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Procedural Memory Deficits in Preschool Children with Developmental Language Disorder in a Spanish-Speaking Population

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Abstract: This study aimed to compare procedural learning skills between Spanish-speaking preschool children (ages 4 years to 4 years, 11 months) with Developmental Language Disorder (DLD) and their typically developing (TD) peers. Using the Serial Reaction Time task, participants (30 DLD and 30 TD children) respond to visual stimuli in a sequenced manner over four blocks, followed by a random order block. The task assessed reaction time (RT) and accuracy. Results showed a significant interaction between group and block for reaction time (RT) and accuracy, with children with DLD exhibiting longer RTs and accuracy deficits across blocks. In contrast, the TD group showed higher RT efficiency and accuracy in the sequential blocks and as expected, decreased performance in the random block according to the experimental manipulation. Overall, the results of this investigation suggest that there was no implicit learning in the DLD group, as indicated by the SRT task paradigms of procedural memory. These findings align with the Procedural Deficit Hypothesis (PDH), suggesting that linguistic deficits in the TD population may derive from a general dysfunction of the procedural memory system domain in the Spanish context.

Keywords: procedural memory; Developmental Language Disorder (DLD); Procedural Deficit Hypothesis (PDH); language acquisition; Serial Reaction Time (SRT) task

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1. Introduction

Developmental Language Disorder (DLD) is a persistent condition impacting language acquisition and development, resulting in substantial challenges in social interactions and educational advancement [1]. This disorder has a global prevalence, estimated to affect approximately 3% to 7% of children [2,3]. As DLD is a universally recognized diagnosis, it shares commonalities across languages, including grammatical errors [4]. In the case of Spanish, one of its grammatical characteristics is the type of conjugation characterized by irregular and regular patterns, as well as grammatical moods, aspects, and tenses with specific morphological features [5].

Common grammatical errors reported in the literature for Spanish-speaking children with DLD are: errors in the use of the nominal phrase and function words; errors in verb use; errors in argument structure; errors in sentences and complex structures; errors in morphosyntactic comprehension, such as the correct assignment of an attribute in sentences with two nouns; all of which are due to a complex Spanish syntax with changing, infrequent structures and several exceptions to the rule [6].

Recent research has established connections between linguistic impairments and non-linguistic deficits encompassing learning and memory [7,8]. As a result, a shift has occurred from the concept of Specific Language Impairment (SLI) towards a broader perspective that views DLD as a language development disorder encompassing both linguistic and non-linguistic components [1]. Under this view there are two main perspectives that attempt to explain the causes of DLD, with one suggesting that the disorder is specifically related to aspects of language [9], while another proposes that it is caused by a non-linguistic processing deficit [4,10]. However, both perspectives have limitations in explaining the range of linguistic and non-linguistic impairments observed in DLD.

The Procedural Deficit Hypothesis (PDH) offers a comprehensive explanation by considering behavioral and neural aspects to elucidate the observed pattern of linguistic and non-linguistic deficits in DLD [10-12]. According to the PDH, abnormalities in the brain's procedural memory system, which involves a network of brain structures, including the basal ganglia, cerebellum, and portions of the parietal and frontal cortices, account for the deficits observed in DLD [11]. This memory system underlies a range of skills, including sequencing [13], learning of probabilistic rules, categorization [14], and the rule-governed aspects of grammar [15,11,12]. In the context of Spanish language acquisition, its grammatical features, such as the gender of Spanish nouns, mandate the consistent recall of adjective, article, and pronoun forms that must agree in gender and number. Additionally, Spanish has extensive and varied verb conjugations, potentially shifting based on subject and tense, which may require participation from procedural memory [6].

Evidence in English context suggests that the procedural memory system reaches a relatively advanced stage of development during the preschool years [16,17]. This developmental aspect can significantly impact the ability to learn and utilize language skills. Individuals with DLD, characterized by deficits in procedural memory, may face challenges in acquiring linguistic rules that typically developing (TD) individuals acquire effortlessly and implicitly. Indeed, findings in language acquisition have shown that procedural memory impacts the learning of grammatical abilities rather than lexical abilities in both children acquiring their first language and adults learning a second language [18]. As a result, considering these findings, one could argue that procedural memory would also have a significant role in the development of grammatical skills of Spanish.

In prior research utilizing an experimental paradigm with children aged 5 to 6 years old, it was observed that individuals with Developmental Language Disorder (DLD) exhibited longer response times (RT) compared to typically developing (TD) children in a go/no-go task designed to assess sentence grammaticality. The task specifically required distinguishing irregular verbs from regular verbs in different verb tenses. The results revealed that children with DLD spent more time identifying irregular verbs compared to regular verbs. Moreover, they took more time identifying verbs in the past simple perfect tense than those in the present tense, as compared to TD children. Similarly, DLD children displayed a higher error rate in inhibition tasks compared to their TD counterparts [19]. This study serves as a precedent for the current research, involving Spanish-speaking preschool children through a classic task, characteristic of an experimental design.

The Procedural Deficit Hypothesis (PDH) has primarily been investigated through a comparison of procedural learning abilities in children with DLD and TD peers, utilizing the experimental paradigm known as the Serial Reaction Time (SRT) task, originally devised by Nissen and Bullemer in 1987 [20]. The SRT task is designed to evaluate how individuals learn patterns without conscious awareness. During the task, participants are presented with a series of visual stimuli and are required to respond swiftly by pressing buttons. As participants encounter the sequence, their reaction times progressively decrease, and their accuracy improves as they unconsciously internalize the pattern. This task's use as an indicator of procedural memory function is substantiated by prior research demonstrating the integral role of procedural memory structures in task performance [21, 22].

A meta-analysis by Lum et al. [8] summarized findings from eight studies examining procedural performance in individuals with DLD, using the SRT classic task as their inclusion criterion. The meta-analysis included 186 participants with DLD and 203 TD peers. The findings revealed that the TD group, overall, demonstrated a greater difference in response times between sequenced and random blocks compared to the DLD group. The meta-analysis yielded an average mean effect size of 0.328, indicating a significant association between DLD and impairments in procedural learning as measured by the SRT task. Worth noting is that the analysis only included studies conducted on English-speaking populations, with no identified publications in the Spanish language.

The overall findings provide support for the Procedural Deficit Hypothesis (PDH). Previous research has found correlations between measures of grammar and procedural learning [12], but most of the research has been conducted with an English-speaking population. As grammar is clearly impaired in DLD across different languages [4], it is crucial to investigate whether this hypothesis applies to Spanish. Spanish grammar is characterized by gendered nouns requiring agreement of

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adjectives, articles, and pronouns, as well as verb conjugations influenced by both regular and irregular patterns based on tense and mode, with a flexible sentence word order [23]. Given these linguistic distinctions, it is intriguing to investigate whether similar outcomes of procedural memory can be observed in Spanish-speaking subjects.

Investigating the disparities in procedural learning between native Spanish speakers with DLD and TD individuals holds significant implications for designing language intervention and early stimulation strategies. Such exploration could potentially mitigate linguistic limitations within this population. Consequently, this study aims to research differences in procedural memory learning between preschool Spanish-speaking subjects with DLD and their TD peers using the Serial Reaction Time (SRT) task developed by Nissen and Bullemer [20]. The study will compare reaction times and the percentage of correct answers to determine if variations in procedural memory exist between the two groups.

2. Materials and Methods

The research design is a mixed intergroup 2 (DLD/TD) and intragroup x5 (blocks: 1, 2, 3, 4, 5) design. Blocks 1 to 4 followed a sequential pattern, whereas block 5 followed a random pattern.

2.1. Participants

Thirty children with DLD and 30 TD children participated in the study (see Table 1 for participants' characteristics of the final set of children). For the estimation of the minimum required sample size, the following parameters were considered: a) Effect size (f) = 0.25, b) Statistical power (1- β) = 0.95; c) Significance level (α) = 0.05; d) Number of measurements = 5. According to these variables, a minimum of 16 individuals per group is needed, as calculated by the G*Power program version 3.1.7. In order to address school dropout effect, which is common in this educational stage, we have considered a sample size almost double that which is required. The children were recruited from schools in Concepción (Chile), and all were native Spanish speakers. The parents and/or legal guardians provided written consent, approved and validated by the ethics committee of Universidad de Concepción (Chile), and the participants gave their verbal assent before participating in the experiment.

Table 1. Participant characteristics.

Variable	DLD (n = 30)		TD (n = 30)		Comparison
	M	SD	M	SD	
Age (months)	55,03	3,85	56,17	2,52	t = -1,35 p = 0.18
TELD3-S rec	82,06	5,36	100,8	5,59	t = -13,24 p = <0.001
TELD3-S exp	82,47	5,85	96,3	5,97	t = -9,06 p = <0.001
TELD3-S total	164,53	3,48	197,1	5,42	t = -27,682 p = <0.001

Note: Group mean values (M), standard deviation (SD) and score from TELD3-S.

None of the participants in the sample had any known sensory or developmental disorders, including autism, cognitive deficits, and cerebral palsy. Additionally, none of the participants had experienced any trauma requiring medical care.

To confirm the language diagnosis of the subjects, the Initial Language Development Test (TELD-3: S) was used. This test is an instrument by the authors Ramos et al. [24], which evaluates the receptive and comprehensive language of subjects from 2 years to 7 years and 11 months old. The receptive subtest consists of 37 items, 24 semantic items and 13 grammar items, measuring the child's proficiency in understanding spoken language. Items for the preschool stage include prompts such as 'Show me the car/Muéstrame el auto' or 'Show me the ball/Muéstrame la pelota.' As the difficulty level increases, children are prompted with more complex tasks like 'Show me the boy that is under the table/Muéstrame al niño que está abajo de la mesa.' Towards the end of the test, participants are presented with questions like 'What goes with the word 'girl': his or hers?/¿Qué va con la palabra

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'niña': suyo o suya?' and 'Tell me if the following words mean the same or mean something different: box, ark/Dime si las siguientes palabras significan lo mismo o significan algo diferente: caja, arca'.

The expressive subtest comprises 21 semantic and 18 grammar items. These items involve tasks such as sentence repetition and responding to questions like 'What is the kid doing?/¿Qué está haciendo el niño?' and 'How old are you?/¿Cuántos años tienes?' Towards the end of the test, participants are prompted with items like 'Tell me the word to finish the sentence/Dime la palabra necesaria para terminar la oración' and 'Make a sentence with the words: see-dog/Elabora una oración con las palabras: ver-perro'. The test, validated in Chile, obtained a Cronbach's Alpha of 0.931 in the receptive subtest, 0.947 in the expressive subtest, and 0.969 in the total test. Based on the results of this test, the two study groups were formed (see Table 1 for participants' characteristics of the final set of children included in statistical analysis).

2.2. Stimuli and procedure

The SRT task has been employed to investigate procedural learning in various clinical populations. In this task, participants are required to press a button according to the location of a visual stimulus presented on a computer screen. Unknown to the participants, the location of the stimulus follows a predetermined sequence. Learning is deemed to have taken place if participants exhibit quicker responses to stimuli presented in a sequence than to those presented randomly.

To present the visual stimulus, a dog was chosen for the study population. Each participant received oral instructions for the task with visual examples presented on a computer screen. They were asked to search for the dog and mark its corresponding position on the serial response box as quickly and accurately as possible. Four practice stimuli were presented to familiarize them with the task, and immediately after, the experimental stage began (see Figure 1).

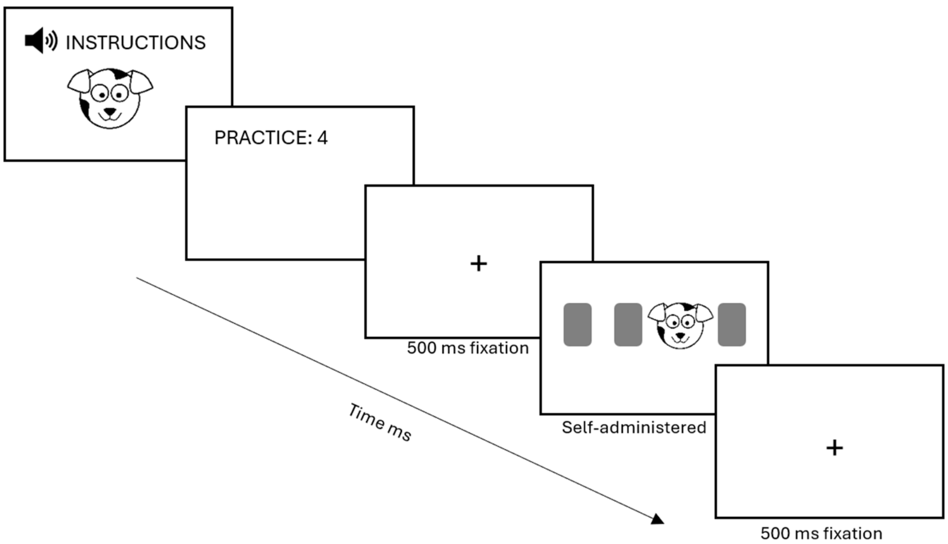

Figure 1. Presentation stimuli.

The dog's appearance was programmed in four different horizontal positions; in the experimental stage, the dog appeared in a predetermined sequence of 10 positions (4-2-3-1-3-2-4-3-2) over blocks 1 to 4, which was repeated six times, resulting in a total of 60 stimuli per block. In block 5, a pseudo-random form was employed where each position appeared the same number of times as in the previous blocks, but the probability of the next location was controlled to avoid coinciding with the serial pattern.

After each block, the participants were given a break. Once they were ready to resume the experiment, they were asked to press a key to continue. At the end of the experiment, the participants

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received an auditory congratulation and were shown an image of a trophy. The activity was administered individually in a quiet room with no distractions.

The dependent variables were reaction time (RT), which is described as the amount of time taken (in ms) by the children to press the response button after the visual stimulus appeared and the accuracy of the answers. Response times were recorded in E-Prime version 3.0. The proportion of median RTs and the percentage of accuracy were computed for each of the five blocks for each child.

3. Results

All statistical analyses were done with SPSS 22. A 2 (Group: DLD, TD) x 5 (Blocks: 1-5) mixed-design factorial ANOVA was conducted to analyze the data for reaction time and accuracy.

3.1. Reaction Time

The results revealed a significant interaction between Group and Block, $F(4, 232) = 41.872$, $p < .001$, η^2partial= .419, indicating that the DLD and TD groups showed different patterns of reaction time performance across the five blocks (*Figure* 2). The observed power for this interaction was 1, suggesting a high likelihood of detecting significant effects. Independent samples t-tests indicated that the DLD group had significantly longer reaction times than the TD group in all blocks (Block 1: $t(58) = 2.974$, $p = .004$; Block 2: $t(58) = 6.718$, $p < .001$; Block 3: $t(58) = 12.838$, $p < .001$; Block 4: $t(58) = 13.991$, $p < .001$; Block 5: $t(58) = 5.712$, $p < .001$).

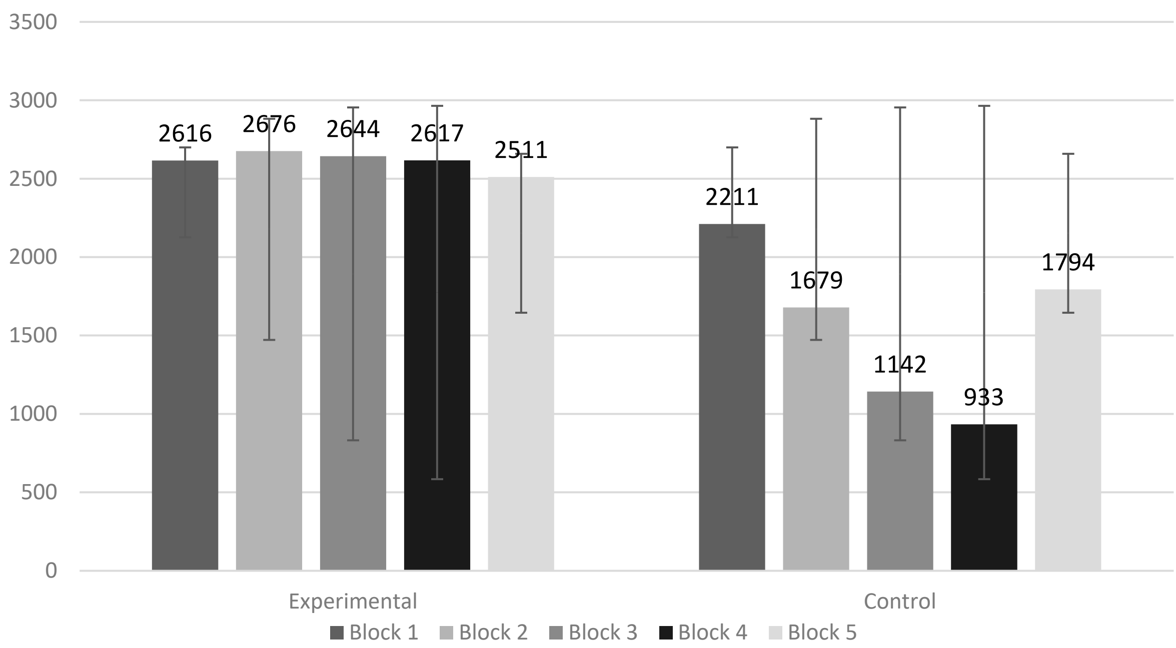

Figure 2. Mean reaction times (RTs;± SE) according to Block and Group.

In the DLD group, no significant effects were observed between blocks, $F(4, 116) = 1.152$, $p = .336$, η^2partial= .038. Conversely, there were statistically significant results in the TD group, $F(4, 116) = 77.128$, $p < .001$, η^2partial= .727, indicating a progressive decrease in reaction times across Blocks 1-4. Furthermore, there was a significant difference between the final serial pattern block (Block 4) and the random block (Block 5), where the TD group's reaction time increased ($t(29) = -9.548$, $p < .001$). These results suggest that no implicit learning took place in the DLD group, as indicated by the SRT task paradigms of procedural memory [17].

3.2. Accuracy

The analysis of accuracy revealed a significant interaction between Group and Block, F(4, 232) = 7.780, p < .001, η^2partial= .118, indicating different patterns of accuracy performance in the DLD and TD groups across the five blocks. The observed power for this interaction was .99, suggesting a high likelihood of detecting significant effects. Independent samples t-tests indicated that the DLD group exhibited a significantly lower level of accuracy compared to the TD group in the serial pattern blocks (Block 1: t(58) = -4.261, p < .001; Block 2: t(58) = -3.359, p < .001; Block 3: t(58) = -4.263, p < .001; Block 4: t(58) = -3.044, p < .001). However, the difference between the groups in the random block was not statistically significant, Block 5: t(58) = -1.740, p = .087 (**Figure** 3).

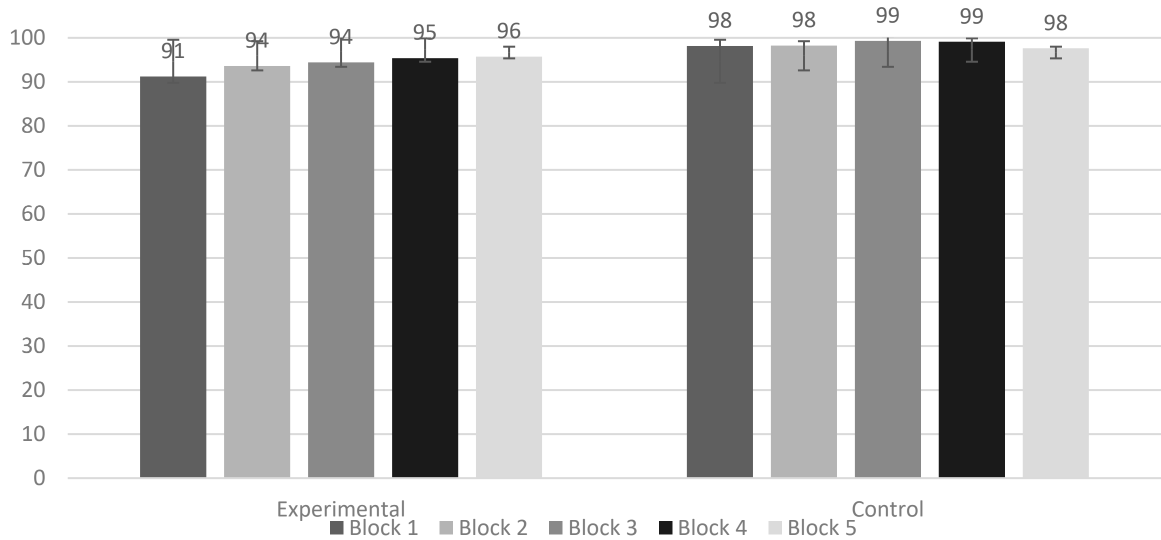

Figure 3. Accuracy (%;± SE) according to Block and Group.

In the DLD group, there was a significant main effect for Block, F(4,116) = 10.036, p < .001, η^2partial= .257, indicating a progressive increase in accuracy performance across all blocks. However, this difference was not significant between blocks 4 and 5 (t(29) = -.604, p = .551). This suggests that the children became more efficient with the task but were not affected by the serial pattern.

In the TD group, there were statistically significant results, F(4, 116) = 4.774, p < .001, η^2partial= 0.141, indicating differences in accuracy across blocks. Furthermore, there was a significant difference between the final serial pattern block (Block 4) and the random block (Block 5), where the level of accuracy decreased (t(29) = -9.548, p < .001). These results suggest that the TD group demonstrated learning in the serial pattern blocks, with an increase in accuracy up to the fourth block, followed by an impact on the fifth block due to its random nature, leading to a decrease in the accuracy percentage.

4. Discussion

The current study aimed to explore the Procedural Deficit Hypothesis [10-12] and its relevance to Spanish-speaking preschool children diagnosed with Developmental Language Disorder (DLD). The hypothesis posits that abnormalities in the procedural memory system, including brain structures such as the basal ganglia, cerebellum, and portions of the parietal and frontal cortices, contribute to language deficits in DLD [11]. These memory processes underlie skills essential for language acquisition, such as sequencing, probabilistic rule learning, categorization, and rule-governed aspects of grammar [15, 10, 11]. The findings presented in this study validate the presence of a procedural learning deficit among the DLD group in the Spanish context.

In terms of reaction time (RT), the significant interaction between the group and block revealed distinct performance patterns across the five blocks for the two groups. Significantly longer RTs consistently observed in the DLD group compared to the TD group across all blocks underscore the substantial differences in their processing speed and learning trajectories. Additionally, the DLD

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group's lack of significant RT differences between blocks suggests that children with DLD did not implicitly grasp the sequence, indicative of a less developed procedural memory. These findings point to the struggles faced by children with DLD in processing and responding to stimuli presented in the Serial Reaction Time (SRT) task. These observations are in consonance with the Procedural Deficit Hypothesis (PDH) [10-12] which posits abnormalities in the brain's procedural memory system among individuals with DLD [24], with implications for language acquisition and proficiency. Correspondingly, Hsu and Bishop [26], employing an SRT task, found that children with DLD performed at the same level as grammar-matched children but showed poorer results than age-matched controls. This suggests that language development, particularly grammatical abilities, may be linked to procedural memory performance. Hsu & Bishop [26] also used a motor procedural learning task that did not involve learning sequential relationships between discrete elements. They found that children with DLD performed similarly to age-matched children and even outperformed younger grammar-matched controls. The researchers concluded that DLD may be characterized by deficits in learning sequence-specific information, rather than exhibiting a general deficiency in procedural learning ability.

In contrast, the TD group demonstrated a progressive decrease in reaction times across Blocks 1 to 4, indicative of an enhanced efficiency in processing the serial pattern. Of particular significance, a substantial difference emerged between the final serial pattern block (Block 4) and the random block (Block 5), resulting in an increase in reaction time. This observation further supports the proposition that the procedural memory system matures relatively early in the developmental journey of Spanish-speaking preschool children. These results corroborate prior studies conducted on English-speaking populations [16,17], suggesting a parallel developmental trajectory of procedural memory across diverse language groups.

Regarding accuracy, a high level of accuracy was observed in both groups, suggesting that the individuals understood the task. The subsequent analysis revealed a significant interaction between Group and Block. In blocks 1 to 4, the DLD group exhibited significantly lower level of accuracy compared to the TD group, indicating a major challenge in accurately responding to the stimuli associated with the procedural memory task. No significant difference was found in the random block, suggesting that the DLD group's performance was similar to the TD group when the sequential pattern is not involved. This lack of difference in the random block could be attributed to a dual effect: the DLD group exhibited an ascending performance trend over time, potentially compensating for the impact of the random sequence, while concurrently, the TD group displayed a decrease in accuracy in the final block, possibly due to the unexpected shift from a learned pattern to a random one.

In the DLD group, a significant main effect for Block was observed, indicating a progressive increase in accuracy performance across all blocks. However, there was no significant difference in accuracy between Blocks 4 and 5, suggesting that the children became more efficient with the task but were not influenced by the serial pattern. This outcome is not well-documented in previous studies [10-12], which mainly focus on the analysis of reaction times. A potential explanation for this divergence could be attributed to the nature of the Serial Reaction Time (SRT) task, where participants are required to rapidly respond to stimuli by pressing a button, involving motor skills encompassing nonoral movements (e.g., hand movements). Considering that both oral and nonoral motor sequencing skills are recognized to be impaired in DLD [27, 11], it is conceivable that these skills show improvement through repetitive training. In other words, there is a motor learning that leads to heightened accuracy in the final blocks.

In contrast, the TD group exhibited significant accuracy disparities across blocks, notably a reduction between the final serial pattern block (Block 4) and the random block (Block 5). This drop in accuracy could be attributed to participants' difficulty in adapting to the random presentation of stimuli, an occurrence anticipated within the SRT task framework of procedural memory [28, 12, 26].

These findings, supported by previous research on procedural memory and grammar correlations [12], contribute to the notion that Spanish-speaking children with DLD face difficulties in procedural learning. The linguistic characteristics of Spanish's structure, including gender agreement and complex verb conjugations, also involve aspects of procedural memory for optimal language acquisition.

However, it is crucial to acknowledge that certain inquiries cast doubt on the adequacy of evidence supporting the Procedural Deficit Hypothesis (PDH). For instance, West et al. [29] conducted meta-analyses on common procedural learning tasks and discovered slight deficits in groups with language impairments compared to controls, particularly within the context of the serial reaction time task. Notwithstanding these findings, they concluded that a generalized procedural learning deficit is not a causal risk factor for DLD. Moreover, Jackson et al. [30] compared procedural, declarative, and working memory performance among children with DLD and typically developing peers. The study, focusing on native English-speaking children, identified significant deficits in procedural and declarative memory for those with DLD. Nevertheless, the authors attributed these difficulties largely to limitations in working memory capacity. It is noteworthy that these findings, originating from English-speaking individuals, may be applicable to the Spanish language due to its linguistic characteristics. Spanish speakers also encounter distinct challenges in acquiring grammatical rules, making it intriguing to assess and compare the performance of other memory systems.

In conclusion, research on procedural memory has witnessed significant diversification over the years. New research paradigms have been introduced [31] and studies have encompassed different age populations [18, 21], including longitudinal studies in the DLD population [17]. The present study introduces novel evidence concerning the role of procedural memory in children with DLD as well as TD children using an experimental paradigm in the process of acquiring the Spanish language. These findings serve as a pivotal steppingstone for further exploration of the role of procedural memory in Spanish-speaking individuals with DLD.

Considering these research insights, the understanding of the role of procedural memory in DLD carries practical implications for the development of language intervention and early stimulation strategies. By concentrating on enhancing procedural memory skills, these interventions have the potential to mitigate linguistic limitations and enhance language outcomes for individuals with DLD.

This study's limitations, such as a single procedural memory task and its focus on preschool children, highlight avenues for future research. A broader range of tasks, age groups, and memory systems should be investigated to provide a more comprehensive understanding. Furthermore, linguistic tasks of a morphosyntactic nature alongside a procedural memory task could explore more directly the relationship between cognitive and linguistic aspects involved in children with DLD. As language intervention and early stimulation strategies are developed, these insights can be instrumental in alleviating linguistic limitations and enhancing language outcomes for individuals with DLD.

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Institutional Review Board Statement: The study was conducted in accordance with the Declaration of Helsinki and approved by the Ethics Committee of Universidad de Concepción (CEBB 731-2020).

Informed Consent Statement: Written informed consent was obtained from all parents/guardians of the children. Additionally, verbal assent was obtained from the children before their participation in the experiment.

Data Availability Statement: : The data generated and analyzed in this study are available on reasonable request from the corresponding author. The data are not publicly available as they are human data from adults and children in neurotypical and clinical groups.

Conflicts of Interest: The authors declare no conflicts of interest.

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