compared to CWNS, and (c) recent theoretical models of stuttering suggest a possible role
114 for inhibitory control/cognitive flexibility weaknesses in the onset and/or persistence of
115 stuttering. However, no direct investigation of the relationship between inhibitory control and
116 cognitive flexibility in CWS has been conducted to date. Therefore, the main research questions
117 of the current study were as follows: (a) Is there an association between inhibitory control task
118 performance (measured in speed or accuracy) and the number of speech disfluencies (i.e., SLDs
119 and/or ODs) produced by CWS when compared to CWNS, and (b) is there an association
120 between cognitive flexibility task performance and the number of speech disfluencies produced
121 by CWS when compared to CWNS? We hypothesized that lower inhibitory control and
122 cognitive flexibility task performance of the CWS group, relative to the CWNS group, would be
123 associated with higher speech disfluency production.

124 **Methods**

125 **Participants**

126 We recruited 38 Cypriot Greek-speaking 6- to 9-year-old children who were attending the
127 mainstream school system as participants in this study, 19 CWS ($M_{\text{age}} = 7.58$ years, $SD = 1$ year)
128 and 19 CWNS ($M_{\text{age}} = 7.58$ years; $SD = 1.08$ years). The groups were matched for gender (18
129 males and 1 female) and age (± 3 months), $t(36) = 0.11$, $p = .91$. The inclusion criteria for the

130 CWS were (a) having a diagnosis of developmental stuttering from a speech-language
131 pathologist, (b) scoring at least “mild” on the Stuttering Severity Instrument–Fourth Edition
132 (SSI-4; Riley, 2009), and (c) having no history of speech and/or language therapy other than for
133 stuttering. Based on the SSI-4 results, seven children were classified as having *mild* stuttering,
134 nine as *moderate*, two as *severe*, and one as *very severe*. The specific inclusion criteria for the
135 CWNS group were (a) having no parental concern regarding stuttering and (b) having no history
136 of speech and/or language therapy. Based on parental questionnaires, (a) Greek was the only
137 language spoken at home; (b) there were no reported psychological, neurological, or
138 developmental problems; (c) most participants were right-handed (except for two CWS and two
139 CWNS who were left-handed); and (d) all participants had normal or corrected-to-normal vision
140 and hearing. All participants passed bilateral tone audiometry screening (Amplivox 240, United
141 Kingdom) with signals at 20 dB and 500, 1000, 2000, and 4000 Hz.

142 We assessed the participants’ cognitive abilities using the vocabulary and block design
143 subtests of the Wechsler Intelligence Scale for Children–Third Edition (WISC-3, Wechsler,
144 1997). The WISC-3 consists of seven performance subtests and six verbal subtests. Given that
145 the participants attended the mainstream school system without any reported concerns by
146 teachers or parents about their cognitive function, only the vocabulary (verbal) and block design
147 (performance) subtests were administered as these correlate well with the overall WISC-3 score
148 (Groth-Marnat, 1997). In the vocabulary subtest, participants were asked to explain the meaning
149 of single words; in the block-design subtest, they were asked to rebuild, as quickly as possible,
150 several geometrical patterns from the picture manual with the use of four to nine two-colored
151 cubes. For the vocabulary subtest, the mean standard scores were 11.80 for the CWS and 14 for
152 the CWNS. For the block-design subtest, the mean standard scores were 12 for the CWS and

153 12.89 for the CWNS. Thus, no significant cognitive abilities differences were indicated between
154 the groups according to either the vocabulary subtest ($U = 114.50, p = .053$) or the block design
155 subtest ($U = 148, p = .35$).

156 No standardized speech and language testing exists for school-aged Greek-speaking
157 children. Therefore, to assess the language abilities of the participants, we administered the Bus
158 Story Test (Renfrew, 2010), which is widely used in its unstandardized form in studies of Greek-
159 speaking populations (e.g., Theodorou et al., 2016). The two groups were compared using 15
160 measures, including subordinate clauses, mean length of utterance, information, T-units, and the
161 total number of words. No significant differences were observed between the two groups ($p >$
162 $.05$).

163 **Data Collection**

164 This study was part of a series of studies, and data were collected during two 35- to 45-
165 minute sessions (1 week apart). In Session 1, we administered the Bus Story Test (story retelling)
166 and collected speech samples from spontaneous casual conversations based on standard
167 questions (about family, school, friends, and hobbies). In Session 2, the participants completed
168 two subtests of the WISC-3 and two computer tasks from the Amsterdam Neuropsychological
169 Tasks (de Sonneville, 2009), and an additional spontaneous speech sample was collected. All the
170 speech samples were video-recorded. Data were collected by the first author, an American
171 Speech-Language-Hearing Association (ASHA)–certified speech-language pathologist, and a
172 European-certified fluency specialist at the child’s school or speech clinic in a room where
173 sounds and other distractions were minimal.

174 All participants were volunteers recruited through an open call sent to registered speech-
175 language pathologists on the island. Participation consent forms were completed by both the

176 parents and participating children. This study was approved by the Cyprus National Bioethics
177 Committee and the Center of Educational Research and Evaluation of the Cyprus Pedagogical
178 Institute.

179 **Measures of Inhibitory Control and Cognitive Flexibility**

180 Computerized testing began with a simple response time task to familiarize the
181 participants with computer testing, followed by the Response Organization Objects (ROO) task.
182 The ROO task is a mixed-block-design task consisting of three blocks, each with a different
183 stimulus–response mapping. The participants were asked to place their index fingers on the two
184 response keys in all blocks. In the first block (compatible block, hereafter), the stimulus was a
185 green ball, and participants were instructed to press the left response key when the ball appeared
186 on the left side and the right when the ball appeared on the right side. In the second block
187 (incompatible block, hereafter), the stimulus was a red ball, and participants were instructed to
188 press the response key opposite the side where the ball appeared. Each block consisted of 30
189 trials. The third block (mixed block hereafter) consisted of 60 trials (30 compatible, 30
190 incompatible) with a fixed random alternation pattern. A more detailed description of the tasks
191 used was reported in a previous study (Paphiti et al., 2022). Inhibitory control was evaluated in
192 terms of performance cost by subtracting the mean response time (speed) and mean error
193 percentage (accuracy) of the compatible block from the speed and accuracy, respectively, of the
194 incompatible block. In Paphiti et al. (2022), we documented that cognitive flexibility can be
195 evaluated in different ways, namely, by subtracting the speed and accuracy results of the
196 compatible block from respectively the speed and accuracy results of (a) all compatible trials of
197 the mixed block, (b) the compatible trials of the mixed block with set shifting, or (b) the
198 compatible trials of the mixed block with no set shifting. Since the highest performance cost for

199 both stuttering and nonstuttering children was consistently found when using compatible trials of
200 the mixed block with set shifting (Paphiti et al., 2022), it was used to operationalize the cognitive
201 flexibility measure for our data analyses.

202 **Speech Sample Analyses**

203 The video-recorded speech samples (story retelling and casual conversations) were
204 orthographically transcribed. Speech disfluencies were consequently identified and categorized
205 as SLDs and ODs, in line with the findings of Ambrose and Yairi (1999). SLDs are (a) part-word
206 repetitions (e.g., “b-but”), (b) single-syllable word repetitions (e.g., “you you you”), (c)
207 dysrhythmic phonations, such as prolongations (e.g., “mmmy” “cooookie”), blocks (e.g.,
208 “#toy”), and broken words (e.g., “o#pen”). ODs are (a) interjections (e.g., “um”), (b)
209 revisions/abandoned utterances (e.g., “Mom ate/Mom fixed dinner,” “I want/Hey look at that”),
210 and (c) multisyllable word/phrase repetitions (e.g., “because because,” “I want I want to go”).
211 Unintelligible utterances and isolated affirmatives and negatives were excluded. If two or more
212 SLDs occurred on the same syllable (e.g., block + sound/syllable repetition), only the first
213 instance of disfluency was documented/counted (cf. Tumanova et al., 2014). For each
214 participant, the speech sample consisted of a minimum of 300 words. The average lengths of
215 speech samples for the CWS were 894 syllables ($SD = 155$ syllables), 438 words ($SD = 82$
216 words), and for the CWNS, 775 syllables ($SD = 95$ syllables) and 383 words ($SD = 45$ words).

217 To determine the coding reliability, 10 speech samples (five from the CWS and five from
218 the CWNS) were also evaluated by a second examiner and an ASHA-certified speech-language
219 pathologist trained in scoring disfluencies. The scores of the two examiners were compared using
220 Krippendorff’s alpha (Hayes & Krippendorff, 2007). The interjudge reliability score for all
221 disfluencies was high, Krippendorff’s $\alpha = .97$, 95% CI [.93, .99].

222 Data Analyses

223 For analysis, we used speech disfluency percentages of SLDs and ODs as the dependent
224 variables. The independent variables were the performance costs for inhibitory control and
225 cognitive flexibility. The group was set as the explanatory variable (value 1 for CWS; value 0 for
226 CWNS). To compare the mean percentages of speech disfluencies (SLDs and ODs) between
227 groups, we conducted nonparametric tests (related-samples Wilcoxon signed-rank tests). Gamma
228 regression models with an identity link function were used to model speech disfluencies,
229 considering that the actual values of disfluencies had small variations (SLDs: 1.36%–14.02%,
230 ODs: 0.45%–4.06% for the CWS and SLDs: 0.60%–2.49%, ODs: 1.38%–5.60% for the CWNS;
231 Figure 1 presents the variation of SLDs). The assumption of the percentages of speech
232 disfluencies was modeled appropriately, as shown by Jones et al. (2006). Speech disfluencies
233 were modeled in response to different performance costs and calculated as response times and
234 error percentages in the ROO task. The gamma regression model was selected because the
235 dependent variables were continuous and had non-negative values. The goodness of fit of the
236 gamma regressions was assessed by checking the deviance residuals. Based on the residual
237 structure, we determined that the gamma regression model was acceptable (see Figure 2). We
238 checked for outliers and removed two outlier points, observations 29 and 33.

239 The aim of the analyses was to identify whether there are associations between the
240 various performance costs and disfluency production. More specifically, each gamma regression
241 analysis sought to determine whether the effect of performance cost on disfluency production
242 was significantly higher for the CWS group, relative to the CWNS group. The significance level
243 for all the analyses was $\alpha = 0.05$. Data analyses were conducted using the R programming
244 language (Version 4.2.2).

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Results

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Inhibitory Control

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Table 1 provides an overview of the means, medians, and standard deviations of SLDs and ODs for both groups. Compared to CWNS, CWS had significantly more SLDs ($Z = 3.823, p < .001$). The two groups had similar OD production ($Z = 1.087, p = .277$). Nevertheless, the CWS had slightly lower standard deviation (1.29 vs 1.39), suggesting that as a group, they were less heterogeneous in terms of OD production. Table 2 presents the means, medians, and standard deviations of the performance costs calculated under the inhibitory control and cognitive flexibility task conditions regarding speed (milliseconds) and accuracy (error %). Although the standard deviation of mean performance costs in speed for the CWS was high, closer inspection of the dataset showed that the CWS group did not consist of different subgroups (see Figure 3). A limited number of participants showed a negative performance cost for accuracy, which means that they made more errors in the compatible (easier) block. This is related to the overall high accuracy rates; for example, some participants made two errors in the compatible block and only one error in the incompatible block.

All inhibitory control results are presented in Table 3. One significant interaction indicated that the effect of the inhibitory control performance cost on disfluency production was significantly higher in the CWS group, compared to the CWNS group. The significant interaction was as follows: group \times inhibitory control performance cost in speed for SLD ($p = .031$). This finding suggests that the performance cost, in terms of speed, had a higher effect on the SLD production for the CWS group, relative to the CWNS group. As illustrated in Table 3, even though the classification group value of ODs in the speed analyses was significant (suggesting that the CWNS had a higher OD value), there was no significant effect of the

268 performance cost on OD production for the CWNS group, as the interaction of group and
269 inhibitory control performance cost was not significant. There were no other significant
270 interactions in either the speed or accuracy analyses. Figure 4 (left panel) displays the
271 relationship between performance cost for speed and the percentage of SLDs for the two groups.

272 **Cognitive Flexibility**

273 As in the inhibitory control analyses, there was one significant interaction, indicating that
274 the effect of cognitive flexibility performance cost on disfluency production was significantly
275 higher in the CWS group, compared to the CWNS group. The significant interaction was group \times
276 cognitive flexibility performance cost in terms of accuracy for the SLDs ($p = .003$). This finding
277 suggests that the cognitive flexibility performance cost, in terms of accuracy, had a higher effect
278 on the SLD production for the CWS group, relative to the CWNS group. Even though the mean
279 performance of the CWS group in terms of accuracy appears to be better than that of the CWNS
280 group (6.32 vs 11.40 error percentage as seen in Table 2), this difference was not found to be
281 significant $t(36) = 1.46, p = 0.15$. No other significant interactions were observed. A summary of
282 all cognitive flexibility results is presented in Table 4. Lastly, Figure 4 (right panel) portrays the
283 relationship between performance cost in accuracy and the percentage of SLDs for the two
284 groups.

285 **Discussion**

286 Previous studies have reported lower complex response inhibition (Anderson &
287 Wagovich, 2017; Eggers & Jansson-Verkasalo, 2017; Paphiti et al., 2022) and cognitive
288 flexibility for CWS (Anderson et al., 2020; Eggers & Jansson-Verkasalo, 2017; Eichorn et al.,
289 2018; Eichorn & Pirutinsky, 2021; Paphiti & Eggers, 2022; Paphiti et al., 2022). However, the
290 relationship between inhibitory control, cognitive flexibility, and speech disfluency has only

291 been studied in non-stuttering populations and AWS. This study is the first to investigate this
292 relationship in CWS in a group of 6- to 9-year-old Cypriot Greek-speaking children. The main
293 finding was that lower proficiency in inhibitory control and cognitive flexibility was associated
294 with increased SLD production in the CWS group, compared to the CWNS group.

295 **Lower Inhibitory Control and Cognitive Flexibility Contribute to More SLD in CWS**

296 Our first hypothesis was that lower inhibitory control would be associated with more
297 speech disfluencies (SLDs and ODs) in the CWS group, relative to the CWNS group. This
298 hypothesis was supported only for SLD. This finding seems to corroborate the results of studies
299 on the AWS, in which poorer inhibitory control performance correlated with increased stuttering
300 frequency in conversations (Bakhtiar & Eggers, 2023). In addition, reports have shown that
301 AWS have difficulty inhibiting their planned speech responses (Ning et al., 2017), and evidence
302 has linked neural pathways associated with inhibitory control with stuttering severity (Neef et al.,
303 2018). Furthermore, our findings partially track with the findings of two studies with non-
304 stuttering populations, documenting that the speech-language production system relies on
305 inhibitory control (Engelhardt et al., 2010) and that a higher proportion of SLDs relates to lower
306 inhibitory control proficiency (Lee et al., 2017).

307 These results may seem, initially, to contradict those of Treleaven and Coalson (2020,
308 2021), who reported that manual and verbal response inhibitions do not predict stuttering
309 severity in AWS. However, it is important to point out that they evaluated possible associations
310 between inhibitory control and stuttering severity as measured by the SSI-4, which includes
311 stuttering frequency, the duration of stuttering moments, and physical concomitants. Moreover,
312 the contrasting results may be due to differences in the types of response inhibition evaluated. In
313 the present study, a task evaluating complex response inhibition was used, whereas Treleaven

314 and Coalson used tasks evaluating manual and verbal response inhibition, and Eggers et al.
315 (2018) hypothesized that reduced inhibitory control efficiency in certain tasks cannot be
316 generalized to all types of response inhibition.

317 Our second hypothesis was that lower cognitive flexibility would be associated with more
318 disfluencies (SLDs and ODs) in the CWS group, relative to the CWNS group. This hypothesis
319 was supported for SLD. All studies on school-age CWS that used computer tasks reported that
320 CWS had lower cognitive flexibility performance than CWNS, suggesting a possible role for
321 cognitive flexibility in developmental stuttering (Eggers & Jansson-Verkasalo, 2017; Eichorn &
322 Pirutinsky, 2021; Paphiti & Eggers, 2022; Paphiti et al., 2022). In one previous study, no
323 cognitive flexibility differences were found between preschool CWS and the CWNS, whereas
324 school-age CWS had significantly higher performance costs regarding both speed and accuracy
325 than the CWNS (Paphiti & Eggers, 2022). The authors interpreted this finding as cognitive
326 flexibility possibly contributing to stuttering persistence. The current study's findings seem to
327 align with these previous findings, as our participants were school-aged children, most of whom
328 had surpassed the age of spontaneous recovery.

329 To our knowledge, no previous studies have investigated the possible link between
330 cognitive flexibility and speech disfluencies in CWS. Only three studies have been conducted on
331 nonstuttering populations, with inconsistent findings. Our findings align with those of Hart
332 (2008) and Dayalu et al. (2022), who reported an association between cognitive flexibility and
333 disfluency in typically developing preschool children and people diagnosed with Parkinson's,
334 respectively. Aylward (2020), on the other hand, found no association between cognitive
335 flexibility and speech disfluencies during a picture description task in children and adolescents
336 with ADHD. The difference in findings may also relate to the tasks in both studies tapping into

337 different domains of cognitive flexibility. In the current study, we measured the ability to set
338 shift between compatible and incompatible trials by executing appropriate motor responses,
339 while in the Aylward study what was measured was the ability to set shift between word reading
340 and naming the dissonant ink color (executing verbal responses).

341 **Theoretical and Clinical Implications**

342 These findings can be linked to different theoretical models of stuttering based on
343 aberrant monitoring during speech-language planning, such as the covert repair hypothesis
344 (Kolk, 1991; Postma & Kolk, 1993; Postma et al., 1990) and the vicious circle hypothesis (Vasić
345 & Wijnen, 2005). Although they do not explicitly discuss inhibitory control and cognitive
346 flexibility, both models support the idea that these executive functioning processes are related to
347 stuttering. The first model speculates that disfluencies (SLDs and ODs) are by-products of covert
348 repairs of internal speech errors (at the phonetic plan level) by the internal monitoring system.
349 People who stutter are thought to have a phonological encoding deficit; that is, phonological
350 processing systems are slower than normal (Anderson et al., 2022). This deficit means that their
351 phonetic plans are vulnerable to errors and provide opportunities for covert self-repairs, which
352 impede the ability to speak fluently. Research has indicated that weaknesses in inhibitory control
353 may lead to less stable phonological representations of words in the mental lexicon (Anderson &
354 Wagovich, 2017; Ofoe et al., 2018), whereas weaknesses in cognitive flexibility may hinder the
355 ability to adjust to a new speech plan, which may consequently lead to increased levels of stress
356 and maladaptive responses to moments of stuttering (Eggers & Jansson-Verkasalo, 2017). Given
357 that the inhibitory control and cognitive flexibility help modulate and regulate cognitive and
358 behavioral responses efficiently (as in the case of speech-language production), slower planning
359 of speech and language processes could result in SLDs (Melnick et al., 2005, p. 104). The

360 vicious circle hypothesis states that, in people who stutter, the internal monitoring system is
361 hypervigilant, and the hypervigilance results in repairs during the articulatory phase, even though
362 they are not warranted. Given that inhibitory control enables the discontinuation of inappropriate
363 responses, any weaknesses would result in an inability to do this and increase speech
364 errors/disfluencies (Vasić & Wijnen, 2005). Furthermore, cognitive flexibility enables shifting
365 from one mental set to another; therefore, any weaknesses in cognitive flexibility would result in
366 an inability to change the articulatory plan timely and effectively prior to the production phase,
367 which would also lead to speech disfluencies. In a recent publication, Usler (2022) related
368 reduced cognitive flexibility to aberrant conflict monitoring and [error] detection processes
369 (p.27) in speech and language processing among CWS.

370 The current findings can also be linked to the executive function model (Anderson &
371 Ofoe, 2019), which specifically addresses the contributing roles of inhibitory control and
372 cognitive flexibility in the onset, development, and persistence of stuttering. This model suggests
373 a bidirectional relationship between inhibitory control and cognitive flexibility's domain-general
374 processes and their domain-specific processes (i.e., emotion, sensory, motor, and language).
375 Specifically, deficiencies in inhibitory control and cognitive flexibility result in deficiencies in
376 domain-specific processes which, in turn, result in deficiencies in the general processes of
377 inhibitory control and cognitive flexibility. Therefore, it is speculated that weaknesses in
378 inhibitory control/cognitive flexibility can either emerge as a result or as a precursor to
379 stuttering.

380 Formulating possible clinical suggestions might be considered premature. However,
381 given that various researchers have reported measurements showing that CWS have low
382 inhibitory control and cognitive flexibility efficiency, in combination with our finding that

383 inhibitory control and cognitive flexibility are associated with SLD, allows for some speculative
384 suggestions. Inhibitory control is considered a core component of self-regulation (Gärtner et al.,
385 2018), and cognitive flexibility has been reported to assist in regulating repetitive negative
386 thinking and disengaging from the emotional aspects of a situation (Gabrys et al., 2018).
387 Therefore, CWS who exhibit lower efficiency in inhibitory control/cognitive flexibility often
388 have difficulty regulating emotional arousal and negative thinking in demanding
389 (communicative) situations. For these children, childhood stuttering interventions could benefit
390 from the inclusion of counseling that helps parents improve their children's self-regulation and
391 reducing environmental barriers to their effective communication (e.g., reducing interruptions,
392 giving ample time to talk, and using slower rate of speech).

393 **Limitations and Suggestions for Future Research**

394 Given that the male-to-female ratio in the current study was higher than that typically
395 reported for this age group (Yairi & Ambrose, 2013), the current findings may be limited—in
396 part or in whole—to males. Although none of the parents, teachers, or speech-language
397 pathologists reported any concerns about co-occurring disorders, such as ADHD during
398 participant recruitment, it cannot be ruled with certainty that some participants may have had co-
399 occurring disorders, resulting in poor inhibitory control/cognitive flexibility.

400 The current study demonstrates that 6- to 9-year-old CWS exhibiting reduced inhibitory
401 control and cognitive flexibility tend to have an increased production of SLD. This effect was not
402 observed for the production of OD. To establish the generalizability of these results, future
403 research may consider cross-sectional or longitudinal studies encompassing a broader age range
404 and including larger numbers of female participants to facilitate comparisons both within and
405 between the two classification groups (CWS and CWNS) and across various age groups

406 (preschool and school-age). Moreover, a longitudinal study would be able to document how
407 these processes play a role in the development of disfluencies (and stuttering) over time.

408 **Conclusions**

409 This was the first study designed to directly evaluate the roles that inhibitory control and
410 cognitive flexibility may have in producing speech disfluencies in CWS. Our findings suggest
411 that CWS with reduced inhibitory control and cognitive flexibility tend to have higher
412 production of SLDs (but not ODs). These findings corroborate some earlier findings concerning
413 nonstuttering participants and AWS and contribute to the expansion of our knowledge and
414 understanding of developmental stuttering appearance and/or persistence.

415 **Data Availability Statement**

416 Data will be made available on request.

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424

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Tables

619

Table 1. Means, medians, and standard deviations of disfluencies (stuttering-like disfluencies

620

[SLDs], other disfluencies [ODs] of children who stutter (CWS) and children who do not stutter

621

(CWNS).

Type	CWS		CWNS	
	<i>M (SD)</i>	Median	<i>M (SD)</i>	Median
SLD				
Monosyllabic word repetition	1.73 (1.37)	1.35	0.45 (0.37)	0.41
Part-word repetition				
Sound repetition	0.22 (0.21)	0.18	0.18 (0.25)	0.15
Syllable repetition	1.55 (1.47)	1.29	0.43 (0.24)	0.41
Dysrhythmic phonation				
Prolongation	0.81 (1.91)	0.16	0.10 (0.14)	0.00
Block	1.27 (1.65)	0.52	0.01 (0.04)	0.00
Broken word	0.47 (0.73)	0.20	0.08 (0.15)	0.00
Total SLD	6.22 (4.51)	4.59	1.09 (0.66)	0.80
OD				
Multi-syllable word repetition	0.27 (0.31)	0.17	0.17 (0.18)	0.15
Interjection	1.48 (0.95)	1.44	1.35 (0.87)	1.13
Phrase repetition	0.36 (0.31)	0.26	0.34 (0.27)	0.23
Revision				
Lexical revision	0.60 (0.46)	0.50	0.63 (0.39)	0.43
Grammatical revision	0.12 (0.16)	0.00	0.21 (0.19)	0.17
Phonological revision	0.02 (0.06)	0.00	0.02 (0.06)	0.00
Unfinished word (or sentence)	0.63 (0.37)	0.61	0.88 (0.51)	0.91
Total OD	3.50 (1.29)	2.97	3.60 (1.39)	3.93

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628 Table 2. Means, medians, and standard deviations of performance costs for the two groups.

Type	CWS		CWNS	
	<i>M (SD)</i>	Median	<i>M (SD)</i>	Median
IC performance-costs in speed (incompatible - compatible block)	308 (242)	246	183 (101)	176
IC performance-costs in accuracy (incompatible - compatible block)	4.56 (5.35)	3.33	4.03 (5.83)	3.33
CF performance-costs in speed (set-shifting compatible trials from mixed block - compatible block)	718 (404)	632	475 (161)	458
CF performance-costs in accuracy (set-shifting compatible trials from mixed block - compatible block)	6.32 (10.99)	3.33	11.40 (10.50)	13.33

629

630 *Note.* CWS = children who stutter; CWNS = children who do not stutter; IC = inhibitory control;

631 CF = cognitive flexibility.

632

633 Table 3. Results of the regression analyses linking the inhibitory control performance costs in
 634 speed with stuttering-like disfluencies (SLDs).

	Dependent variables	Estimate	t value	Sig.
	Intercept	1.293	3.990	< .001*
%SLD	Classification group	1.557	1.375	.871
	IC performance costs in speed	-0.00	-0.163	.871
	Group × IC performance costs in speed	0.011	2.245	.031*
%OD	Intercept	4.243	5.473	< .001*
	Classification group	-2.962	-3.534	< .001*
	IC performance costs in speed	-0.003	-1.042	.305
	Group × IC performance costs in speed	0.005	1.516	.139
%SLD	Intercept	1.349	6.305	< .001*
	Classification group	5.078	4.571	< .001*
	IC performance costs in accuracy	-0.025	-0.999	.325
	Group × IC performance costs in accuracy	-0.108	-0.764	.450
%OD	Intercept	3.426	7.072	< .001*
	Classification group	-1.818	-3.341	.002*
	IC performance costs in accuracy	0.042	0.556	.582
	Group × IC performance costs in accuracy	0.005	0.061	.951

635
 636 *Note.* Sig. = significant; IC = inhibitory control; OD = other disfluency.
 637 * $p < .05$ (significant).

638 Table 4. Results of the regression analyses linking the cognitive flexibility performance costs in
 639 accuracy with stuttering-like disfluencies (SLDs).

	Dependent variables	<i>Estimate</i>	<i>t value</i>	Sig.
%SLD	Intercept	1.238	2.317	0.271
	Classification group	4.195	2.041	0.049*
	CF performance costs in speed	2.131	0.020	0.984
	Group × CF performance costs in speed	7.109	0.223	0.824
%OD	Intercept	5.194	4.005	< .001*
	Classification group	-3.028	-2.144	.040*
	CF performance costs in speed	-0.003	-1.427	.163
	Group × CF performance costs in speed	0.003	1.111	.275
%SLD	Intercept	1.223	5.379	< .001*
	Classification group	5.718	5.501	< .001*
	CF performance costs in accuracy	0.002	0.139	0.890
	Group × CF performance costs in accuracy	-0.142	-3.219	.003*
%OD	Intercept	3.620	6.149	< .001*
	Classification group	-1.646	-2.551	.016*
	CF performance costs in accuracy	-0.002	-0.051	.960
	Group × CF performance costs in accuracy	-0.023	-0.568	.574

640

641 *Note.* Sig. = significant; CF = cognitive flexibility; OD = other disfluency.

642 * $p < .05$ (significant).

643

Figures

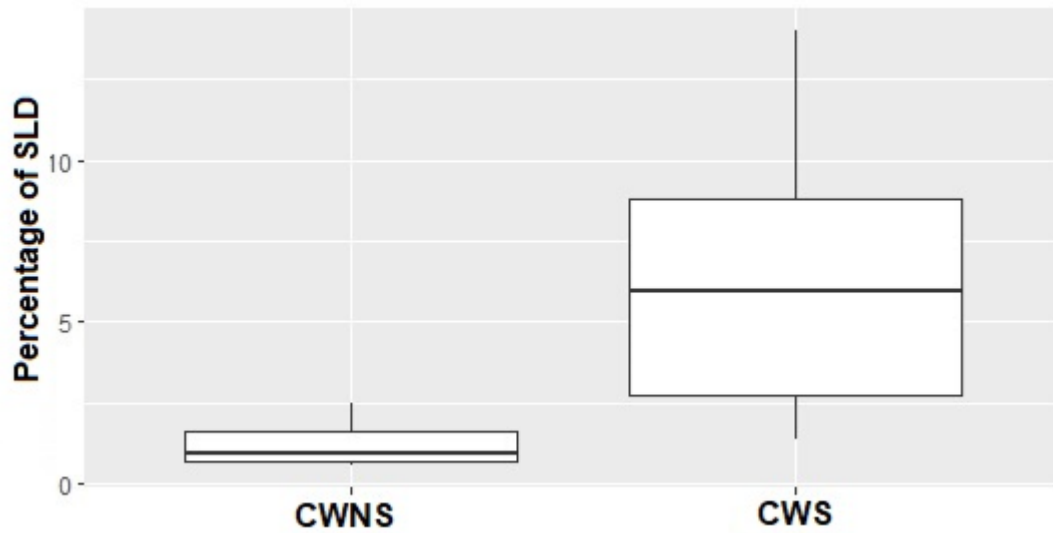
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Figure 1. Box plots of the percentage of SLDs for the CWS and CWNS groups. SLD =

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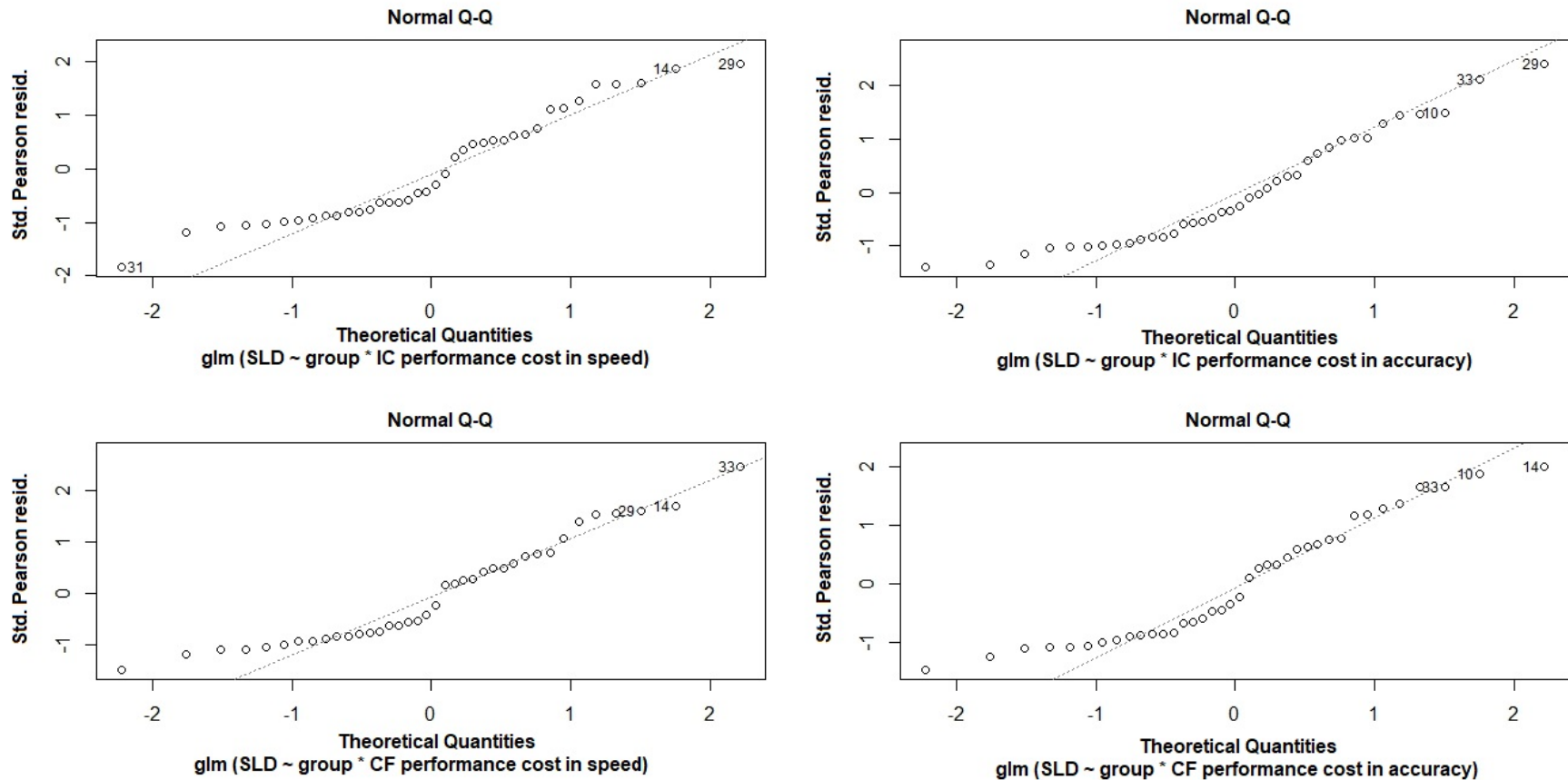
stuttering-like disfluency; CWS = children who stutter; CWNS = children who do not stutter.

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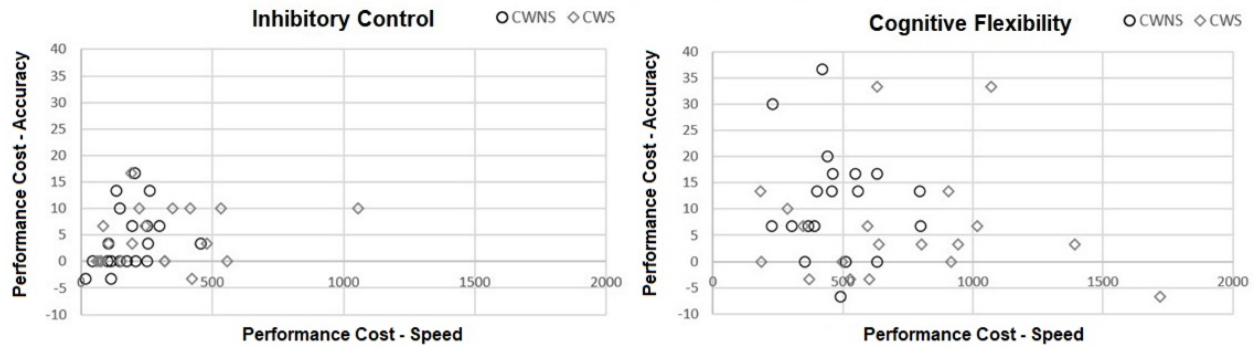
648 **Figure 2.** Quantile-Quantile (Q-Q) plots diagnostics. Std Pearson Resid. = Standardized Pearson Residuals; SLD = stuttering-like
 649 disfluency; glm = generalized linear model; IC = inhibitory control; CF = cognitive flexibility.



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652 **Figure 3.** Scatter plots for inhibitory control (left) and cognitive flexibility (right) displaying the
 653 relationship between performance cost for speed and accuracy for CWS and CWNS. CWS =
 654 children who stutter; CWNS = children who do not stutter.

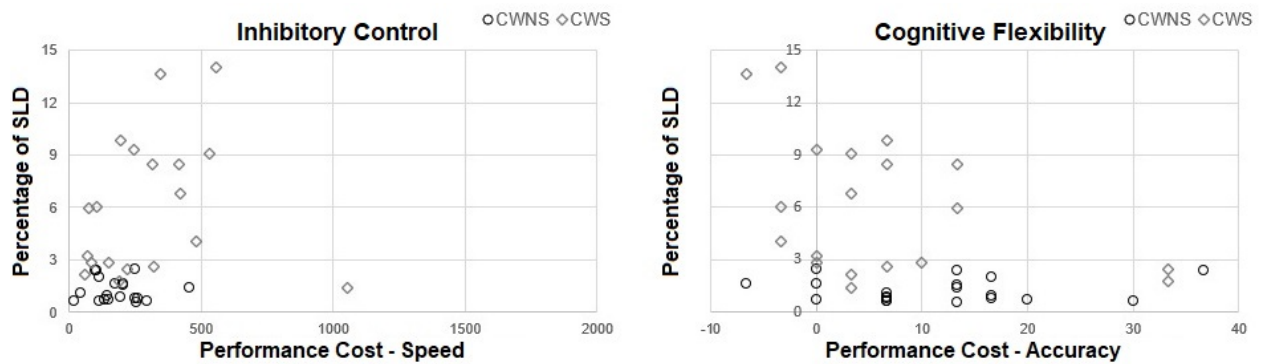


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658 **Figure 4.** Scatter plots for inhibitory control displaying the relationship between performance
 659 cost for speed and the percentage of stuttering-like disfluency (SLD) for the two groups (left),
 660 and for cognitive flexibility displaying the relationship between performance cost in accuracy
 661 and the percentage of SLD for the two groups (right). CWNS = children who do not stutter;
 662 CWS = children who stutter.



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