Research Paper: Exploring the Relationship Between Speech Motor Control and Phonological Processing in Children Who Stutter and Typically Developed Children

Sousan Salehi[1*], Saman Maroufizadeh[2], Zahra Soleymani[3], Seyedeh Zeinab Beheshti[4], Sheida Bavandi[5]

1. Department of Speech Therapy, School of Rehabilitation, Arak University of Medical Sciences, Arak, Iran.
2. Department of Biostatistics, School of Nursing and Midwifery, Guilan University of Medical Sciences, Rasht, Iran.
3. Department of Speech Therapy, School of Rehabilitation, Tehran University of Medical Sciences, Tehran, Iran.
4. Department of Occupational Therapy, School of Rehabilitation, Arak University of Medical Sciences, Arak, Iran.
5. Kalaam speech therapy center, Sari, Iran.

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ABSTRACT

Introduction: Language processing (especially phonology) and speech motor control are disordered in stuttering. However, it is unclear how they are related based on the models of speech processing. The present study aimed to study non-word repetition, rhyme and alliteration judgment, and speech motor control and investigate their relationship in children who stutter (CWS) compared to typically developed children (TDC).

Materials and Methods: Twenty-eight CWS (mean age=5.46 years) and 28 peers TDC (mean age=5.52 years) participated in this study. Phonological processing, according to the speech processing model, is divided into phonological input and output. Phonological input, phonological output, and speech motor control were assessed by rhyme and alliteration tasks, accurate phonological production during non-word repetition task, and Robbins-Klee oral speech motor protocol, respectively. The Pearson correlation coefficient, independent t-test, and Cohen's d were used for data analysis.

Results: Both non-word repetition and speech motor skills were significantly different in CWS than TDC ($P<0.001$). But rhyme and alliteration judgment were similar across groups ($P>0.001$). Phonological processing and speech motor control were not significantly correlated ($P>0.001$).

Conclusion: Phonological processing (output), a level before articulation, and speech motor control are not correlated, but both are disordered in preschool CWS. Additionally, phonological processing (input) is similar in CWS and TDC. That is, phonological input is not affected by stuttering in CWS.

Keywords: Phonological processing, Speech motor control, Children who stutter, Stuttering

*** Corresponding Author:**
Sousan Salehi, PhD.
Address: *Department of Speech Therapy, School of Rehabilitation, Arak University of Medical Sciences, Arak, Iran.*
Tel: *+98 (86) 33685006*
E-mail: *salehi.slp@gmail.com*

1. Introduction

Stuttering is a speech production disorder [1], which is characterized by repetitions, prolongations, and blocks in the speech continuum [2]. Speech production has been investigated in various perspectives, such as psycholinguistic and motor control [3]. A well-documented psycholinguistic model for speech production is Levelt's model. According to this model, motor execution is the next level of processing after phonological processing [4].

On the other hand, phonology is the most related language domain to stuttering [5], so that some phonological theories are proposed for stuttering, such as EXPLAN and covert repair [6]. According to the studies in children who stutter (CWS), we know that phonological processing has a different underlying mechanism [7].

Besides, stuttering has been investigated in many aspects [2]: motor and phonological aspects are well-researched separately in CWS [8-10]. There is a large body of physiological studies that consider stuttering a Speech Motor Control (SMC) disorder, and these studies show differences in speech production between CWS and children who do not [8, 11-15]. But, a few research studies explain this disorder regarding the general speech production model [8].

Across the speech processing models, Stackhouse and Wells's model is a well-accepted model for phonological processing assessment and treatment [16-18]. Notably, in this model, phonological processing is divided into phonological output and input. Furthermore, the speech motor control system plays an essential role in phonological output level. One of the phonological output tasks is non-word repetition, and the next level is oral motor skills [18]. As mentioned earlier, according to Levelt's model, phonological processing is the level before speech motor control [4].

Additionally, few studies examined the interaction between motor and phonological ability in CWS [19]. In other words, it is unclear that which speech and language processing level is disrupted in CWS, phonological processing, or motor execution. Therefore, the present study assessed and compared phonological processing and motor execution in CWS and typically developing children (TDC). This study also examined the relationship between these variables. Phonological output and phonological input (phonological processing), and speech motor control (motor execution) are assessed by defined tasks in this study [18].

Phonological input and stuttering

Phonological input, according to the Stackhouse model, can be measured through rhyme and alliteration recognition [18]. Rhyme and alliteration recognition in stuttering has been conceptualized in different aspects. Weber-fox et al. examined visual rhyming tasks in CWS, finding that CWS performed significantly less well than TDC in behavioral results and found that the neural basis for phonological rhyme recognition in CWS is different from TDC [7]. To our knowledge, there are no other studies about rhyme and alliteration recognition in CWS.

Phonological output (non-word repetition) and stuttering

Non-word repetition is a multidimensional task used as a measure of phonological processing and also for measuring working memory [20, 21]. According to the speech processing model, phonological input and phonological output are involved in this task [18]. Some studies declared that CWS has significantly more phoneme errors than TDC in non-word repetition tasks [22, 23]. Similarly, CWS, who do not experience any disorder in language development or other speech production disorder, performed with the same accuracy in non-word repetition task, but oral motor variability was higher in these children [14]. On the other hand, evidence shows no significant difference between these two groups of children in phoneme errors in non-word repetition tasks [24]. Altogether, non-word repetition skill in CWS is a controversial issue that needs more investigation.

Speech motor control and stuttering

Many investigations are conducted on speech motor control in stuttering and most of them on the adults who stutter [25, 26]. They state that people who stutter are low-performing in motor and linguistic abilities [14]. Also, Walsh et al. (2015) and Usler et al. (2017) examined speech motor control in preschool children who stutter and fluent peers. They found that CWS have atypical speech motor features compared to fluent peers [26, 27]. Similarly, Smith et al. (2012) provided evidence that preschool CWS have delayed speech motor control development compared to fluent peers. Notably, they measured speech motor control in CWS through a non-word repetition task [14]. It has been shown that language factors, such as syntactic complexity and length of sentences, do not affect speech motor control abilities in

CWS. McPherson and Smith found out that CWS, even in fluent speech, has more variability in speech motor control tasks than fluent peers, but it is not dependent on syntactic complexity and length of sentences [12]. Speech motor tasks can be investigated through various tasks, such as the diadochokinetic task [18]. This task is a commonly used task for oral motor skill evaluation in children with speech disorders [18, 28]. Besides, it is utilized for speech motor control assessment in Robbins and Klee protocol [29]. Maximum phonation time (MPT) is another task in the protocol for speech motor control assessment [29]. The previous study has shown that MPT is lower in people who stutter [30].

Given these findings, limited studies investigate phonological processing and speech motor control and their relationship simultaneously. It can be helpful to find out which level of language processing (phonology) and speech motor control is impaired in CWS. So, in the present study, we decided to compare and explore speech motor control and phonological processing (as the nearest processing level to articulation) between CWS and TDC.

1. Materials and Methods

Participants and study design

Twenty-eight preschool CWS (20 boys and 8 girls) and 28 age- and sex-matched preschool TDC (20 boys and 8 girls) who met the inclusion criteria participated in this non-experimental cross-sectional case-control study (CWS: Mean±SD of age was 5.46±0.29 years, TDC: Mean±SD of age was 5.52±0.26 years).

All participants had a normal medical history, normal hearing, and normal or corrected to normal vision and normal speech and language development according to their medical records. The participants passed verbal and non-verbal intelligence test (IQ test), which is routinely done in Iranian preschool children. They all had normal IQ according to their score on Wechsler Intelligence Scale for Children [31]. They had no emotional or behavioral problems, based on their parent's reports. CWS, referred to speech therapists for stuttering, were selected from private clinics and university-affiliated clinics. The stuttering diagnosis was made by an expert speech therapist using the Persian version of the stuttering severity index, version 3 (SSI-3) [32].

The TDC were selected from public preschool centers. They were matched with CWS in age and gender. All parents completed personal information forms and then signed an informed consent form. This study was approved by the Ethics Committee of Arak University of Medical Sciences (Code: IR.ARAKMU.REC.1397.249).

Study procedure

Overall, three assessment sets are done for each participant, including phonological output by accurate phonological production during non-word repetition task [33], phonological input by rhyme and alliteration judgment task [34], and finally, speech motor control by diadochokinetic task [35]. Each child was assessed in a quiet room in the clinic and preschool centers. All tasks were done randomly for each participant according to the examiner's opinion. Total time for all tasks was variable for each child, but the mean time was 45 minutes. It was done in one session, and the rest was allowed if the child requested it. If it was needed, the examiner considered a break in the session.

It is noteworthy that one task involving various levels of speech and language processing, then it cannot be attributed to just one level of speech and language processing. Considering this limitation and based on the Stackhouse model of speech processing, the following tasks were chosen for the investigations.

Phonological input

It was measured using picture rhyme and alliteration judgment subtests in the Persian phonological awareness test [34]. Each subtest had 10-word sets and each word set, including three words with pictures in a sheet. The children were asked to judge which word is different (same or different task) by pointing to the word's picture in sheets. Each word set had one score, and the minimum score is 0, and the maximum score of the subtest is 20.

Phonological output

It was measured using accurate phonological production during non-word repetition tasks by Persian non-word list. This non-word list includes 4 monosyllabic non-words, 13 disyllabic non-words, 6 trisyllabic non-words, and 2 tetrasyllabic non-words, a total of 25 non-words [33]. The children were told to repeat every non-word as soon as they hear it. The number of non-words that repeated correctly was recorded as a score for each child.

As stated above, one task can measure different processing levels. Accordingly, non-word repetition tasks can be used for exploring phonological encoding or input, too [18, 20]. However, we utilized it for phonological output assessment in the present study.

Speech motor control

It was measured using the Persian version of Robins and Klee protocol for oral and motor speech abilities [35]. This assessment protocol includes two main parts: structure and function. Function part had verbal and speech function sections. In the oral function section, coughing, laughing, or crying were assessed. In the speech function section, the maximum phonation time (MPT), speech diadochokinetic, and word repetition were assessed. Word list in Robins and Klee protocol includes 14 words: one-, two-, and three-syllable words. First, the oral structure was checked. Then coughing, laughing, or crying, MPT and speech diadochokinetic were assessed. For the MPT task, children were asked to prolong /a/ as much as possible three times. The examiner calculated the mean value of three times and reported it in seconds.

The participants were instructed to repeat /pa/, /ta/, /ka/, /peteke/ and /pitiku/ in 3 seconds as much as they can. The number of repetitions was calculated as a diado score. Also, didado is a task for phonological output which needs speech motor control contribution [18].

Finally, the word list was read for the children, and they were asked to repeat it as soon as they hear the words. The number of correct repeated words was calculated as an accuracy variable.

Statistical analysis

In the present study, continuous variables were expressed as Mean±SD and categorical variables as frequency (%). The Kolmogorov-Smirnov test was used to examine the normality of data distribution, and the hypothesis of normality was met for all study variables (P>0.05). The Pearson correlation coefficient was used to examine the relationship between speech motor control and phonological processing. The Pearson correlation coefficients of 0.1–0.3, 0.3-0.5, and >0.5 are considered weak, moderate, and strong correlations, respectively [35]. The independent t-test was performed to examine the difference in speech motor control and phonological processing between TDC and CWS groups. Furthermore, Cohen's d, which estimated the magnitude of the mean differences, was calculated. Cohen's d values of 0.2-0.5, 0.5-0.8, and >0.8 are considered small, moderate, and large effect sizes, respectively [35]. Statistical analysis was carried out using SPSS for Windows, v. 16.0 (SPSS Inc., Chicago, IL, USA), and the level of significance was set at 0.05.

3. Results

Characteristics of the TDC and CWS groups

Table 1 shows the demographic characteristics of the participants in TDC and CWS groups. There were no significant differences between TDC and CWS groups in terms of age (P=0.490) and sex (P=1.000).

Group differences

According to Table 2, there are significant differences between CWS and TDC in speech motor control variables, including MPT, diadochokinetic, and accuracy (word repetition) (P<0.001, P=0.007, and P<0.001, respectively). The mean of the non-word repetition task (phonological output) in the CWS group was also statistically lower than the TDC group (P<0.001). The effect sizes, calculated using Cohen's d, were ranged from 0.759 to 1.260, which are considered to be large. The mean phonological input (rhyme and alliteration judgment) score in the CWS group was lower than the TDC group, although this difference was not statistically significant (P=0.207, Cohen's d=0.341).

Correlational analysis

Based on Table 3, there were weak correlations between speech motor control and phonological processing in the TDC group, although these correlations were not statistically significant. The same results were also observed for the CWS group.

4. Discussion

The present study aimed to investigate whether 1) speech motor control and phonological processing (output and input) are different in CWS than TDC, 2) speech motor control and phonological processing are correlated in CWS and TDC.

Our data analysis showed that CWS and TDC were similar in phonological input tasks, including rhyme and alliteration judgment. In other words, stuttering did not affect phonological input processing. It contrasts with the previous study, which declares that normally fluent children are better in rhyme recognition tasks [7]. This contradiction can be explained by different methodology, we used the behavioral method, but Weber-fox et al. used the electrophysiological method [7]. Accordingly,

Table 1. Demographic characteristics of the study participants

Variables		Mean±SD/No. (%)		P
		TDC (n=28)	CWS (n=28)	
Age (y)		5.52 (0.29)	5.46 (0.29)	0.490†
Sex	Male	20 (71.4)	20 (71.4)	1‡
	Female	8 (28.6)	8 (28.6)	
SSI-3	Very mild	-	0 (0)	
	Mild	-	10 (35.7)	
	Moderate	-	13 (46.4)	
	Severe	-	2 (7.1)	
	Very Severe	-	3 (10.7)	

JMR

SD: standard deviation; TDS: typically developing children; CWS: children who stutter; SSI-3: stuttering severity instrument-3.

†: The Independent t-test; ‡: The Chi-squared test.

CWS are similar to TDC in these phonological input tasks in a behavioral investigation, such as our study, but electrophysiological investigation shows a difference in phonological input tasks in CWS and TDC [7].

As mentioned in the introduction, the phonological output processing was measured by non-word repetition task in this study, although it is a multidimensional task, which includes phonological short-term memory [20]. As expected, there was a significant difference in CWS and TDC in phonological output processing. It can be interpreted that CWS was performed less well than TDC in phonological processing (output) as a level before articulation.

But it should be noted that if non-word repetition is stood for short-term phonological memory, CWS perform more poorly than TDC on phonological short-term memory task [20]. It is suggested that the type of tasks and the processing model, which is referred to, are also essential factors. The Stackhouse model is a reference model in this study.

Additionally, CWS and TDC were dissimilar in speech motor control tasks. It means that CWS has experienced

Table 2. Speech motor control and phonological processing in TDC and CWS

Variables	No. (%)		P†	Cohen's d
	TDC (n=28)	CWS (n=28)		
SMC. F. MPT	13.00 (3.08)	10.18 (1.91)	<0.001	1.100
SMC. F. Diado	44.86 (5.91)	39.11 (8.93)	0.007	0.759
SMC. F. Accuracy (word repetition)	13.57 (0.69)	12.39 (1.13)	<0.001	1.2601.
Phono. Input (rhyme)	4.79 (1.40)	4.71 (1.70)	0.864	0.051
Phono. Input (alliteration)	5.50 (2.12)	4.82 (1.85)	0.207	0.341
Phono. Output (non-word repetition)	22.64 (1.57)	21.04 (1.82)	<0.001	0.941

TDC: typically developing children; CWS: children who stutter.

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†: Independent t-test.

Table 3. Correlation between speech motor control and phonological processing in TDC and CWS groups

Variables	TDC (n=28)			CWS (n=28)		
	SMC. MPT	SMC. Diado	SMC. Accuracy	SMC. MPT	SMC. Diado	SMC. Accuracy
Phono. Input (Rhyme)	0.198	0.180	0.209	0.200	0.046	0.311
Phono. Input (alliteration)	0.312	-0.181	0.127	0.230	0.273	0.247
Phono. Output (non-word repetition)	0.115	0.106	0.538**	0.009	0.278	0.119

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TDC: typically developing children; CWS: Children who stutter; SMC: Speech motor control; MPT: maximum phonation time.

**P<0.001.

some problems in both phonological processing and speech motor control. Altogether, it leads to disfluent speech. Our findings are consistent with the aforementioned studies, which declared that the CWS had more errors in the non-word repetition task [22, 23]. But these findings are in contrast to the other previous studies [14, 24]. Non-word repetition is a multidimensional task that can be analyzed from many perspectives; then, it can be interpreted differently. That is why there are contradictive results in various studies.

Furthermore, there is evidence that speech motor control is delayed and disordered in CWS [12, 15, 27]. Our results also pointed out a significant difference between CWS and TDC in speech motor control tasks, diado, MPT, and word repetition. Therefore, our data analysis is supported by the previous studies [12, 14, 15, 27]. Our results suggest that speech motor control can be one of the disordered processing levels in stuttering, even in preschool children.

Findings related to phonological processing (output) and speech motor control were different in CWS and TDC, but there was no significant difference on phonological input tasks across groups. Thus, phonological processing (input and output) is not correlated with speech motor control in both CWS and TDC.

Study limitations

The first limitation in our study is ignoring the onset of stuttering as a variable, which complicates data analysis, but helpful information will be given. The following limitation in our study is the behavioral investigation, although the electrophysiological investigation will give detailed information on phonological and motor processing. Complementary studies in the electrophysiological view will be helpful.

5. Conclusion

Generally, phonological processing (output), as a pre-articulation level, and speech motor control are not correlated. But, both are disrupted in preschool CWS, which leads to non-fluent speech. According to our data analysis, phonological input processing (measured by rhyme and alliteration tasks) is not affected by stuttering in preschool CWS. When the task was changed to a non-word repetition task, differences were significant. It seems that a comprehensive treatment for stuttering in preschool children included both phonological processing and speech motor control.

Ethical Considerations

Compliance with ethical guidelines

This study was registered and approved by the Research Council, Arak University of Medical Sciences (Code: IR.ARAKMU.REC.1397.249). All participants' parents signed a written informed consent.

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Authors' contributions

Conceptualization and supervision: Sousan Salehi and Zahra Soleimani; Methodology: Sousan Salehi, Zahra Soleimani and Seyedeh Zeinab Beheshti; Investigation, Writing – original draft, and writing – review & editing: All authors; Data collection: Sousan Salehi and Sheida Bavandi; Data analysis: Saman Maroufizadeh and Sousan Salehi; Funding acquisition and resources: Sousan Salehi, Saman Maroufizadeh, and Zahra Soleimani.

Conflict of interest

The authors declared no conflict of interest.

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