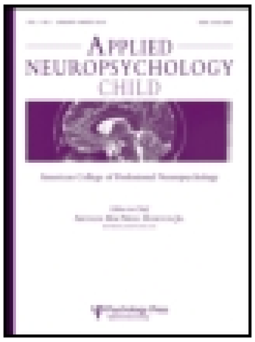

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Executive functions in Persian-speaking preschool children with speech sound disorders and comparison with their typically developing peers

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ABSTRACT
This study aimed to compare working memory, inhibitory control, and cognitive flexibility, the core components of executive functions, among two prevalent subtypes of preschool children with speech sound disorder, i.e., phonological delay ($n = 16$) and consistent phonological disorder ($n = 15$), and a group of typically developing children ($n = 18$). The correlation between executive function components and the accuracy of speech sound production were also investigated. Nonword repetition task and syllable repetition task were used to evaluate the phonological loop of working memory. Backward digit span was administered to examine the central executive of working memory. Cognitive flexibility was assessed using the second selection of the flexible item selection task and inhibitory control using Stroop-like and Go/No-Go tasks. The percentage consonants correct was applied to calculate the accuracy of speech sound production. Results of a one-way multivariate analysis of covariance revealed statistically significant differences between groups in the combined dependent variables after controlling for age ($F(14, 80) = 17.289$, $p < .001$, Pillai's trace $= 1.503$, partial $\eta^2 = .752$). Typically developing children outperformed in all measurements of executive functions than both speech sound disorder subgroups. Moreover, children with phonological delay performed better in nonword repetition and corrected responses of Stroop-like than consistent phonological disorder group. All executive function measurements also correlated with speech sound production. The results of the present study highlight the importance of including domain-general cognitive skills in current assessment protocols for children with phonological delay and consistent phonological disorders.

KEYWORDS
Cognitive flexibility; inhibitory control; preschool children; speech sound disorder; working memory

Introduction

Most children make mistakes in speech sound production. As they grow, accuracy of children's speech improves, and their systematic error patterns fade (Bernthal et al., 2017). The change in error patterns, which reflects the reorganization of the phonological system of a child's language (Ingram, 1976), occurs without intervention given adequate language exposure (Crosbie et al., 2009). However, some children—in the absence of any obvious etiology (e.g., hearing, structural, motor, and/or psychosocial difficulties)—struggle with this reorganization and require intervention to resolve their speech sound errors. Speech sound disorder (SSD) is the most common diagnostic label adopted for this population by clinicians. This most prevalent pediatric disorder (Dodd, 2014) is characterized by a high number of errors in speech sounds or syllable structure of speech, beyond what is observed in typical speech development (Munson & Krause, 2017), which negatively impacts the child's speech intelligibility. Later academic performance and literacy (Lewis et al., 2000), mental health (McCormack et al., 2010), and even future employment opportunities (Law et al., 2017) are affected if SSD does not receive appropriate intervention.

While we have much information about the types of speech errors, less is known about the factors affecting the process of children's phonological acquisition. To understand the ambient language and to express their intentions, children need to decode the sequence of heard sounds (Dodd & McIntosh, 2008). Important questions include: what cognitive mechanisms support phonological acquisition? And, do domain-general cognitive processes underlie SSDs? General cognitive mechanisms, which are considered in most cognitive texts as executive functions (EFs), are a series of top-down processes that enable the individual to regulate thoughts and actions (Friedman, 2016) when an automatic behavior or response is insufficient or irrelevant (Diamond, 2013). Working memory (WM), cognitive flexibility (CF), and inhibitory control (IC) are key components of EFs (Miyake et al., 2000). WM is the ability to temporarily store information and manipulate it (Baddeley, 2012). CF refers to flexibly adapting to new demands or rules, as well as switching between tasks (Diamond, 2013). IC is defined as ignoring a distraction or stopping an impulsive response

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(Zelazo, 2015). Each of these general mechanisms might play an essential role in the transition to adult-like phonology and could be a valuable challenge in research to explain SSDs.

Working memory

Most studies examining WM in children with SSD have used the most cited model of WM–Baddeley and Hitch's three-component model (Baddeley & Hitch, 1974). First, the phonological loop temporarily stores verbal information (Baddeley, 2003a), a process that is required to form stable phonological representations (Tkach et al., 2011). Second, the visuospatial sketchpad has a similar responsibility for visual stimuli (Baddeley, 2003b). Finally, the central executive is responsible for controlling and allocating attention, and synchronizing information on the two "slave" systems (Baddeley, 1996).

Data from several studies have demonstrated poor performance of SSD children compared with their normal counterparts in nonword repetition task (NRT) (e.g., Afshar et al., 2017; Guedes-Granzotti et al., 2017; Munson et al., 2005) and forward digit span (FDS) (e.g., Masso et al., 2017; Murphy et al., 2014; Torrington Eaton & Ratner, 2016). Syllable repetition task (SRT), which is designed by Shriberg et al. (2009) to cover problems with interpreting the results of NRT in SSD children, has received less attention and explored in few studies (Brosseau-Lapré & Rvachew, 2017; Mahrooghi et al., 2015).

In assessing central executive, Afshar et al. (2017) using backward digit span (BDS) and Waring and colleagues' studies using the reverse recall of familiar words and digits showed significantly lower performance in children with phonological delay (PDel) (Waring et al., 2017) and consistent phonological disorder (CPDis) (Waring et al., 2018) than in typically developing (TD) peers. However, the relationship between the severity of SSD and central executive performance was not found (Afshar et al., 2017; Linassi et al., 2005; Torrington Eaton & Ratner, 2016).

Cognitive flexibility

In the recent decade, studies by Dodd and colleagues have shown the more reduced performance of a group of undifferentiated phonologically based speech disordered (Dodd & McIntosh, 2008), and children with CPDis (Crosbie et al., 2009) in CF tasks. The same findings by Dodd (2011), without a control group, revealed that the disordered speech group performed more poorly in CF tasks than their PDel peers. Torrington Eaton and Ratner (2016) used Flexible Item Selection Task (FIST) and hearts and flowers tasks to assess CF in 4–6 years preschool children. Their results did not show the weaker performance of SSD children than of participants with high- and low-average speech production skills. The authors noted that CF might not be considered as an independent construct in this age range. Despite the reasonably high prevalence of color vision deficiency among preschool children (1.4–5.6% in varying ethnicities; Xie et al., 2014), previous studies overlooked the issue that color vision deficiency may contribute to performance in CF tasks, because of the requirement of color abstraction in such tasks.

Inhibitory control

A few published studies described the role of IC in refining speech sound errors. Using a button-press task, within continuous performance protocols, Murphy et al. (2014) examined sustained visual and auditory attention in school-aged SSD children. Both sustained attention and IC are measured in these tasks, where the participants need to maintain readiness responding to a target stimulus or withhold response to a non-target stimulus (Roebuck et al., 2016). SSD children performed significantly weaker than controls in the sustained auditory attention. These findings could be interpreted as a deficit in IC of auditory stimuli. In contrast, Torrington Eaton and Ratner (2016) using day-night Stroop and flowers task—accuracy and reaction time—to compare IC between SSDs and controls did not find differences between the groups in the two tasks. Also, the tasks were not related to the accuracy of speech sound. However, the debate continues about the contribution of IC in speech sound change in preschool children.

Phonological characteristics of Persian

Persian (also referred to as Farsi), one of the Indo-European languages, is the most widely spoken mother tongue in Iran and some countries such as Afghanistan, Tajikistan, and the region around the Pamir mountains. There are 23 consonants and 6 vowels in formal Persian: three short vowels/æ, e, o/and three long vowels/a, u, i/(Samareh, 1999). Persian is a syllable-timed language. Farsi syllables can only be presented in the following way: CV (C) (C). Therefore, a word's beginning vowel must be preceded by a glottal stop/ʔ/(e.g., "asb" /ʔ æsb/ meaning "horse") (Samareh, 1999). Phonological processes (also known as error patterns) involve simplifying a sound by systematically omitting target sounds or substituting them (Bernthal et al., 2017). Frequent phonological processes observed in Persian TD children between 36 and 72 months include gliding, affrication, deaffrication, stopping, fronting, final devoicing, cluster reduction, final consonant deletion, metathesis, and consonant harmony (Zarifian & Fotuhi, 2020).

The present study

The results of previous studies on the relationship between EFs and speech sound accuracy have been scattered and somewhat conflicting. The purpose of this research was to examine core EFs (i.e., WM, CF, and IC) in Persian-speaking preschool children with two prevalent subtypes of SSD (i.e., CPDis and PDel) and compare them with their TD peers that have not been investigated in previous literature. The reason for selecting these two subgroups was twofold; firstly, they are the most common children with SSDs

(PDel: 57% and CPDis: 21% of caseload); secondly, they both have age-inappropriate error patterns and are devoid of oral motor difficulties (Dodd, 2011). Research has also shown that these two subgroups are different in terms of phonological awareness (Preston et al., 2013), reading (Harris et al., 2011), and response to intervention (Alcorn et al., 1995). There is evidence that children with SSDs may have difficulty using phonological information to read and spell, even after their speech errors have been resolved (Gillon, 2004; Raitano et al., 2004). Planning effective interventions in SSDs children requires identifying and understanding the variables that underlie weak phonological knowledge in these children. EF abilities involved in literacy acquisition and academic achievement (Fitzpatrick et al., 2014; Nesbitt et al., 2015; Schmitt et al., 2017) may contribute to the control of early phonological patterns and the process of transition to adult-like phonology. Understanding possible associations between EFs and SSDs could provide some insight into the underlying nature of this prevalent childhood speech disorder. The specific questions of the current study were: (a) Are WM, CF, and IC different among CPDis, PDel, and TD children? and (b) Do EF abilities correlate with the accuracy of speech sound production?

Method

Participants

The present study was a non-experimental, descriptive-analytical, cross-sectional study. Three groups of participants aged 4–6 years were selected: children with PDel ($n = 15$), CPDis ($n = 16$), and TD ($n = 18$). Children with SSD were recruited from public and private speech therapy clinics in Tehran, Iran. Children with TD were selected from among two daycare centers. Children in TD group were matched to the children with CPDis and PDel, based on age within six months. All children were full-term born, and Persian was the only language spoken at home. All participants passed a pure tone audiometric screening test at 25 dB for 500, 1,000, 2,000, and 4,000 Hz bilaterally and had fewer than six reported episodes of otitis media before age three, as reported by the parents. Children with fluency disorders, genetic diseases, neurological disorders, cerebral palsy, uncorrected visual problems, and/or cleft lip/palate were excluded, reported by the parents during a face-to-face interview or written on the participant selection form. All children were required to have normal intelligence defined as a Performance IQ of 80 or above on the Persian version of Wechsler Preschool and Primary Scale of Intelligence (P-WPPSI) (Razavieh & Shahim, 1990) and normal color vision on Ishihara's test for the color deficiency (Choi & Hwang, 2009). Children were not included if they scored 1 *SD* below the mean on each of six main subtests of the Persian version of Test of Language Development-Primary, third edition (P-TOLD-P:3) (Hasanzade & Minaie, 2001), and also for the oral motor subtest of the Persian version of Diagnostic Evaluation of Articulation and Phonology (P-DEAP) (Zarifian, 2014). To screen children with behavioral and attention problems, Persion version of Child Behavior Checklist for ages 1.5–5 (CBCL/1.5–5) (Kiamanesh & Mohammad-Esmail, 2007) was conducted. According to Kiamanesh and Mohammad-Esmail (2007), children with a t-score > 65 were classified as "clinical" and excluded from the study. For TD children, three criteria were considered: obtain a standard score of 8 or above in measures of percentage consonants correct (PCC), percentage vowels correct (PVC), percentage phonemes correct (PPC), and single word vs. connected speech agreement in the P-DEAP phonology subtest (Zarifian et al., 2014); no atypical errors in the phonology subtest of P-DEAP (only chronologically appropriate speech sound errors accepted); and to have never received speech and language interventions. Children with SSD were categorized into CPDis and PDel using the following criteria: participants with CPDis consistently used at least two atypical error patterns (i.e., those that are not made by less than 10% of children of any age group) and had a score below 33.3% on the inconsistency subtest of P-DEAP (Zarifian, 2014). Diagnostic criteria for PDel include performance more than 1 *SD* below the mean in measure of PCC on the phonology subtest of P-DEAP and to have delayed speech error patterns (i.e., those demonstrated by more than 10% of children in a younger age group).

Materials and data collection methods

Persian version of diagnostic evaluation of articulation and phonology (P-DEAP)

The Diagnostic Evaluation of Articulation and Phonology (DEAP) evaluates phonological and phonetic skills of children (Dodd et al., 2002). Five subtests (two screens: diagnostic screen and oral motor; three assessments: articulation, phonology, and inconsistency) constitute the DEAP battery. Zarifian (2014) prepared a Persian version of DEAP and examined its psychometric properties in 387 Persian children aged 3–6 years in Tehran, Iran. Content validity index of the P-DEAP was over 94.92. Significant differences were observed in P-DEAP results between the children with and without articulation and phonological disorder and between different age groups ($p < .001$) confirmed the discriminant validity. Standard error measurements (SEMs), Pearson's correlation, and intra-class correlation (ICC) coefficients for test–retest reliability showed high reproducibility.

Nonword repetition task (NRT)

This task (Afshar et al., 2013), which was used to assess the phonological loop of WM, includes 25 stimuli (8 one-syllable, 9 two-syllable, 5 three-syllable, and 3 four-syllable nonwords) (see Supplemental Appendix 1 for details). After explaining how to perform the task and four practice nonwords, the child was presented with prerecorded stimuli. The child received each stimulus via headphones and had 2 s to repeat it. Each correct syllable repetition was considered one point, providing a range of scores between 0 and 53. In scoring this task, while the children's pronunciation errors were regarded as correct if those were similar to the error patterns in their connected speech, a speech error

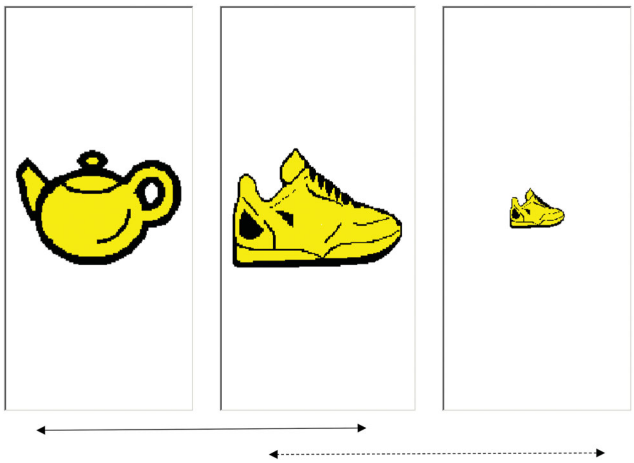

Figure 1. Sample trial of the FIST (Jacques & Zelazo, 2001). A correct pair match (two big items) is represented by the solid arrow, while another pair match (two shoes) is represented by the dashed arrow. Any pairs can be chosen as a first or second matching pair (All cards are the same color and yellow).

absent in the connected speech was considered as incorrect. The content validity ratio (CVR) coefficient was .99. Test–retest reliability of this task and internal consistency was .979 and .972, respectively.

Syllable repetition task (SRT)

Shriberg et al. developed SRT to measure the function of the phonological loop of WM in SSD children with no target speech sounds in their phonetic inventory or in those who habitually produce the desired sounds incorrectly (Shriberg et al., 2009). This task comprises 18 stimuli (8 two-syllable, 6 three-syllable, and 4 four-syllable nonwords), including four voiced consonants (/m/, /n/, /b/, and /d/) and one vowel (/a/). The consonants in this task are present in the phonetic inventory of young children and most children with SSD. Mahroughi et al. examined the validity and reliability of this task in Persian preschoolers (Mahrooghi et al., 2015). They reported a CVR of .57–1, the test–retest reliability coefficient of .87 and an internal consistency of .83.

Backward digit span (BDS)

BDS, a subtest of the Persian version of Wechsler Intelligence Scale for Children-IV (Sadeghi et al., 2011), was used to assess central executive of WM. This task contains seven sets; each set includes two trials. Initially, the child was given practice tests to make sure the child understood the task instructions. In BDS, the child repeats digits after the examiner in reverse order. The participant received one score for successful correct repeating at each trial. If a child failed to repeat both trials in a set, the test was stopped. The maximum score for BDS was 14.

Flexible item selection task (FIST)

In this study, a print version of the FIST (Jacques & Zelazo, 2001) was used to assess CF. In the FIST, the child is asked to select two images (from three items, varying in shape, color or size: e.g., a big yellow teapot, a big yellow shoe, and a small yellow shoe) that are similar in some way (e.g., two big items); next, they are asked to select a second pair that are similar in a different way (e.g., two shoes) (see Figure 1). Before 15 test trials, each child completes two practice trials. The examiner gave feedback to the participant in practice trials, but not in the test trials. CF was measured by the child's scores in the second selection of this task ($FIST_2$). The second selection was considered correct if the child correctly selected the first pair of pictures. The range of scores in this task was 0–15.

Stroop-like task

Adapted from the study of Gerstadt et al. (1994), the Stroop-like task was intended to assess IC. The experiment included 20 trials of two semantically opposite items (10 suns, 10 moons), appearing in random order. The participants were asked to say "sun" when seeing "moon" and vice versa. At first, after familiarization, two practice trials were done, the experimenter in each practice trial provided correcting feedback. No feedback was given during the test trial. Inter-stimulus intervals (ISIs) and scoring were the same as described in Berlin and Bohlin (2002). Each stimulus is presented in a time interval of 1,500 ms, the response time of 1,500 ms, and the waiting time before the next stimulus was presented in 1,500 ms. Three types of responses were registered: false responses (STR_F: naming the picture instead of saying the opposite); corrected responses (STR_C: naming the image or starting to name the image and then spontaneously correcting); and no answer (STR_Na). STR_C is considered the main measure of this task because STR_F and STR_Na could be caused by the child's lack of proper understanding of the task (Berlin & Bohlin, 2002). Lower scores on this task indicate better IC skills. The presentation of stimuli was controlled by DMDX software (Forster & Forster, 2003).

Go/No-Go task

Another task for assessing inhibition, adapted from Müller et al. (2012), was a computerized task in which participants were required to respond to the appearance of target stimuli (Go stimulus, a "circle") by striking a computer button (spacebar, covered with a red sticker) and avoid responding to the appearance of non-target stimuli (No-Go stimulus, a "triangle"). After explaining the rules of the task to the participants, in the practice phase, participants were given four stimuli (two Go and two No-Go, with the order "circle-triangle-circle-triangle"). If the participant correctly responded to two stimuli (one correct response to Go, one correct response to No-Go), the trial phase was presented. If not, the practice phase was repeated once. The experimenter provided correcting feedback during the practice phase. The trial phase was divided into three blocks: a baseline and two test blocks, where each block contained 24 stimuli. During the trial phases, no feedback was given. Each stimulus was presented during a time of 2,000 ms, response time was 3,500 ms, and ISIs were 1,500 ms. For each test trial, circles and triangles appeared in random order. The rate of Go stimuli were 50, 75, and 25%, in the baseline, block 1, and block 2, respectively. Five scores derived from the task including hits (GNG_H: successful pressing the key during a "Go" stimulus presentation), commission errors (GNG_C: pressing the key during a "No-Go" stimulus presentation), omission errors (GNG_O: failing to press the key when a "Go" stimulus was presented), anticipatory errors (GNG_A: pressing the key for "Go" stimulus under 200 ms; according to Davidson et al., 2006) and reaction times (GNG_RTs: Mean of hits during trial phases). GNG_C (Wright et al., 2014) and GNG_A (Davidson et al., 2006) were considered as primary inhibition measures in Go/No-Go task. Lower scores on this task indicate better IC skills. Implementation and scoring were done by DMDX software (Forster & Forster, 2003).

Procedure

The Ethics Committee of the University of Social Welfare and Rehabilitation Sciences approved this project (reference code: IR.USWR.REC.1397.152). Informed consent was obtained from parents and verbal assent from children. Initially, the participant selection form (including questions about some inclusion and exclusion criteria such as the age of the child, bilingualism, and some medical conditions) and CBCL/1.5–5 were provided to the parents of each child. After examining the questionnaires and making sure that children were eligible for inclusion, children were referred to an audiologist to assess their hearing threshold. Children with normal hearing thresholds entered the screening stage. The first session of assessment included Ishihara's test for color deficiency and P-WPPSI. At the end of each of these tests, the results were reviewed by the first author and if the child was not eligible for the study, was excluded and referred to the relevant specialist. In the second session, all children completed P-TOLD-P:3 and two subtests of P-DEAP: diagnostic screen and oral motor. In SSD children, other P-DEAP subtests were assessed at the beginning of the third session, based on the results of the diagnostic screen subtest. In TD children, only the phonology subtest was assessed, and PCC, PVC, PPC, and single word vs. connected speech agreement were calculated. Following the third evaluation session, Go/No-Go, NRT, and BDS tasks were performed. The fourth evaluation session was devoted to FIST, SRT, and Stroop-like tasks. Each session of evaluation lasted a maximum of 45 min. The order of the tasks was similar for all participants. All tests were performed individually for each participant.

Reliability

Test–retest reliability

With one-week interval, test–retest reliability of Go/No-Go, Stroop-like, and FIST was evaluated on 18 typically developing participants by calculating the ICC coefficient, using a two-way mixed-effects model of consistency. To evaluate the level of reliability, 95% confidence interval (CI) of ICC values $< .50$ were considered poor, .50–.75 moderate, .75–.90 good, and $> .90$ excellent reliability (Koo & Li, 2016). The results of test–retest showed moderate to excellent reliability between the two administrations of GNG_C (ICC = .885 [95% CI: .693–.957]), STR_C (ICC = .821 [95% CI: .521–.933]), and $FIST_2$ (ICC = .886 [95% CI: .695–.957]) scores. The excellent reliability was found for GNG_A (ICC = .973 [95% CI: .928–.990]).

Inter-rater reliability

Two raters (first author and one colleague with MSc in Speech-Language Pathology and six years' clinical experience) broadly transcribed and independently scored audio-recorded responses of the phonology subtest of P-DEAP, NRT, and SRT for 20% of participants ($n = 10$, five TD and five SSD) that were randomly selected from the sample. Inter-rater reliability was calculated using a two-way random-effects model of absolute agreement. The agreement was excellent (ICC = .998 [95% CI: .992–.999] for PCC, ICC = .996 [95% CI = .970–.999] for NRT, and ICC = .998 [95% CI = .991–.999] for SRT).

Statistical analyses

The data were analyzed using SPSS version 21.0 (SPSS Inc.). Between-group differences in EF tasks were analyzed using multivariate analysis of covariance (MANCOVA), adjusted for age. The Q-Q plot and Shapiro-Wilk test were used to assess the normality of the residuals from each variable, and the variables that did not have normal distribution were normalized using a logarithmic transformation. To protect against type I error, we used a traditional Bonferroni procedure and tested each ANCOVA at the .007 level (.05 divided by the number of ANCOVAs conducted, which equal the number of dependent variables, i.e., 7). Bonferroni adjusted (.007/3 = .002) post hoc tests were performed to contrast the three groups on EF tasks specifically. Partial correlations with age as a control variable were calculated to determine the relationship between speech sound accuracy and EF tasks. According to Hinkle et al. (2003), $r = .30–.50$ demonstrates low correlation, $r = .50–.70$ demonstrates moderate correlation, $r = .70–.90$ demonstrates high correlation, and $r = .90–1.0$ demonstrates very high correlation.

Results

We compared overall 49 children age 4–6 years ($M = 59.12$ months, $SD = 6.5$) between three groups that met the final criteria and completed experimental tests. Analysis of variance (ANOVA) revealed no significant differences in age ($M \pm SD$: for CPDis 59.88 ± 5.4; PDel: 58.40 ± 6.5; TD: 59.06 ± 7.6; $F(2, 46) = .190$, $p = .828$) neither did gender distribution differ significantly between groups (percent of males per group: CPDis = 62.5%; PDel = 80.0%; TD = 61.1%; $\chi 2$ (2, $n = 49$) = 1.581, $p = .454$). However, a one-way ANOVA yielded a significant difference between groups in PCC scores ($M \pm SD$: for CPDis 64.18 ± 12.67; PDel: 85.96 ± 9.95; TD: $99.41 \pm .95$; $F(2, 46) = 65.209$, $p < .001$).

Table 1. Data of experimental tests.

	CPDis ($n = 15$)				PDel ($n = 16$)				TD ($n = 18$)			
Measure	M	SD	Min	Max	M	SD	Min	Max	M	SD	Min	Max
NRT	22.31	7.70	7	41	32.80	6.08	19	41	50.83	1.97	47	53
SRT	7.00	2.87	1	11	9.20	1.65	6	12	15.39	1.72	13	18
BDS	.19	.54	0	2	.07	.25	0	1	1.44	1.50	0	4
$FIST_2$	5.94	1.12	4	8	8.13	3.04	3	11	13.50	1.29	11	15
STR_C	6.56	1.99	3	9	2.53	.99	1	5	.67	.68	0	2
GNG_C	5.94	2.69	0	11	8.80	6.30	0	26	.61	.60	0	2
GNG_A	3.50	1.78	0	7	4.07	2.68	0	8	.67	.90	0	3

CPDis: consistent phonological disorder; PDel: phonological delay; TD: typically developing; NRT: nonword repetition task; SRT: syllable repetition task; BDS: backward digit span; $FIST_2$: second selection of Flexible Item Selection Task; STR_C: corrected responses of Stroop-like task; GNG_C: commission errors of Go/No-Go task; GNG_A: anticipatory errors of Go/No-Go task.

Table 2. Partial correlation matrix between EF tasks and PCC with age as a control variable.

	1	2	3	4	5	6	7	8
1 PCC	–							
2 NRT	**.857**	–						
3 SRT	**.731**	**.870**	–					
4 BDS	**.395**	**.495**	**.512**	–				
5 $FIST_2$	**.715**	**.872**	**.768**	**.493**	–			
6 STR_C	**−.758**	**−.723**	**−.683**	**−.444**	**−.688**	–		
7 GNG_C	**−.448**	**−.621**	**−.510**	**−.417**	**−.694**	.228	–	
8 GNG_A	**−.458**	**−.490**	**−.455**	−.261	**−.552**	.352	**.507**	–

Note: Significant *p* values are shown in bold.
EF: executive function; PCC: percentage consonants correct; NRT: nonword repetition task; SRT: syllable repetition task; BDS: backward digit span; $FIST_2$: second selection of Flexible Item Selection Task; STR_C: corrected responses of Stroop-like task; GNG_C: commission errors of Go/No-Go task; GNG_A: anticipatory errors of Go/No-Go task.

Post hoc comparisons using Bonferroni revealed significant differences between TD vs. PDel ($p < .001$), TD vs. CPDis ($p < .001$), and PDel vs. CPDis ($p < .001$).

A one-way MANCOVA was conducted to test the hypothesis that there would be one or more mean differences between groups (CPDis, PDel, and TD) and EFs tasks (see Table 1 for details). Bartlett's test of Sphericity was statistically significant (approximate chi-square = 357.884, $p < .001$), indicating a sufficient correlation between the dependent variables to proceed with the analysis. The Box's M value of 217.511 was associated with a *p*-value < .001, which was interpreted as significant. Next, we used Pillai's trace test, because of its robustness in the presence of heterogeneity of variance–covariance matrices (Meyers et al., 2006). The difference between groups on the combined dependent variables after controlling for age was statistically significant ($F(14, 80) = 17.289$, $p < .001$, Pillai's trace = 1.503, partial $\eta^2 = .752$). The effect size was estimated at .752, which implies that almost 75% of the multivariate variance of the dependent variables was associated with the group factor. Results of follow-up univariate ANCOVAs with a Bonferroni adjustment are presented in the following subsections.

Comparison of WM tasks across groups

Phonological loop

Two tasks assessed the phonological loop of WM. TD children had higher means in both NRT and SRT tasks than the SSD subgroups (Table 1). Also, the PDel group had higher scores than CPDis children in both tasks. Differences were statistically significant in adjusted means for NRT ($F(2, 45) = 52.024$, $p < .001$, partial $\eta^2 = .698$). Pairwise comparisons with a Bonferroni adjustment revealed significant differences between TD vs. PDel ($p < .001$), TD vs. CPDis ($p < .001$), and PDel vs. CPDis ($p < .001$). Moreover, group differences on the SRT were statistically significant ($F(2, 45) = 78.852$, $p < .001$, partial $\eta^2 = .778$). Pairwise analysis indicated statistically significant differences between TD vs. PDel ($p < .001$) and TD vs. CPDis ($p < .001$) but not PDel vs. CPDis ($p = .007$).

Central executive

BDS was administered to examine central executive of WM. TD children had better mean scores than PDel and CPDis children. Again, the CPDis group had higher means than PDel children. A comparison of group means on the BDS showed a statistically significant difference ($F(2, 45) = 11.716$, $p < .001$, partial $\eta^2 = .342$). Pairwise comparisons with a Bonferroni adjustment revealed significant differences between TD vs. PDel ($p < .001$), TD vs. CPDis ($p = .001$) but not PDel vs. CPDis ($p = 1.000$).

Comparison of CF across groups

TD children had higher means in the $FIST_2$ than the SSD subgroups. Also, the PDel group had higher scores than CPDis children in this task. Results from an ANCOVA demonstrated statistically significant differences between group means on the $FIST_2$ ($F(2, 45) = 67.994$, $p < .001$, partial $\eta^2 = .751$). Pairwise comparisons with a Bonferroni adjustment revealed significant differences between TD vs. PDel ($p < .001$), TD vs. CPDis ($p < .001$) but not PDel vs. CPDis ($p = .007$).

Comparison of IC tasks across groups

Stroop-like task

Few corrected responses in participants reflect better IC. TD group had fewer corrected responses than PDel and CPDis groups. Also, PDel children had fewer corrected responses than CPDis children. Differences were statistically significant in adjusted means for STR_C ($F(2, 45) = 83.669$, $p < .001$, partial $\eta^2 = .788$). Pairwise comparisons with a Bonferroni adjustment revealed significant differences between TD vs. PDel ($p = .001$), TD vs. CPDis ($p < .001$), and PDel vs. CPDis ($p < .001$).

Go/No-Go task

GNG_C. Few commission errors in participants reflect better IC. Children with TD had fewer commission errors than the two SSD subgroups. Also, CPDis group had fewer errors than PDel group. Differences were statistically significant in adjusted means for GNG_C ($F(2, 45) = 27.655$, $p < .001$, partial $\eta^2 = .551$). Pairwise comparisons with a Bonferroni adjustment revealed significant differences between TD vs. PDel ($p < .001$), TD vs. CPDis ($p < .001$) but not PDel vs. CPDis ($p = .370$).

GNG_A. Few anticipatory errors in participants reflect better IC. Children with TD had fewer anticipatory errors than the two SSD subgroups. Also, CPDis group had fewer errors than PDel group. Group differences on the GNG_A were statistically significant ($F(2, 45) = 15.580$, $p < .001$, partial $\eta^2 = .409$). Pairwise comparisons with a Bonferroni adjustment revealed significant differences between TD vs. PDel ($p < .001$), TD vs. CPDis ($p < .001$) but not PDel vs. CPDis ($p = 1.000$).

Relationships between EF tasks and speech sound accuracy

Pearson's partial correlation, with age as a control variable, calculated the relationships between each of EF tasks and accuracy of speech sound measured by PCC. Results (see Table 2) indicated that NRT ($r = .857$, $p < .001$), SRT ($r = .731$, $p < .001$), and $FIST_2$ ($r = .715$, $p < .001$) highly positively and STR_C ($r = -.758$, $p < .001$) highly negatively correlated with PCC. These findings suggest that children who performed better in EFs had higher speech sound accuracy. Again, GNG_C ($r = -.448$, $p = .001$) and GNG_A ($r = -.458$, $p = .001$) showed low negative correlation and BDS ($r = .395$, $p = .006$) low positive correlation with PCC.

Other strong relationships were found among EF tasks (see Table 2). NRT was highly positively correlated with performance on SRT ($r = .870$, $p < .001$), $FIST_2$ ($r = .872$, $p < .001$) and highly negatively correlated with STR_C ($r = -.723$, $p < .001$). Similarly, SRT was highly positively correlated with $FIST_2$ ($r = -.768$, $p < .001$).

Discussion

This study provides evidence concerning the EFs of two common SSD subgroups compared with a peer control group. Also, the relationship between each EF measurement and the accuracy of speech sound production was measured. TD children performed better in all EF tasks than the two SSD subgroups. Also, PDel children performed better in some EF abilities than the CPDis group. Besides, all EF measurements correlated with speech sound production. Details are discussed in the following subsections.

Between-group differences in WM

Phonological loop

This study showed that both SSD subgroups performed worse in NRT and SRT compared with the TD group, indicating a deficit in the phonological loop of WM. This deficit to retain sufficient traces of speech input can lead to forming incorrect phonological representations (Pennington & Bishop, 2009), which is ultimately reflected in non-age appropriate speech errors (Waring et al., 2018). These findings agree with previous studies (NRT: Afshar et al., 2017; Guedes-Granzotti et al., 2017; Masso et al., 2017; Munson et al., 2005; FDS: Masso et al., 2017; Murphy et al., 2014; Torrington Eaton & Ratner, 2016; SRT: Brosseau-Lapré & Rvachew, 2017; Mahrooghi et al., 2015), which mainly reported weaker performance of undifferentiated phonologically based SSD children in these tasks. The results also showed that both NRT and SRT were highly positively correlated with PCC, which again confirms the relationship between the phonological loop and speech sound accuracy.

The weaker performance of PDel children compared with the TD group confirms claims by Waring et al. (2017) that PDel is more than a "surface error." However, the results disagree with those of Waring et al. (2018) study who found no differences between the performance of CPDis and TD children in the forward recall of familiar words. One possible explanation for this discrepancy may be because nonwords, compared with familiar words, assess the phonological loop more precisely since the participant could not encode it in vocabulary because the stimuli have no semantic representation (Gathercole & Baddeley, 1990).

Children with atypical speech errors performed worse than children with delayed speech errors in NRT. Based on our knowledge, the performance of the phonological loop between these two subgroups has not been studied so far. One possible explanation for a significant difference between the two groups is that reduced speech sound accuracy in CPDis children compared with PDel group could lead to poorer performance of the phonological loop of WM. According to Keren-Portnoy et al. (2010), phonological loop of WM is developed simultaneously with speech sound accuracy, and more accurate speech sound production could lead to more effective storage and mentally manipulate sounds and words. Accordingly, it can be expected that disordered speech production will lead to significant differences in phonological WM. Linassi et al. (2005) also proposed that phonological encoding problems in children with phonological disorders can lead to a lack of proper differentiation of phonological representations. Taken together, it seems that these two SSD subgroups may have different phonological processing problems and profiles, which may reflect their different performance in resolving speech sound errors (Dodd et al., 2018).

Central executive

Similar to previous studies' findings (Afshar et al., 2017; Waring et al., 2017, 2018), both SSD subgroups performed worse in the BDS task than the control group, indicating a defect in the central executive of WM. Theoretically, the central executive of WM may be involved in temporarily storing and manipulating sounds to compare their own production of a word with adult target and then reconstructing the correct phonological rules (Waring et al., 2019).

There was no significant difference between CPDis and PDel groups in BDS performance. It seems that both SSD groups have a reduced ability in central executive, potentially compromising their ability to maintain, compare, and manipulate phonological input. Waring et al. (2017) suggested a different interpretation, attributing the more mediocre performance of children with PDel to the underlying problem of retaining phonological material in mind, rather than the manipulation problems of verbal information in itself. This view is partly supported by the low positive correlation of BDS with the accuracy of speech sound production in this study, similar to the findings of previous research (Afshar et al., 2017; Linassi et al., 2005; Torrington Eaton & Ratner, 2016).

It has been reported that preschoolers have difficulty understanding the concept of backward in WM tasks (Bull et al., 2008), leading to floor effects in assessing central executive in these children (Pickering & Gathercole, 2001). However, due to the limited range of scores in the BDS and the floor effect found in our participants (73.5% of the participants could not pass even one trial), the results are better interpreted with caution.

Between-group differences in CF

In the $FIST_2$, the TD group performed better than CPDis and PDel children, which was statistically significant. Similar to previous studies (Crosbie et al., 2009; Dodd, 2011; Dodd & McIntosh, 2008), the results of the present study suggest that CF could play a key role in SSDs. A child's cognitive flexibility may explain how s/he switches spontaneously from early phonological rules to adult-like phonology. During phonological development, children are listening to and constantly becoming aware of the phonological patterns of surrounding language (Williams, 1993). Flexible cognition, a child's ability to create representations that are dynamically based on information from both his/her linguistic and nonlinguistic environment (Deák, 2003), could be necessary for phonological development. It appears that children who have delayed speech errors (i.e., PDel group) and those using atypical error patterns (i.e., CPDis group) may have difficulty switching flexibly from their early speech patterns to the mature sound system they are exposed to. However, the results contrast with those of Torrington Eaton and Ratner (2016) study that found no difference between SSDs and controls. In their study, participants were not selected based on the type of error patterns, and it was not exactly clear which subgroups and in what proportions were included in the SSD group, which may account for this discrepancy.

In contrast to Dodd (2011) study, the performance of PDel and CPDis groups in the $FIST_2$ was not statistically significant, despite better mean scores in PDel children. One possible explanation for this discrepancy may refer to false negatives due to the correction of alpha level by pairwise Bonferroni method (Perneger, 1998). Further research is needed to compare the underlying characteristics of speech problems in these two subgroups.

Between-group differences in IC

The weaker performance of SSDs in main measures of IC suggests that IC may be included in overcoming non-age appropriate speech errors. Our results are partly similar to Murphy et al. (2014), which showed a significant difference between SSDs and controls in measuring auditory commission errors ("false alarms" in Murphy et al., 2014). The researchers attributed the weaker performance of SSD children to either auditory perceptual or impulsivity skills. More GNG_A in SSD children compared with TD group in the present study could support the impulsivity account. These anticipatory responses that often occur because of participant's eagerness to respond to a stimulus in upcoming trials, or failing to release the button following the previous trial, represent inhibitory failures (Davidson et al., 2006). In Murphy et al. (2014), there was no difference between SSDs and controls in the visual modality. The literacy status of school-age participants of Murphy's study was not reported, given that literacy is a rule-based system whose learning can affect the performance of the visual modality of such tasks. Retrieval efficiency for letter-related codes may be affected by the ability to inhibit irrelevant codes. Longitudinal studies have reported improved IC during the first years of school. For example, TD readers and writers in Altemeier et al. (2008) showed steady improvement in inhibition from Grade 1 to Grade 6. As a result, literacy learning may affect IC abilities. Also, the results of the present study contradict the study of Torrington Eaton and Ratner (2016), which considered the total number of correct answers in day–night Stroop task rather than the "corrected answers" as an IC measurement. In addition to participants' characteristics, a different method of scoring can be a possible reason for this discrepancy.

Previous studies have shown that both inhibition and WM can play a role in Stroop-like tasks (Carlson et al., 2002; Diamond et al., 2002). Given the interaction between WM and IC, especially in preschoolers (Roncadin et al., 2007), more reduced performance in young children could be attributed to short WM span and deficient IC. The high negative correlation of the NRT scores with STR_C supports this claim.

The PDel group performed better in STR_C than the CPDis group. To our knowledge, no study has examined IC in these subgroups. In recent research (Dodd et al., 2018), two-thirds of PDel children identified in age 4 resolved at age 7, compared with one-third of CPDis children that could reflect better skills of PDel children in inhibiting error patterns.

Study limitations and future directions

The first limitation was the design of this study. It is not possible to draw causal inferences between the accuracy of speech sound production and EFs in such study design. Longitudinal studies will allow a more in-depth analysis to explain this association.

Another limitation was the sample size of this study. The sample size was relatively small and homogeneous, and study participants were selected conveniently, which may affect the generalizability of the results of the present study. Also, since the control group was recruited from only two kindergartens, the socio-economic status (SES) of all TD participants was probably almost the same. Further research might match participants based on SES.

Despite resolved speech sound errors, evidence showed that some children with SSD had later problems in literacy acquisition (Gillon, 2004; Raitano et al., 2004). Furthermore, ample evidence has shown that EF of preschoolers predicts school readiness and future academic performance (e.g., Best et al., 2011; Coldren, 2013; Sasser et al., 2015; Vitiello & Greenfield, 2017). A future study investigating the effect of EF training in speech sound accuracy in preschool SSDs would be fascinating.

Conclusion

This study compared two common subtypes of SSDs with a group of TD peers in some tasks measuring EFs. TD group outperformed PDel and CPDis children in the phonological loop and central executive of WM, CF, and main measurements of IC. Also, PDel children were better in NRT (a measurement of the phonological loop of WM) and STR_C (one of the main measurements of IC) than the CPDis group. These results and the high correlation between core EF measures and the accuracy of speech sound highlight the importance of assessing EF abilities in current assessment protocols for SSD children.

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