Declarative and Sequential learning in Spanish-speaking children with Language Impairment

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Language Impairment (LI) is a developmental disorder that mainly manifests impaired language learning and processing. Evidence, largely from English-speaking population studies, has shown that children with LI compared to typically developing (TD) children have low scores in sequential learning tasks but similar performance in declarative learning tasks. According to the declarative/procedural model, LI children compensate for their deficiency in syntactic skills (i.e., deficits in the procedural memory system) by using the declarative memory system (indispensable for vocabulary acquisition). Although there are specific deficits in children with LI depending on the language they speak, it is assumed that this model can explain the shortcomings of such pathology regardless of the language spoken. In the current study, we compared the performance of fifteen school-aged Mexican Spanish-speaking children with LI and twenty TD children during sequential and declarative learning tasks and then analyzed the relationship between their performance in these tasks and their abilities in syntax and semantics. Children with LI displayed lower scores than normal children in the sequential learning task, but no differences were found in declarative learning performance with verbal or visual stimuli. No significant correlations were observed in children with LI between their performance in sequential learning and their abilities in semantics and no significant correlations were observed in TD children between their performance in sequential learning and their abilities in syntax. In contrast, for children with LI, a significant correlation between their performance in declarative learning and their abilities in semantics was observed and for the group of TD children a significant correlation between their performance in declarative learning and their abilities in syntax was observed. This study shows that Spanish-speaking children with LI display a pattern of learning impairment that supports the declarative/procedural model hypothesis. However, they display poor verbal declarative learning skills, probably due to low verbal working memory capacity.

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Declarative and sequential learning in Spanish-speaking children with Language Impairment

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Abstract

Language Impairment (LI) is a developmental disorder that mainly manifests impaired language learning and processing. Evidence, largely from English-speaking population studies, has shown that children with LI compared to typically developing (TD) children have low scores in sequential learning tasks but similar performance in declarative learning tasks. According to the declarative/procedural model, LI children compensate for their deficiency in syntactic skills (i.e., deficits in the procedural memory system) by using the declarative memory system (indispensable for vocabulary acquisition). Although there are specific deficits in children with LI depending on the language they speak, it is assumed that this model can explain the shortcomings of such pathology regardless of the language spoken. In the current study, we compared the performance of fifteen school-aged Mexican Spanish-speaking children with LI and twenty TD children during sequential and declarative learning tasks and then analyzed the relationship between their performance in these tasks and their abilities in syntax and semantics. Children with LI displayed lower scores than normal children in the sequential learning task, but no differences were found in declarative learning performance with verbal or visual stimuli. No significant correlations were observed in children with LI between their performance in sequential learning and their abilities in semantics and no significant correlations were observed in TD children between their performance in sequential learning and their abilities in syntax. In contrast, for children with LI, a significant correlation between their performance in declarative learning and their abilities in semantics was observed and for the group of TD children a significant correlation between their performance in declarative learning and their abilities in syntax was observed. This study shows that Spanish-speaking children with LI display a pattern of learning impairment that supports the declarative/procedural model hypothesis. However, they display poor verbal declarative learning skills, probably due to low verbal working memory capacity.

Keywords: Specific Language Impairment, Language impairment, sequential learning, declarative learning, working memory, syntax, semantics

Introduction

Specific Language Impairment is a term that has been used to describe a developmental disorder that is characterized by a heterogeneous neuropsychological profile (Haskill & Tyler, 2007) with multiple deficits within and outside the linguistic domain (Ullman & Pierpoint, 2005).

Reilly and colleagues (2014) have therefore suggested removing the “specific” term from the diagnostic label and indeed this term is not included in DSM-V (Reilly, Tomblin, Law, McKean, Mensah, Morgan, Goldfeld, Nicholson & Wake, 2014). In agreement with this suggestion and in order to avoid controversies, we will henceforth use the term Language Impairment (LI) to present the findings of this study.

According to the declarative/procedural model (Ullman, 2001), a pattern of deficiencies of two separable memory systems (i.e., the procedural memory system (PMS) and the declarative memory system (DMS)) is attributable to children with LI (for another proposal that there are distinct memory systems see Mishkin, Malamut & Bachevalier, 1984). Previous research has related the PMS to learning of specific kinds of information; the encoding, storing and retrieving of associative, statistical and sequential information (Willingham, 1998). In contrast, the DMS has been related to learning of other kinds of information, such as information that comes from personal experience, or declarative information about words, such as lexical knowledge or vocabulary (Squire & Zola, 1996). Ullman’s proposal (2001) suggests that there is a specific link between sequential learning and the acquisition of syntactic knowledge. Sequential learning has been related to syntactic performance when this depends upon processing of rule-governed sequential information. For instance, Kidd (2012) showed that the sequential learning of children from 4 years 5 months to 6 years 11 months was directly associated with long-term maintenance of the primed syntactic structure during a syntactic priming task. A specific link has also been suggested between declarative learning and the acquisition of lexico-semantic knowledge. Declarative learning is related to lexico-semantic performance because access to vocabulary in part depends on the establishment of networks of form and meaning relationships.

Several studies have provided evidence suggesting that children with LI have a PMS deficit, and preserved DMS (Evans, Saffran & Robe-Torres, 2009; Kemeny & Lukacs, 2010; Leonard, Weismer, Miller, Francis, Tomblin, & Kail, 2007; Lum, Conti-Ramsden, Morgan & Ullman, 2014; Lum, Conti-Ramsden, Page, & Ullman 2012; Ullman & Pierpont, 2005). However, the sequential learning deficit in children with LI remains controversial (Mayor-Dubois, Zesiger, Van der Linden & Roulet-Perez, 2013). Some findings suggest that sequential learning is a complexity-dependent process. For instance, Gabriel, Maillart, Stefaniak, Lejeune, Desmottes and Meulemans (2013), using second-order conditional sequences in an image-learning task, showed that children with LI had longer reaction times in comparison with typically-developing children. This result suggests that sequential learning in children with LI depends on the complexity of the sequence to be learned. In this sense, Tomblin, Mainela-Arnold, and Zhang (2007) also reported slower learning rates in adolescents with LI during a pattern-learning task, in comparison to typically developing adolescents. However, some studies using a serial reaction time task have shown that children with LI were able to learn the sequence as quickly and accurately as typically-developing children (Gabriel, Maillart, Guillaume, Stefaniak & Meulemans, 2010), and that they could exhibit sequential learning even when motor and cognitive demands were controlled (Gabriel, Stefaniak, Maillart, Schimitz & Meulemans, 2012).

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The evidence so far suggests that declarative learning is preserved in children with LI (Lum, & Conti-Ramsden, 2013) and that there is a compensatory role of this system in these children (Ullman & Pullman, 2015). However, it could be that the preserved declarative learning abilities of these children apply specifically to the processing of visual information (Baird, Dworzynski, Slonims, & Simonoff, 2010) and not to verbal information. Lum, Gelgic and Conti-Ramsden (2010) used paired associative learning tasks for verbal and visual information and they found performance differences between the groups on the verbal, but not on the visual task. However, there is evidence to suggest that the problems with declarative learning of verbal information in children with LI might be due to difficulties with verbal working memory (WM). Lum, Ullman and Conti-Ramsden (2015) divided the children with LI into a group with average WM and a group with below average, and examined encoding, recall and recognition of verbal information. They found that the group with below average WM performed significantly worse than the group with average WM. Also, Lum et al (2012) found that the performance of children with LI in declarative learning tasks was similar to that of typically-developing children only for visual information but not for verbal information. These differences between the groups of children disappeared, however, after controlling for working memory. Previously, Lum and Bleses (2011) had reported no significant differences between groups on a declarative learning task, after controlling for verbal working memory.

One of the arguments to support the idea that children with LI use declarative learning in a compensatory way is that these children learn grammar rules by memorizing them. It has been observed that children with LI show an equivalent performance in regular and irregular verbs when frequency effects are controlled for (Ullman, & Gopnik, 1994), as if regular and irregular forms (Gopnik & Goad, 1997) were the same. They can even memorize high frequency phrases and declarative rules, increasing declarative lexicon strategies, especially for complex linguistic representations, compensating for the sequential learning deficit. Paradis and Gopnik (1997) argue that children with LI rely on declarative learning strategies for the acquisition and processing of syntactic information, which suggests a compensatory role of declarative learning (for an explanation of the compensation hypothesis and its main arguments see the recent review by Ullman & Pullman, 2015).

Specific linguistic ability differences have been found among children with LI depending on their native language (Leonard, 2000). English-speaking children with LI have morphosyntactic deficiencies, while Spanish-speaking children with LI do not share this pattern. Instead, Spanish-speaking children show limited use of some grammatical morphemes, for example, significant difficulties with indefinite article production (Bosch & Serra, 1997), as well as agreement errors such as omission and substitution of direct object clitic pronouns (Jacobson & Schwartz, 2002). In fact, it has been suggested that omission and substitution of direct-object clitics is a specific deficit of these children and has diagnostic value (Simon-Cerejido & Gutierrez-Clellen, 2007). These children also show significant difficulties in marking verb tense (Grinstead, Baron, Vega-Mendoza, De la Mora, Cantú-Sánchez, Flores, Oetting & Bedore, 2013), although this is not a very consistent finding (Bedore & Leonard, 2001).

Although these specific linguistic differences among children with LI across languages could be considered as evidence against the declarative/procedural model of language impairment, it can also be argued that all of these deficiencies are related to abilities managed within the PMS. These are syntax-related problems and syntax is learned through procedural memory strategies, so the PMS has been described as deficient in children with LI in several studies of English-speaking children. In brief, children with LI, compared to typically developing children may show deficiencies in the PMS system if they are assessed using tasks where the complexity is controlled. In contrast, differences in the DMS system are not expected between the groups of children when nonverbal stimuli are used.

The current study

A useful procedure to assess procedural learning of sequences is the analysis of performance in artificial grammar-learning (AGL) tasks (Reber, 1989). In a standard AGL task, a finite-state grammar is used to generate stimuli conforming to particular rules that determine the order in which each element of a sequence can occur. First, participants are exposed to the rule-governed stimuli to learn the sequential rule. Second, following exposure, participants' knowledge of the complex sequential structure is evaluated by giving them a test in which they must decide whether a set of novel stimuli follow the previously-learned rule or not. According to Conway and Pisoni (2008), this performance involves automatic learning mechanisms that are used to extract regularities and patterns distributed across a set of exemplars, typically without conscious awareness of the regularities being learned. This kind of sequential learning is believed to be involved in other cognitive domains such as problem solving. For language processing, it has been suggested that there is a specific link between this kind of learning and the acquisition of rule-governed aspects of grammar (Sengottuvel & Rao, 2013).

To assess the encoding, storage and retrieval of information related to DMS, several studies have used list-learning tasks in the verbal and visual domains. In the verbal domain, participants are normally presented with a list of words or word pairs and asked to repeat the items out loud immediately after each presentation and then again after a short and/or long delay. For the visual domain, participants are typically presented with a list of figures and are asked to reproduce the items immediately after each presentation (Lezak, 2004).

In summary, previous studies have reported that English-speaking children with LI show deficits in sequential learning tasks (Lum et al., 2012) and display preserved abilities in declarative learning (Lum & Bleses, 2011; Lum et al., 2010) that help to compensate for these deficits. Given that the vast majority of studies in LI are carried out with English-speaking or Danish-speaking populations, it is essential to explore whether this pattern holds true for other languages- in this case for Spanish-speaking children. Furthermore, findings from this line of research could have important implications for assessment and intervention in children with these developmental impairments (Gutierrez-Clellen, Restrepo, Simon-Cerejido, 2006; Swisher, Restrepo, Plante & Lowell, 1995). In the current study, using the -two-memory system model, we examined the performance of Spanish-speaking children with LI and typically-developing (TD) children during sequential and declarative learning tasks and analyzed the relationship between the performance of the children in these tasks and their abilities in syntax and semantics.

We hypothesized that if the declarative/procedural model assumes a particular pattern of deficiencies related to the two memory systems, this has to be applicable regardless of the language spoken by the individual and so the pattern of deficits in Spanish-speaking children with LI should be very similar to that reported for English-speaking or Danish-speaking children. Furthermore, according to this model, children with LI will display significant positive correlations between performance on declarative learning tasks and abilities in syntax, given the predicted compensatory role of the former. In contrast, TD children will show significant positive correlations between performance on sequential learning tasks and abilities in syntax and between performance on declarative learning and abilities in semantics.

Method

Participants

A total of 35 children (ages 5-9), 15 with Language Impairment (LI) and 20 -age-matched typically developing (TD) children as controls participated in the study. All children were assessed by an audiologist and all had normal hearing thresholds. The main features of each group are shown in Table 1.

PLEASE Insert Table 1 here

All children with LI were recruited from the Child Neurology and Neuropsychology services of the National Institute for Rehabilitation of Mexico (Instituto Nacional de Rehabilitación; INR), the Phoniatrics and Audiology Service of General Hospital of Mexico (Hospital General de México) and the University Clinic of the School of Higher Studies Iztacala at the National Autonomous University of Mexico. The children with LI performed below the 16th percentile on at least two modules of the Battery for Language Assessment (Screening Objective and Criterial Language Battery; BLOC-S; Puyuelo, Renom, Solanas & Wiig, 2002). They had a nonverbal IQ score over 85 in Test of Nonverbal Intelligence (TONI-2; Brown, Sherbenou, & Johnsen, 1995). Also, all children with LI had been classified as such in their schools and were receiving speech and language support. The typically-developing children obtained linguistic scores above the 85th percentile of BLOC-S and a nonverbal IQ score over 85. The BLOC-S has been used in a sample of Chilean children (Castillo, Sierra, Inostroza, Campos, Gómez & Mora, 2007) and in other studies for the diagnosis and treatment of children with LI (Puyuelo, Salavera & Wiigc, 2013).

The BLOC-S battery has 118 items and is divided into four main modules that explore different areas of linguistic knowledge (morphology, syntax, semantics and pragmatics). BLOC-

S is a test to determine whether there may be language problems or not within any of the four modules that it evaluates. The information obtained is related to each module globally, making an estimate of the level of the child on each of the modules, but especially if there is evidence of language problems. As this test allows for an overall benchmark score for each of the four language components to indicate whether there may be deficits in any of these and therefore whether to proceed with further exploration, it significantly reduces application time compared to other tests. Scores from this test can be interpreted as diagnostic criteria.

All the children came from monolingual Spanish-speaking homes. At the beginning of the first testing session, after an appropriate explanation, informed consent was obtained from all participants according to the Helsinki Declaration guidelines. Parents or legal guardians also provided written consent. The Ethics Committee of the Mexican National Institute for Rehabilitation, and the Iztacala School of Higher Studies at the National Autonomous University of Mexico approved the protocol.

Instruments

Declarative learning. This ability was assessed using three subtests from the Child Neuropsychological Assessment Battery (Exploración Neuropsicológica Infantil; ENI; Matute, Rosselli, Ardila, & Ostrosky-Solis, 2007). The ENI battery was designed to assess the neuropsychological development of Latin-American Spanish-speaking children aged between 5 and 16 years. Verbal declarative learning abilities were assessed with the Word List Learning (WLL) subtest and the Story Learning (SL) subtest, as is shown in Table 2. In the WLL, children must repeat all the words after they listen to a list presented four times in a row. In the SL subtest, children must verbally repeat a story that consists of 15 narrative units. Visual declarative learning abilities were assessed with the Figure List Learning (FLL) subtest, which involves showing nine figures to the child, who must then draw them on a sheet of paper. The list is presented four times in a row.

Please Insert Table 2 here

Sequential learning task. Implicit-sequential learning ability was assessed using an Artificial Grammar Learning (AGL) task version for children (López-Ramón, 2006; López-Ramón, Introzzi, & Richards 2009). In this task, instead of a two-phase procedure as in the original version, there is a third phase between the learning phase and the evaluation phase. This middle phase is used to test that children understand what they are supposed to do. Generally, participants display adequate knowledge of the sequential structure despite having very little explicit awareness of what the underlying sequential rules are. We used a version where there are no linguistic processing demands involved, as specific visual stimuli (animal figures) were used (Plante, Gomez & Gerken, 2002). This version uses eight grammatical sequences with four, five or six figures during the acquisition phase (each one repeated twice) and 16 grammatical and 16 ungrammatical sequences with four, five, six, seven or eight figures during the evaluation phase. Ungrammatical sequences were built by inserting a figure into a grammatical sequence that did not follow the sequential rules. This insertion was at the beginning position of a sequence or at the final position. Figures of animals were employed (i.e., lion, fish, dolphin, parrot and elephant) for the sequences instead of abstract symbols or letters. For presentation of sequences during the three phases, a total of sixty-one slides were made, one sequence per slide. These were shown to children on a 14-inch computer screen.

A model of the system and the figures we used in the present study is shown in Figure 1. At the beginning of the task, children were asked to name each animal on the cards to ensure that they were familiar with all the animal figures.

PLEASE Insert Figure 1 here

In the acquisition phase, eight sequences were presented to the child for memorization. Each trial was composed of three parts. In the first part, children were asked to memorize a grammatical sequence presented as a slide on a 14-inch computer screen. The maximum presentation time for each sequence was 15 seconds. After each presentation of a sequence, the second part of the trial was the presentation of a blank slide for 90 seconds. During this time, the child was asked to reproduce the sequence using cardboard squares (8 squares of 10 x 10 cm) of animal figures (those shown in Figure 1) placing them in the same order as the sequence presented. After the blank slide, the third part of the trial was the presentation of the previously-memorized sequence again, so children could compare the sequence they had made with the cardboard squares and the sequence presented for memorization on the computer screen. If there was a 100 % match, the next trial began. Each trial had a maximum of three attempts for playback. The main goal of the acquisition phase is that children memorize the grammatical sequential rule.

The transitional phase which is included in this task version between the acquisition and the assessment phase is to ensure that the children understand the task. In this phase, children were instructed to identify a grammatical sequence as a “related sequence” and an ungrammatical sequence as a “different sequence”, based on the memorized sequential rules during the acquisition phase. For this, a grammatical and an ungrammatical sequence were displayed for a maximum time of 90 seconds. The main goal of the transitional phase is to make sure that children fully understand the procedure of the judgment task in the next phase.

In the evaluation phase, 16 sequences that followed the sequential rules (grammatical) and 16 sequences that did not follow the sequential rules (ungrammatical) were randomly presented. These slides had a maximum presentation time of 10 seconds on a 14-inch computer screen. Grammatical sequences followed the sequential rules implicitly memorized during the acquisition phase. On each trial the examiner asked: "Is this sequence related to the ones you previously memorized?" Children were supposed to answer "Yes" to grammatical sequences and "No" to the ungrammatical ones. All sequences were presented in a randomized order.

Syntax (SYN) This ability was assessed using the raw scores from the syntax module of the BLOC-S battery. In each practice trial the child is shown a picture which is described by the examiner using a specific linguistic structure. In the probe trials, the child has to say something about the picture using the same structure the examiner used. This module consists in 45 items, divided into ten syntactic categories: simple sentences (subject, verb and object: SVO [Adverbial phrase of place]), simple sentences SVO (Direct Object and Indirect Object), passive voice sentences, coordinated subject and coordinated object, coordinated verb and coordinated adjective, comparative sentences, subordinate sentences (cause and consequence), temporal subordinates (after / before), temporal subordinates (when / to) and adversative subordinates. Examples of each syntactic category are shown in table 2. Each syntactic category has 3 or 4 trials and each category begins with some practice trials. For example, in the SVO (AdvP) block, the practice trial has a picture of a cat sleeping on a table. So the examiner says to the child "Look at this picture, the cat is sleeping on the table, now you tell me -where is the cat sleeping? …" and the child must answer "the cat is sleeping on the table". The next picture, which is the item to be scored, shows a cat sitting under the table. Now the examiner only says "tell me what is going on here? …" and the child must answer "the cat is sitting under the table". If the child answers with an incorrect grammatical structure or an item are missing, this is not considered valid, but it is possible to accept other sentences that keep the same structure and are related to the question. Each trial is scored with zero or one depending on performance (zero = fail; there is no sentence uttered or there is no correspondence between picture and the sentence uttered in terms of syntactic structure; and one = correct).

Semantics (SEM). This ability was assessed using the semantics module of the BLOC-S battery and its raw scores were taken into consideration for analysis (total score from 5 categories). This module has a total of 30 items divided into five semantic categories that are: dative, locative, modifiers, quantifiers and time modifiers. Each semantic category has 4, 5 or 7 trials and each category begins with a practice trial. For example, in the locative category, the practice trial has a picture of a cat walking inside a house. So, the examiner says to the child "Look at this picture, there is a cat named Mino, and Mino walks around the whole house, where is Mino? **Mino is on the bookcase,** now you tell me about this picture…" and the child must answer "Mino is on the bookcase". The next picture, which is the item to be scored, has a cat sleeping in a basket, in this case the examiner only says "now, tell me where the cat is…" and the child must answer "the cat is in the basket…". Each trial can be scored with a zero or a one depending on performance (zero = fail, that is, there is no sentence produced; or there is no syntactic correspondence between picture and sentence produced by the child and one= correct). Raw scores from each syntactic category and each semantic category performed by both groups were transformed into a single score by obtaining a total and then computing the percentage of correct responses.

Procedure

All tests were administered to all children (LI and TD) in two 30-minute sessions, during a period not exceeding three weeks. In the first session, syntactic and declarative learning tasks were administered first, then semantic and sequential learning tasks in the second session. The neuropsychological assessment of the TD group was carried out in a small classroom of a Mexican kindergarten. The evaluation of the children with LI group was carried out in a small classroom of FES-I. All the children sat at a table opposite the examiner for behavioral tests and for the sequential learning task all children sat 30 cm away from the computer screen.

Statistical Analysis

In order to approximate our data to a normal distribution, percentages of correct responses from each subtest were transformed using ARCSIN [SQRT (percentage/100)]. A series of analyses of variance (ANOVAs) was performed on these transformed data for the comparisons between children with LI and the control group across all task performances. The Huynh-Feldt correction was applied when there were two or more degrees of freedom in the numerator.

In order to determine the relationship between measures of the children's abilities in syntax and performance in the AGL task, as well as measures of the children's abilities in semantics and performance in the subtests of declarative learning (WLL, SL and FLL), Pearson correlation analyses were performed with data of all subjects (both groups).To look at the specific pattern of relationships depending on the presence or absence of language impairment, we performed Pearson correlation analyses separately by group (i.e., LI and TD groups) These analyses were carried out using data from the AGL task (sequential learning) and data from the WLL, SL and FLL subtests (declarative learning) and the raw scores obtained from SYN and SEM.

Results

A two-way ANOVA was performed in order to analyze the differences between groups regarding the declarative learning task. Group was included as a between-subjects factor and the

Declarative learning task (WLL, SL and FL subtests) was included as a within-subject effect. There were no significant differences between the groups (Main effect of Group $F(1, 33) = 3.3$, $p = .08$ $\eta^2_p = .09$), nor a significant Group by Declarative learning interaction ($F(2, 66) = 1.6$, $p = .22$, $\varepsilon = 1$ $\eta^2_p = .045$; see figure 2a).

PLEASE Insert Figure 2 here

For comparison between groups regarding the sequential learning task, a one-way ANOVA was performed; this analysis revealed strongly significant differences between groups ($F(1, 33) = 15.1$ $p < .001$ $\eta^2 = .314$), where children with LI had a lower percentage of correct responses than the control group (figure 2b).

There was a significant positive correlation between SYN and sequential learning (rho = .55, p = .001), as well as a significant positive correlation between SEM and SL (rho = .57, p < .001) and marginal correlations between SEM and WLL (rho = .32, p = .065) and SEM and (rho = .30, p = .076). Furthermore, significant correlations among the subtests of declarative learning were observed (see table 3 for full correlation values). It should be noted that there were significant correlations between the SEM and AGL tasks (rho = 0.45, p = 0.007) and between SEM and SYN (rho = 0.77, p < .001).

PLEASE Insert Table 3

For the children with LI there was no significant correlation (see table 4 for full correlation values) between SYN and sequential learning (rho = -.08, p = .77), but there was a significant correlation between SEM and SL (rho = .75, p = .001), whereas for TD children there was a significant correlation between SYN and SL (rho = .63, p = .003) but there was no significant correlation between SEM and any of the declarative learning Subtests. For children with LI there were significant correlations among the declarative learning subtests. That is, there was a significant correlation between WLL and FLL (rho = .56, p = .031), WLL and SL (rho = .67, p = .007), and between FLL and SL (rho = 52, p = .047).

PLEASE Insert Table 4

Discussion

In the current study, we examined and compared the performance of Spanish-speaking children with LI and TD children during sequential and declarative learning tasks. Correlation analysis was performed to analyze in each group of children the relationship between their performance during declarative and sequential learning and their abilities in syntax and semantics. According to the declarative/procedural model and previous evidence from studies on English-speaking children with LI, we expected to observe lower scores for Spanish-speaking children with LI than for TD children in the sequential learning task. Our results support this prediction. Similar results were observed in a recent study that used a sequence-learning task (Gabriel et al. 2013), where English-speaking children with LI had longer reaction times and no sign of sequence-specific learning in comparison with TD children. However, it has been argued that performance in sequential learning tasks depends on the complexity of the stimuli (Mayor-dubois, Zesiger, Van der Linden & Roulet-Perez, 2013). For example, one study where an artificial grammar learning task was used (Plante, Gomez & Gerken, 2002) showed that adults with LI exhibited a sequential learning deficit compared to TD adults. Given that linguistic stimuli were included in this study, it is difficult to dissociate the linguistic deficit from a sequential learning problem (Evans et al., 2009). Considering that in the current study the task does not contain linguistic stimuli, nor has more complexity, we can assume that sequential learning skills are effectively impaired in Spanish-speaking children with LI, which is congruent with previous studies (Lum et al., 2011).

We also expected to find no significant differences in declarative learning subtests in LI children compared to TD children. Our hypothesis was that Spanish-speaking children with LI, as is the case of English-speaking children, would compensate for the PMS deficit mainly by

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using the DMS. Although our results support this hypothesis since there were no significant differences between groups in terms of declarative learning, it is important to note that the effect size in the case of the comparison between groups (main effect of Group) in declarative- learning (WLL, SL and FLL) was large enough to believe that an increase in the size of the samples would not make a significant difference. In addition, although the effect size in the Group by Declarative learning (WLL, SL and FLL) interaction was smaller than the main effect of Group, it is likely that the difference between groups was mainly due to SL (contrast between Groups in SL $F(1,33) = 5.1$, $p = .03$, $\eta^2 = .13$). So, we found that children with LI showed normal performance in declarative learning tasks with visual but not verbal information. Preserved declarative learning could therefore be specific for visual information in children with LI (Baird, Dworzynski, Slonims, Simonoff, 2010). Lum, Gelgic, & Conti-Ramsden (2010) used paired associative learning tasks for verbal and visual information and they found differences in performance between the groups on the verbal, but not the visual task. Other evidence suggests that the problems with declarative learning of verbal information in children with LI might be due to a verbal WM failure and difficulties in language processing (Lum, & Conti-Ramsden 2013). Lum et al (2015) examined encoding, recall and recognition of verbal information and did not find performance differences between TD children and children with LI who had average WM. Also, Lum et al. (2011) found that the performance of children with LI in declarative learning tasks using verbal information showed no differences between groups only after controlling for WM and language processing. Although in the current study we did not assess WM, given the evidence from other studies that have reported a WM deficit in children with LI (Archibald & Gathercole, 2006; Baddeley, 2003; Montgomery & Evans, 2009), it is probable that verbal WM deficiencies in Spanish-speaking children have an important effect on their performance in declarative learning of verbal information.

It has been argued that improving declarative lexicon strategies can compensate for the sequential learning deficit, especially for complex linguistic representations. For example, Paradis and Gopnik (1997) argue that children with LI rely on declarative learning strategies for the acquisition and processing of syntactic information, which suggests a compensatory role of declarative learning. If Spanish-speaking children with LI use declarative learning mechanisms to learn the syntactic rules involved in language processing, then we would expect to find in these children that declarative learning significantly correlates with abilities in syntax, given its predicted compensatory role. Meanwhile, the performance of TD children in syntax is expected to correlate with sequential learning and their performance in semantics with declarative learning.

In the present study, the significant correlations between the children's abilities in syntax and their scores in the AGL task, as well as between the children's abilities in semantics and their scores in declarative learning indicate that the tasks we used to measure these processes were effective. However, if correlation analyses are carried out separately by group, then variance importantly decreases and the pattern expected, with the syntax abilities of children with LI correlating with declarative learning is not observed. Our results also show that abilities in syntax did not correlate with performance in sequential learning for TD children. Nevertheless, it should be noted that there was an important, though marginal, correlation (with a large effect size) in Spanish-speaking children with LI, between their performance in WLL and their scores in the AGL task, which implies an important relationship between how the children declaratively learn words and how they perform during artificial grammar tasks. This finding can partially support our hypothesis of compensation in the Spanish-speaking children with LI.

Another interesting result that could support the idea that Spanish-speaking children with LI use different strategies to solve their language problems compared to TD children (showing a pattern of a deficient PMS compensated by DMS) was the significant positive correlation in the group of children with LI between their abilities in semantics and their performance on declarative learning (SL subtest), and the significant correlation in the TD children between their performance on the same declarative learning story-learning task and their abilities in syntax. What these findings could indicate is that in Spanish-speaking children with LI the ability to remember a story is related to semantic knowledge, while in TD children this ability is related to syntactic knowledge. The differential role of syntactic and semantic knowledge in memory tasks has been previously suggested (Van Daal, Verhoeven, Van Leeuwe, & Van Balkom, 2008).

In summary, our findings are consistent with the declarative/procedural model. Spanish-speaking children with LI showed a particular style in learning and processing language. These children displayed a sequential learning deficit even in a non-verbal domain but their performance in declarative learning appears to be preserved both in the visual and verbal domain.

Future research should focus on two main areas: First, on analyzing the relationships between specific syntactic structures and sequential learning in Spanish-speaking children with LI and second, on clarifying what specific compensatory mechanisms are implemented by these children. It is also important to replicate our findings with a larger sample. Obtaining sufficient sample sizes is an important limitation, but considering the paucity of evidence about Spanish-

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speaking children with LI, this kind of research is essential to build a more complete and detailed knowledge-base about this disorder.

Conclusion

In conclusion, Spanish-speaking children with LI, as is the case with English-speaking children, displayed lower scores than typically-developing children in a sequential learning task and no differences in declarative learning, indicating a pattern that supports the declarative/procedural model hypothesis. The marginally lower scores registered in declarative learning of verbal information fit with findings from previous studies. Furthermore, the relationship between performance on sequential and declarative learning and linguistic performance is different between children with LI and typically-developing children, which suggests that Spanish-speaking children with LI process syntactic information based on declarative learning strategies.

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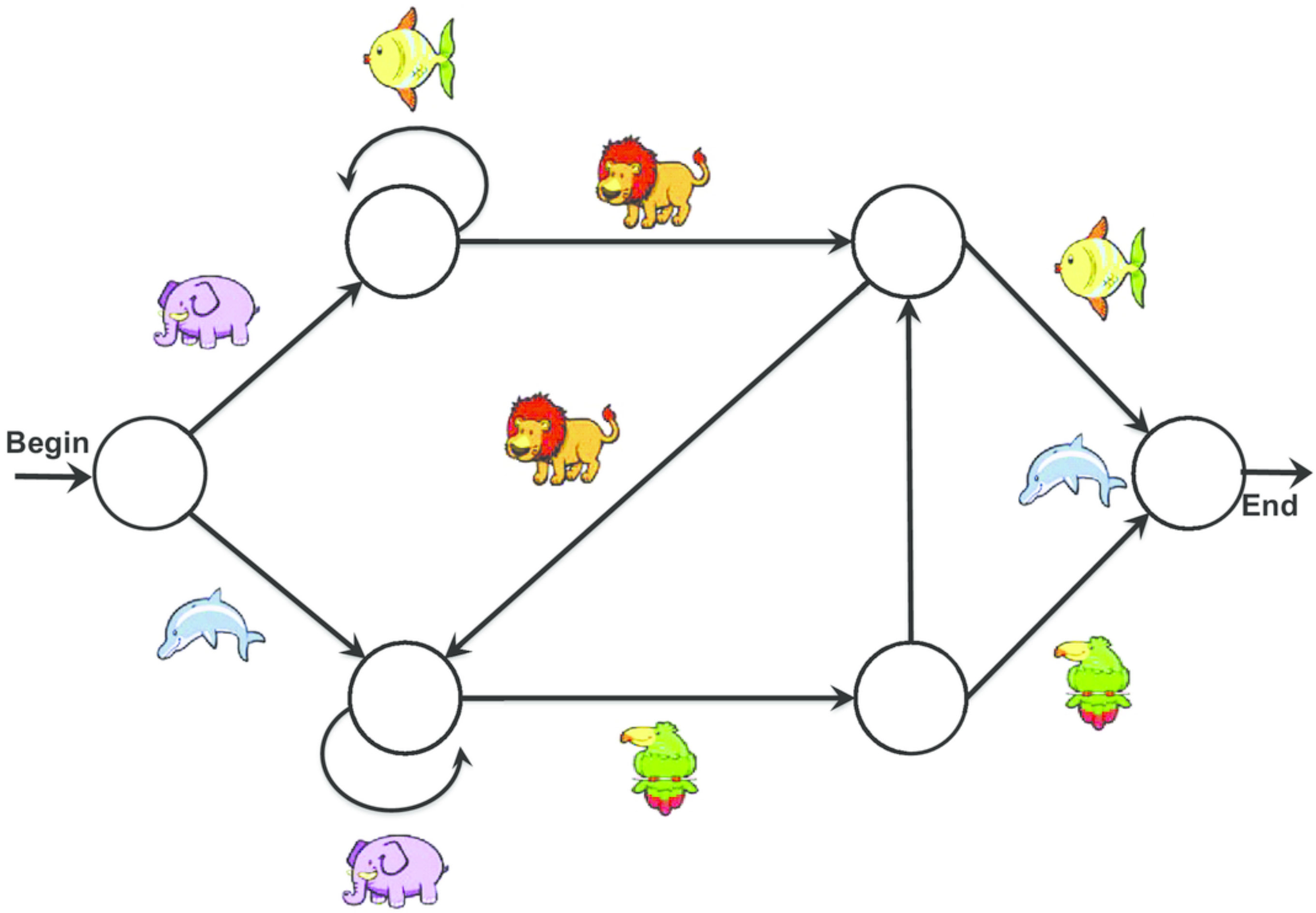
1

Finite state grammar

Shows a finite state grammar used to generate sequences of stimuli that participants are exposed to in sequential learning experiments (from Reber, 1989). Stimuli used show a similar structure, using animal figures instead of letters (modified from López-Ramón, Introzzi, Richards, 2009). Strings are made by starting at IN and then following a path of arrows until OUT is reached. For each arrow traversed the indicated figure is added to the animal figure string. Participants can acquire grammars of this sort and identify valid versus invalid sequences without being explicitly aware of any specific aspects of the grammar.



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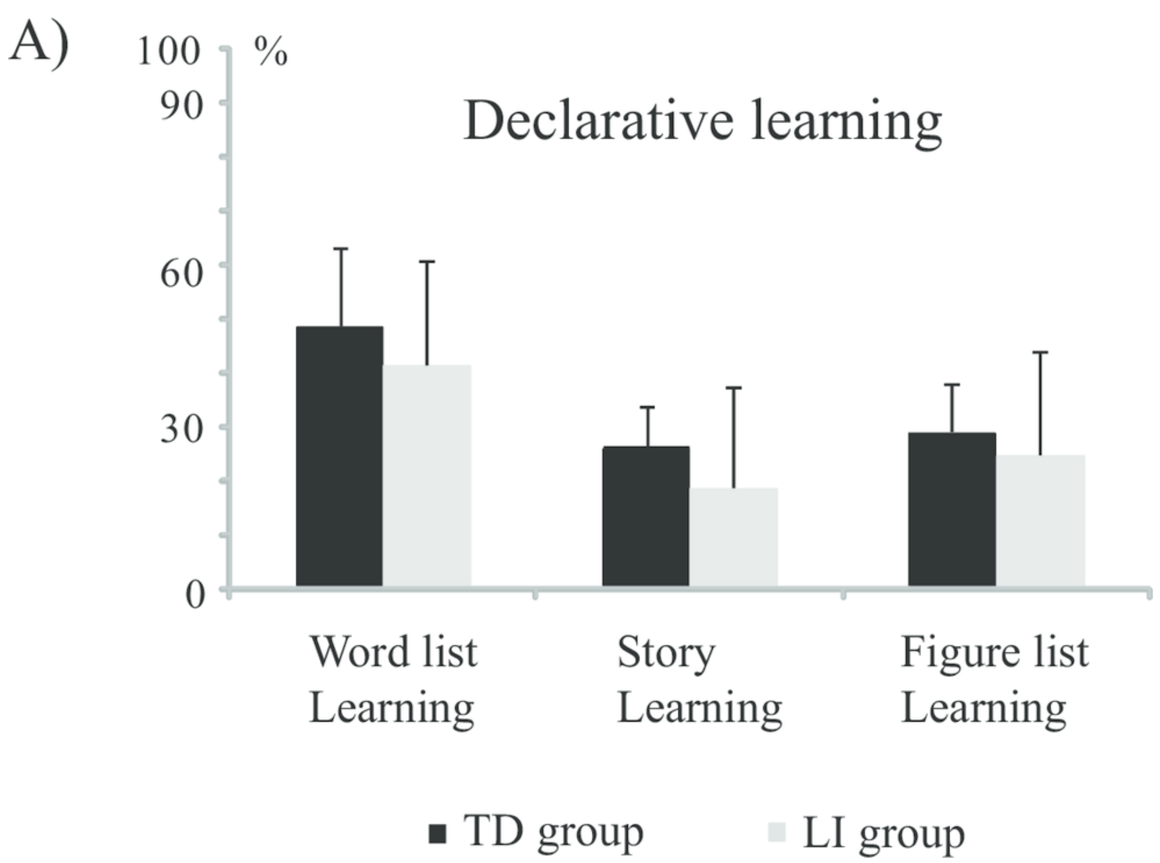
2

Percentage of performance scores

Percentage of performance scores in Declarative and Sequential learning tasks. A) Shows no differences between groups in Word List Learning, Story Learning and Figure List Learning. B) Children with LI clearly showed lower percentage of correct responses than TD children in the AGL task * $p < 0.001$



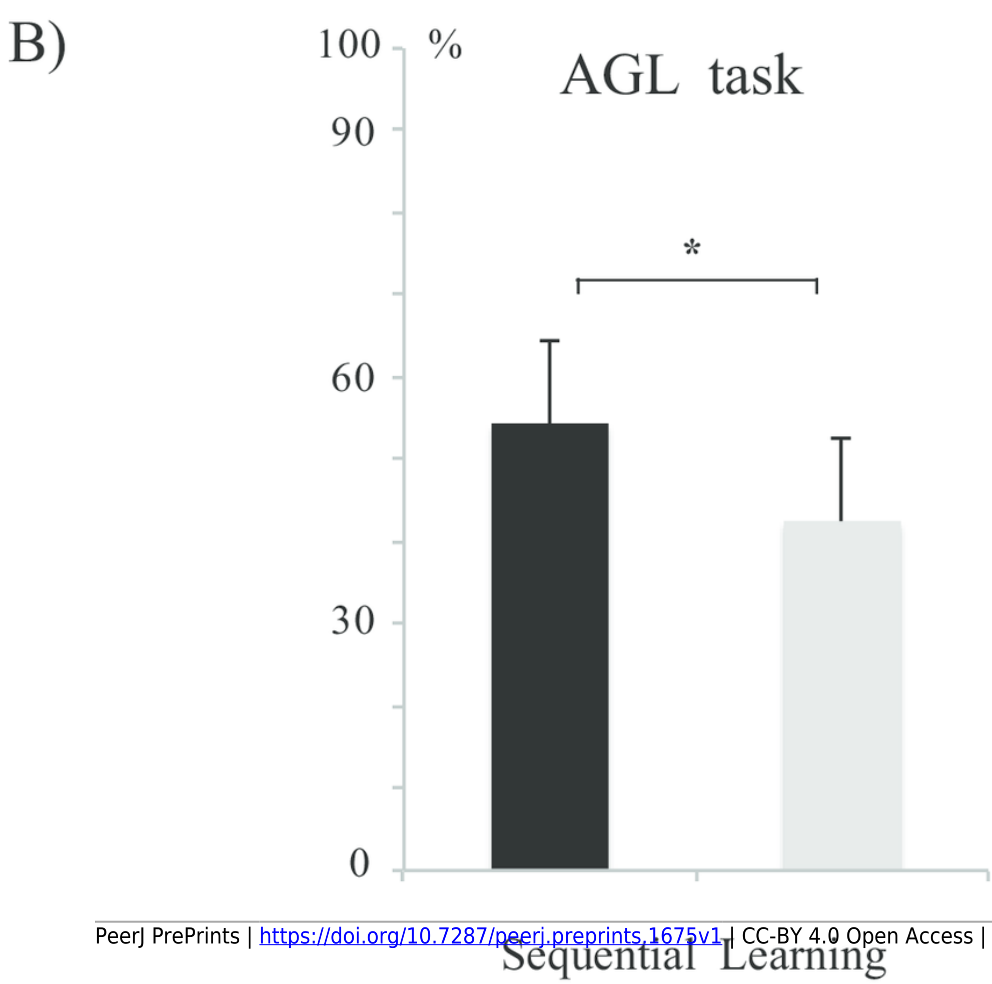


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Table 1 (on next page)

Main characteristics of each group of children

	LI Group n=15			TD Group n=20		
	Mean	SD	Range	Mean	SD	Range
AGE	6.1	1	5-8	6	1.4	5-9
TONI-2	118	14.4	99-138	104.6	13.1	87-128
BLOC-S	26.1	1	6-52	98.1	9.6	83-107

Table 2 (on next page)

Tasks / Subtests used in the study

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Learning	Task/Subtest	Semantic/Syntactic categories	Demonstration items / examples
	Figure List Learning subtest (FLL)		
Declarative Learning	Story learning subtest (SL)		
	Word List Learning subtest (WLL)		
Sequential Learning	Artificial Grammar Learning (AGL) task		
Syntax	Percentage of correct responses	SVO (Adverbial object of place)	El gato está durmiendo encima de la mesa (The cat is sleeping on the table)
		SVO (Direct object and indirect object)	La chica da un plátano al chico (The girl gives a banana to the boy)
		Passive voice sentences	La niña es seguida por el gato (The girl is followed by the cat)
		Coordinated subject and coordinated object	El chico y el chica comen (The boy and the girl eat). Las chicas llevan paquetes y cartas (The girls carry packages and letters)
		Coordinated verb and coordinated adjective	Esta señora dobla y plancha la ropa (This lady folds and irons the clothes). El perro es pequeño y blanco (The dog is small and white)
		Comparative sentences	… más sucias que éstas (… dirtier than those)
		Subordinate sentences (cause and consequence)	La niña se puso las botas porque nevaba (The girl put her boots on because it was snowing). Si sale el sol, los niños irán a nadar a la piscina (If the sun comes out, the children will go to swim in the pool)
		Temporal subordinates (before / after)	Después de lavarse las manos, la niña se come un bocadillo (After washing her hands, the girl eats a

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			sándwich). El niño lava la manzana antes de comérsela (The boy washes the apple before he eats it)
		Temporal subordinates (when / until)	Los niños podrán comer un trozo de pastel cuando se haya enfriado (The children can eat a piece of cake when it has cooled). Los niños no podrán nadar hasta que hayan limpiado la piscina (The children cannot swim until they have cleaned the pool)
		Adversative subordinates	La niña quería un pez, pero se ha comprado una tortuga (The girl wanted a fish, but she has bought a turtle). Aunque el niño quería un perrito, le han regalado un gatito (Although the boy wanted a puppy, he has been given a kitten.)
		(SYN)	Total percentage of correct responses
Semantics	Percentage of correct responses	Dative	… a su profesora (to his/her teacher)
		Locative	… encima del librero (on the bookcase)
		Modifiers	El pájaro grande (the big bird)
		Quantifiers	Poco / unas cuantas monedas (some/a few coins)…)
		Time modifiers	El primero … (the first)
		(SEM)	Total percentage of correct responses

Table 3 (on next page)

Correlation scores rho (p-level) between AGL, WLL, SL, FLL, SYN and SEM in all children

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Measure	AGL	WLL	SL	FLL	SYN	SEM
AGL	-	.271 (.116)	.244 (.157)	.291 (.090)	.550 (.001)	.449 (.007)
WLL		-	.344 (.043)	.539 (.001)	.219 (.206)	.315 (.065)
SL			-	.429 (.010)	.321 (.060)	.566 (<.001)
FLL				-	.151 (.386)	.303 (.076)
SYN					-	.765 (<.001)
SEM						-

Note: AGL = Sequential learning, WLL= Word list learning, SL = Story learning, FLL = Figure list learning, SYN = Syntax, SEM = Semantics.

Table 4(on next page)

Correlation scores rho (p-level) between AGL, WLL, SL, FLL, SYN and SEM in children with LI and TD children

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Measure	AGL	WLL	SL	FLL	SYN	SEM
AGL	-	-.012 (.959)	.315 (.176)	.163 (.492)	.138 (.563)	-.008 (.972)
WLL	.461 (.084)	-	.077 (.747)	.492 (.027)	.105 (.660)	.100 (.676)
SL	.018 (.949)	.591 (.020)	-	.259 (.271)	.625 (.003)	.142 (.550)
FLL	.383 (.159)	.596 (.019)	.593 (.020)	-	.167 (.482)	.251 (.287)
SYN	-.082 (.771)	-.236 (.396)	.041 (.884)	-176 (.530)	-	.165 (.488)
SEM	.094 (.738)	.384 (.157)	.747 (.001)	.386 (.155)	.436 (.104)	-

Note: Correlations for TD children are presented above the diagonal and correlations for children with LI are presented below the diagonal. AGL = Sequential learning, WLL= Word list learning, SL = Story learning, FLL = Figure list learning, SYN = Syntax, SEM = Semantics.

2

3

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