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Sequential diadochokinesis in fluent and stuttering children: rate of production and type of errors

Diadococinesia sequencial em crianças fluentes e com gagueira desenvolvimental persistente: análise da velocidade e tipo do erro da consoante alvo

Fabíola Staróbole Juste[1], Ana Paula Ritto[1], Kalil Garcia do Nascimento Silva[1] Claudia Regina Furquim de Andrade[1]

ABSTRACT

Purpose: To compare the oral motor performance of stuttering and fluent children based on the production rate of sequential diadochokinesis (DDK) and on the type of errors. **Methods:** Participants were 46 children, aged between 4 years and 11 years and 11 months, divided into two groups: Research Group (GI), composed of 23 children with persistent developmental stuttering; Control Group (GII), composed of 23 fluent children, paired by age and gender to participants of GI. For each participant, three samples of sequential DDK were recorded in 15-second windows. These samples were later analyzed considering articulatory rate, and number and type of consonant errors per sample. **Results:** The groups did not present significant differences when considering the analyzed variables. Both fluent and stuttering children presented similar performances for articulatory rate and consonant errors (i.e., the most frequent type of error was consonant exchange). **Conclusion:** Children with developmental stuttering and their fluent peers presented similar performances in all of the tested variables, suggesting that sequential DDK was not enough to identify the stuttering group.

Keywords: Stuttering; Speech; Children; Speech production measurement; Acoustics

RESUMO

Objetivo: Comparar a performance motora oral complexa em crianças com gagueira persistente do desenvolvimento e em crianças fluentes, a partir do cálculo da velocidade de produção da diadococinesia sequencial (DDK/SMR) e análise da tipologia de desvio da consoante alvo. **Métodos:** Participaram do estudo 46 crianças com idades entre 4 anos e 11 anos e 11 meses, divididas em dois grupos: Grupo Pesquisa (GI), composto por 23 crianças com diagnóstico de gagueira; Grupo Controle (GII), composto por 23 crianças fluentes, pareadas por gênero e idade aos participantes do GI. Para cada participante, foram coletadas e gravadas três amostras de DDK/SMR em janelas de 15 segundos cada, sendo analisadas, posteriormente, a velocidade de produção articulatória, o número e os tipos de erros apresentados nas amostras. **Resultados:** Os grupos não se diferenciaram em nenhuma das variáveis testadas, ou seja, apresentaram desempenhos semelhantes quanto à velocidade de produção articulatória, quanto ao número de erros e quanto aos tipos de erros (o desvio da consoante alvo mais frequente foi a inversão, para ambos os grupos). **Conclusão:** As crianças com gagueira do desenvolvimento e as crianças fluentes apresentaram desempenho semelhante nas variáveis testadas, sugerindo que a prova de diadococinesia sequencial não foi eficiente para auxiliar na identificação precoce da gagueira em crianças.

Descritores: Gagueira; Fala; Crianças; Medida da produção da fala; Acústica

Study performed at the Department of Physical Therapy, Speech Therapy and Occupational Therapy, Medical School, Universidade de São Paulo – USP – São Paulo (SP), Brazil.
(1) Department of Physical Therapy, Speech Therapy and Occupational Therapy, Medical School, Universidade de São Paulo – USP – São Paulo (SP), Brazil.
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Corresponding author: Claudia Regina Furquim de Andrade. Email: clauan@usp.br
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INTRODUCTION

Models and studies on speech production are based on how the speaker uses the vocal tract to transmit his potential message to the listener. To understand speech production, it is necessary to distinguish between motor control of speech and nonspeech (non-linguistic oral motor behaviors). Such a distinction involves the basic concept that the underlying mechanism of motor actions is controlled by a process aimed towards a final goal or product[(1,2,3,4,5,6,7,8,9)].

From the perspective of dynamic systems theory, specific tasks demand of skeletal and neuromuscular components that the planned motor act be a single unit, with a self-organized pattern, in synergistic balance, interacting with other units, forming a system that organizes and dissolves spontaneously, depending on the goal to be achieved[(3)].

Motor goals integrate the motor functions of the face, which may be involuntary (those with a metabolic or vegetative basis – breathing, swallowing (from the pharyngeal phase), yawning, hiccupping, etc. – once started, the movement follows a constant and typical sequence, controlled by an autonomous neural net); related to emotional expression (those that signal an affective state – laughing, smiling, crying, sighing – which are controlled by a limbic neural net); related to oral motor activities (used in clinical assessment batteries to test praxic and cranial nerve functional abilities, usually performed through imitation or command); musical (control of certain structures and motor organization to play a certain musical instrument – saxophone, flute, harmonica, etc.); or related to speech (fine and complex motor activity, with simultaneous, parallel processing, acquired through learning and performed according to a phonetic plan determined by the natural language)[(1,2,3,4,5)].

Research on speech production and its relation with other facial motor functions has not yet explained if speech movements are, indeed, controlled by a universal neural arrangement (whose motor commands differ in the goal to be attained) depending on the type of task, or if they stem from a specific motor formulation, provided in levels and engendered for the production of the desired emission (the same apparatus is used, but with specific, complex, and sophisticated commands of force, precision, flow, and compliance)[(1,2,3,4,5,6)].

Speech motor production, in normal conditions, involves temporal control of events, in which motor command and vocal tract configuration are controlled by an internal representation which directs articulatory direction, harmony, precision of the phonetic transition, and the compensatory structure in case of disturbances that may compromise the precision of the speech signal (audited and somatosensory feedback control), generated in real time, to correct articulatory deviations that may cause discrepancies of fluency, speed, and smoothness of speech flow[(6,7,8,9)].

Fluency may be considered a descriptor of speech performance, a product of language, transformed into movements and sounds, in temporal, sequential order pertinent to each natural language. Fluency is distinct from the other language components (grammatical, syntactical, lexical) in being an automatic pattern, which makes it possible for speech to be perceived as continuous. Speed may be understood as a measure of the amount of speech produced in a given time. Speech smoothness is the result of motor production and transition performed effortlessly (a unified motor program which selects the proper phonemes, at the correct time and order, with no attention required to do it)[(10,11,12)].

Fluency and smoothness of speech result from practice and learning. As the motor programs are created, corrected, and repeated, those actions become natural (the motor command is generated, muscle interactions are organized, there is less need for system control, and less effort demanded)[(10,11,12)]. One of the best-known fluency disorders is persistent developmental stuttering.

Persistent developmental stuttering is understood as a hereditary metabolic disorder, of a chronic nature and with variable degrees of severity. The likely source of stuttering that is genetically transmitted is the inability to automatically update internal models (related to the dynamics of the execution motor control effector system), leading to the sensorial consequences of movement repetition or blockage, preventing the completion of the motor order issued, and causing a continuous reinitialization of the system. Stuttering symptomatology (involuntary disruptions of speech flow) changes speech naturalness, making communication stressful, challenging, and frustrating[(13,14,15,16,17,18)].

One of the tests used to assess speech motor production is diadochokinesis (DDK), used to determine the speed and regularity of the movements of the jaw, lips, and tongue. DDK makes it possible to assess articulatory precision, reflecting the maturity and integration of the structures involved in speech[(19,20)]. The speed of repetition of the articulatory segments can be gauged in two different tasks: *alternating motion rate* (AMR) and *sequential motion rates* (SMR). AMR ascertains the speed and the regularity of the reciprocal movements of the jaw, lips, and tongue, making it possible, also, to evaluate articulatory precision as well as respiratory and phonatory support. The SMR task is a measure of the ability to move, quickly and at a predetermined sequence, the articulators, from one position to the other[(21,22)].

Despite the small number of studies in the literature on motor control processing in stuttering children, there is evidence that they have difficulties with planning and programming speech movements[(23)]. A study looking into the DDK rate in stuttering children concluded that a large percentage displayed oral motor alterations, evidenced by their low performance during motor tasks involving speech[(24)]. Conversely, another study, comparing sequential DDK rates between stuttering children and their fluent peers found no statistically significant differences between the groups[(25)].

Considering the above, as well as the challenge of finding instruments that can help early detection of persistent developmental stuttering, the goal of this study was to compare complex motor oral performance in children with persistent developmental stuttering and in fluent children, based on the measurement of the speed of production of sequential diadochokinesis (DDK/SMR) and on the analysis of target consonant deviation typology (TCDT). This goal is justified by the challenge of finding instruments that help in the early identification of persistent developmental stuttering.

METHODS

This investigation was designed as a cross-sectional study. Selection and evaluation processes followed the pertinent ethical processes: approval by the Ethics Committee of the Hospital das Clínicas of the *Universidade de São Paulo* (USP), CAPPesq 266/05, and signing of the consent form by the families of the participants.

Participants

Study participants included 46 children, aged 4 years through 11 years 11 months, divided into groups:

The Research Group (GI) comprised 23 children (18 males and five females, 13 aged between 4 years and 7 years 11 months and 10 aged between 8 years and 11 years 11 months – average age 7.19±2.24), diagnosed with persistent developmental stuttering, with severity above 3% stuttering disruption rate[26] and at least a light degree in the SSI-3[27], and without any other associated communication, neurological, or cognitive deficits. In determining the composition of the group, there were no distinctions regarding race, gender, or socioeconomic level. All participants lived in the city of São Paulo or in greater São Paulo.

The Control Group (GII) comprised 23 children, paired by gender and age to GI, without stuttering complaints, nor any communication, neurological, or cognitive deficits. In determining the composition of the group, there were no distinctions regarding race, gender, or socioeconomic level. All participants lived in the city of São Paulo or in greater São Paulo.

Material

To record the samples of DDK/SMR, a LeSonGooseneck® brand microphone was used, at a previously determined distance of 8-10 cm from the mouth of the child, at a 45° angle.

Samples of DDK/SMR were stored, both for collection as well as for data analysis, in the PRAAT 4.2 software (free to use), installed into a Dell desktop computer. The software is an application that transforms a digitized audio signal into a mathematical representation of the frequency as a function of time.

Procedures

The procedures described below were applied to all participants (GI and GII).

1. Collection of DDK/SMR and composition of DDKs *trials*: after proper positioning in front of the computer, as mentioned above, the child was asked to utter, without stopping, the sequence "pa-ta-ka," as quickly as possible, without losing articulatory precision, immediately after hearing the stopwatch beep. This acquisition was performed three times, with 15-second windows for each sequence. The composition of the DDKs *trials* followed a methodology described in the literature[28], and included 10 repetitions of the target (1 DDK *trial* = 10 repetitions of "pataka"). Each DDK *trial* was constructed taking errors into consideration, that is, if the child uttered, for example, "pa-ta" repeatedly, each utterance counted as a repetition with a deletion error.

2. Calculation of the production speed of the *trials* for the total duration and for the duration of the DDK/SMR sample segments:

a) Total duration of the sample (15 seconds): the speed of the DDKs was calculated, considering a single *trial* (10 repetitions of "pa-ta-ka"), divided by the time necessary for performing this task, for each of the three samples. The analyzed result was the arithmetic mean of the three speeds acquired;
b) Sample segment duration: the speed of the DDKs was calculated in the first sample segment (0-8s), considered the most vulnerable for the stuttering children, and in the second sample segment (8-15s). The analyzed result was the arithmetic mean of the speed of the three samples acquired for each segment.

3. Target consonant deviation typology (TCDT) – error analysis:

The survey of the types of error was performed according to a methodology previously described in the literature[28]. The possible types of error produced are:

a) Insertion: an extra segment or syllable inserted in the original order of the sequence. Example: "pa-ta-ta-ka."
b) Deletion: a segment or syllable deleted from the original order of the sequence. Example: "pa-ta."
c) Voicing: a voiced couple produced instead of a voiceless sound. Example: "ba-da-ga."
d) Placement: a segment is maintained (three consonants), but incorrectly, due to a change in consonants or repetition of a syllable. Example: "pa-ka-ka."
e) Exchange: syllables are uttered outside of their model positions. Example: "pa-ka-ta."
f) Perseveration: syllables are produced and, in the sequence, repeated. Example: "pa-pa-ka."

Thus, the *trial* speed, the 15-second sample segment (the first from 0 to 8 seconds, or the second from 8 to 15 seconds) that displayed the greater number of errors, and the most frequent error were established for each participant from GI and GII.

Data analysis

The descriptive analysis for the quantitative data with normal distribution was performed with the means presented together with their respective standard deviations. The assumptions for normal distribution in each group were verified through the Shapiro-Wilk test.

For the comparison of two groups of quantitative variables with a normal distribution, the Student's t-test was employed. For variables without a normal distribution, the Mann-Whitney test (between groups) and the Wilcoxon signed-rank test (inside groups) were used. Friedman's test was used for comparisons between more than two groups (types of error). For multiple comparisons, the Wilcoxon signed-rank test with Bonferroni correction was used (α=0.03). We assumed a probability of type I error (α) of 0.05 for all inferential analyses.

Descriptive and inferential statistical analyses were performed with SPSS software, version 13 (SPSS 13.0 for Windows).

The Shapiro-Wilk test indicated a normal distribution for the comparisons between groups, both regarding the number of errors and speed. For these quantitative variables, with a normal distribution, and for which comparisons between the two groups (GI and GII) were carried out, the Students t-test was used.

RESULTS

The following results were achieved from the analyses:

The groups, stuttering children and fluent children, presented no significant differences regarding the speed of productions of the trials. The average speed obtained from the three collected samples is presented in Table 1.

Regarding the total number of errors in the average of the three 15-second samples, and the analysis of the number of errors by segment (first segment – from 0 to 8 seconds; and second segment – from 8 to 15 seconds), it was observed that groups GI and GII had no significant differences in the number of errors per segment, for the 15-second samples. Furthermore, for both groups, the first segment had a higher number of errors than the second segment (Table 2).

Table 1. Inter-group analysis of speed of production of the trials

Group	Mean (SD)	T	p-value
GI	0.13 (0.04)	-1.853	0.071
GII	0.16 (0.02)		

Student's t test (p≤0.05)
Subtitle: GI = research group; GII = control group; SD = standard deviation

As for the distribution of types of error for each group, comparing the most frequent types of error, the analyzed variables failed to present a normal distribution, and the Friedman test was used for those comparisons (Table 3).

Concerning the incidence of types of error in GI and GII, results showed that the most frequent error, for both groups, was exchange (p<0.001) (Figure 1 and Figure 2).

DISCUSSION

The aim of this study was to evaluate complex oral motor performance in stuttering children and in fluent children, based on the calculation of the speed of production of sequential diadochokinesis, and to analyze the type of error produced during this activity. The results showed no differentiation between the two groups for any of the tested variables, with both displaying similar performances regarding the measured ability to perform rapid motor transition, the precision and regularity of articulatory movement, the impact of motor action in the initial and final segments of the sample, and the type of error (deviation from the most frequent target consonant).

A previous study, whose goal was to acoustically analyze DDK tasks in stuttering and in fluent children who speak Brazilian Portuguese[29], found no significant difference between those groups regarding syllable generation, mean time between syllables, or peak intensity. At the end of the study, the authors speculated that differences between the groups

Table 2. Intergroup analysis of total number of errors in the sample (15 seconds) and number of errors in each segment (0 to 8s/8 to 15s)

	Group	Mean (SD)	T	p-value
Total number of errors	GI	11.99 (3.75)	-0.195	0.846
	GII	13.91 (4.32)		
Number of errors by segment	GI 0-8s	7.47 (2.94)	-0.187	0.036*
	GI 8-15s	4.52 (1.85)		
	GII 0-8s	9.65 (3.24)	-0.197	<0.001*
	GII 8-15s	4.26 (1.57)		

Student's t test (p≤0.05)
Subtitle: GI = research group; GII = control group; SD = standard deviation

Table 3. Intra-group analysis of GI and GII of the most frequent type of error

Type of error	Mean (SD)	Minimum	Maximum
GI			
Insertion	0.38 (0.52)	0	1.66
Deletion	1.12 (2.34)	0	9
Voicing	0.05 (0.21)	0	1
Placement	0.33 (0.6)	0	2.66
Exchange	3.5 (2.54)	0	8.33
Perseveration	0.6 (1.28)	0	4.33
GII			
Insertion	0.59 (1.99)	0	9.66
Deletion	1.01 (1.93)	0	9
Voicing	0.04 (0.11)	0	0.33
Placement	0.2 (0.44)	0	2
Exchange	4.09 (3.03)	0	9.66
Perseveration	0.34 (1.16)	0	4.66

Friedman test ($p \leq 0.05$)
Subtitle: GI = research group; GII = control group; SD = standard deviation

of stuttering children and fluent children could be found by analyzing the type of errors found in DDK/SMR tasks. In this study, we verified that this variable also failed to differentiate the groups, either quantitatively or qualitatively. Both groups displayed the same most frequent type of error, exchange.

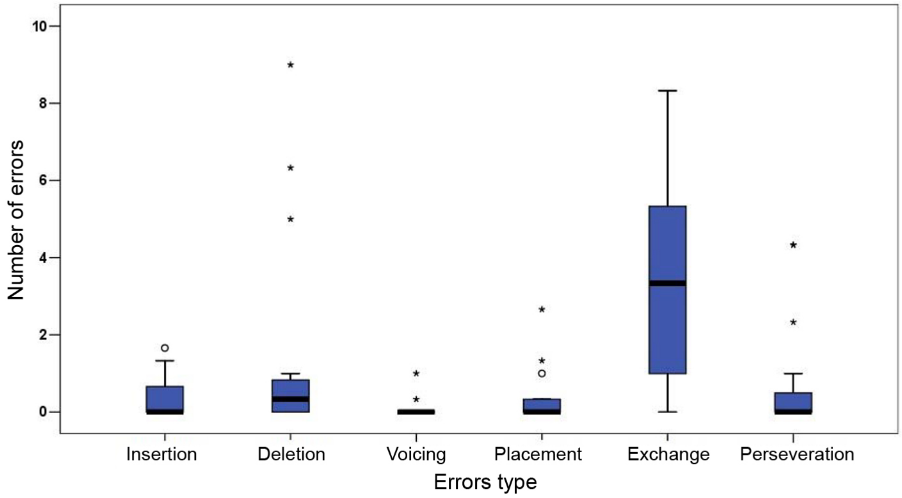
An American study[28], with fluent children, using the same methodology of error analysis employed in this study, indicated that the most frequent type of error was deletion. The authors claim that a possible explanation for this type of error might be that children have trouble performing tests involving nonwords, because when, instead of pronouncing *"puhtuhkun"*, the children were asked to pronounce "*patty-cake*" (same sound sequence, but with semantic meaning), there was a reduction in the number of errors produced by the children. The higher incidence of the exchange error, displayed by both groups in this study, might be understood as an attempt to approximate the target sequence ("pataka") to a more semantically known word ("pacata" or "pocotó," children's onomatopoeias for horse).

The results from this study indicate the need to make a distinction between motor control of speech (production of information) and nonspeech movement. Children from the GI group had a diagnosis of stuttering, which means that, regarding speech movements, this group was consistently different from the control fluent group; however, when nonspeech movements (articulatory movement without production of information) were studied, with DDK, both groups had similar performance. Taking these observations into account, we can suggest the existence of a distinction in the underlying mechanism of motor actions when speech is the goal or final product[1,3,4].

Given the above, these results indicate that the sequential diadochokinesis test did not contribute to the early identification of stuttering in children. From these results, it is possible to suggest that therapeutic processes that use exercises and maneuvers of nonspeech to stimulate fluent speech are not recommended for stuttering children, as they are unlikely to have beneficial effects.

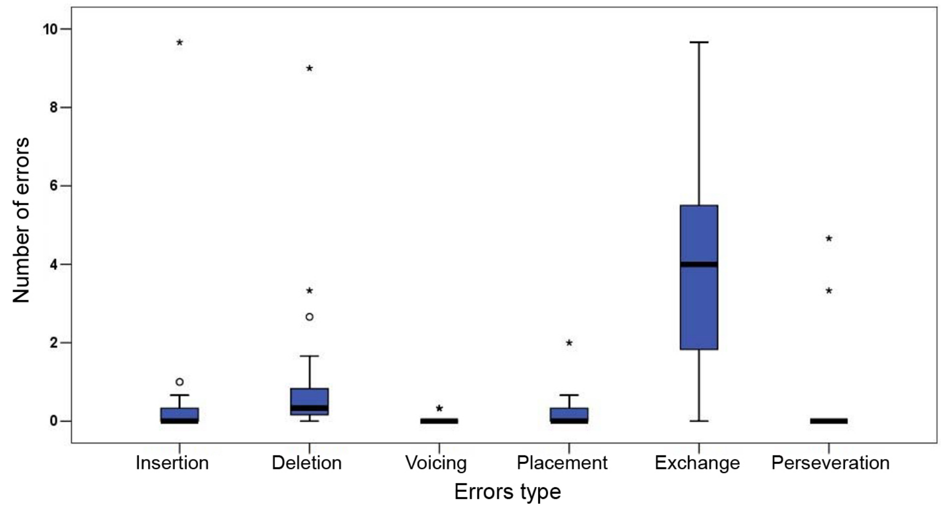
CONCLUSION

Groups of children aged 4 to 11 years, with developmental stuttering, and fluent children, participating in this study, demonstrated similar performance in all tested variables, suggesting that the sequential diadochokinesis test was ineffective for early detection of stuttering in children.



Wilcoxon signed-rank test with Bonferroni correction ($p<0.001$)
Subtitle: GI = research group

Figure 1. Distribution, by type, of total number of errors in GI



Wilcoxon signed-rank test with Bonferroni correction (p<0.001)
Subtitle: GII = control group

Figure 2. Distribution, by type, of total number of errors in GII

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