UNIVERSITAT DE BARCELONA

Statistical Word-Learning in Catalan-Spanish Children with Specific Language Impairment

Nadia Ahufinger Sanclemente

Doctoral thesis

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El futur dels infants sempre és avui,
demà serà tard.

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Table of contents

List of tables

List of figures

List of abbreviations

- ASL: Auditory statistical learning
- CSSL: Cross-situational statistical learning
- DLD: Developmental language disorder
- DSM: Diagnostic and Statistical Manual of Mental Disorders
- GCA: Growth curve analysis
- ICD: International Classification of Diseases
- IL: Implicit learning
- IQ: Intellectual quotient
- LD: Language disorder
- PDH: Procedural deficit hypothesis
- SCD: Social communication disorder
- VSM: Verbal semantic memory
- SES: Socioeconomic status
- SL: Statistical learning
- SLI: Specific language impairment
- SRT: Serial reaction time
- SSD: Speech sound disorder
- TD: Typical development
- TEL: Trastorno específico del lenguaje
- TP: Transitional probability
- VDM: Verbal declarative memory
- VSL: Visual statistical learning
- WM: Working memory

Abstract

This dissertation was written to answer some questions about the different roles played by memory in school-age Catalan-Spanish children with specific language impairment (SLI). Currently, a small but growing body of work suggests that individuals with SLI have difficulty performing tasks that require non-declarative learning. That is, they present with difficulties in the process of extracting abstract knowledge from statistical patterns, probabilistic computations (statistical learning) and procedural skills (procedural learning) embedded in the input. The Procedural Deficit Hypothesis—PDH—(Ullman & Pierpont, 2005) suggests that grammatical impairments observed in SLI may be explained by abnormalities in brain areas associated with procedural memory—a gradual, sequential implicit learning, necessary for acquiring cognitive and motor skills, such as typing and bike riding. The PDH also purports that children with SLI have relative strengths in word learning since their lexical declarative memory systems have remained largely spared. However, the literature shows that children with SLI show difficulties in vocabulary learning in addition to grammatical deficits. First, in this dissertation we wanted to study whether children with SLI have a more general impairment in their non-declarative memory mechanism that is not limited to procedural learning. Second, we wanted to investigate whether statistical learning is also a required mechanism for the word-learning process rather than just declarative memory alone. Third, we examined the role of working and declarative memory in children with and without SLI with regard to lexical knowledge. To carry out our study, a total of 76 children (24 girls, 52 boys), 38 children with SLI (*Mean age*=8.7 years-old; SD=1.10 years) ranging in age from 5.6 to 12.11 years, and 38 typically developing children (*Mean age*=8.9 years; SD=1.10 years) ranging in age from 5.7 to 12.9 years were tested with three types of statistical word-learning tasks involved in a word-learning process (i.e.,

auditory sequential statistical learning, cross-situational statistical learning, and visual statistical learning tasks) and were given different working and declarative memory tests.

The results showed that Catalan-Spanish children with SLI were less accurate at solving the three statistical learning tasks than the group of TD children. Moreover, statistical learning and declarative memory were significant predictors of the vocabulary knowledge in children with and without SLI. Thus, non-declarative learning was shown to be a required mechanism for acquiring vocabulary as well as grammar. Furthermore, children with SLI showed poorer results in the auditory and visual working memory tasks compared to the group of TD children. Equivalent results for declarative memory tests for both groups were found only after controlling for the working memory.

The results of this dissertation encourage current theoretical models of non-declarative learning in children with SLI to be extended beyond the assumption that only procedural sequential learning is impaired in this population, suggesting that a more general non-declarative learning, including non-sequential statistical learning, is affected in children with SLI and that this deficit is related to grammar learning as well as vocabulary acquisition. Finally, the implications of these results on language learning in children with SLI are discussed.

Resum

Aquesta tesi doctoral va néixer per tal de respondre algunes preguntes sobre els rols que tenen les diferents memòries en nens i nenes bilingües català-castellà de Catalunya amb trastorn específic del llenguatge (TEL). Durant els últims anys diferents estudis han suggerit que els infants amb TEL tenen dificultats per resoldre tasques que requereixen de la memòria implícita o no-declarativa. És a dir, presenten dificultats en el procés d'extracció d'informació abstracta que es troba en el nostre entorn a partir de patrons estadístics, càlculs probabilístics (aprenentatge estadístic) o habilitats procedimentals. La hipòtesi del dèficit procedimental (en anglès: *procedural deficit hypothesis o PDH*) (Ullman i Pierpont, 2005) proposa que les dificultats que presenten els infants amb TEL en l'àrea de la morfologia i la gramàtica es poden explicar per anomalies en àrees cerebrals associades a la memòria procedimental. Aquesta memòria sustenta l'aprenentatge implícit seqüencial i gradual que és necessari per adquirir habilitats cognitives i motores, com ara escriure o anar en bicicleta. La PDH també proposa que els infants amb TEL tenen menys dificultats amb l'aprenentatge de vocabulari perquè tenen la memòria declarativa o explícita relativament preservada. Contràriament, però, la literatura mostra que, a més dels dèficits gramaticals, els nens i nenes amb TEL tenen dificultats per aprendre paraules noves. Els objectius d'aquesta tesi doctoral són demostrar si els infants bilingües català-castellà amb TEL presenten la memòria procedimental afectada i si, més enllà d'aquest tipus de memòria no-declarativa també tenen altres mecanismes d'aprenentatge implícit afectat. En segon lloc, hem investigat si l'aprenentatge implícit també té un rol explicatiu en l'aprenentatge de vocabulari a més a més de la memòria declarativa necessària per al procés d'aprenentatge de paraules. En tercer lloc, vam examinar el paper que té la memòria de treball i la memòria declarativa en els infants amb TEL en relació al coneixement del lèxic. Per a

fer-ho, un total de 76 infants en edat escolar (24 nenes, 52 nens) van participar en aquest projecte. El grup amb TEL estava format per 38 nens i nenes (mitjana d'edat= 8,7 anys; DE = 1,10 anys; rang= 5,6 a 12,11). El grup control estava format per 38 nens i nenes amb desenvolupament típic (DT) (mitjana edat=8,9 anys; DE=110 anys, rang=5,7 a 12,9). A tots els participants se'ls va presentar tres tasques que avaluaven l'aprenentatge implícit de paraules: (1) tasca auditiva i seqüencial de segmentació de paraules, (1) tasca visual seqüencial i (3) tasca audio-visual d'aprenentatge de paraules noves no seqüencial -*mapping*-). A més a més, a tots els participants se'ls va avaluar amb diferents bateries de memòria de treball i memòria declarativa.

Els resultats van mostrar que els nens i nenes bilingües català-castellà amb TEL van obtenir un rendiment significativament més baix que el grup control en les tres tasques d'aprenentatge implícit de paraules (seqüencials i no seqüencials). A més, tant l'aprenentatge implícit com la memòria declarativa van ser dos predictors significatius del coneixement del vocabulari dels participants amb TEL i amb DT. Aquests resultats demostren que l'aprenentatge implícit també és un mecanisme necessari per adquirir vocabulari i no només per aprendre morfologia i gramàtica. A més, els nens amb TEL van mostrar resultats més baixos en les tasques de memòria de treball auditives i visuals en comparació amb el grup de nens i nenes amb DT. També es van trobar resultats equivalents en les proves que avaluaven la memòria declarativa per a ambdós grups demostrant que els infants amb TEL podrien tenir la memòria declarativa preservada tal i com apunta la PDH. S'ha de tenir en compte, però, que aquests resultats només es van trobar després de controlar la memòria de treball.

Els resultats d'aquesta investigació suggereixen que els models teòrics actuals que es basen en l'afectació de la memòria procedimental en els infants amb TEL han d'anar més enllà de la hipòtesi que explica que només hi ha un aprenentatge procedimental seqüencial afectat en aquesta població. Aquests resultats també proposen que l'aprenentatge implícit de regularitats no seqüencials també podria estar afectat en els nens i nenes amb TEL i que aquest dèficit podria estar relacionat amb l'aprenentatge de morfologia i gramàtica però també amb l'adquisició de vocabulari. Finalment es discuteixen les implicacions dels resultats obtinguts.

THEORICAL BACKWROUND

1. Introduction

1.1 What is specific language impairment?

Many children around the world have language acquisition difficulties. Although their mastery of language skills is delayed, these children show no other sensorial or developmental impairments that explain their difficulties with language. They are diagnosed with specific language impairment (SLI).

SLI affects about 7% of the general population. This means that approximately two children in every classroom are as able and healthy as their classmates but have significant difficulty talking and understanding language. Leonard (1998, 2014. p. preface) defined children with SLI as "a group of children whose deficits in spoken language ability could not be attributed to neurological damage, hearing impairment, or intellectual disability." Bishop (1992, p. 3), in turn, refers to SLI as a "failure of normal language development that cannot be explained in terms of mental or physical handicap, hearing loss, emotional disorder, or environmental deprivation." SLI can therefore be defined as a neurodevelopmental language disorder that cannot be explained by intellectual disability or other conditions, such as hearing loss, sensory impairment, vocal-motor dysfunction, environmental weakness, emotional impact, or medical or neurological conditions, such as autism Down's or William's syndrome.

1.1.1 Diagnostic criteria

Many diagnostic criteria for SLI have been proposed over the years. The most widely used criteria nowadays are the exclusionary criteria proposed by Stark and Tallal (1981), which are based on the sum of scores for the following areas of functioning: (1) language impairment (a score suggesting language impairment on a test with satisfactory diagnostic accuracy and supportive evidence from independent judgment and clinical reasoning), (2) average non-verbal intelligence quotient (IQ), (3) hearing sensitivity (in screening tests using conventional levels), (4) no recent evidence of repeated episodes of otitis media with effusion and normal oral structure and function, (5) no structural oral anomalies and adequate oral motor function tested by screening, and (6) normal interaction with people and objects (Leonard, 2014).

Although a minimum non-verbal IQ of 85 has been proposed for the diagnosis of SLI, recent evidence confirms that many children with significant language disorders do not have a high enough IQ for this disorder to be diagnosed, resulting in obvious difficulties at the level of service provision. Use thus of non-verbal IQ as an exclusion criterion could prevent access to specialist clinical services (Norbury et al., 2016). Considering that IQ can vary according to the measurement instruments used and that its use could exclude cases of borderline intelligence, Aguado, Coloma, Martínez, Mendoza, and Montes (2015) proposed establishing the minimum non-verbal IQ at 75 for the Spanish population.

1.1.2 Nomenclature

The international scientific community has shown growing interest in understanding how children without specific medical factors known to cause language disorders develop SLI. Numerous terms have been used to refer to this disorder, including *dysphasia* and *developmental dysphasia* (Ingram, 1960), *deviant language* (Leonard, 1972), *delayed language* (Weiner, 1974), *developmental language impairment* (Wolfus, Moscovitch, & Kinsbourne, 1980), *specific language deficit* (Stark & Tallal, 1981), and *language impairment* (Justice, Skibbe, McGinty, Piasta, & Petrill, 2011).

The term *specific language impairment* emerged from the proposals of different authors (Bishop, 1997; Leonard, 1998; Rice, Wexler, & Cleave, 1995) and the recommendations of the American Speech-Language-Hearing Association (ASHA). It has been the most widely used term in the last 30 years, particularly in the research literature, to refer to children with significant language limitations but insufficient evidence of a justifiable cause.

Debate surrounding the use of SLI as a diagnostic label has increased in recent years (see Bishop, 2014), in particular since the term *language disorder* was used in the fifth edition of the *Diagnostic and Statistical Manual of Mental Disorders* (DSM-5) (American Psychiatric Association, 2013). In the DSM-5, language disorder was distinguished from social (pragmatic) communication disorder and speech sound disorder and characterized as "persistent difficulties in the acquisition and use of language across modalities due to deficits in comprehension or production that include reduced vocabulary, limited sentence structure, and impairments in discourse (…)."

The word *specific* is the controversial part of the label, as it seems to describe children whose only weaknesses are language-related. A large part of the literature, however, has demonstrated that the vast majority of, if not all, children with SLI have difficulties with other attentional and cognitive processes. The decision not to use the term *SLI* in the DSM-5 triggered wide discussion among researchers and clinicians, especially in England, about the proper terminology to use to refer to these children. Researchers and other professionals working in education, medicine, and allied fields engaged in heated debates aimed at improving the diagnostic criteria for SLI and identifying an appropriate label. The proposed label, *developmental language disorder*, is now quite widely accepted in England and other English-speaking countries (Bishop, Snowling, Thompson, & Greenhalgh, 2016; Reilly, Bishop, & Tomblin, 2014). The latest edition of the *International Classification of Diseases* (11th ed.), published in 2018, used the term *developmental language disorder* to describe what had previously been known as SLI.

Although the terminology debate is still latent in the clinical community, SLI is still widely used, especially in the research literature. This debate has not yet taken off in Spain, where the most widely used term is *trastorno específico del lenguaje,* which is a direct translation of SLI. In a consensus document published in 2015 by an expert SLI committee in Spain (Aguado et al., 2015), it was considered that the term *SLI* should be maintained for the following reasons: a) greater general acceptance, b) a higher number of entries as a bibliographic search term, and c) an apparently better definition of the affected population. The experts did, however, mention that the term *specific* should be changed at some point.

Because this dissertation was written in Catalonia, I have decided to use the term *SLI* with the particularity that *specific* means idiopathic (of unknown origin) rather than implying that the disorder involves no problems other than language (Bishop, 2014).

1.1.3 Classification and subgroups

Different classification systems exist for SLI, reflecting the considerable heterogeneity in the language symptoms described (Ajuriaguerra et al., 1965; Aram & Nation, 1975; Wilson & Risucci, 1986). The most widely used and cited system is that of Rapin and Allen (1983, 1987), who used a clinical approach to divide the criteria into four language components: (1) phonetics and phonology, (2) morphology and syntax, (3) lexical-semantics, and (4) pragmatics. Children with language difficulties were commonly divided into six subgroups: (1) lexical-syntactic deficit syndrome, (2) verbal dyspraxia, (3) verbal auditory agnosia, (4) phonologic programming deficit syndrome, (5) phonological syntactic deficit syndrome, and (6) semantic-pragmatic deficit syndrome. Four of these subtypes are no longer used. In Spain, the most widely used classification system is the one proposed by the expert committee (Aguado et al., 2015), which, based on the definition of language disorder in the DSM-5, removed four of the six subtypes originally proposed by Rapin and Allen. The new definition covered just two subtypes:

1. Phonological-syntactic deficit:
    - Use of short sentences with grammar errors (e.g., omission of functional words and grammatical inflections).
    - Deficient speech articulation. Frequent word-finding problems.
    - Variable comprehension (e.g., difficulty understanding complex utterances and abstract language).
2. Lexical-syntactic deficit:
    - Word-finding difficulties and problems putting thoughts into words.
    - Lexical, morphological, and word-evocation difficulties.
    - Immature syntax.
    - Normal production of speech sounds.
    - Poor understanding of complex sentences.

The ICD-11 developmental language disorder classification system consists of four subgroups: (1) impairment of receptive and expressive language, (2) impairment of mainly expressive language, (3) impairment of mainly pragmatic language, and (4) impairment of another specific aspect of language. The problem with this system is that there is considerable heterogeneity within and between children with SLI. Although numerous attempts have been made to identify subtypes of SLI, it is not easy to identify meaningful and/or permanent subtypes (e.g., Law, Tomblin, & Zhang, 2008; Leonard, 2009; Tomblin & Zhang, 2006).

1.2 Language difficulties in children with SLI

Because most of the research on SLI has been performed in English-speaking children, there is more knowledge about the grammar and lexical difficulties experienced in this population than in populations who speak other languages.

1.2.1 Morphosyntactic problems in children with SLI

The most salient and widely researched features of SLI in English-speaking children are limitations with the use of morphosyntax. Many studies have investigated the structural relationships and order between language elements (syntax) and the closed-class morphemes of the language (grammatical morphology).

It is well known that children with SLI have difficulties producing complex sentences, such as dependent clauses, in which they omit complement clause finiteness markers (e.g., “should”), complementizers (e.g., “to”) (Owen & Leonard, 2006), obligatory relativizers in relative clauses (e.g., “that” and “who”) (Schuele & Nicholls, 2000), and pronouns (Schuele & Dykes, 2005). They also have difficulty producing passive sentences (Bishop, 1979; van der Lely, 1996) and using wh-object and wh-subject questions (van der Lely & Battell, 2003).

These difficulties are salient in both language production and syntactic comprehension. Children with SLI have difficulties understanding clauses such as dative sentences (e.g., You showed a watch to him) (van der Lely & Margaret Harris, 1990); passive sentences (e.g., The man is bitten by the dog) (Montgomery & Evans, 2009); relative clauses (e.g., The children that are running are in the park) (Robertson & Joanisse, 2010); and wh-questions (e.g., Who was the happy little girl washing?) (Deevy & Leonard, 2004).

In grammatical morphology they have particular difficulty with tense/agreement morphemes, such as pronouns, modal auxiliaries, pluralization, and complementizers, while in verb morphology they use a lot of non-inflected verbs (Fletcher & Peters, 1984) and omit the past tense ending -ed and the 3rd person singular -s inflection (Rice & Oetting, 1993).

1.2.2 Word-learning difficulties in children with SLI

Children with SLI also have difficulties with lexical and semantic features of language. They typically require more exposure and find it more difficult to learn new lexical labels compared with typically developing (TD) peers (Alt & Plante, 2006; Gray, 2004; Rice, Oetting, Marquis, Bode, & Pae, 1994). They also have lower vocabulary test scores (Gray, Plante, Vance, & Henrichsen, 1999) and reduced receptive word learning in naturalistic contexts (Rice et al., 1994).

Lexical difficulties in children with SLI may affect the acquisition, storage, and retrieval of new words. In comparison to TD peers, they use a much higher frequency of verbs and nouns than expected and are slower to acquire functional words (Eyer & Leonard, 1995; Leonard, 1995). Moreover, they do not fast map non-verbal semantic features associated with lexical labels as well as their peers (Alt, Plante, & Creusere, 2004; Rice et al., 1994), present weaker semantic representations of words (Kail, Hale, Leonard, & Nippold, 1984; McGregor, Newman, Reilly, & Capone, 2002), have smaller vocabularies than expected for their age (Rice, Buhr, & Nemeth, 1990), and reduced sensitivity to phonological and semantic features of words (Alt & Plante, 2006).

1.3 Catalan and Spanish-speaking children with SLI

1.3.1 Morphosyntactic problems in Catalan and Spanish-speaking children with SLI

The profiles of children with SLI vary according to the language they speak. Catalan and Spanish are closely related languages, with many similarities. As Romance languages, they are rich in morphology and syntax. The most common morphosyntactic errors produced by bilingual Catalan-Spanish-speaking and monolingual Spanish-speaking children are the omission of function words, such as articles (Anderson & Souto, 2005; Restrepo & Gutierrez-Clellen, 2001), prepositions (Auza & Morgan, 2013), and pronouns (Bedore & Leonard, 2001). They omit inflected forms such as plurals and gender (Anderson, 1999) and verb suffixes (Sanz-Torrent, Serrat, Andreu, & Serra, 2008). These errors are an "influence of weak phonological particles on morphology" (Aguilar, Sanz-Torrent, & Serra, 2007, p. 460). They also make mistakes with adjective and verb agreement, often using singulars in a plural context and the third instead of the first person (Bedore & Leonard, 2001), and show poor comprehension of direct object pronoun sentences when answering comprehension questions (Girbau, 2017). Auza, Harmon, and Murata (2018) showed that Spanish-speaking children with SLI produced a significantly higher percentage of ungrammatical sentences than TD children in a retelling task.

1.3.2 Word-learning difficulties in Catalan and Spanish-speaking children with SLI

Most of the research on SLI in Spanish- and bilingual Catalan-Spanish speaking-children has focused on difficulties with morphosyntax and grammar. Few authors have investigated lexical and semantic problems or the mechanisms used to learn and retain new words. The characteristics of lexicon and word-learning difficulties facing Spanish-speaking children with SLI are currently explained through research with English-speaking children.

Despite the lack of specific research, there is broad agreement in the Spanish clinical community that children with SLI are slower to acquire their first words and know fewer and less diverse words than their TD peers (Andreu, Aguado, Cardona, & Sanz-Torrent, 2013). They also use verbs infrequently (Sanz-Torrent, 2002) and have lexical access difficulties, i.e., problems recovering words already learned and evoking one word when thinking about another (Leonard, 1998). They also have word-finding difficulties and problems putting their thoughts into words and making functional or semi-circular definitions or semantic paraphrases when speaking (Serra & Bosch, 1997).

Some of the above difficulties have been tested in experimental studies. In one study that measured language productivity through a retelling task, a group of monolingual Spanish-speaking children with SLI produced a significantly lower number of total and different words than a group of TD children (Auza et al., 2018).

In a spontaneous speech task used to analyze argument structure and verbs in a group of bilingual Catalan-Spanish children with SLI, Sanz-Torrent (2004) found a low presence of verbs in their vocabulary and a high rate of omissions of copular verbs, with little associated morphology. Andreu, Sanz-Torrent, Guàrdia, and MacWhinney (2011), on analyzing speech production in a retelling task, found that Catalan-Spanish children with SLI made more semantic errors and substitutions than their TD peers. In a subsequent study of bilingual Catalan-Spanish children, Andreu, Sanz-Torrent, Legaz, and MacWhinney (2012) found that those with SLI showed significantly lower accuracy in naming nouns and verbs in a picture-naming task than two control groups formed by adults and age-matched TD children. Their total noun and verb error rates were also higher. In a spoken word-recognition task for nouns and verbs applied using an eye-tracking technique by Andreu, Sanz-Torrent, and Guàrdia (2012), a group of Catalan-Spanish children with and without SLI were presented with a set of pictures in which they had to search for a noun or verb they heard. The children with SLI were slower than the control group at recognizing both nouns and verbs, especially in the case of verbs with more arguments.

In a narrative comprehension task, Coloma and Pavez (2017) assessed the vocabulary of 13 school-aged Chilean children with SLI using the *vocabulario sobre dibujos* test from the Spanish version of the Language Survey-Revised. They found that just 18% of the children had lexical difficulties, but in addition to these difficulties, they performed poorly in the areas of comprehension and grammatical complexity.

Galindo and Rojas-Nieto (2017) analyzed 12 hours of conversation between three 6-year-old monolingual Spanish-speaking Mexican children with SLI and three age-matched TD children and found that lexical searches took longer in the first group. These children also needed more time to achieve a lexical target through elaboration. Their results suggest that children with SLI conduct latent searches and abruptly interrupt their discourse to insert the item they were previously unable to find.

Because research specifically focused on the word-learning process in Catalan-Spanish children with SLI is so scarce, one objective of this dissertation was to add to the body of evidence in this area and shed more light on why Catalan-Spanish children with SLI have difficulties with word learning.

1.4 Theoretical approaches

As stated by Dollaghan (2011, p. 1361), “one of the most basic and long-standing questions about SLI is whether children with the disorder have language skills that differ qualitatively and nonarbitrarily from those of other children or whether their language skills simply fall at the lower end of a continuous distribution, below some arbitrary threshold but not otherwise unique.” These two interpretations are based on two conceptual models: the categorical model and the dimensional model.

The dimensional model conceptualizes SLI as being quantitatively rather than qualitatively different from normal. The dimension concept in the context of language is interpreted as a continuum of language skills along which a child might have differing levels of a given characteristic, such as language standardized test scores, number of words learned, or level of language comprehension. In this model, children with SLI would fall at the lower end of this continuum. The dimensional view of SLI assumes the potential for heterogeneity in symptoms, origins, and causal influences (Sackett, Haynes, Guyatt, & Tugwell, 1991). The categorical model, by contrast, conceptualizes SLI as a discrete diagnostic category that occurs naturally. It clearly differentiates between children with SLI and TD children and assumes that observable deficits are caused by internal characteristics that fall into objectively distinct categories. According to the categorical model, children with SLI would fall into a discrete category with a unique phenotype, etiology, base rate, and therapeutic regimen.

Leonard (1987) was the first to suggest that SLI might be a dimensional construct and subsequent research largely assumed a diagnostic criterion that involved cutoff scores that followed a continuous normal distribution. Few studies have directly addressed the question of whether language deficits in children with SLI might be dimensional or categorical. Dollaghan (2004, 2011) used a taxometric approach to search for mathematical relationships between variables that should exist only if there is a taxon (or group) that is different in kind from another group. They examined vocabulary abilities, mean-length utterance, number of different words, and non-word repetition in children aged 4 and 6 years as potential diagnostic indicators of SLI, but found no evidence of a naturally occurring distinct category of SLI at either age. This dimensional view of SLI is supported by some indirect evidence, such as the failure to identify individual genes strongly or specifically associated with SLI (e.g., Bishop, 2009). The evidence from studies investigating the conceptualization of SLI diagnosis to date suggests that SLI is dimensional rather than categorical.

Theoretical studies of the causes of SLI emerged in parallel to theoretical accounts of language development as a whole. The first theories about the causes of SLI focused on linguistic impairments and were driven by the idea that children with SLI may have an intangibly impaired or weakened grammar system (Gopnik & Crago, 1991; Rice & Wexler, 1996). These theories were in line with Chomsky's (1959) view of language innatism, which holds that humans have innate grammatical knowledge that is not acquired through associative learning. Children with language problems were thus diagnosed with a "deficit in linguistic knowledge" (Leonard, 2014), as SLI was seen as a heritable impairment in which syntax and grammar were especially impaired.

Later theoretical accounts attempted to explain the language difficulties in SLI as a consequence of more general non-linguistic deficits related to cognitive processing and processing of information. These deficits have been explained by "the surface account", proposed by Leonard (1989) based on difficulties in phonetical processing and by the deficient auditory temporal processing account proposed by Tallal et al. (1996). Other authors have suggested that the root of the deficits lies in a limited working memory in the form of (a) a limited capacity for storing phonological information (assessed by the non-word repetition task) (Graf Estes, Evans, & Else-Quest, 2007) and (b) restricted mental manipulation or resource allocation aspects of working memory (assessed by the listening span task) (Archibald & Gathercole, 2006; Weismer, Evans, & Hesketh, 1999). Finneran, Francis, and Leonard (2009), in turn, argued that limited attention could be a non-linguistic causal factor in SLI. Other factors proposed to explain the language limitations in children with SLI include slower general (Kail, 1994; Miller, Kail, Leonard, & Tomblin, 2001) and specific (Kohnert & Windsor, 2004) processing speeds.

The above theories attempted to explain the causes underlying the morphosyntactic and grammar difficulties experienced by children with SLI. Theories to explain the causes underlying word-learning problems include the hypothesis that poor vocabulary could be due to poor phonological working memory (Montgomery, 1995). According to this theory, children would be unable to encode a sufficient amount of information in the phonological working memory due to problems with perception (Tallal & Gaab, 2006) or capacity (Alt, 2011), triggering a breakdown in word retrieval. Additional theories include problems accessing information from long-term memory (Ahissar, 2007; Gupta & MacWhinney, 1997) and slower processing speeds (Leonard et al., 2007).

A small but growing body of work suggests that individuals with SLI have difficulty with tasks that requires non-declarative or procedural learning (e.g., Tomblin, Mainela-Arnold, & Zhang, 2007; Lum, Gelgic, & Conti-Ramsden, 2010; Hsu & Bishop, 2014). This line of research has shown that children with SLI have difficulties extracting abstract knowledge from statistical patterns (Evans, Saffran, & Robe-Torres, 2009), impaired procedural skills (Ullman & Pierpont, 2005), and problems exploiting probabilistic sequences embedded in input (Kemény & Lukács, 2009).

One of the aims of this dissertation was to shed more light on the role of non-declarative memory difficulties in SLI and to examine whether Catalan-Spanish children with SLI have difficulties with word-learning tasks that require the extraction of statistical patterns.

2. Memory and specific language impairment

2.1 The memory system

The memory system is used by humans to encode, store, and retain past experiences and call on different kinds of information as required. It is needed to recall events, facts, and processes. James (1890) distinguished between primary memory (a typified memory with capacity limitations) and secondary memory (an unlimited capacity memory store). In 1968, Atkinson and Shiffrin proposed what they called the *multistore model of memory* to explain memory as a structural model. They suggested that the memory has three stores: (1) a sensorial memory store that needs attention in order to transfer the sensory information to the short-term memory store, (2) a short-term memory store that temporarily holds a restricted and easily retainable amount of information, and (3) a long-term memory store with an enormous capacity to hold unlimited temporary (and mostly semantic) visual and auditory information. The most widely used classification today distinguishes between long-term and short-term memory.

2.1.1 Short-term memory and working memory

The working memory model proposed by Baddeley and Hitch (1974) and subsequently developed by Baddeley and colleagues (Baddeley, 1996, 2000; Baddeley & Logie, 1999) is one of the most accurate explanations of working memory in the literature and is the model used in this dissertation. It holds that the immediate memory is a multicomponent system that involves both a memory process and a complex cognition process (Baddeley, 2000).

Baddeley (1992, p. 556) described the working memory as a "brain system that provides temporary storage and manipulation of the information necessary for such complex cognitive tasks as language comprehension, learning, and reasoning." Following this description, short-term and working memory were theoretically considered to be two distinct memory processes, with the former offering a limited capacity for brief retention of information and the latter requiring simultaneous storage and processing. Short-term memory is frequently viewed as a subcomponent of working memory. While related, however, they have to be differentiated (Baddeley, 1986; Engle, Kane, & Tuholski, 1999), as short-term memory involves retention while working memory involves retention and manipulation.

Baddeley's working memory model has four subcomponents:

1. The central executive. This is the attention-controlling system. It allocates data to two other subcomponents, the phonological loop and the visuospatial sketchpad, and deals with cognitive tasks such as problem-solving and mental calculation.
2. The visuospatial sketch pad (or visuospatial short-term memory). This is the subcomponent that manipulates visual images or spatial forms and operates based on the location and speed of objects in space.
3. The phonological loop (or verbal short-term memory). This is the subcomponent that stores and rehearses speech-based information. It consists of two processes: (1) "the phonological store" for speech perception that holds information in a speech-based form and (2) "the articulatory control process" for speech production that is required to prepare and store verbal information from the phonological store.
4. The episodic buffer. The episodic buffer was proposed by Baddeley (2000) as an additional component of working memory that integrated two other subcomponents: the visuospatial sketchpad and the phonological loop. Baddeley argued that the episodic buffer "comprises a limited capacity system that provides temporary storage of information held in multimodal code,

which is capable of binding information from the subsidiary systems, and from long-term memory, into a unitary episodic representation."

2.1.1.1 Short-term and working memory deficits in SLI

2.1.1.1.1 Verbal short-term memory in SLI (phonological loop)

Verbal short-term memory deficits presented by children and adolescents with SLI have been widely tested using the non-word repetition task (Gathercole, Willis, Baddeley, & Emslie, 1994). Several studies have demonstrated that poor performance in this task is a robust clinical marker of SLI with high heritability (Aguado, 2011; Bishop, North, & Donlan, 1996; Conti-Ramsden, 2003; Dollaghan & Campbell, 1998; Lalioti, Stavrakaki, Manouilidou, & Talli, 2016; Girbau, 2016). Children with SLI have clear difficulties repeating multisyllabic non-words compared with TD children (e.g., Dollaghan & Campbell, 1998; Gathercole, 2006a, 2006b; Gathercole & Baddeley, 1990; Marton & Schwartz, 2003).

The non-word repetition task has been used in many languages, including English (e.g., Botting & Conti-Ramsden, 2001; Estes et al., 2007; Ellis Weismer et al., 2000; Gathercole & Baddeley, 1990a; Jackson, Leitao, & Claessen, 2016; Marton & Schwartz, 2003; Montgomery, 2004), Spanish (e.g., Aguado, Cuetos-Vega, Domezáin, & Pascual, 2006; Aguado, 2011; Girbau & Schwartz, 2007; Girbau, 2016; Villalobos & Jackson-Maldonado, 2017), French (e.g., Le Foll, Godin, Jacques, & Taillant, 1995), Italian (e.g., Bortolini, Arfe, Caselli, Degasperi, Deevy, & Leonard, 2006), Portuguese (e.g., de Vasconcellos Hage, Nicolielo, & Guerreiro, 2014), and Swedish (e.g., Bathelom & Åkesson, 1995; Sahlén, Reuterskiöld-Wagner, Nettelbladt, & Radeborg, 1999).

Other conventional tests have been used to detect difficulties with verbal short-term memory, and children with SLI have been found to have difficulties with tasks involving the recovery of series of digits and words (Hick, Botting, & Conti-Ramsden, 2005; Lum, Conti-Ramsden, Page, & Ullman, 2012). Examples of these tests include the digits forward and digits backward span assessment subtests (Wechsler, 2003), the digit recall subtest, and the word list matching and recall subtests (Pickering & Gathercole, 2001).

2.1.1.1.2 Visual short-term and working memory in SLI

Inconsistent findings have been reported for visuospatial working memory in children with SLI, with some authors showing deficits in the visual domain, and others finding no significant differences in comparison to TD children.

Archibald and Gathercole (2006), on testing a group of school-aged children with SLI using a comprehensive battery of short-term and working memory tests, found that a considerable minority had visuospatial short-term memory deficits. In a study by Weismer et al. (2017), three groups of children (TD children, children with SLI and autism spectrum disorder) were given a visual working memory task called N-back in which they were presented with a sequence of stimuli and asked to indicate when a given stimulus matched one from *n* steps earlier in the sequence. The results showed equivalent non-verbal working memory abilities in all three groups.

In a meta-analysis published in 2013, Vugs, Hendriks, Cuperus, and Verhoeven (2013) compared data from children with and without SLI to determine whether visuospatial storage and the visuospatial central executive might be relevant components for the diagnosis of SLI. The results showed significant effect sizes for both components, indicating the presence of visuospatial working memory deficits in SLI. Bavin, Wilson, Maruff, and Sleeman (2005) compared performance in six visuospatial tasks between children with SLI and age-matched TD children. The tasks ranged in difficulty from simple recall to a search-based working memory task. The children in the SLI group showed significantly less accuracy than the controls in recalling patterns but not locations.

They also showed a shorter spatial span and were significantly less able to link a given pattern to a given location. Marton (2008), in turn, found that children with SLI performed significantly worse in all three visuospatial working memory tasks tested: space visualization, position in space, and design copying abilities.

2.1.1.1.3 Verbal working memory in SLI

A substantial number of studies have shown that children with SLI show deficits in more complex verbal tasks that require simultaneous storage and processing of information. Weismer et al. (1999) tested deficits in verbal working memory by administering a listening span task in which school-aged participants were asked to mentally reorder items before evoking them. They found that children with SLI had significantly poorer word recall than age-matched TD children. The competing language processing task, developed by Gaulin and Campbell (1994), was used by Weismer, Evans, and Hesketh (1999) to compare verbal working memory between children with SLI and TD peers. This task is a judgment/recall task in which children are asked to judge the truth of a series of sentences and recall the last words of each sentence in a group. The authors found that the children with SLI were significantly less accurate when it came to recalling words but performed similarly to their peers in the true or false judgment comprehension task. The results of numerous other studies (Lum, Conti-Ramsden, Page, & Ullman, 2012; Lum, Conti-Ramsden, & Ullman, 2013) have shown that children with SLI perform significantly worse than their TD peers in all the subtests of the Verbal Working Memory Test Battery for Children (WMTB-C, Pickering & Gathercole, 2001), specifically the central executive composite score, which is made up of scores from the listening recall, digits backward, and counting recall subtests.

2.1.2 Long-term memory

The findings of many brain studies undertaken in TD population, individuals with brain injuries or amnesia, and animals throughout history indicate that there are essentially two distinct long term-memory processes: a "kind of memory that is accessible to conscious recollection (declarative memory or explicit memory) and another kind that is not (implicit memory)" (Squire, 2004, p. 171). This dichotomous distinction led researchers to shift their focus to multiple memory systems. As stated by Squire (2009, p. 173), "declarative memory refers to one memory system and non-declarative memory is an umbrella term referring to several additional memory systems" (see Figure 1). Declarative memory is the term used to explain the ability to consciously recover facts and events. It is subdivided into (1) semantic memory, which is used to store facts about the world and helps to accumulate general world knowledge, and (2) episodic memory, which is related to the capacity to collect events and past personal experiences in the context (time and place) in which they originally occurred.

Non-declarative memory has been described as the memory used to gradually extract common elements from a series of separate events and to perform procedural abilities (e.g., skills and habits). It involves different mechanisms associated with distinct areas of the brain such as priming and perceptual learning, simple classical conditioning in relation to emotional and skeletal responses, and non-associative learning (Squire & Zola, 1966) (see Figure 1).

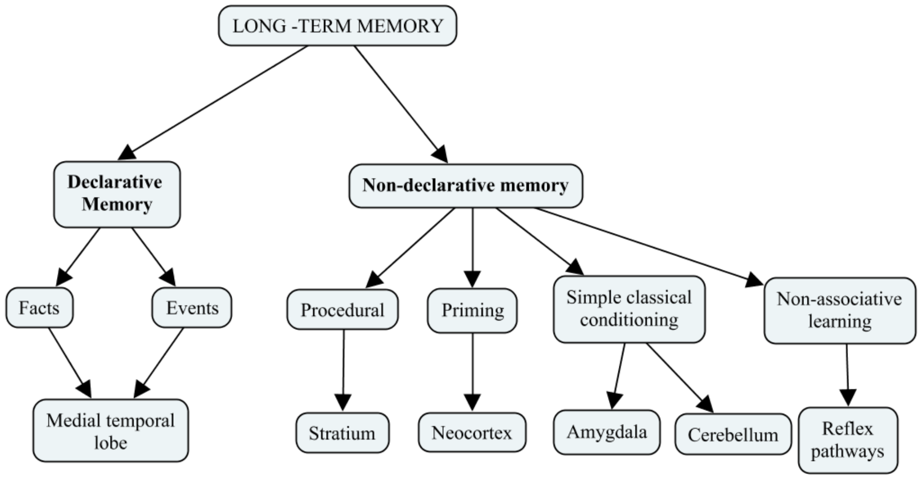

Figure 1. A taxonomy of long-term memory systems together with the specific brain structures involved in each system (adapted from Squire & Zola, 1966).

2.1.2.1 Implicit learning and statistical learning

The term *implicit learning* was used for the first time by Reber (1967) to refer to linguistic, perceptive, motoric, and social vital human abilities that are learned without intention, i.e., that are acquired through the adaptation and extraction of regularities in input received. One of the first studies to explain language learning from this new perspective was that of Servan-Schreiber and Anderson (1990), who built a precise theory known as *competitive chunking*. Their aim was to demonstrate that "grammatical knowledge is implicitly encoded in a hierarchical network of chunks" (p. 592). In their study, adult participants were trained in an exemplar sentence and induced to form specific chunks. Their knowledge was then assessed through judgments of grammatical and non-grammatical strings. They found that participants were less sensitive to violations that preserved their chunks than to those that did not and they also demonstrated that patterns were learned by extracting abstract rules. They referred to this process as *the rule learning of grammar mechanism*.

The concept of statistical learning emerged from the work of Saffran, Aslin, and Newport (1996), who demonstrated that infants were able to extract words embedded in a continuous stream of spoken artificial language. They proposed the term *statistical learning* to refer to this process in which learners acquire information about distributions of elements within input. They demonstrated that after just 2 minutes of exposure, 8-month-old infants could successfully complete a fundamental language acquisition task, namely the segmentation of words from fluent speech based exclusively on the statistical relationships between neighboring speech sounds. Saffran et al. (1996) suggested they can do this by exploiting transitional probabilities (TP), which are statistical cues that language learners compute to extract words from spoken language. These probabilities are more apparent and greater within a word than across word boundaries.

Perruchet and Pacton (2006) investigated differences in implicit learning and statistical learning research. They argued that both approaches were very close but had different interpretations, with the former focusing on construction chunks and the latter focusing on statistical and transitional computations. The two approaches are sometimes said to be equivalent, but the theories underlying their study differ somewhat. Perruchet and Pacton showed that studies of both implicit and statistical learning investigated mechanisms used by humans to learn automatically, incidentally, spontaneously, and by simple observation, unaware of the implicit structure of the material. The difference lay in the interpretations of data.

Twenty years ago, implicit learning researchers started to turn their attention to syntax acquisition through the rule learning of grammar mechanism, while those interested in statistical learning focused on lexicon formation where rules are considered to be irrelevant. The difference between the competitive chunking and statistical computation approaches is that the first assumes that humans code information by memorizing chunks or fragments of linguistic input, while the second assumes that humans have the ability to extract and compute conditional probabilities between successive or contiguous elements.

The literature on statistical learning in language acquisition has grown exponentially since Saffran et al. (1996) first published their findings. Researchers today no longer apply the limited assumption that language is segmented into a continuous stream of word-like units but take the broader view that other more complex language structures and modalities are involved (see Appendix A for the statistical learning research map). They also consider that certain word-learning processes occur through an unconscious mechanism that is not strictly serial or sequential (Smith & Yu, 2007). The implicit learning concept, in turn, has become almost synonymous with non-declarative learning. These terms are umbrella concepts that embrace different processes that humans use to learn, in an automatic, incidental, or spontaneous fashion, hidden structures in different domains such as language, audition, vision, and music.

2.1.2.2 The declarative/procedural model

Ullman (2001, 2004) proposed that language learning depended on two mental capacities: a memorized mental lexicon and a computational mental grammar. This dual model was called the *declarative/procedural model*. The main evidence supporting this model is that "aspects of the lexicon/grammar distinction are tied to the distinction between two well-studied brain memory systems—declarative and procedural memory—that have been implicated in non-language functions in humans and other animals" (Ullman 2001, p. 718).

The hippocampus is the region of the medial temporal lobe that supports declarative memory. It is principally connected to the temporal and temporoparietal neocortical regions (see Figure 2). It is the only long-term memory system underlying the explicit knowledge where lexicon (sounds and meanings) and static and visual mental images (semantic memory and episodic memory) are stored.

The procedural memory system is involved in implicit learning, control, and memorization of new stable motor and cognitive skills. It is "particularly important for acquiring and performing skills involving sequences—whether the sequences are serial or abstract, or sensori-motor or cognitive" (Ullman & Pierpont, 2005, p. 401). The procedural system stores dynamic and spatial mental images and forms the basis of grammar rules (morphology, syntax, and phonology). It is supported in the frontal cortex (Broca's area), the basal ganglia, the parietal cortex, and the dentate nucleus of the cerebellum (see Figure 2).

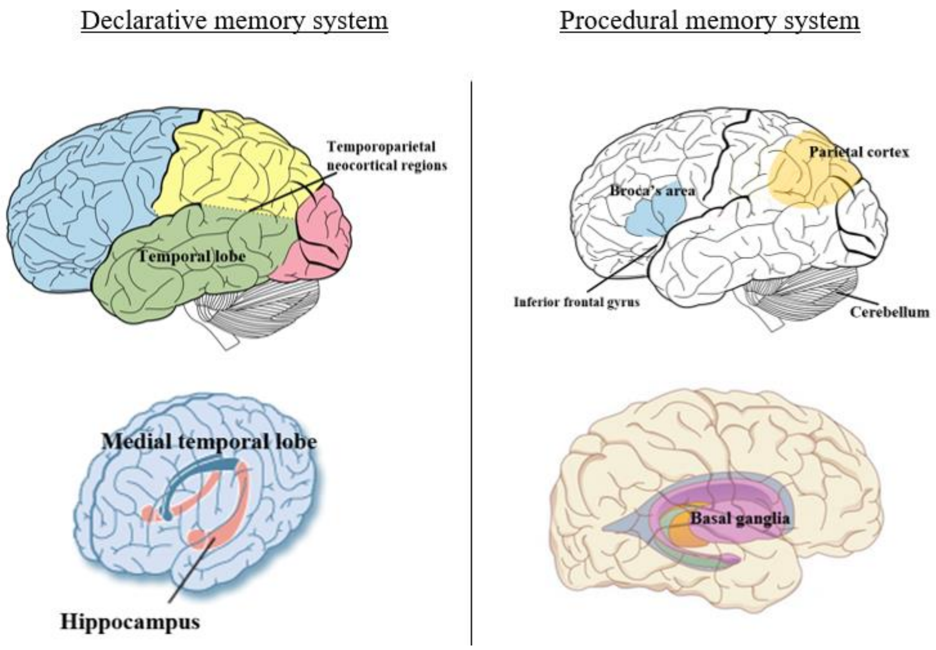

Figure 2. Brain regions that support the declarative memory system (left) and the procedural memory system (right). Source: own elaboration.

2.1.2.2.1 The procedural deficit hypothesis

Ullman and Pierpont (2005) built on Ullman's declarative/procedural model (2001) to propose a new approach to language difficulties in children with SLI. In 2005, these authors published a special issue that paved the way for new research in the area of language impairment. They claimed that SLI could not be explained by innatism theories that argue a deficit in the "grammar box in the brain" or by non-linguistic processing theories, and presented an alternative perspective based on brain structures that they called the *procedural deficit hypothesis or PDH*. They argued that if SLI is at all specific, it is specific to the procedural memory system and not to language.

According to the procedural deficit hypothesis, there are abnormalities in the brain structures underlying the procedural system in children with SLI. These abnormalities are described as a "dysfunction of different portions of structures—especially of those structures that constitute the frontal/basal ganglia circuitry" (Ullman & Pierpont, 2005, p. 406) (see Figure 2). Because the procedural system is the basis of grammar rule learning, children with SLI would have significant difficulties with this part of language learning and accordingly have more difficulties with grammar than with other aspects of language. They claimed that "children with SLI may be characterized as having procedural language disorder or PLD", p. 405). The heterogeneous levels of severity and dysfunction across this population could be explained by the heterogeneous involvement of the brain channels that make up the procedural system. The deficits associated with this hypothesis include problems with grammar, rapid naming, working memory, dynamic mental imagery, auditory temporal processing, motor coordination, and lexical retrieval.

According to the procedural deficit hypothesis, one might expect lexical retrieval to be unaffected in SLI because lexicon is supported by the declarative memory. The literature shows, however, that children with SLI have enormous difficulties with this part of the expressive lexical process, as indicated earlier. Ullman and Pierpont justify these difficulties by stating that lexical retrieval also depends on the brain structures underlying the procedural system—the inferior frontal gyrus (see Figure 2)—which can affect specific aspects of learning and word use.

Others lexical tasks such as lexical comprehension/recognition and lexical semantic organization are sustained by the declarative memory. According to the procedural deficit hypothesis, these abilities are not affected, or at least, are less affected, in SLI. As seen in the introduction of this dissertation, however, most children with SLI have impaired lexical ability.

Ullman and Pullman (2015) argued that declarative memory is largely spared in children with SLI and that it plays a compensatory role by retaining numerous types of information, functions, and tasks that would typically be performed by the procedural system. This compensatory role hypothesis assumes that the procedural and declarative systems must interact and are therefore not totally independent.

2.1.2.2.1.1 Research in children with SLI and the procedural deficit hypothesis

Research focusing on implicit, statistical, and procedural learning and language acquisition in SLI emerged at the beginning of the 21st century. The first work in the field following Ullman and Pierpont's publication in 2005 was produced by Tomblin et al. (2007), who investigated whether deficits in procedural learning were related to language abilities and, in particular, grammar difficulties in adolescents with SLI. Using a serial reaction time (SRT) task, they assessed implicit visuospatial sequence learning in children with SLI and TD children and found the first evidence to support the procedural deficit theory.

As explained by Robertson (2007, p. 10073), in the classic SRT task:

> a visual cue can appear at any one of four positions arranged horizontally on a computer screen. Each screen position, designated 1–4, corresponds to a button on a response pad. When a cue appears, at the start of each trial, a participant selects the appropriate response button, which ends the trial. The duration of each trial, defined by the participant's response time, is the primary task measure. At the end of each trial, there is a short-fixed delay, often between 200 and 500 ms, before another cue is presented. The visual cues play out a repeating sequence of positions (for example, 2-3-1-4-3-2-4-1-3-4-2-1). These sequential trials are then followed by random trials in which the visual cue no longer plays out a repeating pattern of positions.

By testing children with SLI using the SRT task, Tomblin et al. were able to assess procedural learning without having to test language ability, providing thus the opportunity to prove that SLI was not language-specific. Considering the large body of evidence on the role played by other kinds of tasks involved in the learning of regularities in sequential patterns in language learning, children with SLI would be expected to perform less well in procedural learning tasks. Tomblin et al. therefore predicted that children with SLI would not show a typical response profile, defined by a decrease in response times across the trials during the pattern phase and an increase in response times during the random phase. In their 2007 study, they showed that adolescents with SLI were able to learn the regularities of the sequence presented in the SRT task but that they learned more slowly than TD children during the pattern phase. In the SLI group, the slowest learning rates were observed in adolescents with the greatest grammar difficulties. By contrast, those with the greatest vocabulary difficulties showed similar learning rates to their TD peers. These results suggested, for the first time in the SLI literature, that procedural learning deficits were associated with both language and grammar learning difficulties.

The SRT task has since been used in many studies to assess procedural memory in children with SLI (e.g., Conti-Ramsden, Ullman, & Lum, 2015; Gabriel et al., 2011; 2012; 2013, 2015; Hsu & Bishop, 2014; Lum et al., 2010; Hedenius et al., 2011; Lum & Bleses 2012; Mayor-Dubois et al., 2012; Lum et al., 2012). Conflicting results, however, have been reported. While almost all the studies found evidence to support the procedural deficit hypothesis by showing poorer performance by children with SLI compared to controls (e.g., Lum et al., 2010; Hedenius et al., 2011; Lum et al., 2012; Hsu & Bishop, 2014; Lum & Bleses, 2012; Mayor-Dubois et al., 2012), some found that children with SLI performed similarly to TD children (e.g., Conti-Ramsden et al., 2015; Gabriel et al., 2011; 2012; Lum et al., 2012).

Mayor-Dubois et al. (2012) found that some of the participants with SLI in their study (which also used an SRT task) had an associated developmental coordination disorder. They considered the possibility of associated motor impairment, a common finding in children with SLI (Hill, 2001), and also referred to the importance of the method used to collect responses in the SRT task.

Lum, Conti-Ramsden, Morgan, and Ullman (2014) investigated whether the varying results reported might be explained by differences in study design. In a meta-analysis of some of these studies, they found that the method for collecting participant responses (e.g., keyboard, response box, or touchscreen) did not influence results. They did, however, find that results were influenced by number of exposures to the test sequence, with fewer differences observed between children with SLI and controls with increased exposure. Age was also found to be a significant predictor of differences, with older children performing better.

Research on non-declarative memory in children with SLI has not been limited to sequential visuo-motor procedural learning. Several authors have replicated the experiment described by Saffran et al. (1996) to assess statistical learning (e.g., Evans, Saffran & Robe-Torres, 2009; Mayor-Dubois et al., 2012; Mainela-Arnold & Evans, 2014; Haebig, Saffran, & Weismer, 2017). Procedural and statistical learning are different mechanisms. The former is needed to implicitly learn motor skills and habits, while the latter is needed to implicitly extract word category prototypes, learn structure regularities in order to acquire vocabulary, and compute frequencies hidden in an ambiguous word-learning process (Bishop, 2014) (See Figure 3). The above studies showed that TD children were equipped with computational tools to harness statistical information and detect word boundaries whereas children with SLI had difficulties using this information.

Kemény and Lukács (2009) used the probabilistic category learning weather prediction task to assess probabilistic and non-sequential learning in the visual domain in children with SLI and found that they showed very little learning and use of strategy.

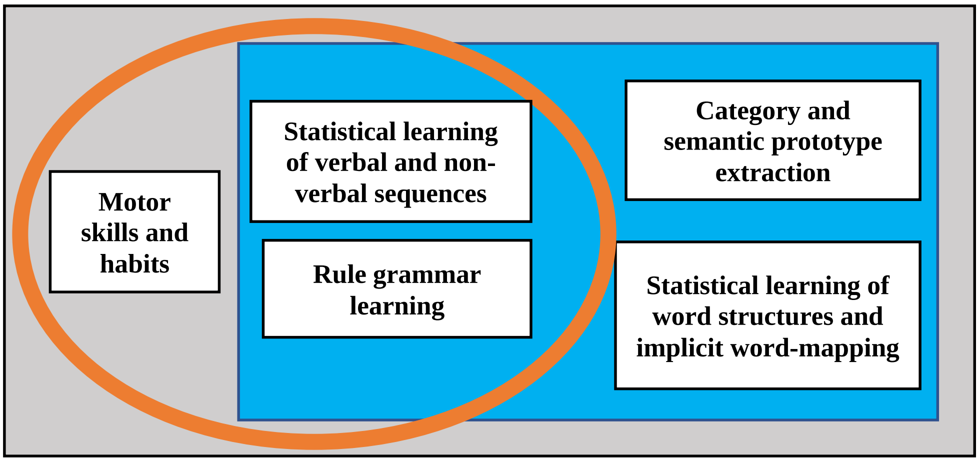

Figure 3. Aspects of non-declarative memory. The skills in the gray box involve non-declarative memory while those in the blue box involve statistical learning. The skills bounded by the orange line involve procedural learning and are hypothesized to be impaired in children with SLI according to the procedural deficit hypothesis of Ullman and Pierpont (2005). Source: figure adapted from Hsu & Bishop (2011).

Non-sequential implicit learning in the motor domain was assessed by Adi-Japha, Strulovich-Schwartz, and Julius (2011) using the invented letter task and by Hsu and

Bishop (2014) using the pursuit rotor task to determine whether SLI affected non-sequential procedural memory in the motor domain and sequential procedural learning in the visual domain. The results of the first study showed that children with SLI had difficulties acquiring and consolidating a new grapho-motor symbol into long-term memory. The second study, however, found that children with SLI performed comparably to same-age peers and better than children with similar grammar abilities in the grapho-motor task.

According to the procedural deficit hypothesis, declarative memory is largely spared in children with SLI. To prove this theory, many studies have analyzed both declarative and procedural memory. Lum et al. (2010) showed that verbal declarative memory, working memory, and procedural memory were all affected in children with SLI. They assessed verbal declarative memory using the word pair subtests from the Children's Memory Scale (WPCMS; Cohen 1997) and found that children with SLI learnt fewer semantically unrelated word pairs than non-impaired children. In subsequent studies, different authors proposed that these results, which were inconsistent with the procedural deficit hypothesis, could be explained by interference between working memory and performance of declarative memory tasks (Lum & Bleses, 2012; Lum et al., 2012; Lum, Ullman, & Conti-Ramsden, 2015; Bishop & Hsu, 2015). As stated earlier, verbal working memory deficits have been widely documented in children with SLI. In this respect, measures of declarative memory in these studies did not appear to differ between children with SLI and TD children once working memory had been controlled for. With respect to non-declarative memory assessed by the SRT task, compared to TD children, children with SLI were found to have impaired procedural memory, even when working memory was held constant. The evidence therefore showed that working memory was more closely related to declarative memory than to non-declarative memory (Unsworth & Engle, 2005; Weitz, O'Shea, Zook, & Needham, 2011).

The vast majority of studies that have addressed this new perspective of SLI have focused on testing the procedural deficit hypothesis, which holds that grammar impairments in SLI are explained by abnormalities in brain areas associated with procedural memory. This hypothesis, however, does not take into account other theoretical perspectives such as the statistical learning paradigm, which addresses issues in addition to sequences and grammar learning. The statistical learning approach supports the idea that lexical comprehension and recognition are learning processes that can be achieved through extraction of implicit patterns and computation of frequencies. According to the procedural deficit hypothesis, the core of SLI lies in grammar, not lexical difficulties, even though some patients with SLI have obvious problems with vocabulary.

Within the framework of the procedural deficit hypothesis, certain lexical processes, such as impaired lexical retrieval and word segmentation in children with SLI, can be explained by deficits in the procedural system. This dissertation, however, examines other non-sequential mechanisms, such as lexical recognition and the learning of new words, which can be achieved through statistical learning, to determine whether or not they are affected in Catalan-Spanish speaking children with SLI. It also examines other sequential statistical learning tasks related to word learning in this population.

AIMS AND HYPOTHESES

3. Research questions, aims and hypotheses

The vast majority of studies that have addressed new theories on the nature of SLI in relation to difficulties with tasks that require implicit, unconscious, and incidental learning have focused on testing the procedural deficit hypothesis (Ullman & Pierpont, 2005). According to this hypothesis, grammar difficulties in children with SLI are caused by a deficit in procedural memory, which involves the gradual, sequential, and implicit learning needed to acquire cognitive and motor skills, such as typing or riding a bike.

Few studies have analyzed the role of non-declarative learning from the perspective of statistical learning in children with SLI (Evans et al., 2009; Mayor-Dubois et al., 2012; Hsu et al., 2014; Mainela-Arnold & Evans, 2014). The statistical learning approach assumes that our world is embedded with different frequencies, probabilities, and statistics that humans have to unconsciously compute to understand all the input they receive. This ability is also needed for the acquisition of language.

The procedural deficit hypothesis also proposes that children with SLI have relative strengths in word learning explained by the sparing of the lexical declarative memory system, which is supported by brain systems involving the hippocampus and neocortex. Nonetheless, while it has historically been argued that the lexicon is an area of “relative” strength in SLI, some work has shown that children with SLI consistently have smaller vocabularies than expected for their age (e.g., Rice et al., 1990; Rice, Buhr, & Oetting, 1992; Rice et al., 1994) as well as difficulty learning novel lexical labels (e.g., Alt & Plante, 2006). Finally, word-learning studies have shown that children with SLI need more exposure in order to establish initial maps of new words compared to controls (Gray, 2004; Rice et al., 1994).

3.1 Research questions

This dissertation was undertaken to answer a number of key research questions regarding different memory roles in Catalan-Spanish children with SLI. The first question was whether they had difficulties resolving statistical learning tasks, i.e., whether they had problems extracting regularities from sequential and/or non-sequential input. We also wished to examine the idea that non-declarative learning is not required to acquire vocabulary by determining how much variance in vocabulary knowledge is accounted for by non-declarative statistical learning in children with SLI and TD children. An additional aim was to prove the association between preserved declarative memory and vocabulary knowledge in Catalan-Spanish children with SLI. Finally, we wished to obtain more evidence on deficits relating to solving verbal and non-verbal short-term and working memory tasks.

3.2 General aims

1. To study whether Catalan-Spanish children with SLI have difficulties with tasks that require unconscious, automatic, incidental, and spontaneous learning, i.e., whether they have difficulties with statistical learning tasks involved in word learning.
2. To investigate the assumption that statistical learning is required for word learning. Specifically, we wanted to determine the degree to which this type of learning accounted for visual and auditory word learning in children with SLI and TD peers.
3. To examine whether children with SLI have a non-declarative memory impairment that extends beyond procedural learning. Specifically, we wanted to know if they had difficulties with sequential and non-sequential statistical learning.

If the aims of this dissertation are achieved, current theoretical models of non-declarative learning in children with SLI will need to be extended beyond the assumption that only procedural sequential learning is impaired in this population. If our hypotheses are correct, then it would suggest that more general non-declarative learning, including non-sequential statistical learning, is impaired in children with SLI and that it is linked to both grammar learning and vocabulary acquisition.

3.3 Specific aims

1. To examine the relative contributions of three types of statistical word learning—sequential statistical learning, cross-situational statistic learning, and visual statistical learning—on vocabulary knowledge in school-aged Catalan-Spanish children with and without SLI.
2. To determine whether Catalan-Spanish children with SLI are as able as their TD peers to solve three statistical learning tasks in the auditory, visual, and audio-visual domains.
3. To assess short-term working memory and verbal declarative memory in Catalan-Spanish children with and without SLI and determine how much variance in vocabulary knowledge is accounted for by verbal declarative memory.

3.4 Hypotheses

- Hypothesis 1: We assume children with SLI don't have a deficit limited to the procedural learning but they also have a broader non-declarative system affected that includes the statistical learning mechanism. Thus, we expect to find children with SLI will perform significantly worse in sequential and non-sequential statistical learning tasks than their TD peers.

- Hypothesis 2: We assume statistical learning and not only declarative memory is a mechanism related to vocabulary learning. We predict statistical word learning tasks will add a significant amount of variance to both group of children's expressive and receptive vocabulary knowledge.
- Hypothesis 3: Because the previous literature shows deficits in working memory in children with SLI, we predict Catalan-Spanish children with SLI should perform worse in auditory and visual working and short-term memory tasks than their TD peers.
- Hypothesis 4: If declarative memory is preserved in children with SLI, as proposed by the procedural deficit hypothesis, there will be no differences in verbal and visual declarative memory task performance between children with SLI and TD children.
- Hypothesis 5: According to the procedural deficit hypothesis, declarative memory is used to learn vocabulary, and accordingly the verbal declarative memory tasks should add a significant portion of variance to vocabulary knowledge in children with and without SLI.

EXPERIMENTAL PART

4. General methodology

4.1 Participant selection

The sample for this dissertation, which includes four studies, was formed by two groups of school-aged children: children with SLI and a control group of TD children.

4.1.1 Selection of children with SLI

The members of the final sample were selected with the help and support of different institutions, organizations, and schools around Catalonia. To select the children with SLI, we received help from the Catalan Center of Resources for Hearing-Impaired People (CREDA) and members of the Catalan Service for School Counseling and Guidance (EAP). These two services work in conjunction with public and private schools throughout Catalonia and helped put us in contact with schools and families with children with SLI or children with language difficulties (diagnostic impression of SLI) who might be interested in participating in the project. We also received help from the Catalan Association of Specific Language Impairment (ATELCA), which contacted families of children with SLI to ask if they would like to participate.

All the families who agreed to participate in the study were asked to sign an informed consent form and fill in a background information questionnaire (see section on questionnaire below for details of information collected). The full questionnaire and informed consent form are provided in Appendix B. A final report containing the results of all the tests administered to the children was given to the family as a token of gratitude for their commitment and contribution to the study (see Appendix C for the complete report). The children were each given a toy.

All the children with SLI approached participated in an initial screening session. If they met the diagnostic inclusion criteria, they participated in three more sessions, and if they did not, they were excluded from the study. Over a period of 6 months, 21 children, accompanied by their families, attended the study sessions at the Universitat Oberta de Catalunya and the Universitat de Barcelona. In addition, 31 schools and other educational centers around Catalonia were visited. In total, 79 children diagnosed with SLI or with language difficulties were seen (see Appendix D for the list of the schools visited).

The diagnostic inclusion criteria for the study were (a) an IQ > 75 (Kaufmann Brief Intelligence Test Matrices section [K-BIT Mat]) (Aguado et al., 2015); (b) a score of 1.25 SD below the mean on one of the three scales of the Clinical Evaluation of Language Fundamentals - Fourth Edition, Spanish (CELF-4): expressive language, receptive language, and language content (Tomblin, 2008; p. 95 in Tomblin, Norbury, & Bishop, 2008); (c) normal hearing at 500, 1000, 2000, and 4000 Hz at 20 dB based on the ASHA 1997 guidelines for hearing screening; (d) normal or corrected-to-normal vision; (e) normal oral and speech motor abilities; (f) absence of other medical or neurological conditions; and (g) age range from 5 to 13 years-old. All the participants were bilingual Spanish-Catalan native-speakers.[1]

Of the 79 children with language difficulties initially screened, 38 were included (12 girls and 26 boys, mean age=103.15 months, range=66-155 months) and 45 were excluded. Six had a comorbid condition, one had hearing loss, 20 did not meet the CELF-4 < 1.25 SD criterion, three did not meet the IQ > 75 (K-BIT Mat) criterion, two were not native Catalan-Spanish speakers, three were too old for the sample, and 11 quit the study. All 38 children included were administered three experimental tasks and the language and test batteries used in the four studies that comprise this dissertation (see Appendix E for the inclusion criteria map).

[1] In Catalonia, both Spanish and Catalan are official languages and therefore proficiency in both languages is, if not native, native-like. Accordingly, it is very difficult to separate monolingual and bilingual children in Catalonia.

4.1.2 Selection of TD children

The members of the TD group were selected with the help of three public schools located in Premià de Mar, Montgat, and Badalona (three cities in the metropolitan area of Barcelona). Each child with SLI was matched to a TD child of the same gender and age (+/- 3 months) at the time of the experimental tasks. The teachers from the three participating schools were asked to select children with typical language development and a standard academic level for their age. They provided the families of the selected children interested in participating with the informed consent form and the background information questionnaire. The TD children were administered the same tests as the children with SLI.

The inclusion criteria for the group of TD children were: (a) an IQ >75 (K-BIT Mat); (b) standardized language scores in the expressive language, receptive language, and language content CELF-4 scales; (c) absence of prior history of speech or psychological therapy; and (g) age range from 5 to 13 years-old. As with the SLI children, the TD children also had to be native Catalan-Spanish speakers. Over a period of 4 months, three public schools were visited and 61 TD children assessed. Of these, 58 were included and three were excluded (two did not meet the CELF-4 criteria and one quit the study). Of these 58 children, we selected those who best matched the 38 children in the SLI group (12 girls and 26 boys, mean age=105.47 months, range=67-157 months). The 38 TD children were administered the same tests and tasks as the SLI children (see Appendix E for the inclusion criteria map).

4.2 Material assessment

This section describes the materials used to compile personal data and assess language and memory. The specific materials used to design and administer the experimental tasks in the four studies that make up this dissertation are presented in the corresponding studies.

1) Standardized assessment tests, clinical screening methods, and assessment questionnaires for the subject classification criteria:
   - *Background information questionnaire*. This questionnaire was designed *ad hoc* to collect the following background information on the participants and their families: (a) contact information, (b) socioeconomic status, (c) parents' level of education, (d) history of language problems in the family, (e) number of siblings, (f) significant medical history, (g) oral structure and motor function, (h) neurological dysfunctions, (i) academic performance, (j) normal-to-corrected vision, normal oral and speech motor abilities, and absence of significant medical or neurological conditions (see Appendix F to learn how socioeconomic status was measured).
   - *Spanish version of K-BIT* (Kaufman & Kaufman, 2004). Non-verbal intelligence test for assessing IQ.
   - *Audiometer (Maico MA 25e)*. Hearing screening for each ear (25 db at 500, 1000, 2000, and 4000 Hz) for children with SLI to rule out hearing loss.
2) *Spanish version of CELF–4* (Semel, Wiig & Secord, 2006). Linguistic ability assessed by core language, expressive language, and receptive language scores.
3) Standardized language and memory assessment measures included in the analysis of the data:
   - *Peabody - Picture Vocabulary Test, Third Edition; Spanish version* (Dunn, Dunn & Arribas, 2006) to assess receptive vocabulary.
   - *K-BIT* (Kaufman & Kaufman, 2004). Verbal IQ test to assess expressive vocabulary.

- *Non-word repetition task* (Aguado, 2005) to assess phonological working memory.
- *TOMAL – Spanish version of the Test of Memory and Learning* (Reynolds & Bigler, 2012; adapted by Goikoetxea):
    (1) *Digits forward and digits backward* subtests to measure verbal working memory.
    (2) *Paired recall* subtest to measure verbal declarative memory.
    (3) *Visual selective reminding* subtest to measure visual working memory.
    (4) *Facial memory* and *delayed facial memory* subtests to measure visual declarative memory.
- *Spanish version of CELF-4* (Semel, Wiig & Secord, 2006) *word association* subtest to measure semantic declarative memory.

4.3 General procedure

In line with the aims and hypotheses of this dissertation, the participants were administered three statistical learning tasks and a series of vocabulary and memory tests.

The auditory statistical learning (ASL) and cross-situational (audio-visual) statistical learning (CSSL) tasks were designed to simulate two different processes used to learn words. The ASL task was a laboratory adaptation of the word segmentation process that humans use to discover individual words within speech. The CSSL task was designed to test, in a controlled environment, the ability to map spoken words to visual objects in an unambiguous context like the natural world. The third task was a visual statistical learning (VSL) task analogous to the ASL task but designed to obtain more evidence on whether non-declarative deficits in Catalan-Spanish children with SLI are domain-specific or domain-general. Although the details of the materials, design, stimuli, and procedures used for each of the studies are presented in the corresponding studies, below is a description of the material and equipment used to collect data across the three studies (see Appendix O for photographs of the process of data collection).

- Tobii T120 Eye Tracker. The stimuli for the CSSL task were presented and recorded using an eye-tracking tool integrated into a 17” TFT monitor that can measure point of gaze, i.e., where someone is looking. This device consists of a small infrared camera that allows measurement of eye position and movement. Using the eye tracker, we were able to analyze online each moment of the cognitive process during performance of the task using the gaze patterns recorded in response to the visual stimuli. Although the visual stimuli for the VSL task were not recorded using Tobii T-120, its integrated monitor was used to present the stimuli in order to be able to present two visual tasks on the same monitor.
- Laptop. An additional laptop was required to run the experiments with the Tobii T-120. The laptop was also used to present the auditory stimuli for the ASL task.
- Samsung Galaxy Tab 4. All the language and memory tests that required verbal interaction were recorded on a tablet to allow subsequent revision of the responses recorded by the experimenters during the tasks.

5. Study 1: Sequential auditory statistical learning in Catalan-Spanish children with specific language impairment

5.1 Introduction

Lexical acquisition is a complex process in which words can only be acquired if they are understood. Speech segmentation is an important ability because from the moment they are born, infants are presented with continuous streams of sounds in which they have to discover where words start and finish. Natural speech segmentation abilities are related to prosodic and phonological cues, such as silence, pitch, and intonation. The additional ability to compute sequential statistics is needed to correctly segment speech into words.

Saffran et al. (1996) demonstrated that 8-month-old infants were able to extract words embedded in a continuous stream of spoken artificial language. Segmentation of words from fluent speech is a basic language acquisition task, and Saffran et al. showed that these infants were able to do this by simply computing the statistical relationships between neighboring speech sounds after just 2 minutes of exposure. These statistical cues that language learners compute to extract word from spoken language are known as *transitional probabilities (TP)*. Transitional probabilities are more apparent and greater within a word than across word boundaries: (TP=P (Y|X)= Frequency (XY) / Frequency (X)). The syllable "ca" from the Spanish word "casa" (house), for example, can be followed by numerous syllables such as "sa", "pa", and "la" to form a word. The probability of "ca" preceding "sa" is high in the infant's language context. However, in the phrase "la casa pequeña" (the small house), the final syllable "sa" can appear before any syllable of another Spanish word, resulting in a very low probability of "sa" being followed by "pe". Due to differences in sequential probabilities of syllables, the set of syllables that compose "casa" are more likely to become a word than those that compose "sape" (Saffran, 2003).

Few authors have tested sequential statistical word segmentation using the same paradigm as Saffran et al. (1996). Evans et al. (2009) were the first to study statistical learning abilities in children with SLI in relation to vocabulary knowledge. In their study, the children performed two analogous tasks that differed only in linguistic and non-linguistic cues. In the first task, they were exposed to a stream of speech, while in the second task they were exposed to a stream of tones with an identical statistical structure to the speech version used for the word segmentation tasks in the study by Saffran et al. The results showed that children with SLI needed over twice as much exposure to the input sequences than TD children to successfully discriminate words from non-words in a post-test segmentation task. In addition, after 42 minutes of tone stream exposure, the children with SLI were not able to solve the non-word test significantly better than chance. Evans et al. also tested the children's expressive and receptive vocabulary knowledge using standardized vocabulary tests. They found that the ability to track sequential regularities in word syllables was associated with the participants' vocabulary knowledge, suggesting that non-declarative learning impairments in children with SLI may affect vocabulary in addition to grammar learning. It was the first evidence that children with SLI have implicit learning deficits that go beyond the procedural sequential–grammar syntax problems proposed by the procedural deficit hypothesis.

In a later study, Mainela-Arnold and Evans (2014) investigated the relationship between sequential statistical learning and two aspects of lexical ability—lexical-phonological ability and lexical-semantic ability—in children with and without SLI. All the children were assessed using Saffran et. al's (1996) statistical word segmentation task and two additional lexical tasks: a lexical-phonological access task (gating task[2]) and a word definition task. The results showed that poor statistical learners (children with worse

[2] Gating task: spoken word recognition task. Participants are presented with fragments of a word of gradually increasing duration and are asked to guess which word is about to finish.

results in the word segmentation task) also performed worse at managing lexical-phonological competition during the gating task. Performance in the word segmentation task, however, was not a significant predictor of semantic performance in the word definition task. Overall, the study's findings showed that the ability to track statistical sequential regularities may be important for learning the inherently sequential structures of lexical-phonological knowledge, but not so important for acquiring lexical-semantic knowledge. These conclusions were consistent with the procedural deficit hypothesis.

In 2017, Haebig et al. assessed auditory statistical learning (ASL) (using a word segmentation task) and fast-mapping abilities (using an object-label association task) in children with SLI, children with autism spectrum disorder (ASD) and TD children. Children with SLI had poorer performance on the word segmentation (i.e. performed at chance in the ASL) and fast-mapping tasks relative to the TD and ASD group.

One aim of this study was to add to the body of evidence on statistical learning in children with SLI. The specific aim was to determine how bilingual Catalan-Spanish children with SLI solved a statistical word learning task compared with gender- and age-matched TD controls. As noted earlier, Catalan and Spanish are Romance languages while English is Germanic. Consequently, the languages differ in terms of certain prosodic, phonologic, and morphologic cues that have a role in the word-segmenting process. Catalan and Spanish are morphologically and syntactically richer than English and also differ in aspects related to vowel sounds and sentence stress. Speakers of the three languages also use different combinations of pitch, intonation, and rhythm in sentences (Coe, 2001).

By testing Catalan-Spanish speakers, we should be able to show that the poor statistical learning abilities observed in children with SLI in previous studies (Evans et al., 2009; Mainela-Arnold & Evans, 2014; and Haebig et al., 2017) are not unique to

English-speaking children. If we demonstrate poor ASL in our population, we will have shown that statistical learning deficits in children with SLI are cross-linguistic. We also explored the possible contribution of ASL to vocabulary knowledge and shed more light on the assumption that children with SLI have non-declarative memory deficits that go beyond the procedural learning syntax problems proposed by the procedural deficit hypothesis.

5.2 Specific aims and hypotheses

Aims

The aim of this study was to investigate how bilingual Catalan-Spanish children with SLI solve a sequential statistical word segmentation task compared to gender- and age-matched TD children. This allowed us to determine whether children with SLI who speak languages other than English also have statistical learning deficits. To do this, we looked at the strength of the transitional probabilities embedded in the task stimuli to see whether they play a role in how well TD children and children with SLI perform. A final aim was to explore the contribution of ASL to vocabulary knowledge.

Hypotheses

The first hypothesis of this study is that TD children will perform better at solving an ASL task than children with SLI. They are expected to show significantly higher accuracy in the task compared to children with SLI. Furthermore, we expect that children with SLI will show chance-level performance in a task that requires the ability to exploit transitional probabilities to discover tone words embedded in an auditory stream and that TD children will show significant differences in terms of extracting tone words with high within-word transitional probabilities compared to those with low within-word probabilities. If we find poor ASL in this group of Catalan-Spanish children with SLI, we will have shown that statistical learning deficits in SLI are cross-linguistic.

Additionally, if ASL performance accounts for significant variance in vocabulary knowledge, we will have provided additional evidence to support the assumption that children with SLI have non-declarative memory deficits that go beyond the procedural learning syntax problems proposed by the procedural deficit hypothesis.

5.3 Methodology

5.3.1 Participants

Seventy-six children participated in the study but three children with SLI were excluded because they did not understand the task.[3] Accordingly, the data for their matched pairs were removed from the data analysis. Seventy children (22 girls and 48 boys) were thus included: 35 children with SLI (mean age=8.9 years, SD=1.9 years, range=5.6-12.11 years) and 35 age- and gender-matched TD children (mean age=8.9 years, SD=1.9 years, range=5.6-12.9 years). All the children met the inclusion criteria for their group (see participant selection section). The results of the corresponding tests are given in Table 1. Socioeconomic status, calculated from the data provided in the background information questionnaire, was controlled for in the analyses (see Appendix F for information on how socioeconomic status was calculated).

[3] We considered that a child did not understand the task when they did not give any answers in three or more test trials or if they showed rigid behavior by indicating the same choice in several test trials during the two-alternative forced-choice task (e.g., 1, 1, 1, 1, 1, 1, 1, 1 ...).

Table 1. Age and standardized scores for language and cognitive assessment measures for children with specific language impairment (SLI) and typically developing (TD) children (study 1).

	SLI (n=35)			**TD (n=35)**			**Comparison**	
Variable	**Mean**	**SD**	**Range**	**Mean**	**SD**	**Range**	**t(68)**	***p***
Age in months	105.34	21.27	66-155	107.80	21.26	67-153	-.48	p=.63
K-BIT mat (IQ)[a]	99.08	11.69	82-119	103.51	9.76	88-125	-1.72	p=.09
CELF- CLS[b]	72.57	10.89	45-89	108.74	6.09	95-125	17.14	***p*<.01**
CELF- ELS[c]	73.22	8.77	52-87	108.45	8.11	89-128	-17.43	***p*<.01**
CELF -RLS[d]	77.45	10.19	59-97	105.82	5.55	94-118	14.45	***p*<.01**
K-BIT voc[e]	77.14	11.65	53-96	106.40	10.20	83-127	-11.17	***p*<.01**
PPVT-III[f]	77.80	11.87	55-105	106.25	12.59	83-127	-9.72	***p*<.01**

Note. For each variable, age-scaled scores have a mean of 100 and an SD of 15 (except age in months).

[a] K-BIT mat=Kaufman Brief Intelligence, Spanish version: Non-verbal intelligence score (Kaufman & Kaufman, 2004)

IQ=non-verbal intellectual quotient

[b] CELF-4 CLS=Spanish Clinical Evaluation of Language Fundamentals, Fourth Edition: Core Language score (Semel, Wiig & Secord, 2006).

[c] CELF-4 ELS=Spanish Clinical Evaluation of Language Fundamentals, Fourth Edition: Expressive Language score (Semel, Wiig & Secord, 2006).

[d] CELF-4 RLS=Spanish Clinical Evaluation of Language Fundamentals, Fourth Edition: Receptive Language score (Semel, Wiig & Secord, 2006).

[e] K-BIT voc=Kaufman Brief Intelligence, Spanish version: Verbal intelligence score (Kaufman & Kaufman, 2004)

[f] PPVT-III=Peabody Picture Vocabulary Test, Third Edition, Spanish version (Dunn, Dunn & Arribas, 2006)

5.3.2 Materials, stimuli, and design

Experimental task

The stimuli for this study were adapted from the design used by Evans et al. (2009) for the tone language 1 experiment described in Saffran et al. (1999).

- Learning phase stimuli

A continuous tone stream was constructed using 11 pure tones, each lasting 0.33 seconds. The tones were taken from the same octave (starting at middle C within the chromatic set A, B, C, C#, D, D#, E, F, F#, G, G#). Each tone was considered to be a single tone syllable. In order to form six tone words, the 11 pure tones were combined into groups of three tone syllables. In total thus there were six three-syllabic tone words (GG#A, CC#D, D#ED, FCF#, DFE, and ADB). The tone words were not combined to follow the rules of a melodic or standard musical composition. The stream was generated using the SoundEdit 16 sine wave generator (Adobe, San Jose, CA).

We decided to use tones instead of non-words to create the artificial language to be learned, as by removing language-specific features (words and pseudowords) we were able to ensure that any difficulties children might have extracting statistical information would not be due to language.

On creating the stream of tones, we checked that the transitional probabilities between syllables within the tone words were higher than those between the syllables across tone words. The within-tone probabilities averaged 0.65 (range=0.37-1.00); while the across-tone probabilities averaged 0.14 (range=0.05-0.60) (see Figure 4 and 5). Although the two distributions overlapped, the overlap only occurred for three of the 30 across-word tone instances.

Tone words	Tone non-words
GG#A (1.0)	AC#E
CC#D (.75)	F#G#E
D#ED (.65)	GCD#
FCF# (.50)	C#BA
DFE (.42)	C#FD
ADB (.37)	G#BA

Figure 4. The transitional probabilities for the different tone words are shown in parentheses.

The final tone stream was created by randomly concatenating the six tone words and leaving no silences between the words and the acoustic tone word boundary markers. This process resulted in six blocks each containing 18 tone words, none of which occurred twice in a row. The six blocks were joined to form a 7-minute continuous stream, which was then concatenated three times to create a 21-minute stream. This design ensured that the only consistent cues that participants could extract to detect the beginning and end of tone words were the transitional probabilities between tones.

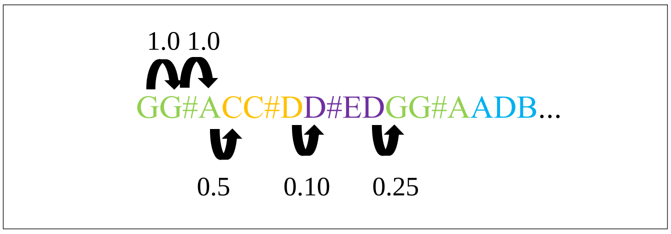

Figure 5. Visual representation of the artificial tone word stream. Each color represents a single tone word. The transitional probabilities between and within tone words are shown by the black arrows.

- Test phase stimuli

In addition to the tone stream, six tone non-word foils were created from the tone inventory for the test phase. These comprised syllables that did not follow each other in the tone stream (AC#E, F#G#E, GCD#, C#BA, C#FD, G#BA). In the test phase, the children were presented with 36 pairs of tone word and non-word sequences (see Appendix H for the order of the pairs) and instructed to choose the sound sequence that sounded most familiar to the word tone stream from among two alternatives. This is known as a *two-alternative forced-choice task (2AFC).*

Vocabulary assessment

To examine associations between sequential ASL and vocabulary knowledge, the Peabody Picture Vocabulary Test, Third Edition; Spanish version (Dunn, Dunn & Arribas, 2006) and the Spanish version of the K-BIT verbal intelligence test (Kaufman & Kaufman, 2004) were administered to both groups to assess receptive and expressive vocabulary knowledge, respectively (see Table 1).

5.3.3 Procedure

In the learning phase, children participated in a manual coloring task (coloring mandalas or cartoons with color pencils) while the tone stream played in the background. They were exposed to the stream for 21 minutes. The instructions for the task were as follows: "You are going to have about 20 minutes to color. While you are coloring, some weird computer music will be playing in the background, but I would like you to focus on your coloring. When the music finishes, I will ask you some questions."

The test phase started at the end of the 21-minute stream. The children were then presented with auditive pairs of tone word and tone non-word sequences and asked to choose the sequence that sounded most familiar to the song they had just heard while coloring. To ensure that the children understood the task, practice trials were run before the test phase in which the children were exposed to pairs of short melodies created from familiar Catalan-Spanish children's songs presented in the right or wrong order (e.g., the tune, without words, from "*Quan les oques van al camp*" vs. "*les van camp al quan oques*"). Following the practice trials, the children completed 36 test trials containing the tone word and non-word pairs. The experimenter noted down the participants' answers (see Appendix G for the answer template). The instructions for the test phase were as follows:

a) Instructions for stimuli example: *Now you are going to hear two sets of sounds and I want you to choose the set that sounds most like the weird computer music. If you do not know, it is ok to guess. First, we will practice. I'm going to present two different sets of sounds. I want you to tell me if set "one" or set "two" sounds more like the song you know.*

b) Instructions for test phase: *Well done! You are now going to hear two sets of sounds. I want you to tell me if set "one" or set "two" sounds most like the computer music. Remember, it's ok to guess.*

5.4 Results

General results

A generalized linear mixed model was applied with accuracy as the dependent variable (Poisson distribution, log link). Accuracy was measured as the mean proportion of correct responses out of 36 for each group. A random intercept was set for subject within group, and the residual effect of repeated measures was also controlled for. Group (TD, SLI) was set as the fixed factor. The results indicated a main effect for group, [$F(1,418)=12.302$; $p=.001$; $\beta=.603$] showing that the children with SLI performed significantly worse than the children in the TD group when it came to using transitional probabilities to discover tone words embedded in the auditory stream (mean=56.74%, SD=10.55 vs. mean=66.89%, SD=13.51). The results for the two groups are shown in Figure 6.

Chance was set at 50%. Two single-sample two-tailed t-tests calculated separately for each group showed that both groups performed significantly better than expected by chance: $t(34)=3.70$, $p<.01$ for the SLI group and $t(34)=7.67$, $p<.001$ for the TD group.

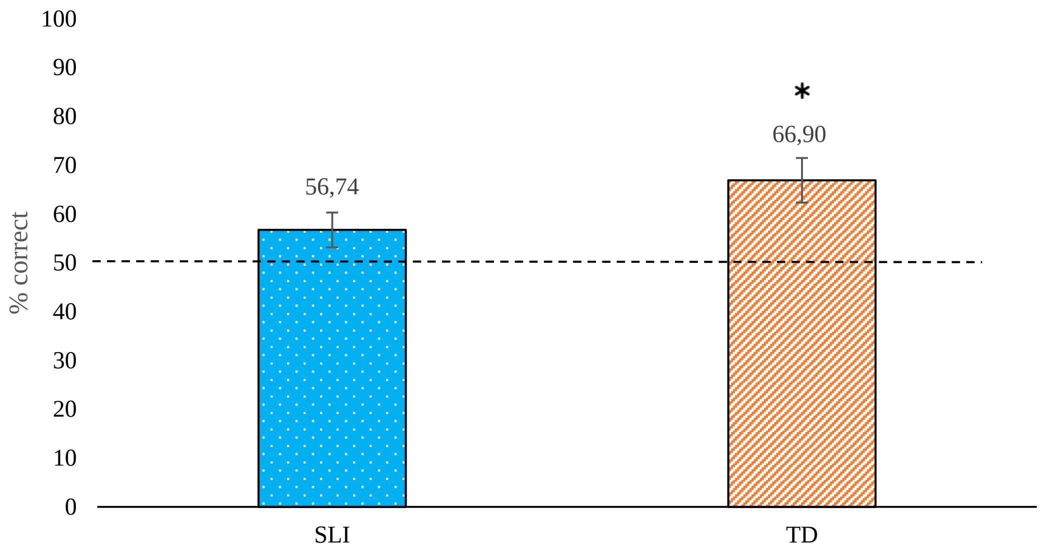

Figure 6. Percentage of correct answers in the ASL task for the group of children with specific language impairment (SLI) and the group of typically developing (TD) children.
Mean performance in the SLI group=56.74% (SD=10.55)
Mean performance in the TD group=66.89% (SD=13.51)
Chance equals 50%.
The error bar shows the 95% confidence intervals around the means.

Individual differences

Although the mean performance rates were significantly above chance for both groups, we explored specific behaviors within the groups by calculating the percentage of children who performed above and below chance in each group (see Figure 7). In the TD group, 94.2% of children performed above chance while just 5.71% performed below chance. The respective rates for the SLI group were 60% and 40%.

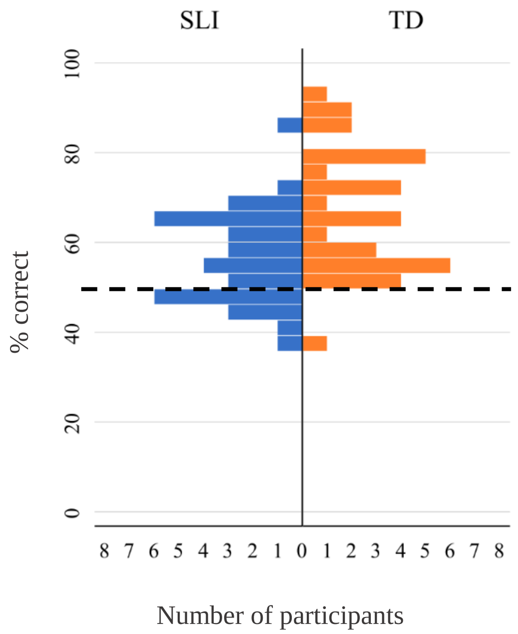

Figure 7. Number of children in the specific language impairment (SLI) and typically developing (TD) groups who performed above and below chance in the auditory statistical learning task. Chance equals 50%.

Transitional probabilities

Another of the aims of the study was to investigate whether the strength of transitional probabilities between and within words influenced how well individual words were learned. As noted earlier, the transitional probabilities within words ranged from 0.37 to 1.0. Analysis of the individual target words for the SLI and TD groups indicated that all six tone words were learned significantly better than expected by chance (p<.01), suggesting that after just 21 minutes of exposure, both children with SLI and TD children were easily able to exploit transitional probabilities to discover tone words embedded in the tone stream. A marginal model was applied to the data, with number of tone words as the dependent variable (Possion distribution, log link). Group, tone word, and their interaction were set as fixed factors. A main effect was found for group [F(1, 408)=18.623, p<.001, β=.592] with TD children selecting more tone words than children with SLI. The main effect for tone word was, however, not significant at [F(5, 408)=2.087, p=.066]. Finally, the interaction group × tone word was significant, at [F(5, 408)=3.024, p=.011]. This finding has two possible interpretations. First, TD children obtained higher values than children with SLI for the tone words GG#A$^{TP=1.0}$ (β=1.257, p<.001) and CC#D$^{TP=0.75}$ (β=1.400, p<.001), but not for the other words. Second, children with SLI showed no significant variations in tone words (overall test results: F(5, 408)=.622, p=.683), while the TD children did (overall test results: [F(5, 408)=5.028, p<.001)]. The results are presented in Figure 8. More specifically, the pairwise comparison revealed that the tone words GG#A$^{TP=1.0}$ and CC#D$^{TP=0.75}$ received higher values than FCF#$^{TP=0.50}$ and ADB$^{TP=.37}$ (GG#A$^{TP=1.0}$ > FCF#$^{TP=0.50}$: β=1.029, p<.05; GG#A$^{TP=1.0}$ > ADB$^{TP=.37}$: β=1.229, p<.01; CC#D$^{TP=0.75}$ > FCF#$^{TP=0.50}$: β=1.029, p<.05; CC#D$^{TP=0.75}$ > ADB$^{TP=.37}$: β=1.229, p<.01), indicating that TD children, but not children with SLI, were better able to detect tone words with high within-word transitional probabilities than those with low within-word transitional probabilities. As seen in Figure 8, the tone word DFE$^{TP=.42}$ was selected a similar number of times to tone words with high within-word probabilities. Although the difference between the choice of DFE$^{TP=.42}$ and tone words with low within-word probabilities was not statistically significant, we were interested in determining why the children in the TD group seemed to have a preference for this specific tone word, despite its relatively low transitional probability. We asked a professional musician whether the combination of DFE tones had any special musical characteristics that might attract the children's attention more than the other five tone words and he told us that this combination was free of chromatics, i.e., it was closer to a pleasant melody than the other five combinations.

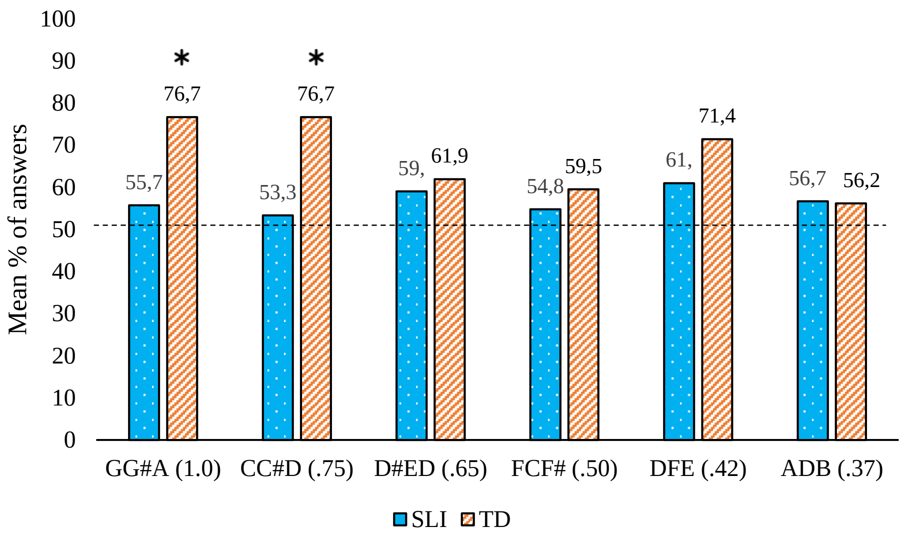

Figure 8. Distribution of answers to tone word task in the auditory statistical learning test phase. The different transitional probabilities are shown in parentheses. Chance equals 50%.

Relationship between vocabulary knowledge and ASL scores

Correlational analyses

We ran a bilateral correlation analysis between age, IQ, socioeconomic status, ASL score, and expressive and receptive vocabulary scores. Age, IQ, and socioeconomic status were chosen because they have been shown to impact language acquisition and statistical learning (Dollaghan, et al., 1999; Schuele, 2001). The correlation matrices between age, IQ, socioeconomic status, ASL score, and expressive and receptive vocabulary scores are shown in Table 2. The four variables were significantly and positively correlated with expressive and receptive vocabulary scores, as follows: age with receptive vocabulary $r(70)=.65$, $p<.01$; age with expressive vocabulary $r(70)=.70$, $p<.01$; IQ with receptive vocabulary $r(70)=.55$, $p<.01$; IQ with expressive vocabulary $r(70)=.53$, $p<.01$; socioeconomic status with receptive vocabulary $r(70)=.45$, $p<.01$; socioeconomic status with expressive vocabulary $r(70)=.37$, $p<.01$; ASL with receptive vocabulary $r(70)=.24$, $p<.05$; and ASL with expressive vocabulary $r(70)=.30$, $p<.05$.

Table 2. Correlation matrix for cognitive variables, ASL performance, and vocabulary scores for all study participants.

	IQ	**SES**	**ASL**	**PPVT-III**	**K-BIT-voc**
IQ					
SES	.22				
ASL	.13	.13			
PPVT-III	.55**	.45**	.24*		
K-BIT-voc	.53**	.37**	.30*	.85**	
Age (months)	.60**	.22	.02	.65**	.70**

Note. ASL=auditory statistical learning task; IQ=non-verbal intellectual quotient; K-BIT voc=verbal intelligence score from Kaufman Brief Intelligence Test (expressive vocabulary); PPVT-III=Peabody Picture Vocabulary Test (receptive vocabulary); SES=socioeconomic status.
* p<.05. level (two-tailed). ** p<.01. level (two-tailed).

Regression analyses

We ran a two-step hierarchical regression analysis to determine whether sequential ASL performance was a predictor of expressive and/or receptive vocabulary knowledge in children with SLI and TD children. Age, IQ, and socioeconomic status were entered as covariates in step 1 (Model 1) to control for possible effects. The rate of correct responses in the ASL task was added as a predictor in step 2 (Model 2). Receptive and expressive vocabulary scores were entered as dependent variables in two separate analyses.

The results for the overall expressive vocabulary model are presented in Table 3a. Age, IQ, and socioeconomic status (Model 1) accounted for unique portions of variance in expressive vocabulary knowledge ($R^{2=}$.55, adj. $R^{2=}$.53, $F(3,66)=26.95$, $p<.001$). The follow-up regression analysis revealed that ASL (Model 2) was also a significant source of additional variance ($R^{2=}$.61, adj. $R^{2=}$.59, R^2 change$^=$.06, F change (1,65)=9.75, $p<.01$). The coefficient results showing the specific predictors of expressive vocabulary knowledge are shown in Table 3b. Age (β=.56, $t(66)=5.40$, $p<.001$, pr^2=.30), socioeconomic status (β=.22, $t(66)=2.53$, $p<.05$, pr^2=.09), and ASL performance (β=.25, *t*(65)=3.12, *p*<.01, pr^2=.13) were all significant predictors. IQ, by contrast, was not (*β*=.15, *t*(66)=1.43, *p*=.16, pr^2=.02).

Table 3a. Regression model to predict expressive vocabulary knowledge for all study participants (ASL).

Model	***R***	R^2	**Adj** R^2	**SE of estimate**	R^2 **change**	**F change**	***df*** **1**	***df*** **2**	**Sig,** ***F*** **change**
Model 1	.74	.55	.53	20.47	.55	26.91	3	66	.00***
Model 2	.78	.61	.58	7.29	.06	9.74	1	65	.00**

Note. Adj=adjusted; ASL=auditory statistical learning task; Sig=significance.
Model 1 predictors: (constant), Age, socioeconomic status, IQ
Model 2 predictors: (constant), ASL. * *p*<.05. ** *p*<.01. *** *p*<.001.

Table 3b. Coefficients and significance levels for predictors of expressive vocabulary knowledge (ASL).

Model 1	***Standardized Beta coefficients***	***T***	**Sig.**	pr^2
Age	.56	5.40	.00***	.30
SES	.22	2.53	.01*	.09
IQ	.15	1.43	.16	.02
Model 2				
ASL	.25	3.12	.00**	.13

Note. Adj=adjusted; ASL=auditory statistical learning task; IQ=non-verbal intellectual quotient; SES=socioeconomic status; Sig=significance.
Model 1 predictors: (constant), Age, SES, IQ
Model 2 predictors: (constant), ASL task. * *p*<.05. ** *p*<.01. *** *p*<.001.

The results for the overall receptive vocabulary model are shown in Table 4a. Age, IQ, and socioeconomic status (Model 1) accounted for unique portions of variance in receptive vocabulary knowledge ($R^{2=}$.55, adj. $R^{2=}$.53, *F*(3,66)=26.91, *p*<.001). The follow-up regression analysis revealed that ASL performance (Model 2) accounted for significant additional variance ($R^{2=}$.58, adj. $R^{2=}$.55, R^2 change$^=$.03, *F* change (1,65)=4.19, *p*<.05). The coefficient results showing the specific predictors of receptive vocabulary knowledge are shown in Table 4b. Age (*β*=.46, *t*(66)=4.38, *p*<.001, pr^2=.22), socioeconomic status (*β*=.31, *t*(66)=3.62, *p*<.01, pr^2=.17), IQ (*β*=.21, *t*(66)=2.00, *p*=.05,

pr^2=.06), and ASL performance (β=.17, t(65)=2.05, p<.05, pr^2=.06) were all significant predictors.

Table 4a. Regression model to predict receptive vocabulary knowledge for all study participants (ASL).

Model	***R***	***R²***	**Adj *R²***	***SE* of estimate**	***R²* change**	**F change**	***df* 1**	***df* 2**	**Sig, *F* change**
Model 1	.74	.55	.53	7.76	.55	26.95	3	66	.00**
Model 2	.76	.58	.55	20.00	.03	4.19	1	65	.00*

Note. Adj=adjusted; ASL=auditory statistical learning task; Sig=significance
Model 1 predictors: (constant), Age, socioeconomic status, non-verbal intellectual quotient
Model 2 predictors: (constant), ASL. * p<.05. ** p<.01. *** p<.001.

Table 4b. Coefficients and significance levels for predictors of receptive vocabulary knowledge (ASL).

Model 1	***Standardized Beta coefficients***	***t***	**Sig.**	***pr²***
Age	.46	4.38	.00**	.22
SES	.31	3.62	.00**	.17
IQ	.21	2.00	.05*	.06
Model 2				
ASL	.17	2.05	.04*	.06

Note. Adj=adjusted; ASL=auditory statistical learning task; IQ=non-verbal intellectual quotient; SES=socioeconomic status; Sig=significance.
Model 1 predictors: (constant), Age, SES, IQ
Model 2 predictors: (constant), ASL * p<.05. ** p<.01. *** p<.001.

5.5 Discussion

Overall, the results of this study show that children with SLI and TD children performed better than chance at tracking transitional probabilities in a tone word segmentation task. Caution should, however, be exerted when interpreting the data. First, although the children with SLI performed better than would be expected by chance, they showed significantly less accuracy when it came to solving the task compared to their TD peers. These results partially differ from those found in Evans et al. (2009), Mainela-Arnold and Evans (2014) and Haebig et al. (2017), in which children with SLI performed at chance level in a statistical learning word segmentation task. The reason for these differences could be that past studies have assessed sequential ASL in children with SLI using speech streams made up of non-words instead of tone words. Moreover, the differences between our results and those of Haebig et al. 2017 could be explained by the exposure of the input. They only exposed children to 4.75 minutes of speech stream. Surprisingly, the only study that assessed children with SLI with a tone condition such as the one used in our study was that of Evans et al. (2009). They used double the exposure of tone stream than that used in this study and found that after a 42-minute tone stream the SLI group's performance was at chance levels whereas after the 42-minute speech condition, the SLI group's performance was significantly greater than chance. They argued that the non-linguistic materials in this task were more difficult for the children with SLI than the linguistic materials, perhaps due to the relative novelty of the tone sequences. We deliberately used non-linguistic stimuli to avoid language cues because we thought it could facilitate the task for the children with SLI. It is therefore important to highlight that even though the language cues in our task were removed, children with SLI showed a significantly poorer performance than their TD peers. Another way to interpret the tone results in Evans et al. (2009) is that exposing children with SLI to 42 minutes of tone-words may be too much of a novelty and too overlapping for them, thus constraining learning. This is the first time that a 21-minute statistical tone language has been run with a group of children with SLI. Hence, more studies using this same amount of exposure and duration need to be conducted to gather more data for discussion.

Likewise, it should be noted that while mean performance in the SLI group was above chance, a higher number of these children performed worse than would be expected by chance than in the TD group. In addition, on analyzing the results for all the children who performed above chance, we found a higher number of children with correct response rates (> 80% correct) in the TD group. These results show that children with SLI are less able than TD children to successfully complete a task that involves using statistical information based on implicitly extracting embedded tone word boundaries from a 21-minute continuous tone stream. It can therefore be concluded that children with SLI have an impaired ability to solve a sequential ASL task.

To further compare performance between groups, we analyzed the transitional probabilities between tone words in greater depth to determine whether the strength of within-word probabilities influenced how well individual words were learned. Analysis of individual tone words for the SLI and TD groups indicated that all six tone words were learned significantly better than expected by chance in both groups, but that only the TD children were better at selecting tone words with high within-word probabilities compared to tone words with low within-word probabilities. The children with SLI selected all the tone words equally and showed no capacity for detecting variability in the transitional probabilities presented in the tone word stream. These results indicate that children with SLI were confused when it came to making decisions based on statistical learning and were not using information from the embedded transitional probabilities to solve the task. The first conclusion of this study thus is that Catalan-Spanish-speaking children with SLI also have statistical word learning deficits. Thus, although the past studies discussed above found chance-level results in children with SLI but in ours they were above chance, overall the results suggest cross-linguistic statistical learning deficits in children with SLI.

Natural speech segmentation abilities, which include cues such as silence, pitch, intonation, and sequential statistics, predict later vocabulary outcomes (Newman, Bernstein Ratner, Jusczyk, Jusczyk, & Dow, 2006; Evans et al., 2009). In this study we replicated the results of Evans et al. (2009) showing that children's ability to track transitional probabilities in a word segmentation task were related to their vocabulary knowledge. The results show that better ASL performance was associated with higher expressive and receptive vocabulary scores. The fact that ASL performance did not add a high portion of variance to the model can be explained by the fact that the test was designed to avoid other intrinsic and natural cues that infants need in order to learn the limits of words. The statistical learning laboratory experiment was designed to “purely” assess statistical learning abilities by creating a controlled variable to investigate the specific role played in the process of identifying individual words within speech. The significant correlation observed between statistical learning and vocabulary knowledge indicates that statistical learning is a skill children need in order to acquire vocabulary. The results also show that ASL abilities contributed to a unique portion of additional variance above and beyond measures (age, IQ and SES) that influence vocabulary knowledge. Our findings in this respect highlight the need to extend current theoretical models of non-declarative learning in children with SLI beyond the assumption that only procedural sequential learning related to grammar and syntax deficits is impaired in this population.

In summary, the overall results of this study indicate that even though mean performance in the SLI group was above chance, the children showed significantly less accuracy than their TD peers when it came to solving an ASL task. More in-depth analysis showed that they were not able to detect variability in the transitional probabilities embedded in the tone words to be learned. Our findings support the cross-linguistic nature of statistical learning deficits in children with SLI. Finally, contrary to the procedural deficit hypothesis, the ability to track transitional probabilities in a word segmentation task was a significant predictor of vocabulary knowledge in Catalan-Spanish children with and without SLI, showing that statistical learning is needed to acquire vocabulary in addition to learning grammar.

6. Study 2: Sequential visual statistical learning in Catalan-Spanish children with specific language impairment

6.1 Introduction

Different studies of visual statistical learning (VSL) have demonstrated that information regarding relationships between objects in space and time can be automatically extracted by the visual system of adults and infants (Fiser & Aslin, 2001, 2002a; 2002b). The vast majority of studies assessing sequential VSL in children with SLI have used the serial reaction time (SRT) task, which requires the production of a motor response. In this task, participants are presented with a screen featuring four horizontally arranged empty squares. Each square corresponds to a button on a keyboard or response pad. When a cue appears in one of the squares, the participants have to press the corresponding button. The emergence of cues is designed to show a pattern that is repeated during the task. Once these pattern trials are complete, the participants are presented with some random trials. They are unfamiliar with the design and are simply asked to press the corresponding button whenever they see the visual cue in the squares. The task is designed to measure non-declarative learning through response time. Response times are expected to increase during the pattern trials and decrease during the random trials. The task provides a means of measuring whether participants are learning the embedded pattern without being aware they are doing so.

As reported in earlier, most studies that have used the SRT task to assess children with SLI have shown that these children do not perform as well as their typically developing (TD) peers (e.g., Lum et al., 2010; Hedenius et al., 2011; Lum et al., 2012; Hsu & Bishop, 2014; Lum & Bleses, 2012; Mayor-Dubois et al., 2012). Nevertheless, because the task requires motor abilities and children with SLI may have motor problems

(Hill, 2001), it may not be the best way to test sequential statistical learning in this population.

One of the aims of this second study was to assess sequential VSL abilities in children with SLI by removing the need for motor response. To do this, we analyzed the statistical learning literature describing studies performed with TD children and adults without difficulties to identify a new VSL task to apply in our study. Fiser and Aslin (2002a) created a sequential VSL experiment in which participants were presented with a central square around which a single object rotated on a horizontal path. The object cycled continuously back and forth behind the central square. The shape of the rotating object changed shape each time it passed behind the central square. Participants were asked to watch the screen for 6 minutes. The order in which the shapes were presented was structured as a sequence made up of triplets, similarly to the design used in the auditory statistical learning (ASL) study by Saffran et al. (1996) (e.g., ABC, GHI, DEF, ABC, JKL). To assess whether the participants were capable of extracting the triplets embedded in the sequence by tracking the statistical information available, they were presented with a two-alternative forced-choice task (2AFC) in which they had to choose between a set of triplets that had appeared in the same order in the learning task (e.g., ABC) and another set that had not appeared in that order in the previous task (e.g., AEI). The results of the study showed that adult participants correctly identified 95% of the triplets, indicating robust sequential VSL. This visual task can be considered analogous to the sequential ASL task described by Saffran et al. (1996).

Arciuli and Simpson (2011) tested 183 TD children aged 6 to 12 years using a sequential VSL task based on the design by Aslin and Fiser (2002), but they used stimuli more suited to children. Instead of using abstract shapes they used cartoon-like alien figures. They wanted to investigate, among other things, whether the children's VSL performance would vary according to the different speeds at which the stimuli were presented. In each experiment, individual aliens were presented every 800, 400, or 200 msecs. The results showed above-chance performance for each of speeds, but the best results were found for the 800-msec version.

This study was the first to assess a group of school-aged Catalan-Spanish children with and without SLI using Aslin and Fisher's (2002a) task. Apart from providing more evidence on sequential VSL in the SLI population, we hoped to shed more light on general-domain statistical learning deficits in children with SLI using an alternative to the SRT task. Finally, we investigated the role played by VSL in vocabulary acquisition to determine whether a visual-domain statistical learning task can influence the learning of words.

6.2 Specific objectives and hypothesis

Aims

The overall aim of this study was to contribute to the existing evidence in the visual statistical learning research field focused on children with SLI. The specific aim was to investigate how bilingual Catalan-Spanish children with SLI solve a visual sequential statistical learning task compared with age- and gender-matched TD controls. It was the first time that a group of school-aged children with SLI were tested using a VSL task that is analogous to the ASL task described by Saffran et al. (1996) and different to the most widely used motor-visual SRT task used in this population. Finally, we wished to explore how VSL might contribute to children's vocabulary knowledge.

Hypotheses

The hypothesis of this study is that TD children will perform better (i.e., show more accuracy) at solving a VSL task than children with SLI. We expect the children with SLI to show chance-level performance in this task, which requires the ability to exploit transitional probabilities to discover a pattern embedded in a visual stream. If they do show less accuracy than their TD peers, we will be able to assume a general-domain deficit in statistical learning in this population.

Finally, if VSL accounts for significant variance to vocabulary knowledge, we will have found evidence to support the assumption that children with SLI have non-declarative memory deficits that go beyond the procedural learning syntax problems proposed by the procedural deficit hypothesis.

6.3 Methodology

6.3.1 Participants

Of the 76 children who participated in the study, three children with SLI were excluded because they did not understand the task.[4] Their matched pairs were removed from the data analysis. We thus included 70 children (22 girls and 48 boys): 35 with SLI (mean age=8.11 years, SD= 1.8 years, range= 6.3-12.11 years) and 35 age- and gender-matched 35 TD children (mean age=8.9 years, SD= 1.9 years, range=6.2-12.9 years). All the children met the inclusion criteria described in the participant selection section (see Table 5). Information on socioeconomic status and parental level of education was taken from the background information questionnaire to control for these factors.

[4] We considered that a child did not understand the task when they did not give any answers in three or more test trials or if they showed rigid behavior by indicating the same choice in several test trials during the two-alternative forced-choice task (e.g., 1, 1, 1, 1, 1, 1, 1, 1 ...).

Table 5. Age and standardized scores for language and cognitive assessment measures for the children with specific language impairment (SLI) and the typically developing (TD) children (study 2).

	SLI (n=35)			TD (n=35)			Comparison	
Variable	**Mean**	**SD**	**Range**	**Mean**	**SD**	**Range**	**t(68)**	***p***
Age in months	107.08	20.44	75-155	108.00	20.89	74-153	-.185	*p*=.85
K-BIT mat (IQ)[a]	99,00	11.65	82-119	103.80	9.68	88-125	-1.87	*p*=.06
CELF- CLS[b]	72.34	10.74	45-89	108.62	6.14	95-125	14.51	***p*<.01**
CELF- ELS[c]	73.00	8.70	52-87	108.45	8.11	89-128	-17.62	***p*<.01**
CELF -RLS[d]	77.25	9.93	59-97	105.57	5.88	94-118	14.51	***p*<.01**
K-BIT voc[e]	77.14	11.65	53-96	106.65	10.40	83-127	-11.17	***p*<.01**
PPVT-III [f]	77.60	11.97	55-105	106.65	10.40	83-127	-9.77	***p*<.01**

Note. For each variable, age-scaled scores have a mean of 100 and an SD of 15 (except age in months).
[a] K-BIT mat=Kaufman Brief Intelligence, Spanish version: Non-verbal intelligence score (Kaufman & Kaufman, 2004)
IQ=non-verbal intellectual quotient.
[b] CELF-4 CLS=Spanish Clinical Evaluation of Language Fundamentals, Fourth Edition: Core Language score (Semel, Wiig & Secord, 2006).
[c] CELF-4 ELS=Spanish Clinical Evaluation of Language Fundamentals, Fourth Edition: Expressive Language score (Semel, Wiig & Secord, 2006).
[d] CELF-4 RLS=Spanish Clinical Evaluation of Language Fundamentals, Fourth Edition: Receptive Language score (Semel, Wiig & Secord, 2006).
[e] K-BIT voc=Kaufman Brief Intelligence, Spanish version: Verbal intelligence score (Kaufman & Kaufman, 2004).
[f] PPVT-III=Peabody Picture Vocabulary Test, Third Edition; Spanish version (Dunn, Dunn & Arribas, 2006).

6.3.2 Materials, stimuli and design

Design of the experimental task

The stimuli for the VSL task were an adaptation of the cartoon aliens used by Arciuli and Simpson (2011). Instead of aliens, we used 18 happy cartoon-like monsters. We chose monsters that did not differ greatly from each other in terms of the emotions they were displaying to avoid use of verbal information about these emotions and ensure the exclusive use of visual information to extract the statistical information embedded in the task. Six of the monsters were used only for instructional purposes during the practice trials and were not used in the learning stream or test phase. The remaining 12 monsters were divided into three groups of three (three base triplets) referred to as ABC, DEF, and GHI (see Figure 9).

For the test phase we created four new triplets called *impossible triplets*. These triplets (GBF, AEI, and DHC) each contained one monster from each of the three base triplets and were not used in the learning stream (see Figure 9). Constructing the impossible triplets in this manner meant that the transitional probabilities of the internal pairs were zero. This contrasts with the transitional probabilities of the base triplets, which were 1.0.

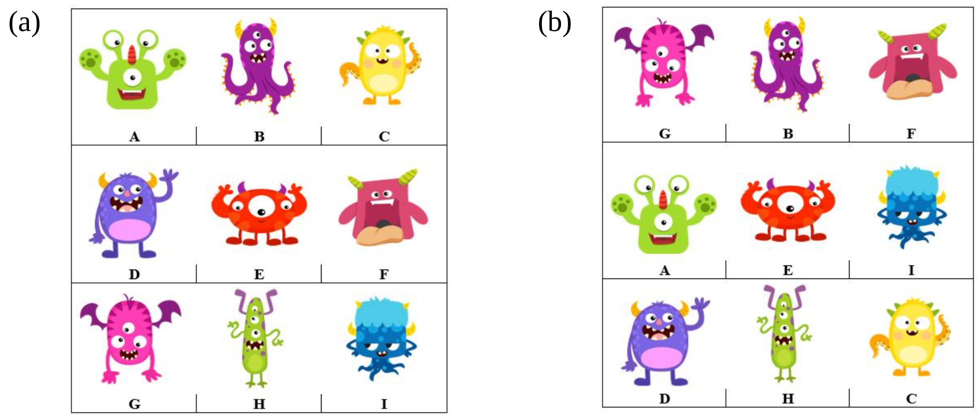

Figure 9. (a) The nine monsters that formed the three base triplets for the learning phase and (b) the same nine monsters reordered to form the three impossible triplets for the test phase.

The experiment consisted of three phases: (1) a practice phase, (2) a learning phase, and (3) a test phase.

The learning phase started with a continuous stream of monsters shown one at a time for 5 minutes and 5 seconds in the center of the display against a black background. Each monster was visible for 800 ms with a black screen interstimulus interval of 200 ms. The monsters were always displayed as part of a base triplet, with all the monsters from a given triplet appearing before any of the monsters from another triplet. The monsters in each triplet were presented in alphabetical order. In the case of triplet ABC, for example, monster A was always displayed before monster B and monster B was always displayed before monster C. Each of the three base triplets appeared in the learning stream 32 times, giving a total of 96 exposures for each triplet.

In the learning phase, the participants were given a cover task to ensure their attention. For six of the 32 instances of each monster, one was presented twice in a row and the children were required to press a button whenever they saw a repeated monster. These repetitions were counterbalanced among the three monsters within each triplet. For example, for base triplet ABC, there were two occurrences of AABC, two occurrences of ABBC, two occurrences of ABCC, and 26 occurrences of ABC. The learning stream thus consisted of 306 individual presentations of the monsters, with each of the nine types of monsters appearing 32 times. The order of the triplets within the learning stream was randomized but with two constraints proposed by Turk-Browne et al. (2005): no repeated triplets (e.g., ABCABC) and no repeated pairs of triplets (e.g., ABCGHIABCGHI). These constraints did not take into consideration repeated monsters and therefore the sequence ABCCABC was still invalid as it was considered to be a repetition of the triplet ABC. We created two different lists to balance the order in which the triplets appeared (see Appendix I).

The practice phase was presented before the learning phase and consisted of a continuous stream of six monsters chosen to test understanding of the instructions. This resulted in 19 presentations. The monsters were not displayed as part of a base triplet. Instead they were presented randomly, one at a time, in the center of the display against a black background. As in the learning phase, each monster was visible for 800 ms with a black screen interstimulus interval of 200 ms. Five of the six monsters were repeated in two consecutive trials to show an example of the cover task that the children would have to perform in the following blocks.

The test phase was composed of two practice trials and 18 test trials. For each test trial, one base triplet was displayed along with one impossible triplet. Children had to decide which of the two triplets had appeared in the same order as in the learning phase. The monsters in each triplet were presented one at a time using the same presentation time and interstimulus interval used in the learning phase. After the six monsters had been presented, a black screen appeared on the computer and the participants had to verbally identify which of the two triplets had previously appeared in the learning phase by saying “one” or “two”. No time constraints were imposed. The experimenter noted down each participant's answers (see Appendix J for the answers template).

Each base triplet was presented with each impossible triplet on six separate occasions with a counterbalanced presentation order. The three base triplets and the three impossible triplets were paired exhaustively to generate an 18-trial, two-alternative forced-choice task (2AFC). Half of the test items contained a base triplet as the first member of a pair and the other half contained an impossible triplet as the first member. Assessment of the same triplet was not allowed in two consecutive trials (e.g., ABC vs. AEI and GKC vs. ABC was not possible). In the 18 test trials, each base triplet and each impossible triple were seen six times. This ensured that if any statistical learning took place during this phase, the opportunities to learn would be equal for both types of triplet (see Appendix K).

Vocabulary assessment

To examine whether sequential VSL was related to vocabulary knowledge, the receptive and expressive vocabulary knowledge of the two groups of children were assessed respectively using the Peabody Picture Vocabulary Test, Third Edition; Spanish version (Dunn, Dunn & Arribas, 2006) and the verbal intelligence score from the Kaufman Brief Intelligence Test, Spanish version (Kaufman & Kaufman, 2004) (see Table 5).

6.3.3 Procedure

The children were presented with a black computer screen and the experimenter introduced the task by saying "We are going to play a game with funny monsters! You have to watch the screen really carefully and when you see two identical monsters in a row, you have to click the space bar as quickly you can. Do you understand?"

The practice trials started with the presentation of the practice monsters in a continuous stream. To ensure the children understood the task, during the practice phase the experimenter was able to reinforce performance with instructions like: "Well, because these two monsters are identical, you clicked the space bar, well done!"

Participants were not able to proceed to the learning phase until all of the practice trials were successfully executed. When the practice phase had finished, the experimenter said: "You did really well! Let's play again but for longer. Remember: When you see two identical monsters in a row, click the space bar as quickly as you can. Are you ready?"

On completion of the learning phase, the experimenter introduced the test phase by saying: "Now we are going to see if you noticed that there were monsters that were often lined up together in groups of three. You are going to see two groups of three monsters in a row: one after the other. I want you to tell me which group of three monsters feels as if they are in the same order as before. If you think it is group 1, say ‘one’, if you think it is group 2, say ‘two’.”

The experimenter was allowed to repeat the full set of instructions if the participant was unclear on what was required. The experimenter clicked on the space bar and the two practice test trials started. After the practice trials, the test phase started with the 18 test trials described in the procedure section.

6.4 Results

General Results

A generalized linear mixed model was applied with accuracy as the dependent variable (Poisson distribution, log link). Accuracy was calculated as the mean proportion of correct responses out of 18 for each group. A random intercept was set for subject within group, and the residual effect of repeated measures was also controlled for. Group (TD, SLI) was set as the fixed factor. The results indicated a main effect for group [$F(1, 208)=5.006$, $\beta=.495$, $p=.026$], indicating that the children with SLI showed significantly less accuracy when it came to exploiting transitional probabilities to discover the triplets embedded in the visual stream (mean=59.04%, SD=15.42% vs. mean=67.29%, SD=15.23% for the TD group) ($p<.05$). The results for the two groups are shown in Figure 10.

Chance was established at 50%. Two single-sample t-tests (two-tailed) calculated for each group individually indicated that both groups performed significantly better than would be expected by chance: $t(34)=3.46$, $p<.01$ for the SLI group and $t(34)=6.71$, $p<.001$ for the TD group.

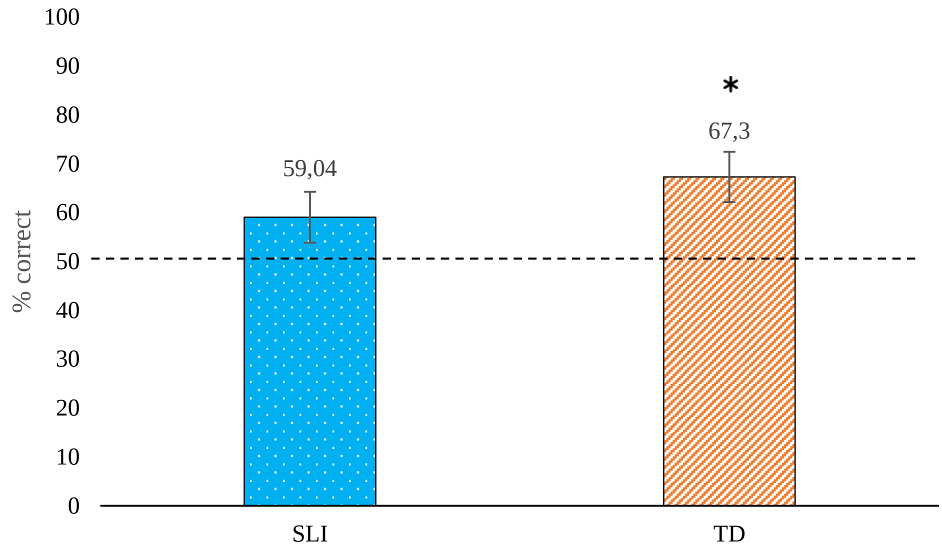

Figure 10. Percentage of correct answers in the visual statistical learning task for the children with specific language impairment (SLI) and typically developing (TD) children.
Mean for SLI group=59.04% (SD=15.42)
Mean for TD group =67.29 % (SD=15.23)
Chance equals 50%.
The error bar reflects 95% confidence intervals around the means.

Individual differences

Although the mean performance rate was significantly above chance for both groups, we calculated the percentage of children who performed above and below chance in each group (see Figure 11). The results showed an above-chance rate of 85.71% for the TD group (below-chance rate=14.28%) and 68.57% for the SLI group (below-chance rate=31.42%).

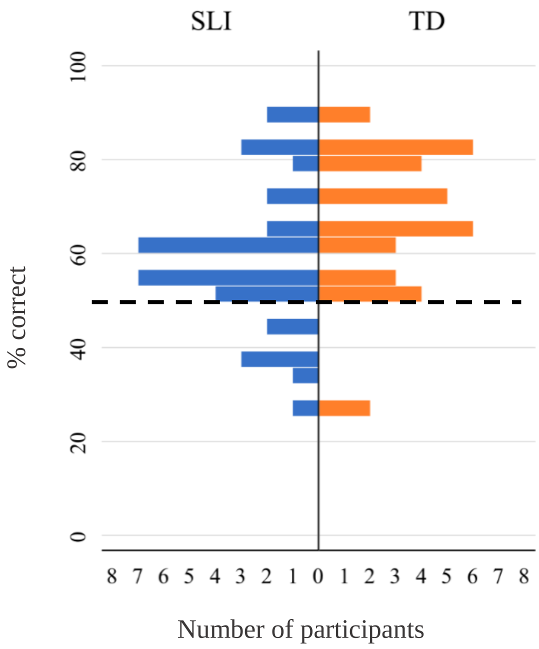

Figure 11. Number of children in the specific language impairment (SLI) and typically developing (TD) group who performed above and below chance in the visual statistical learning task. Chance equals 50%.

Relationship between vocabulary knowledge and VSL task

Correlational analyses

We ran a bilateral correlation analysis between age, IQ, socioeconomic status, VSL score, and expressive and receptive vocabulary scores. We entered age, IQ, and socioeconomic status because they have been shown to impact language acquisition and statistical learning (Dollaghan, et al., 1999; Schuele, 2001). The correlation matrices between age, IQ, socioeconomic status, VSL score and expressive and receptive vocabulary scores are shown in Table 6. The four variables were significantly and positively correlated with expressive and/or receptive vocabulary knowledge as follows: age with receptive vocabulary $r(70)=.57$, $p<.01$; age with expressive vocabulary $r(70)=.63$, $p<.01$; IQ with receptive vocabulary $r(70)=.55$, $p<.01$; IQ with expressive vocabulary $r(70)=.53$, $p<.01$; socioeconomic status with receptive vocabulary $r(70)=.46$, *p*<.01; socioeconomic status with expressive vocabulary *r*(70)=.38, *p*<.01; and VSL with receptive vocabulary *r*(70)=.31, *p*<.05 but not expressive vocabulary *r*(70)=.22, *p*=.07.

Table 6. Correlation matrix for cognitive variables, VSL performance, and vocabulary scores for all study participants.

	IQ	**SES**	**VSL**	**PPVT-III**	**K-BIT-voc**
IQ					
SES	.25*				
VSL	.18	.17			
PPVT-III	.55**	.46**	.31*		
K-BIT-voc	.53**	.38**	.22	.85**	
Age (months)	.51**	.21	.08	.57**	.63**

Note. IQ=non-verbal intellectual quotient; K-BIT voc=verbal intelligence score from the Kaufman Brief Intelligence Test (expressive vocabulary); PPVT-III=Peabody Picture Vocabulary Test (receptive vocabulary); SES= socioeconomic status; VSL=visual statistical learning task.
* *p*<.05. level (two-tailed). ** *p*<.01. level (two-tailed).

Regression analyses

We ran a two-step hierarchical regression analysis to determine whether sequential VSL was a predictor of expressive and/or receptive vocabulary knowledge in children with SLI and TD children. Age, IQ, and socioeconomic status were entered as covariates in step 1 (Model 1) to control for possible effects. The percentage of correct responses in the VSL task was entered in step 2 (Model 2) as a predictor variable. Receptive and expressive vocabulary scores were entered as dependent variables in two separate analyses.

The results for the overall expressive vocabulary model are presented in Table 7a. Age, IQ, and socioeconomic status (Model 1) accounted for unique portions of variance in expressive vocabulary ($R^{2=}$.50, adj. $R^{2=}$.48, *F*(3,66)=22.29, *p*<.001). The follow-up regression analysis revealed that VSL performance (Model 2) also accounted for an additional significant portion of variance ($R^{2=}$.51, adj. $R^{2=}$.48, R^2 change$^{=}$.01, *F* change

(1,65)=1.47, p=.23). The coefficient results corresponding to the predictors of expressive vocabulary knowledge are presented in Table 7b. Age (β=.47, t(66)=4.59, p<.001, pr^2=.24), socioeconomic status (β=.22, t(66)=2.50, p<.05, pr^2=.08), and IQ (β=.23, t(66)=2.28, p<.05, pr^2=079) were significant predictors but VSL was not (β=.11, t(65)=1.21, p=.23, pr^2=.02).

Table 7a. Regression model to predict expressive vocabulary knowledge for all study participants (VSL).

Model	***R***	***R*²**	**Adj *R*²**	***SE* of estimate**	***R*² change**	**F change**	***df* 1**	***df* 2**	**Sig, *F* change**
Model 1	.71	.50	.48	8.11	.55	22.29	3	66	.00**
Model 2	.72	.51	.48	8.08	.01	1.47	1	65	.23

Note. Adj=adjusted; IQ=non-verbal intelligence quotient; SES=socioeconomic status; Sig=significance; VSL=visual statistical learning task.
Model 1 predictors: (constant), Age, SES, IQ.
Model 2 predictors: (constant), VSL * p<.05. ** p<.01. *** p<.001.

Table 7b. Coefficients and significance levels for predictors of expressive vocabulary knowledge (VSL).

Model 1	***Standardized Beta coefficients***	***t***	**Sig.**	***pr*²**
Age	.47	4.59	.00***	.24
SES	.22	2.50	.01*	.08
IQ	.23	2.28	.03*	.07
Model 2				
VSL	.11	1.21	.23	.02

Note. Adj=adjusted; IQ=non-verbal intellectual quotient; SES= socioeconomic status; Sig=significance
VSL=visual statistical learning task.
Model 1 predictors: (constant), Age, SES, IQ.
Model 2 predictors: (constant), ASL. *p<.05. ** p<.01. *** p<.001.

The results for the overall receptive vocabulary model are presented in Table 8a. Age, IQ, and socioeconomic status (Model 1) accounted for unique portions of variance in receptive vocabulary knowledge ($R^{2=}$.51, adj. $R^{2=}$.49, F(3,66)=22.77, p<.001). In the follow-up regression analysis, VSL performance (Model 2) was a significant additional source of variance (R^2=.54, adj. R^2=.51, R^2 change=.03, *F* change (1,65)=4.40, $p<.05$). The coefficient results for the specific predictors of receptive vocabulary knowledge are shown in Table 8b, with significant results found for age (β=.36, $t(66)$=3.57, $p<.001$, pr^2=.16), socioeconomic status (β=.32, $t(66)$=3.58, $p<.01$, pr^2=.16), IQ (β=.28, $t(66)$=2.76, $p<.01$, pr^2=.10), and VSL (β=.18, $t(65)$=2.10, $p<.05$, pr^2=.06).

Table 8a. Regression model to predict receptive vocabulary knowledge for all study participants (VSL).

Model	***R***	***R²***	**Adj *R²***	***SE* of estimate**	***R²* change**	**F change**	***df* 1**	***df* 2**	**Sig, *F* change**
Model 1	.71	.51	.49	21.28	.51	22.77	3	66	.00***
Model 2	.73	.54	.51	20.76	.03	4.40	1	65	.04*

Note. Adj=adjusted; IQ=non-verbal intelligence quotient; SES=socioeconomic status; Sig=significance; VSL=visual statistical learning task.
Model 1 predictors: (constant), Age, SES, IQ.
Model 2 predictors: (constant), VSL. **p*<.05. ** *p*<.01. *** *p*<.001.

Table 8b. Coefficients and significance levels for predictors of receptive vocabulary knowledge (VSL).

Model 1	***Standardized Beta coefficients***	***t***	**Sig.**	***pr²***
Age	.36	3.57	.00*	.16
SES	.32	3.58	.00*	.16
IQ	.28	2.76	.01**	.10
Model 2				
VSL	.18	2.10	.04*	.06

Note. Adj=adjusted; IQ=non-verbal intellectual quotient; SES= socioeconomic status; Sig=significance; VSL=visual statistical learning task.
Model 1 predictors: (constant), Age, SES, IQ.
Model 2 predictors: (constant), VSL. * *p*<.05. ** *p*<.01. *** *p*<.001.

6.5 Discussion

Both children with SLI and TD children were able to track transitional probability information in a VSL task better than expected by chance. The group children with SLI, however, performed significantly worse than their TD peers. These results are similar to those observed for the analogous ASL task in study 1. Statistical learning deficits in children with SLI, therefore, are present in both the auditory and visual domains, indicating that statistical learning deficits in this population are domain-general. Although children with SLI performed above chance overall, more children in this group performed below chance than in the TD group. Individual differences are an important consideration when interpreting the data because children with SLI are well-known to vary in terms of individual strengths and difficulties.

This is the first time that a group of school-age children with SLI have been tested using a visual statistical learning task that is not the most widely used motor-visual SRT task used on this population. Conflicting results, however, have been reported when using this task. In a study conducted by Mayor-Dubois et al. (2012) in which the SRT task was used, they found that the reaction times of the children with SLI were longer and learning slower than in TD controls. However, the learning effect was not significant in children with SLI with an associated Developmental Coordination Disorder (DCD).

One of the aims of our study was to avoid motor abilities in a visual sequential statistical learning task in order to clarify whether visual sequential statistical learning could be caused by motor difficulties. Thus, although the design of the SRT task differs to that of the VSL task conducted in this study, the results presented above are in accordance with those studies that argued that children with SLI show difficulties when solving tasks that require extracting patterns embedded in a visual sequential statistical learning task (e.g., Lum et al., 2010; Hedenius et al., 2011; Lum et al., 2012; Hsu & Bishop, 2014; Lum & Bleses, 2012).

Contrasting with the ASL task performed in study 1, the transitional probabilities between the visual objects that constituted the base triplets for the VSL task were 1.0. The probabilities between the impossible triplets were thus 0 and as a result it was not possible to analyze the potential influence of transitional probabilities within triplets on differences in statistical abilities in both groups. We decided to use absolute transitional probabilities for the VSL task, as we followed the design used by Arciuli and Simpson (2011), who were the first to apply this task in primary school TD children. Our study, thus, was the first to use the task in children with SLI and we wanted to ensure that it was suitable. Now that we know that both groups performed above chance, in future experiments, we plan to alter the transitional probabilities between the visual objects in the base triplets to investigate whether the strength of these probabilities influences how well individual triplets are learned in children with and without SLI.

The behavioral results of the TD children in this study are in the same line as those found in Arciuli and Simpson (2011), which showed that TD school-age children were able to track visual sequential probabilities from the input in the same VSL task used in this study. The group of TD children in our study showed accuracy of 67.9% in the post-test and the TD children in Arciuli and Simpson’s study showed accuracy of 61.3%. They also found that the role of speed of presentation affected the level of performance of VSL among the TD children population. They ran the same task on TD children at three rates of speed (using stimulus durations of 800, 400 and 200 ms). The results showed that although the performance was worse in the faster conditions, all the groups performed the task above chance. Now that this task has been tested on children with SLI, more studies are needed to compare the role of the speed of presentation in this population to prove whether children with SLI have slower related processing speeds (Leonard et al., 2007) when solving statistical learning tasks.

VSL performance was a significant predictor of receptive but not expressive vocabulary knowledge. Although VSL accounted for relatively little variance in the model, it still contributed to a unique portion of additional variance above and beyond other measures (age, IQ, and socioeconomic status) that influence vocabulary knowledge. Contrary to the procedural deficit hypothesis, these results indicate that aspects of vocabulary learning are also supported by the implicit system. We can therefore assume that the ability to implicitly decode pure visual statistical information is a factor in word acquisition. Our findings indicate the need to extend current theoretical models of non-declarative learning in children with SLI beyond the assumption that only procedural sequential learning related to grammar and syntax deficits is impaired in this population.

In summary, the overall results of this second study indicate that although children with SLI were able to use statistical information to implicitly extract embedded information in a visual context from a 5-minute continuous stream, they showed less accuracy than their TD peers in solving the task. Moreover, we found that the ability to track transitional probabilities in a visual segmentation task in Catalan-Spanish children with and without SLI was a significant predictor of receptive but not expressive vocabulary knowledge, showing that statistical learning is also needed to acquire vocabulary, not just grammar.

7. Study 3: Cross-situational statistical learning in Catalan-Spanish children with specific language impairment

7.1 Introduction

Lexical acquisition is a complex cognitive process that requires different steps until words are acquired. The first step required for vocabulary learning is to discover the sounds and phonological structure of the words. Then, words need to be segmented from fluent speech. Saffran et al., (1996) examined the problem of word segmentation and suggested that learners, including infants, may detect word boundaries, in part, by tracking the statistical properties of the sound combinations that they hear. While sequential statistical learning is key to the child's ability to discover the lexical-phonological form from a stream of speech, word learning requires more than just discovering the word form. After learning the phonetic form of the words, the next step for lexical acquisition is to link each word to a visual referent. This process has been investigated by using the fast-mapping mechanism that occurs after a single exposure, or a few exposures, to a new word and involves the acquisition of an initial link between a word and its referent.

A growing body of research has explored whether a different mapping word-learning process exists. This is one mechanism that extends over multiple encounters, trying to simulate an everyday context where the ambiguity and exposure to many different words and possible referents at the same time is usually presented. This research field suggests that humans learn the meaning of words using a cross-situational statistical learning (CSSL) mechanism. Smith and Yu (2007, p.414) argued that "the process to map a phonological form to a visual representation, such as associating the sound "ball" to the object of ball in naturalistic learning environments is supported by a cross-situational statistics learning strategy based on computing distributional statistics across words, across referents, and across the co-occurrences of words and referents at multiple moments". Smith and Yu briefly exposed a group of adults to a set of trials each containing multiple spoken words and multiple pictures of individual objects. There was no information about the correspondence between the word-picture pairs within a trial. In other words, participants did not have information about which spoken word corresponded to which visual object. The participants showed that they learned the word-picture mappings through cross-trial statistical relations because they selected the correct items more often than they would have by chance in an alternative forced choice (AFC) post-test. The authors claimed that statistical learning was the mechanism used to track and update probabilities that co-occurred across trials and maintain multiple hypotheses simultaneously in solving the task.

Different studies have shown successful CSSL in adults (Fitneva & Christiansen, 2011; Yurovsky, Yu, & Smith, 2012; Yu, Zhong & Fricker, 2012), infants (Smith & Yu, 2008) and school-age children (Suanda, Mugwanya, & Namy, 2014). This would suggest that more than one type of statistical word learning may be required to learn words.

Suanda et al. (2014) tested 5- to 7-year-old children's cross-situational learning by presenting children with a 2x2 CSSL task. Children successfully learned word-to-object mappings by observing the co-occurrence regularities across these ambiguous naming events. This study demonstrated that the diversity of learning contexts affected children's performance by manipulating the number of different sets of stimuli with which each word-object pairing co-occurred across the learning trials. Children were divided into three different conditions according to the contextual diversity of the learning environment (high, moderate or low). That means that each contextual diversity condition was created by taking into account that the accompanying word-picture pair for any given word-picture pairing was always different (high condition) or in some cases repeated (moderate and low conditions). Using this design manipulation, the authors could see that children were using the computation of the embedded frequencies to learn that the highest frequencies were correct word-picture matches and to reject the low frequencies.

Kemény and Lukács (2009) were the first authors that investigated whether children with SLI could learn probabilistic categories by testing them with a task that was not built on sequential information. A group of children with SLI and a group of TD children performed a special version of The Weather Prediction Task (Knowlton et al., 1994). They were presented with an image of a combination of one, two or three of four cues (i.e., geometrical shapes) and they had to decide whether the pattern they saw predicted sunshine or rain and had to respond accordingly. As soon as they had made their choice, they were given feedback to show whether they were right or wrong. The task could be solved using different implicit probabilistic computations. Strategy analysis showed that children with SLI were unable to make use of any of the possible probabilistic strategies, and even best-fit strategies seemed to be less efficient and lead to a lower performance for them.

Following the evidence found by Kemény and Lukács (2009), one of the aims of this study was to contribute to see whether bilingual Catalan-Spanish children with SLI can solve a word-mapping non-declarative task that is not sequential in time and to investigate whether non-declarative memory deficits in children with SLI go beyond the procedural sequential memory.

The PDH supports the theory that children with SLI have spared learning in the use of declarative memory to learn words by mapping sounds and meanings but contrary to this, the CSSL task is a mapping task designed to learn new words through statistical learning. For this reason, another aim of the study is to investigate whether a different word-learning process related to the non-declarative learning inherent in the word-mapping strategy and based on computing distributional statistics across words, referents and the co-occurrences of words and referents at multiple moments is affected or not in children with SLI.

Some studies applied an eye-tracker method to record the gazes of the participants over the word-learning part of the CSSL task to see what cognitive process was used while the multiple spoken words and multiple pictures of individual objects were presented in the different trials. In Fitneva and Christiansen's (2011) study, forty undergraduate students were tested with a CSSL task while their looking patterns were recorded. They investigated whether learners who showed more accurate initial word-referent mappings performed better or worse in the post-test than those with fewer accurate initial mappings. To do so, participants were classified as having high or low initial accuracy in their looking patterns depending on the proportion of correct mappings—when participants were looking to the correct visual referent while the corresponding auditory label was presented—in the first learning block. They found that those participants who had worse initial mapping performed better in the final 2AFC, suggesting that when there is a disfluency experience with a cognitive task, there is a tend to engage in more systematic and elaborate processing.

In the study carried out by Yu and Smith (2011), 14-month-old babies were tested with a 2x2 — two spoken words and two visual referents in each learning trial— CSSL task. The nature of the looking patterns during the learning phase of the experiment was assessed by recording the moment-by-moment eye movement data while infants were engaged in the task. Authors wanted to see whether the learners were looking to the correct or incorrect target during the learning phase. They built a simple associative learning model to link fine-grained analyses of looking behavior observed in the experiment to learning measured at post-testing. Infants who showed strong learning in post-testing exhibited a pattern of stable looking across the different learning trials; and over trials, these infants began to look more often to the right referents for the word heard. Conversely, weak learners started the task by showing looking patterns like those of the strong learners, but their looking became more variable within a same trial. They showed short looks and many switches back and forth and they built generally weaker associations; these weaker associations were distributed over many more incorrect pairs.

Ellis, Borovsky, Elmanc and Evans (2015) examined online moment-by-moment processing of novel word learning in 18-month-old TD and late-talking toddlers. Infants were trained on two novel word-picture pairs and were then tested using an adaptation of the looking-while-listening paradigm. The task used in the study was not a CSSL task but rather a visual fast-mapping in which the eye-tracking methodology was applied and the online cognitive process examination was allowed. After infants were presented with a training phase consisting of being presented with two novel label-objects to be learned, repeated one at a time, they were presented with a testing phase in which they were presented with two novel object pictures on the screen. Accuracy in the task was defined by whether a greater proportion of the infant's looking was at the target than at the distractor across the test trials. Eye movement results through the testing phase showed that both groups had similar overall learning of the novel words. However, further analysis showed that the point of divergence between target and distractor objects was different for each group. The late-talker group had an initial overlap of looking to both the target and the distractor but did not show a significant distinction between the two pictures, while the typical group initially showed more separation in looking to the two pictures and ultimately distinguished the target-word picture at an earlier time point. Further, the moment-by-moment processing in the time-course plots revealed emerging group differences in the mean proportion of time spent fixating during the test trials with typical infants spending a greater proportion of time fixating on the target. These results suggested that there might be emerging differences between late talkers and TD toddlers in learning and interpreting novel words.

In the following study we recorded the eye movements of children with SLI and of TD children while they performed the CSSL task to explore whether the online cognitive processes of both groups differ when learning new words implicitly in an ambiguous context.

7.2 Specific aims and hypotheses

Aims

In the following study, we wanted to contribute more evidence to the audio-visual SL research field focused on the population with SLI. Specifically, investigated whether bilingual Catalan-Spanish children with SLI can solve a word-mapping statistical learning task that is not sequential in time. We explored whether the performance of a CSSL task is similar for school-age bilingual Catalan-Spanish children with SLI as compared to age-matched TD children controls.

Moreover, we explored the possible contribution of CSSL to the children's vocabulary knowledge: we kept investigating whether non-declarative learning impairments in children with SLI may also result in vocabulary impairments related to the process of mapping one word to one specific object rather than only focusing on the process of finding the word boundaries within one auditory stream, as has been proven in study 1 of this dissertation.

The aim of monitoring participants' eye movements in this study was to investigate whether children with SLI and TD children show differences in their moment-by-moment visual attention pattern while performing a cross-situational statistical learning task.

Hypotheses

According to the PDH, this kind of task could be successfully solved by children with SLI to the same degree as by TD children because it involves lexical learning and assumes that only procedural sequential learning related to grammar and syntax deficits is impaired in this population. Contrary to the PDH, the hypothesis of this study is that TD children should be better at solving CSSL tasks than children with SLI. We expect that TD children will show significantly higher accuracy in the task compared to children with SLI. Moreover, we expect that children with SLI but not TD children will show a chance-level performance in a task that requires the ability to compute distributional statistics across words, referents and the co-occurrences of words and referents at multiple moments by using a word-mapping strategy. Furthermore, we expect that the group of TD children but not the group of children with SLI will use the embedded variability frequencies of the task to learn that the highest frequencies correspond to a correct word-picture match and reject the low frequencies as incorrect word-picture pairs.

If we find that CSSL accounts for significant variance in vocabulary knowledge, we will have provided further evidence to suggest that children with SLI have non-declarative memory deficits that go beyond the procedural learning syntax problems proposed by the PDH.

Since we expect to find that TD children will show significantly higher accuracy in the task compared to children with SLI, we also expect to find different online cognitive processes during the learning and testing phases of the task. That is, we expect to see the TD group show a higher proportion of looks to the target, i.e., more looks to the visual object that represents the spoken word in a specific temporal time window, than the SLI group. Another way to find differences between groups is in terms of time in addition to magnitude. That means that we may find that both groups will show a similar pattern of looks but the effect will emerge later on in children with SLI (i.e., children with SLI will be slower when showing the correct looks to the target in comparison to the TD children).

7.3 Methodology

7.3.1 Participants

Seventy-six children (24 girls, 52 boys), 38 children with SLI (mean age=8.7 years; SD=1.10 years, range=5.6-12.11 years), and 38 age- and gender-matched TD children (mean age=8.9 years-old; SD=1.10 years, range=5.7-12.9 years) were included in the study. All the children met the inclusion criteria for their group. The results of the corresponding tests are given in Table 1. Socioeconomic status, calculated from the data provided in the background information questionnaire, was controlled for in the analyses.

Table 9. Age and standardized scores for language and cognitive assessment measures for children with specific language impairment (SLI) and typically developing (TD) children (study 3 and study 4).

	SLI (n=38)			**TD (n=38)**			**Comparison**	
Variable	***Mean***	***SD***	***Range***	***Mean***	***SD***	***Range***	**t(74)**	***p***
Age in months	103.15	21.82	66-155	105.47	21.95	67-153	-.46	*p*=.64
K-BIT mat (IQ)[a]	99.28	11.52	82-119	103.36	9.41	88-125	-1.69	*p*=.09
CELF- CLS[b]	73.31	10.84	45-89	108.68	5.9	95-125	17.65	***p*<.01**
CELF- ELS[c]	73.60	8.60	52-87	108.42	7.83	89-128	-34.81	***p*<.01**
CELF -RLS[d]	78.73	10.83	59-100	105.57	6.04	94-118	13.33	***p*<.01**
K-BIT voc[e]	78.28	12.16	53-105	106.23	10.25	83-127	-10.82	***p*<.01**
PPVT-III[f]	78.57	12.50	55-106	106.47	12.13	83-127	-9.86	***p*<.01**

Note. For each variable, age-scaled scores have a mean of 100 and an SD of 15 (except age in months).
[a] K-BIT mat=Kaufman Brief Intelligence, Spanish version: Non-verbal intelligence score (Kaufman & Kaufman, 2004)
IQ=non-verbal intellectual quotient
[b] CELF-4 CLS=Spanish Clinical Evaluation of Language Fundamentals, Fourth Edition: Core Language score (Semel, Wiig & Secord, 2006).
[c] CELF-4 ELS=Spanish Clinical Evaluation of Language Fundamentals, Fourth Edition: Expressive Language score (Semel, Wiig & Secord, 2006).
[d] CELF-4 RLS=Spanish Clinical Evaluation of Language Fundamentals, Fourth Edition: Receptive Language score (Semel, Wiig & Secord, 2006).
[e] K-BIT voc=Kaufman Brief Intelligence, Spanish version: Verbal intelligence score (Kaufman & Kaufman, 2004)
[f] PPVT-III=Peabody Picture Vocabulary Test, Third Edition, Spanish version (Dunn, Dunn & Arribas, 2006)

7.3.2 Materials, stimuli and design

Apparatus

The stimuli were presented in a format of 800 x 600 pixels and they appeared on the integrated 17" TFT monitor of the *Tobii T120 Eye Tracker* at a horizontal distance of approximately 22" from the eyes of the participant. Both the presentation of the stimuli and the collection of the eye movement data were carried out using *Tobii Studio* software. At the beginning of the experiment a calibration of 20 sec was carried out in order to validate the tracking and registration of the eye movement.

Stimuli

The stimuli for this study was adjusted following the design used by Suanda et al. (2014), adapting a CSSL task (Yu & Smith, 2007) to render the task suitable for young children. Eight recorded bi-syllabic CV-CV non-words paired with eight pictures of robot-cartoons resulting in eight to-be-learned word-object pairs were included for the learning phase. The new words were bi-syllabic and recorded by a native Catalan-Spanish speaker (pimo, lasi, zepi, rile, teco, mepo, buna and datu). The eight pictures to be learned were funny robots (see Figure 12). Four additional novel word-object pairings were used for the practice phase (bose, sime, coti, fela) (see Figure 13).

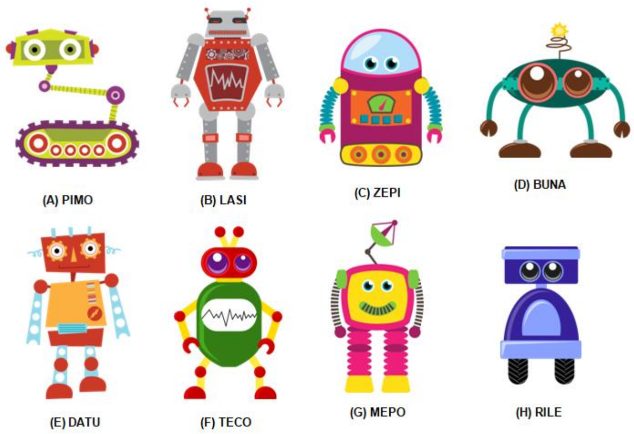

Figure 12. The eight to-be-learned word-object pairs used in the learning phase.

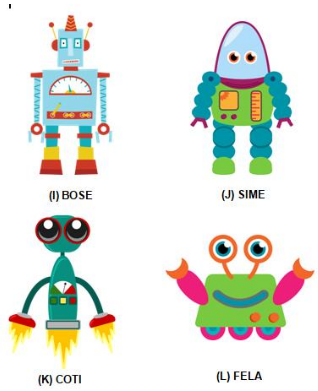

Figure 13. The four word-object pairs used in the practice phase.

One learning trial was composed of the presentation of two spoken word forms and two potential referents (within-trial ambiguity=2x2) with no information about which word was related to which referent. Half the learning trials were presented in a normal condition, which means the first spoken word was represented in the visual object situated on the left side of the screen and the second spoken word was represented in the visual object situated on the right side of the screen. The other half of the learning trials were presented in a cross condition, meaning that the first spoken word was represented in the visual object situated on the right side and the second spoken word was represented in the visual object situated on the left side (see Figure 14). Each word-object pair occurred in four trials (word-referent frequency=4) throughout the learning phase (see Appendix L). Thirty-two instances of word-object pairings were presented two at a time in each trial. The learning phase therefore consisted of 16 total learning trials.

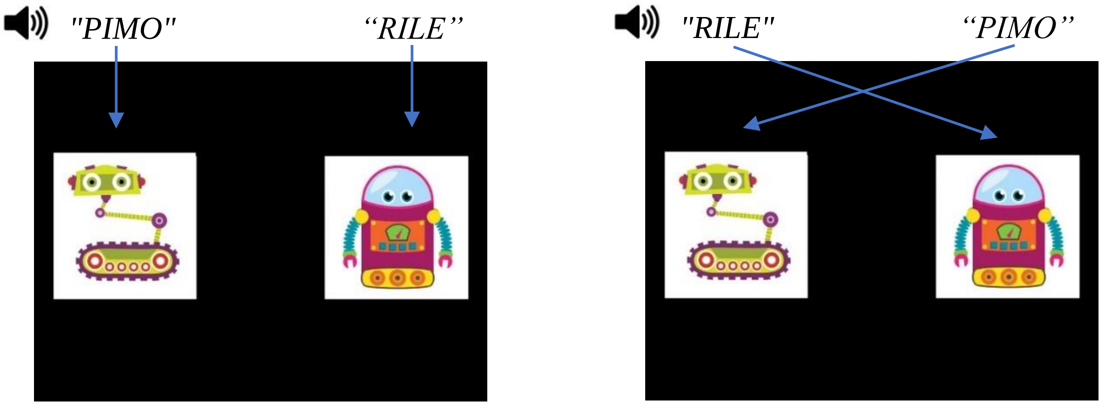

Figure 14. (a) Example of one learning trial in a normal condition and (b) example of a learning trial in a cross condition. The blue arrows indicate the visual objects that represent each spoken word.

Contextual diversity refers to the number of different pairs a particular word-object pair is presented with across the trials. The condition used in this study is a moderate level of contextual diversity, which follows the design of Suanda et al., (2014) and assesses both the learning of the associations as well as the strength of the representations. Therefore, over the 16 trials, each word-object pair co-occurred with one word-object pair in two trials, and two different word-picture pairings on the other two trials (see Figure 15).

	(a) PIMO	(b) LASI	(c) ZEPI	(d) BUNA	(e) DATU	(f) TECO	(g) MEPO	(h) RILE
A	4	2	1	1				
B	2	4	1	1				
C	1	1	4	2				
D	1	1	2	4				
E					4	2	1	1
F					2	4	1	1
G					1	1	4	2
H					1	1	2	4

Figure 15. Contextual diversity in the CSSL task: total frequencies of the co-occurrences between the spoken words (columns) and the visual objects (rows).

To test how well the participants had learned the names of the eight robot-objects, they were instructed to select the visual referent from four alternatives (4AFC) over 16 test trials, considering that each word was assessed twice. The four different alternatives in the 4AFC consisted of three foil elements: (1) The target—which was the correct visual object paired with the presented spoken word; (2) two competitors—which included the strong competitor that had co-occurred with the target word in two of the four learning trials (50% of the presentations)—and the weak competitor—which had co-occurred with the target word only once during the learning phase (25% of the presentations); and (3) one distractor—which had never co-occurred with the target word during the learning phase (0% of the presentations) (see Figure 16). The location of the four visual options in the test trials was randomized over the trials (see Appendix M).

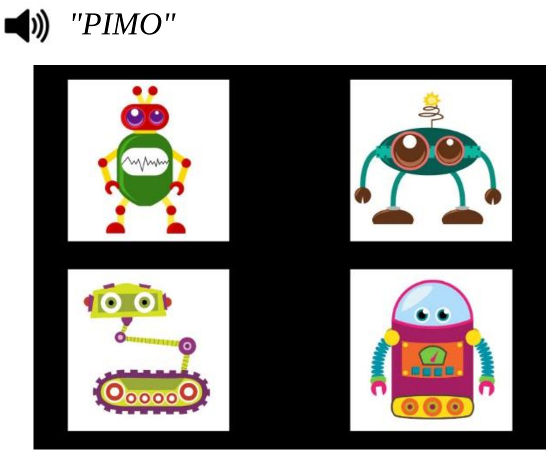

Figure 16. Example of one of the test trials in the 4AFC. The auditory word “PIMO” was heard. The participants saw 4 visual objects on the screen while hearing the spoken word. One of the objects is the target—the visual object paired with the spoken word. Another one is one object that had appeared with the target twice in the learning phase. Another one is one object that had appeared with the target only once in the learning phase and the last one is an object that had never appeared with the target in the learning phase.

7.3.3 Procedure

Practice phase

The goal of the practice phase was to introduce children to the experimental settings and to engage children in play that consisted of learning the name of a happy dog's new robot toys. The experimenter showed the participants a picture of the happy dog on the screen and said: "*This is Bobby and he is really happy because he has new robot toys! We are going to learn the names of his robots! Look! These are Bobby's new funny robot toys!"*

Then, a picture of the twelve toys appeared on the screen simultaneously (the eight to-be-learned pictures and the four additional practice robots). The experimenter said: "*Ok, now you are going to hear all the names of the new toys"*. Immediately, an audio recording of the twelve novel words that corresponded to each of the pictures was played in a random order while a black screen was presented. Consecutively, a yellow smiley face appeared on the screen and the experimenter said: *"Ok, now we are going to learn which name goes with each robot. First you will see a green dot. Click on the green dot to see a picture of the toy and hear its name"*. Two practice trials in a row were presented, both starting with a green fixation point in the middle of the screen that had to be clicked. After the participant's click, one practice robot object was presented on the screen. After 1000 ms the corresponding word for the object was played ("coti" for the first practice trial and "fela" for the second one). A yellow smiley face appeared on the screen and the experimenter said: "*Let's see if you learned the names of these new toys! You will see a picture with four of the new toys. When you see the green dot, I want you to click on it, then I want you to click on the picture of the toy that was named. I want you to click on the picture of that toy as quickly as you can. Are you ready to try some?"*

The two practice test trials then commenced. Both trials consisted of a presentation of four objects on the screen followed by the playing of an auditory word. Participants had to click on the object they thought was the auditory word presented. When the participant clicked on one of the options the trial finished automatically and the next practice test trial began. During these two practice test trials the experimenter was allowed to reinforce the child's performance through comments and verbal feedback.

Learning phase

When the participant was ready to start the task, the experimenter introduced the learning phase by showing a picture of Bobby and saying: *"Okay! You did it very well! Now we are going to learn all the names of Bobby's new robots! Just like before, you are going to click on the green dot to hear the names of the toys. Are you ready?"*

The 16 learning trials then commenced. Each trial began with a green fixation point in the middle of the screen that had to be clicked on. After that, the two images were presented side by side on the screen simultaneously (see Figure 14). One second later, the two words were played consecutively with a 750 ms silence between them. The 16 trials that comprised the learning phase all finished with a smiley face appearing on screen. The experimenter then introduced the test phase in the same way as in the practice trials.

Test phase

The test phase consisted of the same procedure as in the practice test trials but was composed of the 16 test trials. During the test trials, the experimenter was not allowed to provide any feedback or reinforcement while the participant was making his or her choices. The experimenter noted down the child's performance on a sheet (see Appendix N).

Eye-tracking data

To discover the moment-by-moment online cognitive process that both groups exhibited when presented with a cross and ambiguous lexical mapping task, we relied on the proportion of looks as an index of the direction of visual attention. For this purpose, eye position data obtained from the Tobii Studio software were used to calculate the proportion of looks made by participants at the target and competitor pictures, as defined by areas of interest corresponding to the location and size of the displayed pictures during two temporal time windows.

Vocabulary assessment

To examine whether CSSL was related to vocabulary knowledge, the Peabody Picture Vocabulary Test, Third Edition; Spanish version, PPVT-III (Dunn, Dunn & Arribas, 2006) and the verbal intelligence score from the Kaufman Brief Intelligence Test, Spanish version (K-BIT) (Kaufman & Kaufman, 2004) were also administered to both groups to assess their receptive and expressive vocabulary, respectively (see Table 9).

7.4 Results

General results

A Generalized Linear Mixed Model was applied with accuracy as the dependent variable (Binomial distribution, Logit link). A random intercept was set for Subject within group, and the residual effect of repeated measures was also controlled. Group (TD, SLI) was set as a fixed factor. The results indicated a main effect of group, [$F(1, 1214)=4.721$, β =.115, p<.05] indicating that the group of children with SLI was significantly less accurate (M=37.01%; SD=17.46) than the TD group (M=47.70%; SD=24.59) (p=.029). The results for the two groups (TD and SLI) are presented in Figure 17.

For each child, we computed the proportion of test trials answered correctly. Chance equals 25%. Single-sample t-tests (two-tailed) calculated for each group individually indicated that both groups performed significantly better than would be expected by chance: SLI, *t*(37)=4.23, *p*<.01, TD group, *t*(77)=5.53, *p*<.001.

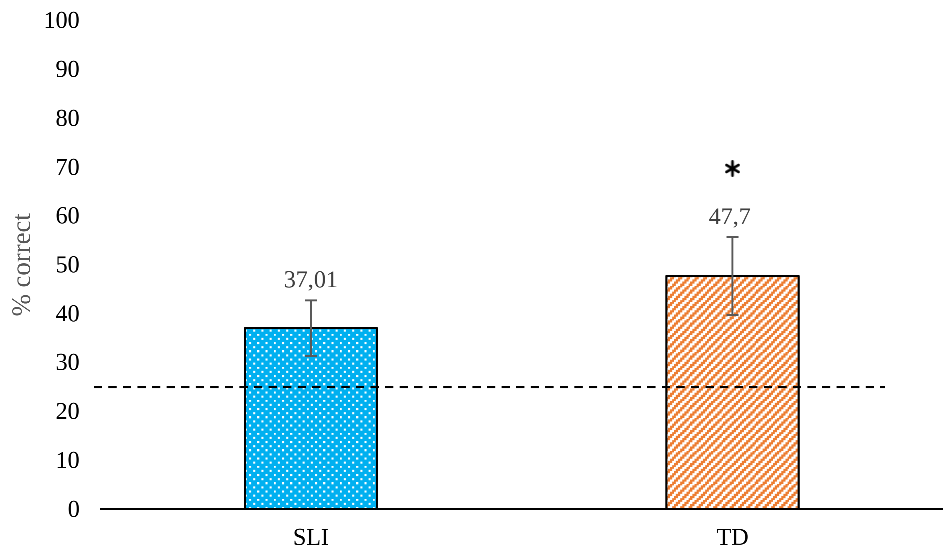

Figure 17. Percentage of correct answers in the CSSL task for the group of children with specific language impairment (SLI) and the group of typically developing (TD) children.
Mean performance in the SLI group=37.01% (*SD*=17.46)
Mean performance in the TD group=47.7 % (*SD*=24.59)
Chance equals 25%
The error bar shows the 95% confidence intervals around the means.

Individual differences

Although the mean performance rates were significantly above chance for both groups, we explored specific behaviors within the groups by calculating the percentage of children who performed above and below chance in each group (see Figure 18). In the TD group, 73.68% of children performed above chance while just 26.36% performed below chance. The respective rates for the SLI group were 65.75% and 34.21%.

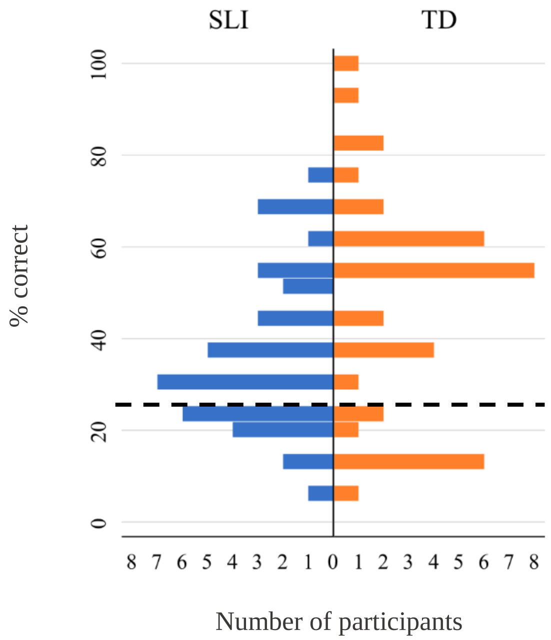

Figure 18. Number of children in the specific language impairment (SLI) and typically developing (TD) groups who performed above and below chance in the cross-situational statistical learning task. Chance equals 25%.

Contextual diversity results

We also examined the nature of the children's response patterns, investigating the extent to which the item selected in each test trial reflected the co-occurrence frequency between the target word and each of the three foil elements in that trial. Suanda & Namy (2002) and Vouloumanos (2008) demonstrated that there was a relation between frequency of co-occurrence and item selection: the more frequently a word and picture co-occurred during learning, the more often that picture was selected during testing. Those findings suggested that children's mappings reflect the statistical structure of the learning environment.

To investigate the effect of the competitors and distractor during the learning phase based on their selection in the test phase, a Generalized Linear Mixed Model was run over the two types of foil elements (the two competitors and one distractor), with the number of recalled elements (Poisson distribution and Log link) as the dependent variable. A random intercept was set for Subject within group, and the residual effect of repeated measures was also controlled. Group (TD, SLI), competitor and foil element (strong competitor, weak competitor and distractor) and their paired interaction were set as fixed factors. The results are presented in Figure 19.

The two main effects were found to be significant. First, group, [$F(1, 222)=7.724$, $\beta=.717$, $p<.01$], indicated that the group of children with SLI obtained more recalls related to foil elements than the TD group ($p<.01$). Second, Foil element, [$F(2, 222)=13.625$, $p<.001$], indicated that the distractor obtained less responses than both the strong competitor ($\beta=1.318$, $p<.001$) and the weak competitor ($\beta=1.260$, $p<.001$), but no significant difference between strong competitor and weak competitor were found ($\beta=.058$, $p=.846$).

Finally, the interaction group × foil element can only be read in terms of a trend, [$F(2, 222)=2.347$, $p=.098$], which would suggest that the group of children with SLI provided more responses than the TD group only for the distractor ($\beta=1.028$, $p<.01$), but not for the strong competitor ($\beta=.138$, $p=.757$) or the weak competitor ($\beta=.742$, $p=.095$).

The TD group preferred the strong competitor and the weak competitor over distractor 3 (strong competitor vs. distractor: $\beta=1.704$, $p<.001$); weak competitor vs. distractor: ($\beta=1.363$, $p<.001$), with no significant difference between the strong competitor and the weak competitor ($\beta=.341$, $p=.406$). The group of children with SLI preferred the weak competitor over the distractor ($\beta=1.077$, $p<.05$), with no significant difference between the strong competitor and the other two levels of the variable (strong competitor vs. weak competitor: $\beta=-.263$, $p=.548$; strong competitor vs. distractor: $\beta=.814$, $p=.091$).

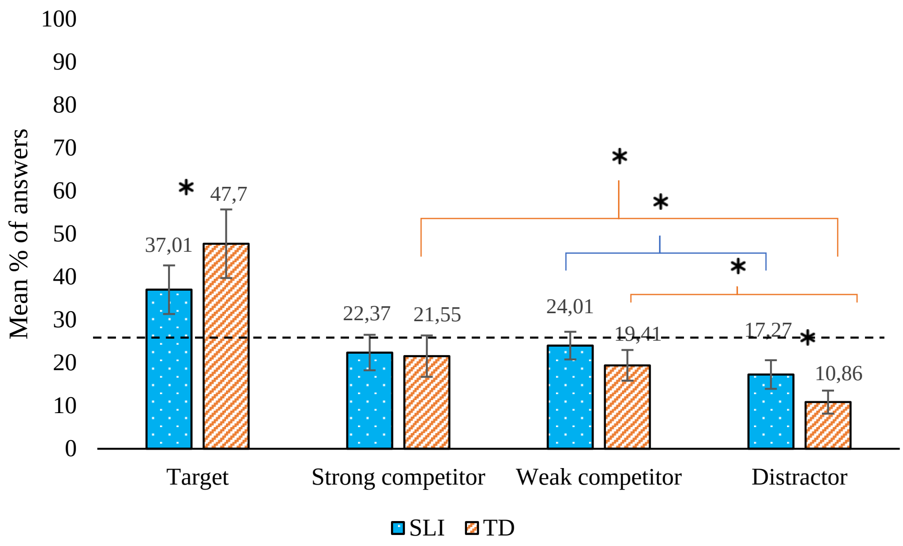

Figure 19. Distribution of answers in the CSSL task to objects in the test phase differing in co-occurrence frequency with target word.
Chance equals 25%
The error bar shows the 95% confidence intervals around the means.

Relationship between vocabulary knowledge and CSSL scores

Correlational analyses

We ran a bilateral correlation analysis between age, IQ, socioeconomic status, CSSL score, and expressive and receptive vocabulary scores. Age, IQ, and socioeconomic status were chosen because they have been shown to impact language acquisition and statistical learning (Dollaghan, et al., 1999; Schuele, 2001). The correlation matrices between age, IQ, socioeconomic status, CSSL score, and expressive and receptive vocabulary scores are shown in Table 10. The four variables were significantly and positively correlated with expressive and receptive vocabulary scores, as follows: age with receptive vocabulary $r(76) = .66$, $p<.01$, age with expressive vocabulary $r(76) = .71$, $p<.01$, IQ with receptive vocabulary $r(76) = .58$, $p<.01$, IQ with expressive vocabulary $r(76)=.58$, $p<.01$, socioeconomic status with receptive vocabulary $r(76) = .45$, $p < .01$, SES with expressive vocabulary $r(76)=.44$, $p<.01$, CSSL with expressive vocabulary $r(76)=.24$, $p<.05$, but not with receptive vocabulary $r(76)=.16$, $p=.17$.

Table 10. Correlation matrix for the cognitive variables, CSSL task and vocabulary scores for all study participants.

	IQ	SES	CSSL	PPVT-III	Kbit-voc
IQ					
SES	.19				
CSSL task	.02	-.04			
PPVT-III	.58**	.45**	.16		
Kbit-voc	.58**	.44**	.24*	.86**	
Age (months)	.65**	.19	.09	.66**	.71**

Note. CSSL=cross-situational statistical learning task; IQ=non-verbal intellectual quotient; K-BIT voc=verbal intelligence score from Kaufman Brief Intelligence Test (expressive vocabulary); PPVT-III=Peabody Picture Vocabulary Test (receptive vocabulary); SES=socioeconomic status.
* $p<.05$. level (two-tailed). ** $p<.01$. level (two-tailed).

Regression analyses

We ran a two-step hierarchical regression to determine whether CSSL performance was a predictor of expressive and/or receptive vocabulary knowledge in children with SLI and TD children. Age, IQ and socioeconomic status were entered as covariates in step 1 (Model 1) to control for possible effects. The rate of correct responses in the CSSL task was added as a predictor in step 2 (Model 2). Receptive and expressive vocabulary scores were entered as dependent variables in two separate analyses.

The results for the overall expressive vocabulary model are presented in Table 11a. Age, IQ and socioeconomic status (Model 1) accounted for unique portions of variance in expressive vocabulary, (R^2=.56, adj. R^2=.54, $F(3,71)=30.32$, $p<.001$). The follow-up regression analysis revealed that the CSSL variable (Model 2) was a significant source of additional variance (R^2=.60, adj. R^2=.58, R^2 change=.04, F change (1.70)=6.98, $p<.01$). The coefficient results showing the specific predictors of expressive vocabulary knowledge are shown in Table 11b. Age (β=.56, t(71)=5.48, p<.001, pr^2=.29), socioeconomic status (β=.22, t(71)=2.69, p<.01, pr^2=.09) and CSSL performance (β=.20, t(70)=2.64, p < .05, pr^2=.09) were all significant predictors. IQ, by contrast, was not (β=.16, t(71)=1.56, p=.12, pr^2=.03).

Table 11a. Regression model to predict expressive vocabulary knowledge for all study participants (CSSL).

Model	***R***	***R²***	**Adj *R²***	***SE* of estimate**	***R²* change**	**F change**	***df* 1**	***df* 2**	**Sig, *F* change**
Model 1	.75	.56	.54	7.60	.56	30.32	3	71	.00***
Model 2	.78	.60	.58	7.29	.04	6.98	1	70	.01**

Note. Adj=adjusted; CSSL=cross-situational statistical learning task; Sig=significance
Model 1 predictors: (constant), Age, socioeconomic status, IQ
Model 2 predictors: (constant), CSSL. * p<.05. ** p<.01. *** p<.001.

Table 11b. Coefficients and significance levels for predictors of expressive vocabulary knowledge (CSSL).

Model 1	***Standardized Beta coefficients***	***t***	**Sig.**	***pr²***
Age	.56	5.48	.00***	.29
SES	.22	2.69	.01**	.09
IQ	.16	1.56	.12	.03
Model 2				
CSSL	.20	2.64	.01*	.09

Note. Adj=adjusted; CSSL= cross-situational statistical learning task; IQ=non-verbal intellectual quotient; SES=socioeconomic status; Sig=significance.
Model 1 predictors: (constant), Age, SES, IQ
Model 2 predictors: (constant), CSSL task. * p<.05. ** p<.01. *** p<.001.

The results for the overall receptive vocabulary model are shown in Table 12a. Age, IQ, and socioeconomic status (Model 1) accounted for unique portions of variance in receptive vocabulary knowledge, (R^2=.56, adj. R^2=.55, F(3,71)=30.75, p<.001). The follow-up regression analysis revealed that CSSL performance (Model 2) did not account for significant additional variance (R^2=.58, adj. R^2=.56, R^2 change=.02, F change (1.70)=2.91, p=.09). The coefficient results showing the specific predictors of receptive vocabulary knowledge are shown in Table 12a. Age (β=.45, t(71)=4.45, p<.001, pr^2=.22), socioeconomic status (β=.32, t(71)=3.95, p<.01, pr^2=.18) and IQ (β=.20, t(71)=2.17, p<.05, pr^2 =.06) were all significant predictors. CSSL performance, in contrast, was not

Table 12a. Regression model to predict receptive vocabulary knowledge for all study participants (CSSL).

Model	***R***	***R²***	**Adj *R²***	***SE* of estimate**	***R²* change**	**F change**	***df* 1**	***df* 2**	**Sig, *F* change**
Model 1	.75	.56	.55	19.99	.56	30.75	3	71	.00***
Model 2	.76	.58	.56	19.72	.02	2.91	1	70	.09

Note. Adj=adjusted; CSSL=cross-situational statistical learning task; Sig=significance
Model 1 predictors: (constant), Age, socioeconomic status, non-verbal intellectual quotient
Model 2 predictors: (constant), CSSL task. *p<.05. **p<.01. ***p<.001.

(β =.13, t(70 =1.17, p=.09, pr^2=.04).

Table 12b. Coefficients and significance levels for predictors of receptive vocabulary knowledge (CSSL).

Model 1	***Standardized Beta coefficients***	***t***	**Sig.**	***pr²***
Age	.45	4.45	.00**	.22
SES	.32	3.95	.00**	.18
IQ	.20	2.17	.03*	.06
Model 2				
CSSL	.13	1.70	.09	.04

Note. Adj=adjusted; CSSL= cross-situational statistical learning task; IQ=non-verbal intellectual quotient; SES=socioeconomic status; Sig=significance.
Model 1 predictors: (constant), Age, SES, IQ
Model 2 predictors: (constant), CSSL * p<.05. ** p<.01. *** p<.001.

Eye tracking results

- Learning phase

Two areas of interest corresponding to the location and size of the displayed pictures (i.e., the target and competitor) were defined using the Gaze analyzer software. This software provides the participants' gaze location at both the horizontal and vertical axes at a sample rate of 120 Hz (approximately every 8 ms). Consequently, it was possible to determine, for each gaze sample, whether it was located inside any of the areas of interest.

It takes approximately 200 ms to plan and launch an eye movement in response to an auditory cue (Viviani, 1990). Consequently, critical time windows begin 200 ms after the onset of a word. Two temporal time windows of 800 ms were created for the learning phase of the task: (1) The first time window (window 1) starts 200 ms after the onset of the first spoken word and ends with the onset of the second spoken word in the same trial (1000 ms after word onset). The second window (window 2) started 200 ms after the onset of the second spoken word in a trial to 1000 ms after word onset.

Because one learning trial was composed of the presentation of two spoken word forms and two potential referents, each visual object in every trial had a different role according to the two previously defined time windows, that is, according to the first or second spoken word presented in every trial. The first word participants heard (time window 1) referred to one of the visual objects that could be on the right side or on the left side of the screen. Thus, the visual object that was referred to by the first word took the "target" role and the other object that was not referred to took the "competitor" role while the first word was heard. The same visual objects had the opposite roles during the spoken presentation of the second word (time window 2).

Statistical analysis – General analysis learning phase

Using the R Project software (R Core Team, 2018), steps of one ms were inspected per participant and trial for each of these time windows. A value of 1 was given to the area of interest that the participant was fixating on at each time step. The sum of the looks and the proportion of looks (number of looks to an area of interest/total number of looks) was calculated per participant on a trial basis for the two areas of interest (the target and the competitor). To visualize the proportion of looks of both groups to the target and competitor during window 1 (first word) and window 2 (second word) over the 16 learning trials, see Figure 21.

For statistical analysis, the log-transformed proportion of looks ratio between the target and the competitor (log-ratio, see Arai, Van Gompel & Scheepers, 2007) was computed per participant and per trial. To obtain the log-ratio, we divided the proportion of looks towards the target plus a constant value (i.e., 1) by the proportion of looks towards the competitor plus that constant. Thus, positive values represent the preference towards the target, while negative values represent the preference towards the competitor in the log-transformed scale. Whether these values significantly depart from zero will be determined, at each point of time, by whether the preference observed is significant.

Inferential analysis was conducted using linear mixed-effects regressions (henceforth LMER) with the *lme4* package (Bates, Maechler, Bolker & Walker, 2015). This multilevel approach is an alternative to by-participants by-items separated analysis (F1, F2 analyses) because it can include crossed random predictors for participants and items in a single analysis. In addition, LMER analysis can model the random variation of participants and items around the predictors. This characteristic is particularly valuable in the context of psycholinguistics data due to the known intrinsic variation of participants and items added to that of the experimental manipulation (see Clark, 1973). Finally, LMER models are robust against missing values as they do not assume data homoscedasticity and sphericity (Baayen, Davidson & Bates, 2008).

In recent years, psycholinguistic research has adopted the use of fully specified models, that is, the inclusion of the maximal random effects structure justified by the design (see Barr, Levy, Scheepers & Tily, 2013). However, some authors have recently warned against the overfitting of the data in the use of LMER (see Matuschek, Kliegl, Vasishth, Baayen & Bates, 2017). For the present data, we began using maximal structure and simplified it whenever the model did not converge, as per the recommendations given in Barr et al. (2013).

We compared the experimental group (SLI) against the group of TD children with time window (1 and 2) as a factor. The analysis used a deviation contrast for the time window factor and a treatment contrast for the comparison between the two groups. This coding scheme compares the mean of both time windows for the reference group (i.e., SLI group) against the other group (i.e., the TD group). This meant that in the analysis, the intercept of the model represented the mean log-ratio proportion of looks difference between target and competitor for the group of children with SLI. The coding was accomplished by assigning 0 to the reference level and 1 to the other group. Time window factors were coded as -1 and 1.

The LMER structure of the first analysis included the fixed factors of participants' group as the between-subject predictor, time window as the within-subject predictor and the interaction between them. It also included random intercepts for participants and items, a random slope of time window for subjects, group and their interaction for items.

Results – General results learning phase

The LMER results from the first general analysis (estimates, standard error of the mean, t-values, and p-values) are presented in Table 13. They show that, overall, the group of children in the SLI group did not prefer the target object to the competitor (=-.001, *se*=.012, *t*=-.1405, *p*=.889). Moreover, the results revealed that there were no differences in the proportion of looks between the group of children with SLI and TD children (*β*=.010, *se*=.017, *t*=.580, *p*=.564). Similarly, the time window did not differ between the groups (*β*=.010, *se*=.011, *t*=1.316, *p*=.192). Finally, the LMER showed that there was no significant interaction effect between groups and the proportion of looks between time windows 1 and 2. This reflects that no advantage was observed for the TD children when looking to the target during any of the two windows throughout the learning phase. The log-ratio values are presented in Figure 20 for both groups and windows. In summary, there was no preference for any of the targets or competitors for either of the groups and no group differences were found.

Table 13. Main and interaction effects in the linear mixed-effects regression on log-transformed proportion of looks ratios between target and competitor throughout the learning phase.

Effect	***β***	***se***	***t*-value**	***p*-value**
Intercept (children with SLI)	-.001	.012	-.140	.889
Group	.010	.017	.580	.564
Time window	.010	.011	1.316	.192
Group*time window	.005	.015	.347	.729

**p*<.05. ***p*<.01.

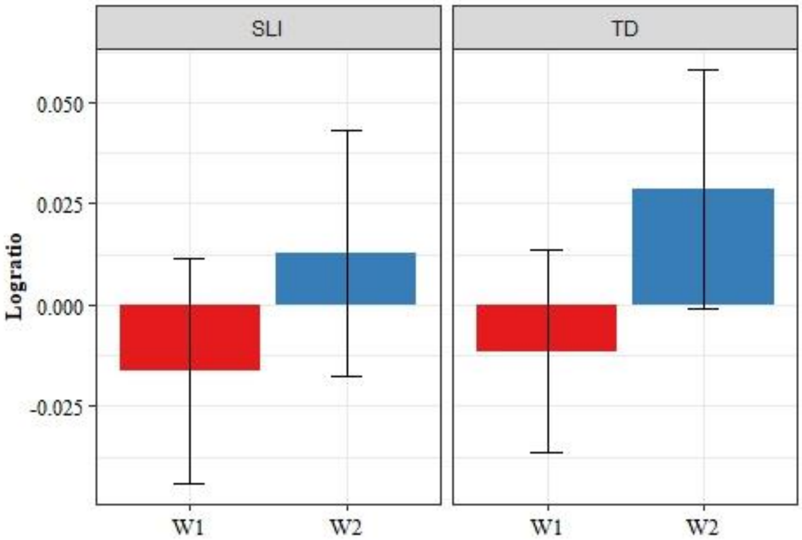

Figure 20. Log-ratios for groups (SLI, TD) and windows (1, 2). Positive numbers represent the preference towards the target and negative numbers represent the preference towards the competitor.

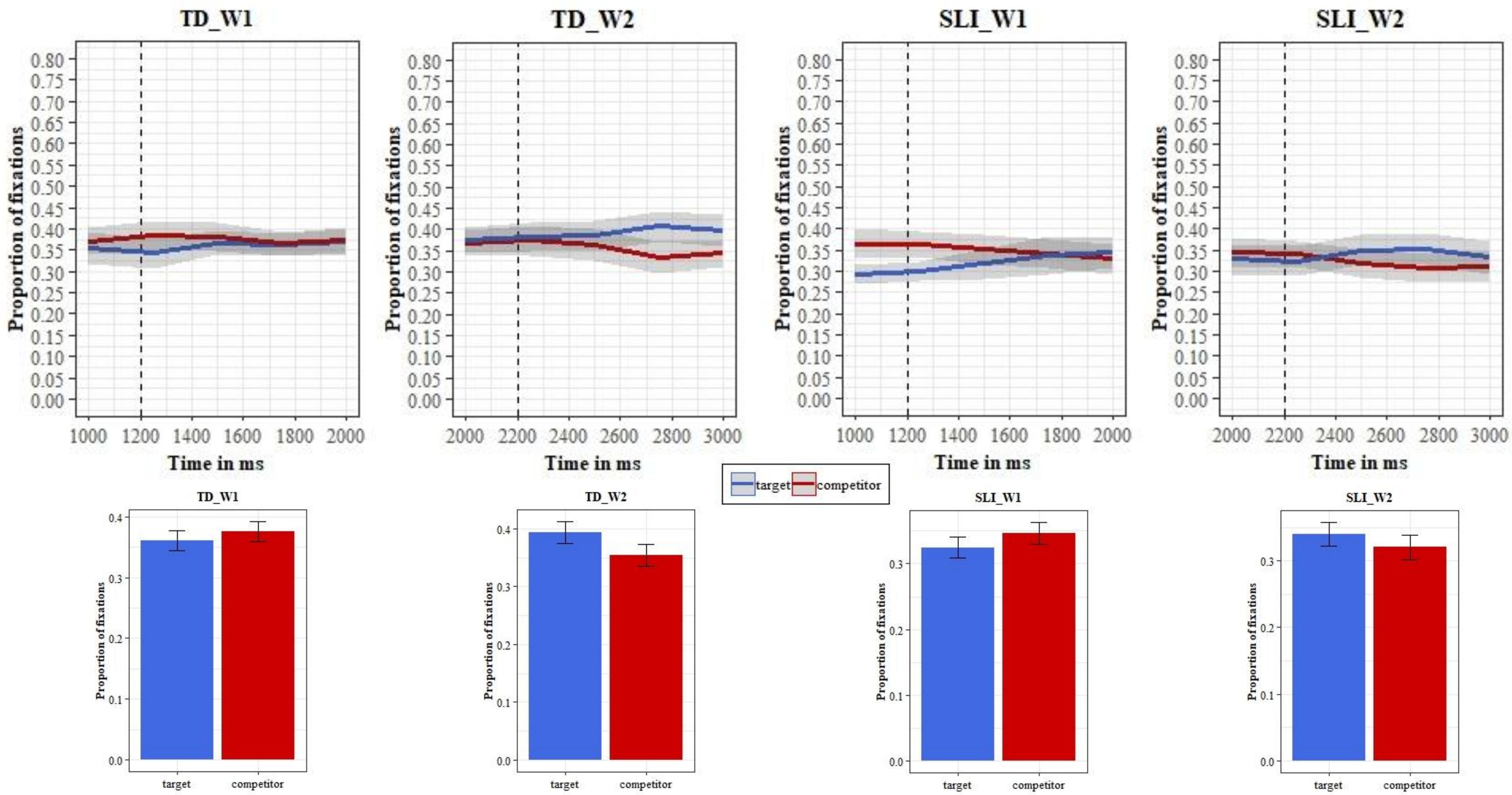

Figure 21. For groups (SLI, TD): Proportion of looks to target and competitor by groups (SLI, TD) and time window throughout the 16 trials that formed the learning phase of the experiment. The graphs on the top represent visual results during the timeline for the first and second time windows. The graphs on the bottom represent the mean proportion of looks aggregated across the time window.

Statistical analysis – order position learning phase

As described above, the CSSL tasks were designed with "normal position" trials in which the first spoken word corresponded to the visual object that was on the left side of the display and the second spoken word corresponded to the visual object that was situated on the right side of the display, and with "crossed position" trials in which the first spoken word of the trials corresponded to the visual object that was on the right side of the display and the second spoken word corresponded to the visual object that was situated on the left side of the display (see Figure 14).

Because the general eye-tracking results showed no differences in the moment-by-moment online cognitive process between groups but the behavioral results showed significantly better performance accuracy results for TD children in the CSSL, we ran a second gaze analysis of the data, taking into account the particularity of the position condition design of this experiment. Thus, the order position of the visual objects (i.e., target and competitor) in reference to the spoken words was entered into the statistical analysis as a new predictor. We compared the experimental group (SLI) against the TD children group in relation to the time window (1 and 2) and position (normal and crossed) variables. The following analysis shows the differences between the proportion of looks to the target and competitor through window 1 in normal and crossed conditions and through window 2 in normal and crossed condition for both groups.

Again, we compared the experimental group (SLI) against the group of TD children, taking the factors of time window (1 and 2) and order of presentation. The analysis used a deviation contrast for the time window and position factors and a treatment contrast for the comparison between the two groups. The coding was accomplished by assigning 0 to the reference level and 1 to the other group. Time windows and position factors were coded as -1 and 1.

As in the previous analysis, we adopted a model comparison approach in which the complexity of the random structure was increased incrementally. Each model structure included the fixed factors of participants' group as the between-subject predictor, and time window and position as the within-subject predictor and the interaction between them. The first model had no random slopes introduced, just random intercepts. The second model had random slopes for all main effects when justified. The third model had random slopes for all main effects and two-way interactions only when justified. The fourth model had random slopes for all main effects, two-way interactions, and the only three-way interaction justified by the design. The models were compared and the best-fit model was used.

Results – order position learning phase

The LMER results from the order position analysis (estimates, standard error of the mean, t-values, and p-values) are presented in Table 14. They show that, overall, the group of children in the SLI group did not prefer the target object to the competitor (β=.004, *se*=.012, *t*=.316, *p*=.753). Moreover, the results revealed that there were no differences in the proportion of looks between the group of children with SLI and TD children (β=.018, *se*=.016, *t*=1.093, *p*=.283). The time windows did not differ from each other (β=.018, se=.010, *t*=1.848, *p*=.068) but the order position (normal vs. crossed) was significantly different (β=-.046, *se*=.014, *t*=-3.255, *p*=.001). Finally, the LMER showed no significant interaction effect between groups and the proportion of looks between time windows 1 and 2. This reflects that no advantage was observed for the TD children when looking to the target during either of the two windows during the learning phase. There was a significant interaction effect between the groups and the position variable, suggesting that TD children showed a different pattern of looking to the target and competitor according to the position of the visual object in relation to the spoken words presented.

Table 14. Main and interaction effects in the linear mixed-effects regression on log-transformed proportion of looks ratios between target and competitor through all the learning phase by order position.

Effect	***β***	***se***	***t*-value**	***p*-value**
Intercept (children with SLI)	.004	.012	.316	.753
Group	.018	.016	1.093	.283
Time window	.018	.010	1.848	.068
Position	-.046	.014	-3.255	.001**
Group*Time window	.004	.014	.279	.781
Group*Position	-.051	.020	-2.522	.013*
Time window*Position	-.019	.012	-1.534	.129
Group*Time window*Position	.000	.018	.012	.990

*p<.05. **p<.01.

Finally, the LMER showed that there was no significant interaction effect between the groups and the proportion of looks between time windows 1 and 2 (β=.004, *se*=.014, t=.279, p=.781). There was a significant interaction effect between the groups and the position variable (β=-.051, *se*=.020, t=-2.522, p=.013). This reflects the different looking patterns between the groups in relation to the target and competitor according to the position of the visual object with respect to the spoken words presented. This difference is shown in Figure 22a. Meanwhile, Figure 22b makes it clear that the group of TD children showed a preference for looking to the target when the trials were "normal" and a preference of looking to the competitor when the trials were "crossed" while the group of children with SLI did not show any preference for looking to the target or competitor for any of the order position conditions. Moreover, there was no significant interaction effect between time window and position (*β*=-.019 *se*=.012, *t*=-1.534, *p*=.129) nor between the group, time window and position (*β*=.000, *se*=.018, *t*=.012, *p*=.990).

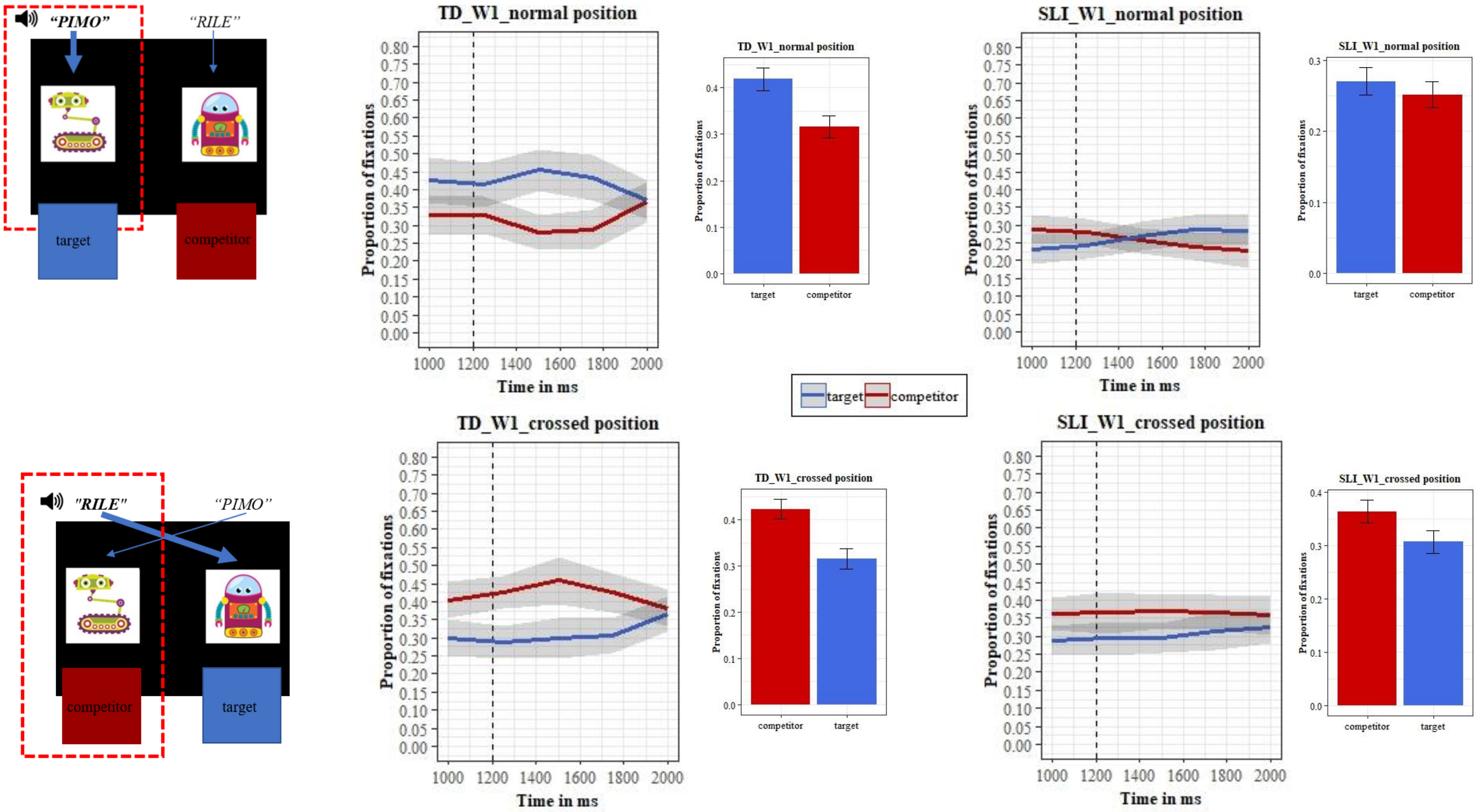

Figure 22a. For groups (SLI, TD): Proportion of looks to target and competitor by groups (SLI, TD), time window and order position trials throughout the 16 trials that formed the learning phase of the experiment. The top graphs represent the visual results during the timeline for the first time window when the trials were “normal”, with the mean proportion of looks aggregated across the time window (bar graphs). The graphs at the bottom show the visual results during the timeline for the first time window when the trials were “crossed” with the mean proportion of looks aggregated across the time window (bar graphs).

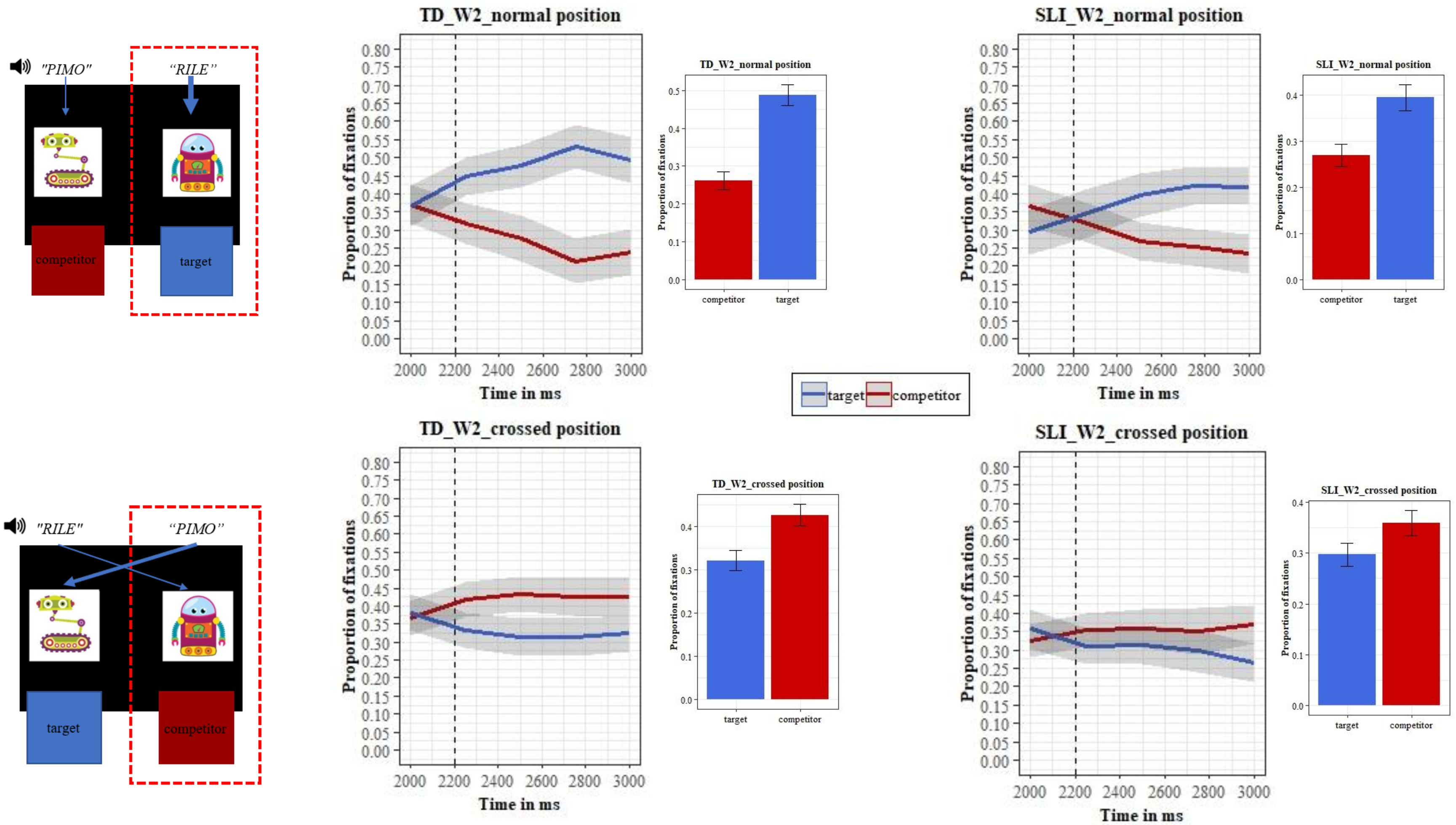

Figure 22b. For groups (SLI, TD): Proportion of looks for target and competitor by groups (SLI, TD), time window and order position trials throughout the 16 trials that formed the learning phase of the experiment. The top graphs represent the visual results during the timeline for the second time window when the trials where "normal" with the mean proportion of looks aggregated across the time window (bar graphs). The graphs at the bottom show the visual results during the timeline for the second time window when the trials where "crossed" with the mean proportion of looks aggregated across the time window (bar graphs).

- Testing phase

Each trial in the testing phase was composed of the presentation of one spoken word and four visual objects. One of the visual objects was the referent that corresponded to the spoken word and the other three objects were distractors. Thus, four areas of interest corresponding to the location and size of the displayed pictures (i.e., the target and the three distractors) were defined using the Gaze analyzer software as described above for the learning phase. To analyze the pattern of looks during the test phase, we took only those test trials where participants had responded correctly. This means that we only analyzed those trials in which participants selected the correct referent of the spoken word from the four visual objects presented.

Statistical analysis – testing phase

We calculated the proportion of looks to the target and to the three distractors for each group. Then, the proportion of looks to the three distractors were averaged, resulting in a single measure called "distractors" (i.e., mean proportion of looks between the three distractors).

Two different analyses that permit complementary inferences by attempting different aspects of eye-tracking data were used to analyze the testing phase data: (1) A complementary approach based on confidence intervals and the quantifiable effect size of proportion of looks over time (see Cumming, 2014; Janse & Huettig, 2016; Huettig & Guerra, 2019), plus (2) a quasi-logistic growth curve analysis (GCA) approach (Mirman, Dixon & Magnuson, 2008; Mirman, 2014) on empirical logit transformation of the proportion of looks (Barr, 2008). The confidence intervals approach is based on a graphical description of the looking patterns in relation to the defined visual objects across time. This approach shows a continuous evaluation of differences between them (i.e., every 100 ms). The statistical significance differences between the looking patterns can be directly inferred for time windows from these visual graphs when the plotted confidence intervals between two conditions do not overlap. This analysis clearly shows *when* and *how much* two conditions differ but it can, on occasions, be underpowered and unable to identify gradual effects over time because every time window is compared separately, as if they were independent from the adjacent ones, thus requiring corrections for multiple comparisons.

In contrast, a GCA approach explicitly integrates time as a continuous variable into a single analysis. That means that it is possible to avoid multiple comparisons and it reduces the loss of power. The GCA model justifies time window dependency and provides a strategy for quantifying changes over time. GCA is a multilevel analysis that is implemented through a mixed-effects regression (Bates, Maechler, Bolker & Walker, 2015). This approach uses orthogonal higher-order polynomials (see Figure 23) as predictors of the time course, accommodating the non-linear changes of proportion of looks over time that characterize visual attention when language is involved. The way to determine the polynomial order is by model comparison.

To analyze our data, we compared four models that differed only in their number of polynomial terms from a single linear term to a quartic term in ascending order. Before analysis, an empirical logit transformation was applied to the proportion of looks for each time window, scaling binary data to a continuous variable (Barr, 2008; Mirman, 2014). All four models had the empirical logit for the target object on the display as the dependent variable and the polynomial as fixed effects, as well as the interaction between group and polynomials. The random structure of the models included cross-random intercepts for participants and items, and random slopes for each polynomial predictor. To facilitate convergence, the models did not include random correlations between random factors (see Barr et al., 2013).

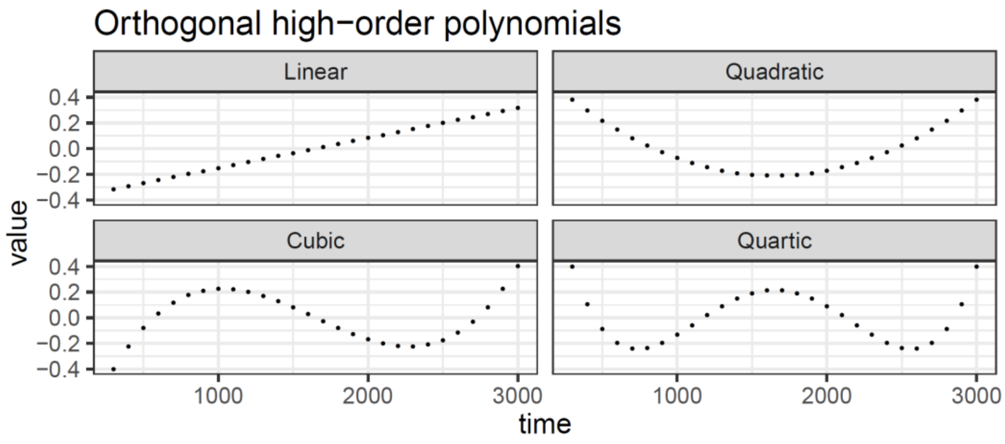

Figure 23. Orthogonal high-order polynomials.

A first broad time window for the confidence intervals and the quantifiable effect of proportion of looks over time was considered. The time window started 500 ms before the onset of the spoken word and ended 2800 ms after the onset of the word. A second time window was created for the GCA analysis, which was adjusted to start 200 ms after the onset of the word and end 2800 ms after the onset of the word.

Results – testing phase

In Figure 24, the blue line represents the mean proportion of looks to the target and the red line represents the mean proportion of looks to the distractors. Gray-shaded areas represent the upper and lower boundaries of the corresponding 95% confidence intervals, adjusted for within-subject designs (see Cousineau & O'Brien, 2014) in time steps of 100 ms. Plots are time-locked to the onset of the spoken word and divided into panels per group (SLI, TD). Time 0 is the onset of the spoken word. Figure 24 reveals that target objects were preferred compared to the distractors in both groups, particularly once 500 ms had passed since the onset of the spoken word. Moreover, the confidence intervals suggest that there is a main effect that should be considered significant. Although both groups show this preference to the target, it is clear that the curve difference between the target and distractors is much steeper for the group of TD children than for the group of children with SLI.

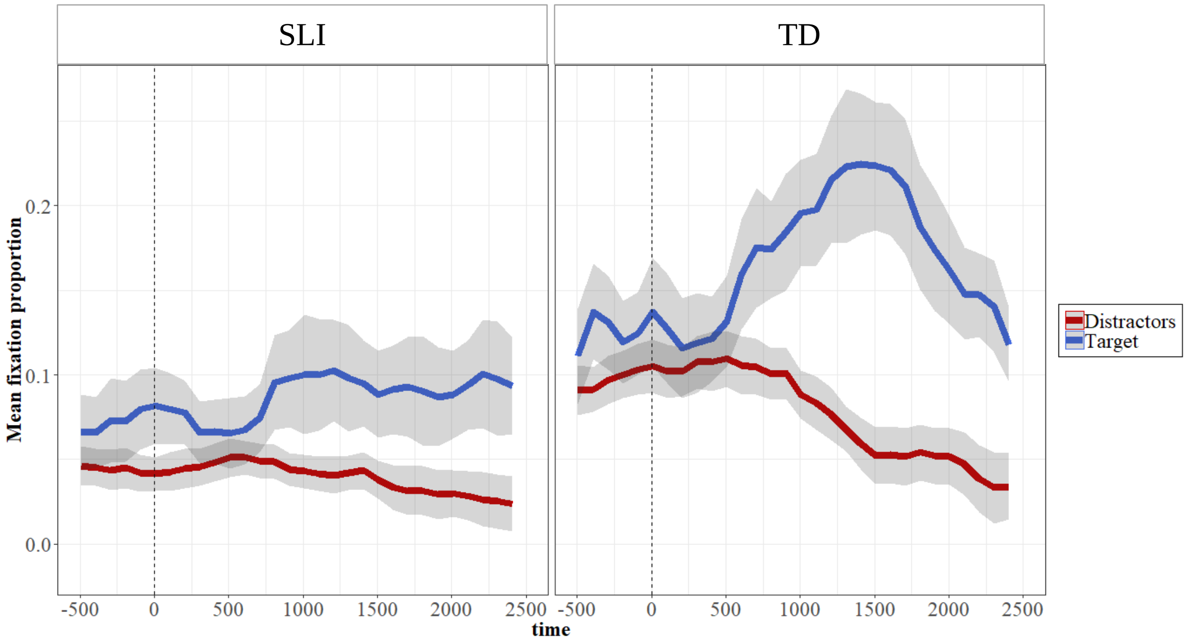

Figure 24. Mean proportion of looks (aggregated by participants) to the target and distractors during the test trials answered correctly for both groups (TD, SLI). Shaded areas around lines represent 95% confidence intervals adjusted for within-subject designs and multiple time windows. Dashed line is the onset of the spoken word.

To corroborate the previous results, we turned to the GCA (Growth Curve Analysis) approach, using a quasi-logistic regression model. Figure 25 is a completeness graph that represents the empirical log transformation of the proportion of looks to the target in the TD children (orange line) and children with SLI (blue line). Again, the shaded areas around lines represent 95% confidence intervals adjusted for within-subject designs and multiple time windows. Because TD children showed significantly higher accuracy in the task compared to children with SLI (i.e., children with SLI answered fewer test trials correctly than the TD children) the base line of both groups was adjusted by fixing the elog mean to zero in the 200 ms window. Thus, the differences between groups cannot be explained by a mismatched number of trials for the groups.

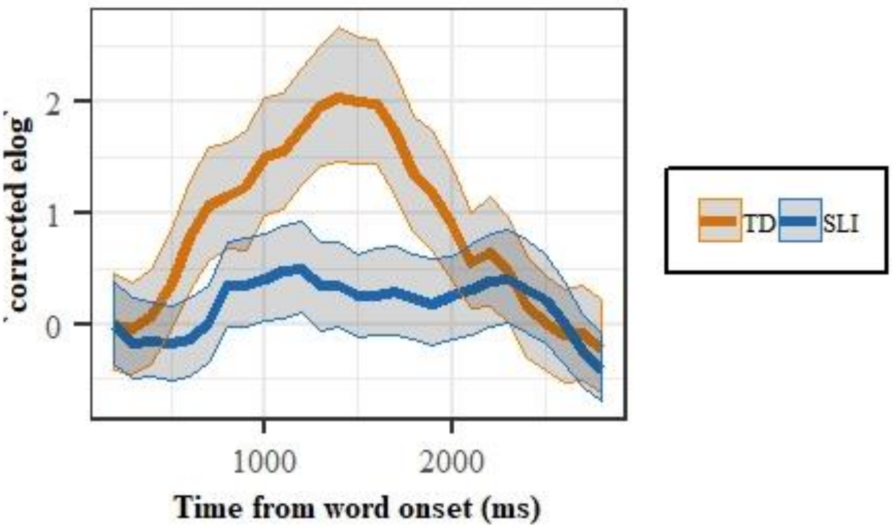

Figure 25. Elog. Mean proportion of looks (aggregated by participants) to the target in the test trials answered correctly for both groups (TD, SLI). Orange line represents mean proportion of looks to the target for the group of TD children and blue line represents mean proportion of looks to the target for the group of children with SLI.

We turned to a model comparison approach in which we increased the complexity of the random structure incrementally. As described by Mirman (2014), it is important to introduce polynomial predictors that are justified by the data. Thus, the model comparison was centered around the polynomial predictors, with the simple random structure kept constant. Four models were created to conduct the comparison: First, we ran a linear term (model 1), second the linear and quadratic term (model 2), then the linear, quadratic and cubic (model 3) and finally the linear, quadratic, cubic and quartic (model 4). We began by comparing the four models that increasingly included higher-order polynomials as predictors through a likelihood-ratio test using the anova function (R Core Team, 2017). The results of these model comparisons showed that the inclusion of each polynomial term increased the fit of the model (all χ^2-values>43.87, df=4, all *p*-values<.001).

Consequently, we reported the results of the linear mixed model fit based on maximum likelihood with fourth-order orthogonal polynomials as time course predictors. Table 15 shows fixed effects parameter estimates, standard errors and t-values for main and interaction terms in the GCA model. The results for each polynomial show that the quadratic and quartic components (*t*-values > |2|) have significant main effects but not the linear and cubic components (*t*-values < |2|). This means that quadratic and quartic polynomials are the predictors that significantly account for the time course, regardless of the group. In reference to the group effect, the model shows reliable differences between groups (t-values > |2|), corroborating the conclusions inferred in the first analysis (see Figure 24). Finally, in terms of the interaction effect between groups and the polynomial predictor of changes over time, we found a reliable effect for each of the polynomial components and groups (see Table 15). If we rely on the results shown in the GCA visual graphs (see Figure 26), it can be seen that the linear and quadratic components are the best predictors for the group of children with SLI while the cubic and quartic are the best predictors for the group of TD children.

Table 15. Main and interaction effect in the quasi-logistic GCA mixed model analysis.

	Estimate	*se*	*t*
(Intercept)	-6.17	0.33	-18.68
Linear	-0.82	0.57	-1.43
Quadratic	**-3.56**	**0.50**	**-7.08**
Cubic	0.66	0.46	1.43
Quartic	**0.97**	**0.29**	**3.20**
Group	**-0.72**	**0.05**	**-12.80**
Linear * Group	**0.91**	**0.29**	**3.10**
Quadratic*Group	**2.54**	**0.29**	**8.65**
Cubic * Group	**0.84**	**0.29**	**-2.89**
Quartic *Group	**-1.14**	**0.29**	**-3.91**

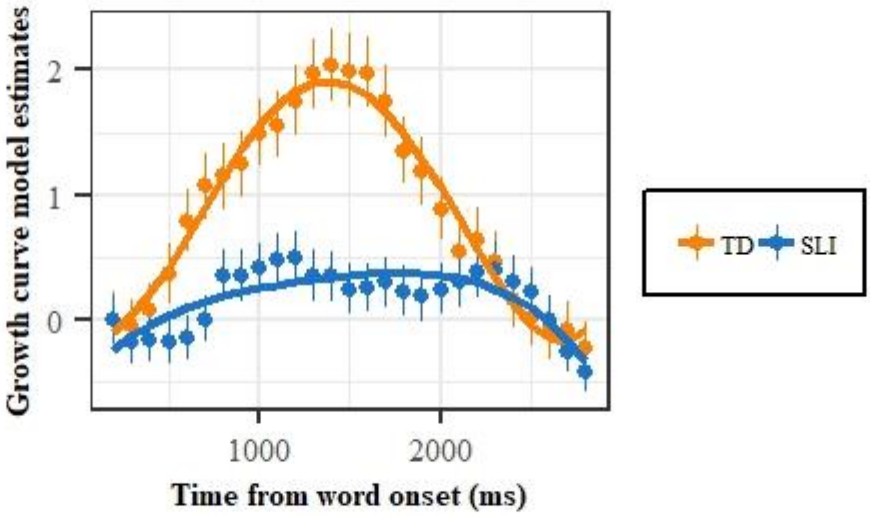

*Figure 26***.** GCA model fit (lines) of empirical logit (points) as a function of proportion of looks to the target for both groups (TD, SLI).

7.5 Discussion

Both children with SLI and TD children showed a mean performance above chance in the CSSL task but the results for the group of children with SLI were significantly poorer than for the group of TD children. These results are contradictory to the PDH, which expects preserved vocabulary learning in children with SLI (Ullman & Pierpont, 2005). Therefore, these results suggest an alternative perspective on non-declarative deficits in children with SLI to that proposed by the PDH. These results are in accordance with the probabilistic deficit shown in children with SLI proposed by Kemény and Lukács (2009) in addition to the procedural memory deficit. The results of this study suggest that the non-declarative abilities impaired in children with SLI are not only seen in sequential patterns but also in probabilistic computations.

Furthermore, considering the contextual diversity of the task, it can be observed that the selection pattern for the foil objects that co-occurred more or less frequently with the target word were different for both groups in the 4AFC post-test. Although it seems that the distractor was the less frequently selected option for both groups, the results for the group of TD children showed significant differences between the distractor and the two competitors. For the children with SLI, on the other hand, there were only significant differences between the competitor and the weak distractor but not between the distractor and the strong competitor. In addition, the between-group analysis showed that the group of children with SLI selected the competitor significantly more often than the group of TD children. In this sense, TD children showed a clearer pattern of correct extraction and computation frequencies, echoing the study carried out on English-speaking TD school-age children in Suanda et al., (2014). Thus, when TD children selected the wrong visual object in the test phase, they were more accurate at then selecting the competitors co-occurring more times with the target option as a correct response during the learning phase than the children with SLI. The results of the TD children are similar to those found in the TD children tested in Suanda et al. (2014) and are consistent with the CSSL studies conducted on typical populations (Fitneva & Christiansen, 2011; Yurovsky, Yu & Smith, 2012; Yu, Zhong & Fricker, 2012; Smith & Yu, 2008).

Moreover, contrary to Ullman and Pierpont (2005), who argued that the mapping of visual objects to a word label is supported by the declarative system, the results of this study showed that the CSSL task was a significant predictor of expressive vocabulary knowledge, showing that the better the performance in the CSSL task, the better the expressive vocabulary scores were. Moreover, CSSL was not a predictor of the receptive vocabulary knowledge. This means that CSSL was a significant predictor of the vocabulary learned and the children's ability to generate spoken labels for a picture. Conversely, it was not a predictor of the children's ability to accurately link a label to a picture of a word known by children of the same age. We would expect the CSSL task to be one of the predictors of receptive vocabulary knowledge because CSSL is a receptive learning task in which participants have to link a spoken label to one picture from a set of four. However, the results suggest that there is a greater relationship between the skills involved in solving a CSSL task and the consolidated and productive vocabulary that children have. More studies assessing this kind of ambiguous fast-mapping task with other receptive vocabulary assessment tests need to be conducted in order to gather more evidence about the relationship between the CSSL task and vocabulary knowledge.

In summary, the behavioral results of this study indicated that although children with SLI showed a mean performance above chance in a task that involves a strategy based on computing distributional statistics across words, referents and co-occurrences of words and referents at multiple moments, they were significantly less accurate than the group of TD children at solving the task. In addition, children with SLI were not able to implicitly compute the frequency contextual diversity embedded in the task while the TD children were able to do so. Moreover, there was a significant correlation between expressive but not receptive vocabulary knowledge and the performance in the CSSL task among the Catalan-Spanish children with and without SLI.

As regard to the eye-tracking data, we expected to find different online cognitive processes between the two groups during the learning and testing phases of the task because TD children showed significantly higher behavioral accuracy results compared to children with SLI. Our first hypothesis was to see higher proportion of looks to the target, i.e., more looks to the visual object that represents the spoken word in a specific time window, in the TD group relative to the SLI group.

Refuting our main hypothesis, the first general analysis for the learning phase showed that no advantage was observed for the TD children when looking to the target during either of the two windows throughout the learning phase. Consequently, we looked more closely at the gaze patterns of the participants, taking into account an important characteristic of the experimental design. In half the trials, the first spoken word corresponded to the visual object that was on the left side of the display and the second spoken word corresponded to the visual object that was situated on the right side of the display while in the other half, the first spoken word of the trials corresponded to the visual object that was on the right side of the display and the second spoken word corresponded to the visual object that was situated on the left side of the display. These two presentation schemas were labeled “normal” trials and “crossed” trials, respectively. We explored whether this aspect of the design could be of relevance by turning it into a factor and examined its potential effect on both groups. To do this, we ran a second gaze analysis of the data, taking into account the particularity of the position condition design of this experiment; the results revealed that the group of TD children showed a preference for looking to the target when the trials were “normal” and a preference for looking to the competitor when the trials were “crossed” while the group of children with SLI did not exhibit any preference for the target or competitor in any of the order position conditions, except for time window 2 when they preferred the target.

These results suggest that TD children but not children with SLI were using a specific and constant strategy during the task to learn the word-object pairs. The fact that in the “normal” trials they preferred the target and in the “crossed” trials they preferred the competitor showed that TD children were always looking from the left to the right side of the display no matter whether the position of the visual objects corresponded to the first or second word presented. Thus, the left-to-right direction used to read and write was the dominant visual pattern used by the school-age TD children but not by children with SLI when performing a statistical learning word-mapping strategy based on computing distributional statistics. These results can be interpreted by the assumption that TD children were using a strategy of updating statistical probabilities of co-occurrence and computing the word-object frequencies by maintaining a left-to-right pattern of looks.

This suggests that multiple hypotheses regarding the word-object pairs may have been sustained for TD children throughout the learning phase that would be confirmed in the subsequent test phase.

Children with SLI, on the other hand, did not show a preference for looking to the target or the competitor according to the order position of the trials. This means that they did not use a specific or constant gaze strategy that permitted them to compute the frequencies of the input in the same way that the TD children did. The dispersion of the pattern of looks of children with SLI might be the reason for a weaker computation of frequencies embedded in the task. These results can be interpreted as an indicator of differences in the level of knowledge of the newly implicit learned word in children with SLI. Limited work has been conducted on exploring the visual processing of novel objects in school-age children and even more limited on populations with SLI. In this sense, it is difficult to draw a main conclusion about the online cognitive process used when learning new words in a CSSL task. Nevertheless, our results support the work carried out by Akshoomoff, Stiles and Wulfeck (2006), which suggested that children with SLI may have an immature and less efficient approach to visual spatial processing tasks.

It is important to note that only 16 trials were included in the learning phase of this task because it was designed to be suitable for school-age children. Future studies should be carried out to test school-age children with and without SLI performing a CSSL task with more learning trials that will enable researchers to analyze a longer online cognitive process. It will then be possible to see whether children with SLI need more time to acquire a specific strategy for learning word-object pairs. Moreover, with more exposure to the word-object pairs in an ambiguous context, TD children may show, later on, a change in the pattern of looks required to solve the task. Alternatively, the study could be carried out using the same design but reducing the number of words to be learned. Giving more trials per word might give children with SLI more opportunities to catch the embedded frequencies without extending the length of the task.

Results for the testing phase corroborated our hypotheses: although the within-group results showed that both groups had a significantly higher proportion of looks to the target in comparison to the distractors in those test trials in which participants selected the correct referent of the spoken word, the difference between the proportion of looks to the target and distractors was bigger for the TD children. These are similar results to those found in Erica et al. (2015), a study in which late talkers and TD infants showed differences in the point of divergence between target and distractor objects in two-alternative testing trials after a word-learning task. The late-talker group had an initial overlap of looking to both the target and distractor but did not show any significant distinction between the two pictures, while the typical group initially showed more separation in looking to the two pictures and ultimately distinguished the target-word picture at an earlier time point.

Altogether, the results showed that both groups had a different pattern of looks to the target during the testing phase. On the one hand, in terms of magnitude, the group of TD children showed a higher proportion of looks to the target in comparison to the group of children with SLI. On the other hand, the polynomial component predictors for each group give a qualitative perspective of the data. Cubic and quartic components appear to show that the proportion of looks to the target appears early in time. Conversely, the linear and quadratic components appear to show that the proportion of looks to the target increase gradually over time. Accordingly, this data suggests that the differences between groups when looking to the target might also be explained in terms of time. It seems that TD children looked to the target a short time after hearing the spoken word while children with SLI had more of a delay in looking to the target.

These results can be interpreted as a rate of confidence in their responses. (i.e., how confident children were of their choice when answering correctly). That is, when TD children chose the correct visual object (i.e., target), they showed a strong preference for looks to the target over looks to the distractors. The group of children with SLI, on the other hand, showed less of a preference for looks to the target compared to the TD children when they answered correctly. It seemed that the children with SLI were not as confident as the TD children when answering correctly because their proportion of looks was more widely distributed across the target and distractors.

Overall, children with SLI and TD children showed differences in the moment-by-moment visual attention pattern while performing a cross-situational statistical learning task. Specifically, TD children but not children with SLI showed a clear pattern of looks from left to right throughout the learning phase, which enabled them to extract the embedded frequencies in the input, resulting in them learning more words than children with SLI. Moreover, the fact that TD children were more accurate at doing the task was related to a higher proportion of looks to the target throughout the testing phase in comparison to children with SLI. These results suggested that there are differences between children with and without SLI in the online cognitive process when learning and interpreting novel words implicitly. Moreover, the data suggests that children with SLI may have an immature and less efficient mechanism for detecting the visual spatial process regularities embedded in a word-learning task.

8. Study 4: Declarative memory and working memory in Catalan-Spanish children with specific language impairment

8.1 Introduction

The focus on language in research with children with SLI was broadened to include memory following the publication of studies showing that SLI also involved memory deficits. Many studies have focused on working memory impairment in children with SLI, and, as explained above, there is a general consensus that phonological working memory deficits are involved (Archibald & Gathercole, 2006; Ellis Weismer et al., 1999; Gathercole & Alloway, 2006). The results for visual working memory deficits are not so clear. One of the aims of this study was to provide more evidence on working memory deficits in Catalan-Spanish children with SLI. To do this we assessed the three components of working memory proposed by Baddeley (2000)—the central executive, the phonological loop, and the visuospatial sketchpad—in children with and without SLI using a set of standardized subtests. We specifically wished to contribute to knowledge on visual working memory considering the dearth of research in this field.

Research into different types of memory in children with SLI increased following the publication of the procedural deficit hypothesis by Ullman and Pierpont (2005), which holds that people with SLI have procedural memory deficits that cause difficulties with grammar and syntax but that their declarative memory is preserved and their vocabulary knowledge unaffected. A number of authors have sought to demonstrate that children with SLI have declarative as well as non-declarative memory deficits (Baird, Dworzynski, Slonims, & Simonoff, 2010; Duinmeijer, de Jong, & Scheper, 2012; Lum et al., 2010; Lum et al., 2012a).

In 2013, Lum and Conti-Ramsden (2013) published a meta-analysis of studies performed up to 2012 that tested declarative memory in children with SLI, among other memories. One of the aims of the meta-analysis was to clarify the inconsistent results observed for declarative memory in the verbal and visual domains. The studies they analyzed had tested verbal declarative memory using list learning and retrieval tasks, which evaluate how children encode and repeat arbitrary pieces of verbal information following repeated exposure. The results of the meta-analysis showed that children with SLI retrieved significantly fewer words than the control groups. The authors thus concluded that children with SLI have difficulties related to the mechanisms of declarative memory. The studies that had assessed visual declarative memory had used non-verbal analogues of the list tasks used to assess verbal declarative memory. As an example, participants were presented with a repeated image that could not be easily verbalized and then asked to identify the image from among a set of distractors. Learning was quantified by measuring increases in non-verbal information remembered during the learning trials. The results showed no differences between the children with SLI and the control groups in visual declarative memory task performance.

Despite the findings of the above meta-analysis, Lum and Bleses (2012) questioned the assumption of an impaired declarative memory system in children with SLI, arguing that preserved working memory abilities were necessary in order to properly use declarative memory, as the initial holding and learning process for the declarative memory system is sustained by working memory. To provide evidence of this, they tested children with SLI and typically developing (TD) children using a variety of memory tests to investigate differences between abilities to solve tasks involving the declarative, procedural, and working memory systems. To validate their hypothesis, children with and without SLI were tested using two verbal working memory tasks and one verbal declarative memory task. A subsequent analysis of covariates demonstrated non-significant effects for group (SLI and TD) on verbal declarative memory performance after controlling for verbal working memory, proving thus that declarative memory depends on working memory to work properly. Lum and Bleses were thus able to explain the deficits observed in verbal declarative memory in previous studies by the presence of working memory deficits. Subsequent studies by Hsu and Bishop (2015), Lum and Bleses (2012), Lum et al. (2012), and Lum et al. (2015) reported similar results showing that, once verbal working memory is controlled for, the verbal domain of declarative memory is unaffected in children with SLI.

In view of these more recent findings, we also wished to investigate declarative memory abilities in the verbal and visual domains in Catalan-Spanish children with SLI.

8.2 Specific aims and hypotheses

Aims

The aim of this study was to investigate differences between Catalan-Spanish children with and without SLI in terms of their ability to solve tasks involving the working and declarative memory systems in the verbal and visual domains. We also wished to investigate whether working memory interfered with the declarative memory abilities of children with SLI. A third aim was to explore the contribution of verbal declarative memory to vocabulary knowledge in both groups, i.e., to determine how much variance in vocabulary knowledge was accounted for by this memory.

Hypotheses

We expect children with SLI to show poorer results in all the auditory and visual working memory tasks compared to TD children. If we assume that the declarative memory is spared in children with SLI, as proposed by the procedural deficit hypothesis, there should be no differences between children with SLI and TD children in terms of their performance in verbal and visual declarative memory tasks. If the results show that declarative memory is not spared, the results for both groups should be equivalent after controlling for working memory, as it has been proposed that this memory interferes with declarative memory. We also expect to find non-significant differences between children with SLI and TD children in terms of their performance in visual declarative memory subtests, since it has been demonstrated that this memory is preserved in children with SLI. Finally, we expect to find that verbal declarative memory accounts for significant variance in vocabulary knowledge according to the dual declarative/procedural system proposed by Ullman (2004), in which vocabulary learning is mainly sustained by the declarative memory system.

8.3 Methodology

8.3.1 Participants

Seventy-six children (24 girls and 52 boys) were included in the study: 38 children with SLI (mean age=8.7 years, SD=1.10, range=5.6-12.11) and 38 age- and gender-matched TD children (mean age=8.9 years, SD=1.10, range=5.7-12.9). All the children met the inclusion criteria for their respective groups described in participant section (see Table 9).

8.3.2 Materials, design and procedure

A variety of memory test subscales were administered to assess (1) the three components of the working memory proposed by Baddeley (2000) (the central executive, the phonological loop, and the visuospatial sketchpad) and (2) verbal and visual declarative memory and verbal semantic memory.

Working memory assessment:

- Phonological loop

The phonological loop component was assessed using two tasks that assess the ability to temporarily store verbal information: (1) the TOMAL digits forward subtest (Reynolds & Bigler, 2012; adapted by Goikoetxea), which requires participants to repeat an increasingly long sequence of digits in the order in which they were presented, and (2) the non-word repetition task (Aguado, 2005), which requires participants to repeat a list of 40 non-words composed of two to five syllables from the Spanish language. Performance in the task was audio-recorded and subsequently corrected according to the test's correction rules.

- The central executive

The central executive component was assessed using the TOMAL digits backward subtest (Reynolds & Bigler, 2012; adapted by Goikoetxea). This subtest assesses the ability to temporarily store and then process or manipulate verbal information. It requires participants to repeat an increasingly long sequence of digits in the opposite order in which they were presented.

- Visuospatial sketchpad

The visuospatial sketchpad or visual short-term memory was assessed using the TOMAL visual selective reminding subtest (Reynolds & Bigler, 2012; adapted by Goikoetxea). This task assesses the ability to temporarily store visual information. It requires children to manually repeat a visual sequence of dots previously presented by the experimenter by touching them on a sheet.

Declarative memory assessment:

- Verbal declarative memory

The TOMAL paired recall subtest (Reynolds & Bigler, 2012; adapted by Goikoetxea) was used to measure children's ability to encode and retrieve verbal information from their declarative memory. In this task, children are auditorily presented with a list of pair words. Some of the pairs in the list are semantically related while others are not. After presenting the list, the experimenter reads out one of the two words from the pair and the participant has to recall the missing word.

- Visual declarative memory

Two tasks were used to measure the children's ability to encode and retrieve visual information from their declarative memory: the facial memory subtest and the delayed facial memory subtest from TOMAL (Reynolds & Bigler, 2012; adapted by Goikoetxea). In this task, the examiner presents a number of faces that the children have to commit to memory. They are then asked to identify the faces previously studied in a set containing previously unshown distracter faces in two different phases: a short recognition phase and a delayed recognition phase.

Verbal semantic memory assessment:

The word association subtest from the Spanish Clinical Evaluation of Language Fundamentals, Fourth Edition (CELF-4) (Semel, Wiig & Secord, 2006) was used to assess the children's ability to recall words from a semantic category within a fixed time limit. This test requires children to think and verbally recall as many items from a semantic category (e.g., animals, food, or clothes) as they can in 1 minute. Although this is a semantic task that theoretically could be classified as a verbal declarative memory task, in this dissertation it was classified as a separate verbal semantic memory task. It was not categorized as either a declarative or a procedural memory task because it requires abilities associated with both memory systems. On the one hand, it assesses language ability as a semantic component of the declarative memory while, on the other hand, it assesses the ability to recover and retrieve words already learned. As discussed in the introductory section to this dissertation, Ullman and Pierpont (2005) argued that lexical retrieval depends on the brain structures underlying the procedural system and abnormalities in these structures can affect specific aspects of word learning and use, such as retrieval and evocation. Thus, although the content of the task is semantic, the cognitive process that it demands can be supported by the non-declarative memory.

Vocabulary assessment

To examine whether sequential declarative memory was related to vocabulary knowledge, the receptive and expressive vocabulary knowledge of the two groups of children were assessed respectively using the Peabody Picture Vocabulary Test, Third Edition; Spanish version (Dunn, Dunn & Arribas, 2006) and the verbal intelligence score from the Kaufman Brief Intelligence Test, Spanish version (Kaufman & Kaufman, 2004) (see Table 9).

8.4 Results

Declarative memory and working memory subtests in children with SLI and TD children

Independent-sample t-tests were performed to compare performance in all the verbal and visual declarative memory tasks and working memory subtests between children with SLI and TD children. The results and corresponding significance levels are shown in Table 16. Children with SLI showed significantly less accuracy than TD children in all the verbal and visual declarative memory tasks and all the subtests that assess the three working memory components, showing that working memory and verbal and visual declarative memory were affected in children with SLI.

Table 16. Standardized scores and significant differences for declarative memory and working memory subtests for the children with specific language impairment (SLI) and the typically developing (TD) children.

Memory Scores	**SLI (n=38)**			**TD (n=38)**			**Comparison**	
Variable	**Mean**	**SD**	**Range**	**Mean**	**SD**	**Range**	**t(74)**	***p***
Working memory								
Central executive								
Digits backward	7.21	2.30	3-13	10.78	2.30	5-18	-6.77	***p*<.01**
Visuospatial sketchpad								
Visual selective reminding	8.34	3.12	4-18	10.76	3.02	6-19	-3.43	***p*<.01**
Phonological loop								
Non-word repetition	42.22	14.23	12-67	70.28	5.86	55-79	10.98	***p*<.01**
Digits forward	6.05	1.62	1-9	10.81	3.03	7-17	-8.53	***p*<.01**
Declarative memory								
Verbal								
Paired recall	8.23	3.02	1-14	11.97	2.86	6-17	-5.53	***p*<.01**
Visual								
Facial memory	9.02	2.25	5-13	12.15	2.63	5-17	-5.56	***p*<.01**
Delayed facial memory	10.78	1.97	6-14	12.00	2.20	4-16	-2.52	***p*<.01**
Verbal semantic memory								
Word association	32.31	11.79	14-69	44.23	12.04	21-74	-4.35	***p*<.01**

Note. The scores for all variables (except non-word repetition and word association variables, which have raw scores) have a mean of 10 and SD of 3

Because there is a line of research that shows that verbal declarative memory deficits in children with SLI are a consequence of verbal working memory deficits (Hsu & Bishop, 2015; Lum & Bleses, 2012; Lum et al., 2012; Lum et al., 2015), we compared performance in the verbal declarative and verbal semantic memory subtests after controlling for verbal working memory.

The data were first analyzed by analysis of covariance (ANCOVA). The first analysis examined between-group differences in the paired recall subtest, used to assess verbal declarative memory. The analysis was undertaken using a z-composite score corresponding to overall verbal working memory performance comprised of scores from the digits forward, digits backward, and non-word repetition subtests. The results showed that there was no longer a significant main effect for group ($F(1, 72)=2.19$, $p=.14$) on verbal declarative memory after controlling for verbal working memory.

The second analysis examined between-group differences for performance in the word association test, which assessed verbal semantic memory. The analysis was undertaken using a z-composite score to produce a single verbal working memory variable formed by the digits forward, digits backward, and non-word repetition subtests as a covariate. The results showed that the main effect for group on verbal semantic memory remained significant ($F(1, 72)=7.36$, $p<.01$) after controlling for verbal working memory.

Contrary to our hypothesis, the children with SLI performed less well than their TD peers at solving the visual declarative memory tasks. We therefore decided to investigate whether visual working memory (the visuospatial sketchpad component) might have interfered with visual declarative memory as verbal working memory had with verbal declarative memory.

As above, the data were first analyzed by ANCOVA. Two analyses were performed to determine between-group differences for the facial memory subtest and the delayed facial memory subtest. The analyses were undertaken using the total score from the visual selective reminding subtest as a covariate. After controlling for visual working memory, the main effect for group remained significant for the facial memory subtest ($F(1,73)=25.56$, $p<.01$) and the delayed facial memory subtest ($F(1,73)=5.69$, $p<.05$).

Relationship between verbal declarative memory and verbal semantic memory and vocabulary knowledge

Correlational analyses

We ran a bilateral correlation analysis between age, IQ, socioeconomic status, verbal declarative memory score, visual semantic memory score, and expressive and receptive vocabulary scores. Age, IQ, and socioeconomic status were entered because they have been shown to impact language acquisition and statistical learning (Dollaghan, et al., 1999; Schuele, 2001). The correlation matrices between age, IQ, socioeconomic status, verbal declarative memory score (VDM), verbal semantic memory score (VSM), and expressive vocabulary and receptive vocabulary scores are shown in Table 17. All the variables were significantly and positively correlated with expressive and receptive vocabulary knowledge as follows: age with receptive vocabulary $r(76)=.66$, $p<.01$; age with expressive vocabulary $r(76)=.71$, $p<.01$; IQ with receptive vocabulary $r(76)=.58$, $p<.01$; IQ with expressive vocabulary $r(76)=.58$, $p<.01$; socioeconomic status with receptive vocabulary $r(76)=.44$, $p<.01$; socioeconomic status with expressive vocabulary $r(76)=.35$, $p<.01$; verbal declarative memory with receptive vocabulary $r(76)=.65$, $p<.01$; verbal declarative memory with expressive vocabulary $r(76)=.71$, $p<.01$; verbal semantic memory with receptive vocabulary $r(76)=.57$, $p<.01$; and verbal declarative memory with expressive vocabulary $r(76)=.63$, $p<.01$.

Table 17. Correlation matrix for cognitive variables, VDM and VSM performance, and vocabulary scores for all study participants.

	IQ	**SES**	**VDM**	**VSM**	**PPVT-III**	**K-BIT-voc**
IQ						
SES	.19					
VDM	.55**	.25*				
VSM	.35**	.37*				
PPVT-III	.58**	.44**	.65**	.57**		
K-BIT-voc	.58**	.35**	.71**	.63**	.86**	
Age (months)	.65**	.54**	.54**	.46**	.66**	.71**

Note. IQ=non-verbal intellectual quotient; K-BIT voc=verbal intelligence score from the Kaufman Brief Intelligence Test (expressive vocabulary); PPVT-III=Peabody Picture Vocabulary Test (receptive vocabulary); VDM=verbal declarative memory task; SES=socioeconomic status; VSM= verbal semantic memory task.
* $p<.05$. level (two-tailed). ** $p<.01$. level (two-tailed).

Regression analyses

We ran two separate two-step hierarchical regression analyses to determine whether sequential verbal declarative and semantic memory scores were predictors of expressive and/or receptive vocabulary knowledge in children with SLI and TD children. Age, IQ, and socioeconomic status were entered as covariates in step 1 (Model 1) to control for possible effects. The verbal declarative (VDM) and semantic memory (VSM) scores were added in step 2 (Model 2) as predictor variables for the first and second analyses, respectively. The respective dependent variables were receptive vocabulary scores and expressive vocabulary scores.

Verbal declarative memory

The results for the overall expressive vocabulary model are presented in Table 18a. Age, IQ, and socioeconomic status (Model 1) accounted for unique portions of variance in expressive vocabulary knowledge ($R^{2=}$.56, adj.$R^{2=}$.54, $F(3,71)=30.33$, $p<.001$). The follow-up regression analysis revealed that VDM (Model 2) also accounted for an significant portion of additional variance ($R^{2=}$.67, adj. $R^{2=}$.65, R^2 change$^{=}$.11, F change(1,70)=23.20, $p<.01$). The coefficient results for the specific predictors of expressive vocabulary knowledge are shown in Table 18b. Age (β=.56, $t(71)=5.48$, $p<.001$, pr^2=.29), socioeconomic status (β=.22, $t(71)=2.69$, $p<.01$, pr^2=.09), and VDM (β=.41, $t(70)=4.82$, $p<.001$, pr^2=.25) but not IQ (β=.16, $t(71)=1.56$, p=.12, pr^2=.03) were all significant predictors.

Table 18a. Regression model to predict expressive vocabulary knowledge for all study participants (VDM).

Model	***R***	***R²***	**Adj *R²***	***SE* of estimate**	***R²* change**	**F change**	***df* 1**	***df* 2**	**Sig, *F* change**
Model 1	.75	.56	.54	7.60	.56	30.33	3	71	.00***
Model 2	.82	.67	.65	6.63	.11	23.20	1	70	.00***

Note. Adj=adjusted; IQ=non-verbal intelligence quotient; SES=socioeconomic status; Sig=significance; VDM=verbal declarative memory task.
Model 1 predictors: (constant), Age, IQ, SES.
Model 2 predictors: (constant), VDM. * $p<.05$. ** $p<.01$. *** $p<.001$.

Table 18b. Coefficients and significance levels for predictors of expressive vocabulary knowledge (VDM).

Model 1	***Standardized Beta coefficients***	***t***	**Sig.**	***pr²***
Age	.56	5.48	.00***	.29
SES	.22	2.69	.01**	.09
IQ	.16	1.56	.12	.03
Model 2				
VDM	.41	4.82	.00***	.25

Note. Adj=adjusted; IQ=non-verbal intellectual quotient; SES= socioeconomic status; Sig=significance; VDM=verbal declarative memory task.
Model 1 predictors: (constant), Age, IQ, SES.
Model 2 predictors: (constant), VDM. * $p<.05$. ** $p<.01$. *** $p<.001$.

The results for the overall receptive vocabulary model are given in Table 19a. Age, IQ, and socioeconomic status (Model 1) accounted for unique portions of variance in expressive vocabulary knowledge ($R^{2=}$.56, adj. $R^{2=}$.55, $F(3,71)=30.75$, $p<.001$). The follow-up regression analysis showed that VDM (Model 2) accounted for an additional significant portion of variance ($R^{2=}$.63, adj. $R^{2=}$.61, R^2 change$^{=}$.07, F change $(1,70)=13.22$, $p<.01$). The coefficient results showing the specific predictors of receptive vocabulary knowledge are shown in Table 19b. Age ($\beta=.45$, $t(71)=4.45$, $p<.001$, $pr^2=.22$), socioeconomic status ($\beta=.32$, $t(71)=3.95$, $p<.01$, $pr^2=.18$), IQ ($\beta=.22$, $t(71)=2.17$, $p<.05$, $pr^2=.06$), and verbal declarative memory ($\beta=.33$, $t(70)=3.63$, $p<.01$, $pr^2=.16$) were all significant predictors.

Table 19a. Regression model to predict receptive vocabulary knowledge for all study participants (VDM).

Model	***R***	***R*²**	**Adj *R*²**	***SE* of estimate**	***R*² change**	**F change**	***df* 1**	***df* 2**	**Sig, *F* change**
Model 1	.75	.56	.55	19.99	.56	30.75	3	71	.00***
Model 2	.80	.63	.61	18.46	.07	13.22	1	70	.001**

Note. Adj=adjusted; IQ=non-verbal intelligence quotient; SES=socioeconomic status; Sig=significance; VDM=verbal declarative memory task.
Model 1 predictors: (constant), Age, IQ, SES
Model 2 predictors: (constant), VDM. * *p*<.05. ** *p*<.01. *** *p*<.001.

Table 19b. Coefficients and significance levels for predictors of receptive vocabulary knowledge (VDM).

Model 1	***Standardized Beta coefficients***	***t***	**Sig.**	***pr*²**
Age	.45	4.45	.00**	.22
SES	.32	3.95	.00**	.18
IQ	.22	2.17	.03*	.06
Model 2				
VDM	.33	3.63	.00**	.16

Note. Adj=adjusted; Sig=significance
IQ=non-verbal intellectual quotient; SES= socioeconomic status; VDM=verbal declarative memory
Model 1 predictors: (constant), Age, IQ, SES
Model 2 predictors: (constant), VDM task. * *p*<.05. ** *p*<.01. *** *p*<.001.

Verbal semantic memory

Results for the overall expressive vocabulary model are shown in Table 20a. Age, IQ, and socioeconomic status (Model 1) accounted for unique portions of variance in expressive vocabulary knowledge ($R^{2=}$.56, adj. $R^{2=}$.54, F(3,71)=30.33, p<.001). The follow-up regression analysis showed that verbal semantic memory (Model 2) accounted for an additional source of significant variance ($R^{2=}$.6a, adj. $R^{2=}$.62, R^2 change$^{=}$.08, F change (1,70)=15.02, p<.01). The coefficient results showing the specific predictors of expressive vocabulary are shown in Table 20b. Age (β=.56, t(71)=5.48, p<.001, pr^2=.29), socioeconomic status (β=.22, t(71)=2.69, p<.01, pr^2=.09), and VSM (β=.33, t(70)=3.88, p<.001, pr^2=.18) but not IQ (β=.16, t(71)=1.56, p=.12, pr^2=.03) were significant predictors.

Table 20a. Regression model to predict expressive vocabulary for all study participants (VSM).

Model	***R***	***R*²**	**Adj *R*²**	***SE* of estimate**	***R*² change**	**F change**	***df* 1**	***df* 2**	**Sig, *F* change**
Model 1	.75	.56	.54	7.60	.56	30.33	3	71	.00***
Model 2	.80	.64	.62	6.94	.08	15.02	1	70	.00***

Note. Adj=adjusted; IQ=non-verbal intelligence quotient; SES=socioeconomic status; Sig=significance; VSM=verbal semantic memory task.
Model 1 predictors: (constant), Age, IQ, SES
Model 2 predictors: (constant), VSM * p<.05. ** p<.01. *** p<.001.

Table 20b. Coefficients and significance results for the predictors for expressive vocabulary knowledge (VSM).

Model 1	***Standardized Beta coefficients***	***t***	**Sig.**	***pr*²**
Age	.56	5.48	.00***	.29
SES	.22	2.69	.01**	.09
IQ	.16	1.56	.12	.03
Model 2				
VSM	.33	3.88	.00***	.18

Note. Adj=adjusted; IQ=non-verbal intellectual quotient; SES= socioeconomic status; Sig=significance
VSM=verbal semantic memory task.
Model 1 predictors: (constant), Age, IQ, SES.
Model 2 predictors: (constant), VSM * p<.05. ** p<.01. *** p<.001.

The results for the overall receptive vocabulary model are shown in Table 21a. Age, IQ, and socioeconomic status (Model 1) accounted for unique portions of variance in expressive vocabulary knowledge ($R^{2=}$.56, adj. $R^{2=}$.55, $F(3,71)=30.75$, $p<.001$). The follow-up regression analysis revealed that verbal semantic memory (Model 2) accounted for a significant additional portion of variance ($R^{2=}$.61, adj. $R^{2=}$.58, R^2 change$^=$.04, *F* change (1,70)=7.22, $p<.01$). The coefficient results showing the specific predictors of receptive vocabulary knowledge are shown in Table 21b. Age ($\beta=.45$, $t(71)=4.45$, $p<.001$, $pr^2=.22$), socioeconomic status ($\beta=.32$, $t(71)=3.95$, $p<.01$, $pr^2=.18$), IQ ($\beta=.20$, $t(71)=2.17$, $p<.05$, $pr^2=.06$), and verbal semantic memory ($\beta=.24$, $t(70)=2.69$, $p<.01$, $pr^2=.09$) were all significant predictors.

Table 21a. Regression model to predict receptive vocabulary knowledge for all the participants (VSM).

Model	***R***	***R^2***	**Adj R^2**	***SE* of estimate**	**R^2 change**	**F change**	***df* 1**	***df* 2**	**Sig, *F* change**
Model 1	.75	.56	.55	19.99	.56	30.75	3	71	.00***
Model 2	.78	.61	.58	19.16	.04	7.22	1	70	.009**

Note. Adj=adjusted; IQ=non-verbal intelligence quotient; SES=socioeconomic status; Sig=significance; VSM=visual semantic memory task.
Model 1 predictors: (constant), Age, IQ, SES.
Model 2 predictors: (constant), VSM. * $p<.05$. ** $p<.01$. *** $p<.001$.

Table 21b. Coefficients and significance levels for predictors of receptive vocabulary knowledge (VSM).

Model 1	***Standardized Beta coefficients***	***t***	**Sig.**	***pr^2***
Age	.45	4.45	.00**	.22
SES	.32	3.95	.00**	.18
IQ	.22	2.17	.03*	.06
Model 2				
VSM	.24	2.69	.01**	.09

Note. Adj=adjusted; IQ=non-verbal intellectual quotient; SES= socioeconomic status; Sig=significance
VSM=verbal semantic memory task.
Model 1 predictors: (constant), Age, IQ, SES.
Model 2 predictors: (constant), VSM. * $p<.05$. ** $p<.01$. *** $p<.001$.

8.5 Discussion

Almost all the hypotheses posed in this study were validated. First, the results for the phonological memory subtests were consistent with results from previous studies showing that children with SLI have problems storing and holding phonological information in a speech-based form (Archibald & Gathercole, 2006; Ellis Weismer et al., 1999; Gathercole & Alloway, 2006). In our study, the children with SLI were significantly less accurate at holding and retrieving non-words and verbal numbers.

Second, we found that the ability to store and repeat a visual pattern for a short period of time was also impaired in children with SLI, supporting findings from studies that have reported working memory and short-term memory deficits in the visual domain in this population (Vugs, Cuperus, Hendriks, & Verhoeven, 2013).

Third, we observed significant differences in verbal declarative performance between the groups, with children with SLI performing less accurately than TD children at solving tasks that assess the use of memory to consciously recall information. Previous studies, however, have demonstrated that this deficit in SLI is predicted by short-term memory deficits (Lum & Conti-Ramsden, 2013; Lum et al., 2015; Conti-Ramsden et al., 2015). Accordingly, we reanalyzed verbal declarative memory performance, assessed using the word-pair retrieval list task, for both groups by controlling for verbal working memory and found that the differences were no longer significant. They remained significant, however, for the verbal semantic memory task in which infants had to recall as many items as possible from a given category. Our findings thus show that declarative learning is preserved in SLI, supporting previous reports that verbal declarative memory might be impaired in this population because initial learning is affected by poor working memory (Lum & Conti-Ramsden, 2013; Lum et al., 2015; Conti-Ramsden et al., 2015). The question that arises from our results, however, is why verbal semantic memory abilities were also affected after controlling for working memory. One explanation could lie in the specific cognitive process required for this task. The verbal semantic memory task used requires the ability to recover and retrieve semantically related words and not to assess deep semantic information with semantic tasks involving the definition of meanings. Ullman and Pierpont (2005) argued that lexical retrieval depends on the brain structures underlying the procedural system and that abnormalities in this area can affect specific aspects of word learning and use, such as recovering and evoking words already acquired. We may not have observed significant differences for verbal semantic memory performance after controlling for verbal working memory because the cognitive process required to successfully complete this task is supported by the non-declarative memory, which is less dependent on the working memory (Weitz et al., 2011). Our results thus add to the evidence that cognitive processes sustained by the non-declarative memory are affected in children with SLI. Verbal declarative memory was also a significant predictor of expressive and receptive vocabulary knowledge, providing further evidence on the role that this memory system has on vocabulary acquisition in infancy. Verbal semantic memory, in turn, was a significant predictor of expressive vocabulary knowledge, indicating that word retrieval abilities are also needed for verbal expression.

Our results for the verbal declarative memory assessment are contrary to one of our hypotheses, as they showed that children with SLI performed less accurately than TD children in a task in which they had to distinguish previously seen faces from new faces in a short and delayed recognition task. The differences remained significant even after controlling for visual working memory. We may have needed to control for an additional visual working memory task, as we only used the visual selective reminding task as a covariate. This task assesses the short-term memory component of Baddeley's working memory model (Baddeley, 2000): the visuospatial sketchpad. Had we used another visual working memory task that requires a more complex cognitive process and created a composite score (as we did for verbal working memory), we might have found evidence of preserved verbal declarative memory in the SLI group. The application of even more memory system subtests for this dissertation, however, was not possible, as the children were tested with a predefined battery of tasks. Time was limited and, as we were concerned about the children's attention span, we prioritized the use of verbal word memory tests. Nonetheless, Riccio, Cash, and Cohen (2007) and Lum et al. (2012) tested a group of children using the same face recognition task and found no significant differences between children with and without SLI for short or delayed recognition. No other studies to our knowledge have used the facial memory subtest to assess verbal declarative memory in children with SLI. There are other types of tasks that can evaluate the retrieval of non-verbal and visual information from the declarative memory, such as the dot locations task from the Children's Memory Scale (Cohen, 1997), which has been used in more studies than the facial memory subtest (e.g., Baird, Dworzynski, & Simonoff, 2010; Dewey & Wall, 1997; Lum et al., 2012; Riccio et al., 2007) Findings have shown that children with SLI are able to retrieve non-verbal information from the declarative memory with the same proficiency as TD children of the same age. We decided to use the facial memory subtest because the Spanish version of TOMAL does not have an analogous task to the dot locations task. More studies using the facial memory subtest are needed to explore in greater depth children's abilities in this area and clarify the contradictory results observed in this study about the ability of children with SLI to memorize and identify known faces in a series of distractor faces, an ability that depends on the verbal declarative memory.

GENERAL DISCUSSION

9. Summary of the results and general discussion

9.1 Summary of the results

Comparison between the performance results in children with SLI and TD children for all the memory tasks.

Taking the four studies carried out in this dissertation together, a global summary about the memory capacities that bilingual Catalan-Spanish children with SLI have in comparison to age-matched TD children is presented in this section:

The general results of the three SL tasks showed that children with SLI were significantly less accurate than TD children at solving the ASL, VSL and CSSL tasks. In addition, children with SLI were significantly less able to perform correctly all the visual and spoken working memory tasks in comparison to TD children. Finally, both children with SLI and TD children showed comparable results in the verbal declarative memory tasks when controlling for working memory measures. According to the verbal semantic memory, children with SLI showed significantly poorer results when solving the task than the group of TD children. Finally, unexpected visual declarative memory deficits were found in children with SLI because they performed the task significantly worse than TD children even when controlling for the working memory (see Figure 27 for a visual summary of all the results).

SL tasks	Visual and verbal short-term, working and declarative memory tasks
ASL → SLI < TD **VSL** → SLI < TD **CSSL** → SLI < TD	**Visual stM** → SLI < TD **Verbal stM** → SLI < TD **Phonological WM** → SLI < TD **Verbal WM** → SLI < TD **Verbal DM** → SLI = TD (controlling for verbal WM and verbal stM) **Verbal SM** → SLI < TD (controlling for verbal WM and verbal stM) **Visual DM** → SLI < TD (controlling for visual stM)

Figure 27. Summary scheme: comparison between groups (TD, SLI). Results for the SL tasks on the right and short-term, working and declarative memory results on the left. ASL=Auditory statistical learning; VSL= visual statistical learning; CSSL=cross-situational statistical learning; stM=short-term memory; WM=working memory; DM=declarative memory; SM=semantic memory; SLI=specific language impairment; TD=typical development.

Statistical learning and declarative memory as predictors of vocabulary knowledge

In addition to the behavioral results, this dissertation explored the contribution of declarative and non-declarative memory to the children's vocabulary knowledge. Figure 28 illustrates the partial correlations between the memory tasks and the receptive and expressive vocabulary knowledge. In brief, we found that the three statistical learning tasks and the verbal declarative subtests had a significant role in introducing variance into the children' vocabulary knowledge. The verbal declarative memory task was the predictor that added a higher percentage of variance to the vocabulary knowledge.

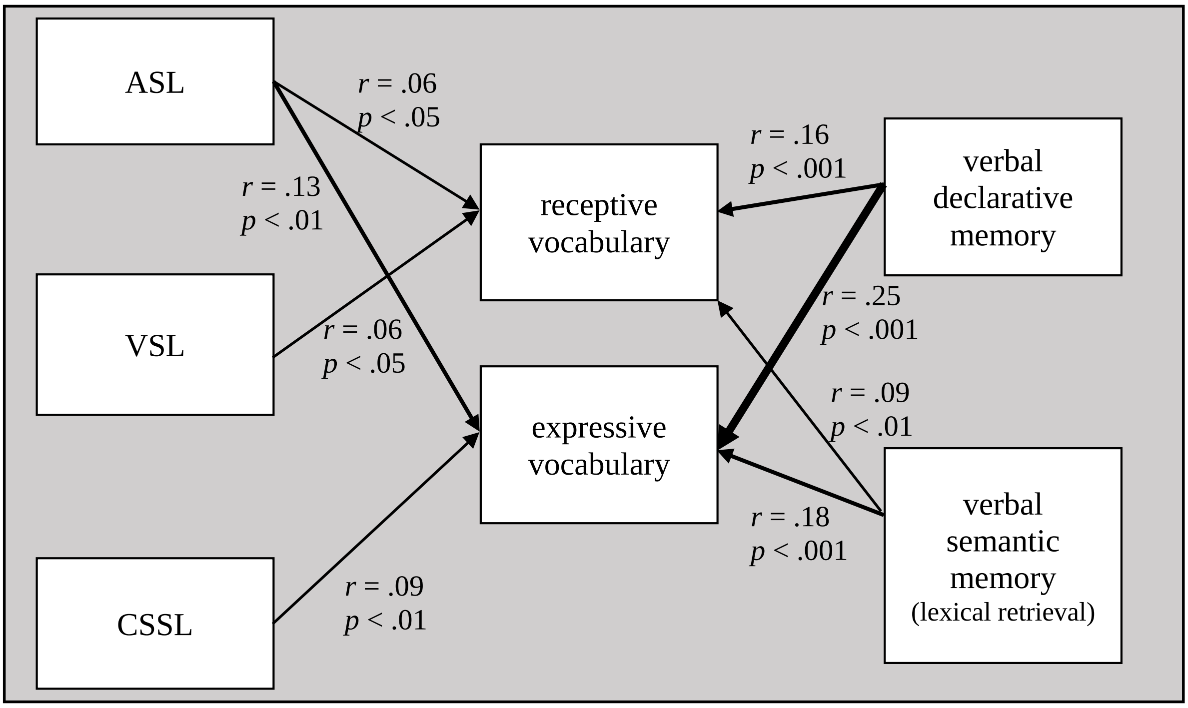

Figure 28. Summary scheme: partial correlations between the three SL tasks (ASL, VLS, CSSL) and receptive and expressive vocabulary (left) and between verbal DM and VSM subtests and receptive and expressive vocabulary (right). The *r* value indicates the strength and direction of the relationship between the two variables whilst controlling for the effect of the IQ and SES variables. Thus, r is a partial correlation. The *p*-value indicates the significance of the correlation.

9.2 Discussion

Statistical word learning in Catalan-Spanish children with SLI

There is some agreement in the conclusion that children with SLI struggle to solve tasks that require the non-declarative memory system. However, non-declarative memory is a huge concept that has been theorized and investigated from different perspectives. The literature related to the non-declarative memory in this population attempts to demonstrate which kind of non-declarative memory out of the many that fall under the umbrella of this system is the one affected in children with SLI and why. The first studies carried out in the field used the SRT task to assess one part of the non-declarative memory called procedural memory. The reason for using this task was to validate the PDH raised by Ullman and Pierpont (2005), which proposed that children with SLI have brain structure abnormalities related to the memory that humans need to implicitly learn and extract new stable sequential or serial motor and cognitive skills from the environment. Procedural learning is also required to learn, more specifically, grammar rules because it is full of embedded linguistic patterns and regularities that allow language learners to acquire the number and gender nominal inflection and agreement and the regular verb tenses, among others.

The literature has shown small but significant effects of SLI on the SRT task compared to age-matched TD children (Lum et al., 2014). The problem of using this task is that it emphasizes the motor aspects of procedural learning. Furthermore, it has been found that children with SLI still show learning impairments in non-motor implicit memory tasks (Hsu et al., 2014; Kemény and Lukács, 2009; Mayor-Dubois et al., 2012).

In addition to procedural learning, other non-declarative mechanisms such as statistical learning mechanisms have been studied in children with SLI. Statistical learning is an implicit mechanism that requires humans to compute the transitional probabilities and frequencies embedded in an input of visual or auditory information. It has been demonstrated that infants to adults are capable of extracting this statistical information from the environment (Saffran et al., 1996, 1996b; Graf Estes, Evans, Alibali & Saffran, 2007). Both procedural and statistical learning are broadly defined as the ability to detect regularities but are in fact two different mechanisms that need a specific structure of the input to be learned (e.g., sequential pattern for procedural learning and irregular spatial locations and identity mapping for statistical learning). Both implicit and statistical learning are mechanisms integrated into the broad non-declarative system.

It is well known that the most affected language area in children with SLI is related to grammar-learning abilities. For this reason, the PDH was raised to explain the grammar problems in this population. The declarative/procedural memory neurological system (Ullman & Pierpont, 2005) stated that vocabulary learning is supported by the declarative memory system and grammar learning is supported by the procedural memory system. This hypothesis claimed the idea that declarative memory—and hence word learning—is preserved in children with SLI. In contrast to this hypothesis, there is significant evidence about difficulties in lexical acquisition in children with SLI (e.g., Alt & Plante, 2006; Gray, 2004; Rice, et al., 1990; Rice, et al., 1992; Rice, et al., 1994). On the other hand, and also contrary to the PDH, the statistical learning literature proposes that some word-learning processes can also be acquired through an implicit and unconscious mechanism that does not need to be strictly serial or sequential.

The statistical learning mechanism perspective in children with SLI has only been tested using the word segmentation task performed by Saffran et al. (1996), and all the studies that tested it showed that children with SLI were not able to track the transitional probabilities information from an auditory word stream (Evans et al., 2009; Mayor-Dubois et al., 2012; Mainela-Arnold & Evans, 2014; Haebig et al., 2017).

The motivation of this dissertation was to contribute within the research field to having more evidence about the role of different memories in children with SLI. Thus, in light of all the unequal results shown in past studies on non-declarative memory in children with SLI, we selected three general aims to investigate: First, we wanted to know whether Catalan-Spanish children with SLI were as capable as TD children at solving three statistical learning tasks in different domains (auditory, visual and audio-visual). Second, we wanted to examine the relative contributions of three types of statistical word learning to vocabulary knowledge in school-age children with and without SLI. Finally, in addition to statistical learning abilities, we wanted to know the role of working memory and declarative memory in children with and without SLI in terms of vocabulary knowledge.

Three statistical learning tasks were designed to investigate these three main objectives. An auditory (ASL) and an audio-visual (CSSL) task were designed to simulate two different processes for learning words. The ASL task was a laboratory adaptation of the word segmentation process that humans carry out to discover the individual words that comprise an entire speech stream. The CSSL task was designed to test, in a controlled environment, the ability to map spoken words to visual objects in an unambiguous context such as the natural world. In addition, a visual (VSL) task was designed to have an analogous task to the ASL task in order to gather more evidence about whether the non-declarative deficits in Catalan-Spanish children with SLI were domain-specific or domain-general.

In addition to the experimental tasks, different memory tests were used to test working and declarative memory for both groups.

Performance in statistical learning tasks

The results in studies 1 (ASL), 2 (VSL) and 3 (CSSL) showed that both Catalan-Spanish children with and without SLI performed above chance in all of the three tasks. Thus, initially these results suggested that both groups could use the implicit information to learn the patterns and computational frequencies hidden in the input in auditory, visual and audio-visual domains. Neither VSL nor CSSL tasks had ever been tested on children with SLI but an ASL task had been tested by Evans et al. (2009); Mainela-Arnold & Evans (2014) and Haebig et al. (2017) and the results found in our study differed from the results of those studies. English-speaking children with SLI in these past studies showed performance at chance in the same ASL task. These contradictory results encouraged us to examine the data in our study more closely. Thus, although in the first instance these results might be understood as a preserved statistical learning in children with SLI, it is important to note that the performance of the TD children was significantly higher than the performance of the children with SLI in all three of the statistical learning tasks. These results suggest that although children with SLI showed some statistical learning abilities that permitted them to learn language regularities, they were not as proficient as TD children in doing so. A more in-depth analysis of the data was performed to see whether children with SLI and TD children were able to detect the variability in transitional probabilities in the ASL task and the frequency variability in the CSSL task. The results showed that children with SLI did not show a preference for stimuli that were more frequent and easier to detect. In contrast, the group of TD children showed a significant preference for those stimuli with high statistical learning characteristics. Moreover, taking into account the number of children in each group that were above and below chance, there were more TD children than children with SLI that performed above chance and had a high correct percentage in the three tasks. These results give more evidence about a compromised statistical learning mechanism in children with SLI and are in accordance with past studies that showed that children with SLI present with difficulties in the process of extracting abstract knowledge from statistical patterns (Evans, et al., 2009; Mayor-Dubois et al., 2012; Hsu, et al., 2014; Mainela-Arnold & Evans, 2014; Haebig, et al., 2017) and probabilistic computations (Kemény & Lukács, 2009) embedded in the input.

The results of study 3 (CSSL task) demonstrated that children with SLI not only showed difficulties in solving sequential non-declarative tasks as the PDH proposes, but also showed difficulties with a non-sequential statistical learning task. These results are related to the findings of Kemény and Lukács (2009) in which children with SLI were not able to solve tasks that required the computation of frequencies that were not sequential in time. This finding sheds more light on the assumption that children with SLI might not only have a deficit in procedural learning but they might also have a more broadly affected non-declarative system that includes the statistical learning mechanism. It suggests that the non-declarative system comprises abilities that are not necessarily related to sequential patterns such as the computation of frequencies—required to solve the CSSL task.

In addition to behavioral results, we wanted to look more deeply into the process of learning new words through a statistical learning paradigm. To do so, we used an eye-tracking methodology to gather information about the moment-by-moment cognitive process children with and without SLI perform when doing a CSSL task. Specifically, we recorded the eye movements during the learning and testing phases of the task. The results showed that there were differences between the groups in their online visual attention patterns while performing the task. Specifically, TD children but not children with SLI showed a clear pattern of looks from left to right through the learning phase, which, it seems, enabled them to extract the embedded frequencies in the input and learn more words than children with SLI. Moreover, TD children showed a higher proportion of looks to the target through the testing phase in comparison to children with SLI. These results suggest that there are differences between children with and without SLI in the online cognitive process when learning and interpreting novel words implicitly. Moreover, this finding suggests that children with SLI may have an immature and less efficient mechanism for detecting the visual spatial process regularities embedded in a word learning task.

The eye-tracking results of the testing phase in the CSSL task showed that the group of TD children had a higher proportion of looks to the target in comparison to the group of children with SLI. Also, the GCA analysis suggested that TD children looked to the target a short time after hearing the spoken word while children with SLI looked to the target later on. Thus, the representation of the new words learned was activated faster for the TD children than for children with SLI. Although there are age-sample differences, these results are similar to those found in Erica et al. (2015), a study in which 18-month-old late talkers and TD infants showed differences in the point of divergence between target and distractor objects in a two-alternative testing trial after a word-learning task. The late-talker group had an initial overlap of looking to both the target and distractor but did not show significant distinction between the two pictures, while the typical group initially showed more separation in looking to the two pictures and ultimately distinguished the target-word picture at an earlier time point. Our results and those found in Erika et al. (2015) can be interpreted as children with SLI possibly having weak representations in learning implicitly novel words. Moreover, they may also have deficits in visual processing in addition to their verbal word impairments (Alt, 2013).

Relationship between statistical learning and vocabulary knowledge

The ASL and CSSL are two statistical learning tasks that reproduce and simulate specific abilities required to acquire vocabulary in a controlled environment. The decision to use these two tasks was to investigate whether non-declarative memory is also a mechanism required for acquiring vocabulary. As was noted above, the results for both tasks showed a deficit in children with SLI compared to the group of TD children. Contrary to past studies that studied the relationship between procedural learning and grammar abilities (Gabriel et al., 2013; Tomblin et al., 2007; Lum et al., 2012), in this dissertation we wanted to investigate the assumption that statistical learning is one of the mechanisms related to lexical knowledge. To do so, participants' receptive and expressive vocabulary scores, assessed with standardized tests (i.e., the child's ability to accurately link a label to a picture of words known by children this age and the ability to generate the spoken label for a picture), were used as complementary variables for performing statistical regression analysis between the three statistical learning tasks and the vocabulary knowledge. The results showed that the three tasks were statistically significant predictors of vocabulary knowledge. These results are in accordance with those found in Evans et al., 2009 in which vocabulary knowledge was related to the ability to extract the embedded non-word from a continuous stream of sounds. Conversely, these results contradict the PDH and other studies that argued that lexical knowledge is not related to the ability to implicitly extract regularities from the input (Hedenius et al., 2011; Lum et al., 2012; Tomblin et al., 2007).

The small but significant effects in the regressions are coherent with other studies that showed that multiple variables are involved in a language-learning process, specifically in word-learning acquisition (Newman, et al., 2006; Evans et al., 2009). This dissertation has not focused on considering that statistical learning is the only mechanism humans need to acquire language abilities but rather that it is one of the main processes involved in this extended process. Thus, the fact that statistical learning was not a strong predictor of vocabulary knowledge is comprehensible. It suggests that it is only one of the multiple mechanisms needed to acquire vocabulary. By conducting research using experimental and controlled tasks, researchers can assess the specific abilities and variables involved in a complex process consisting of multi-components. In turn, the results of the studies carried out in this dissertation make it clear that statistical learning is an important cognitive base process required for acquiring vocabulary. We must not lose sight of the fact that word learning requires many interactive variables such as prosody (de Clerck, Pettinato, Verhoeven, Gillis & Steven, 2017), gestures (Vogt & Kauschke, 2017), visual contact (Parise, Handl, Palumbo & Friederici, 2011), joint attention (Rohlfing, Wrede, Vollmer & Oudeyer, 2016), imitation (Gampe, Brauer & Daum, 2016) and socioeconomic status (Hoff, 2006), among others to be acquired.

Taking all this together, the behavioral results of the three statistical learning tasks corroborated the first two hypotheses put forward in this dissertation: the results suggested a more general non-declarative memory deficit in children with SLI that goes beyond the procedural deficit proposed by the PDH because children with SLI were less accurate and showed no evidence of extracting the implicit regularities from the input compared to the group of TD children in the three statistical learning learning tasks, even when the task was not sequential in time. Moreover, although the tasks did not account for a high amount of variance in vocabulary knowledge, they were significant predictors of the vocabulary knowledge. The results suggested that the ability to implicitly extract regularities from the input contributes to vocabulary acquisition. The studies conducted in this dissertation therefore led us to suggest that non-declarative learning is a required mechanism for acquiring vocabulary and not just grammar.

Working memory and children with SLI

The results in study 4 about working memory abilities in children with SLI corroborated one of the hypotheses proposed: children with SLI were significantly less accurate than TD children at performing phonological, verbal and visual working memory tests. These results are in accordance with many studies conducted that showed similar results (Archibald & Gathercole, 2006; Ellis Weismer et al., 1999; Gathercole & Alloway, 2006; Vugs, et al., 2013). Although many investigations have been conducted with English-speaking children with SLI and there is broad consensus about the working memory deficit in this population, little research has been carried out on working memory deficits in the Catalan-Spanish context. These results, therefore, again confirm that children with SLI have not only language difficulties but, potentially, also working memory deficits. These findings have important clinical implications because in the same way that language skills are part of standard speech and language assessments, information regarding working memory must be available for speech language therapists and other professionals to diagnose children with SLI. Working memory measures should be included in psychoeducational and psychological assessments as part of standard testing. Moreover, the fact that visual working memory also appears to be affected in children with SLI implies that tests to detect SLI should also include the visual component in addition to a phonological working memory assessment.

Declarative memory in children with SLI

Previous studies have demonstrated a preserved declarative memory in children with SLI, thus supporting the PDH (Hsu & Bishop, 2015; Lum & Conti-Ramsden, 2013; Lum et al., 2015; Conti-Ramsden et al., 2015). For that reason, another goal of this dissertation was to examine how Catalan-Spanish children with SLI performed in a series of declarative memory tasks in the auditory and visual domains. The results for study 4 about declarative memory confirmed one of the hypotheses posed and supported the results of these past studies: children with SLI performed as accurately as the TD children in a spoken-word learning list only when verbal working memory was controlled for. One of the hypotheses was partially corroborated because children with SLI still displayed a significantly less accurate performance in a verbal semantic task even after controlling for the verbal working memory. As discussed above, the explanation for their poor performance in the semantic task might be explained because although it was a lexical assessment task that was supposed to be solved by using declarative memory, it requires a lexical retrieval cognitive process. In turn, lexical retrieval is supported by brain areas that related to the non-declarative memory that is impaired in children with SLI (Ullman & Pierpont, 2005).

These results are important for clinical implications because there is growing evidence about working memory deficits in children with SLI and these deficits affect preserved declarative memory, which could serve as a compensatory mechanism for learning language regularities in grammar and lexical acquisition. For this reason, taking working memory deficits into account in this population is a key strategy when designing activities, programs and guidelines to help them improve their language skills. There is no clear evidence about the impact of training working memory capacity directly. A meta-analysis carried out by Melby-Lervåg and Hulme (2013) about intervention programs designed to improve working memory skills concluded that after directly training the working memory capacity, reliable short-term improvements were detected but there was no generalization. In the same vein, Kamhi (2014) made a review of language interventions and showed that working specifically on memory has no positive effects and the idea of treating it directly stems from false beliefs. However, intervention strategies do exist to manage these deficits. For example, monitoring the students by asking them to verbalize their steps while carrying out tasks they often struggle to complete, breaking tasks into smaller chunks, reducing the amount of material to be learned, repeating the information as many times as they need or encouraging the practice of increasing the amount of information encoded into memory (CanLearn Society, 2013).

In addition to the strategies for managing working memory deficits, it is important that the clinical implications of preserved declarative memory abilities are taken into account. The PDH suggests that children with SLI use the declarative memory system as a compensatory mechanism for acquiring the information that cannot be achieved through procedural memory. In this respect, Finestack (2018) tested the efficacy and reliability of an explicit intervention in children with SLI designed to help them acquire or improve grammar rules that should be acquired through an implicit process. Finestack found children were more likely to acquire, maintain, and generalize novel grammatical forms when they were taught with explicit instructions in comparison to a group which was trained with implicit instructions. This dissertation provides more evidence about the non-declarative memory deficit in this population, which is also extended to word-learning abilities, and reveals the need to conduct further research to evaluate the use of explicit instructions when teaching both lexical and grammatical forms to children with SLI.

One question that may arise from the investigation carried out in this dissertation is whether the deficit in working memory capacity in children with SLI could also be a factor that has influenced their low statistical learning performance. This question has not been broached because previous studies and lines of research have shown a stronger relationship between working memory and declarative memory rather than with non-declarative memory (e.g., Frensch & Miner, 1994; Unsworth & Engle, 2005; Weitz, O'Shea, Zook & Needham, 2011). Moreover, neurological evidence suggests that working memory is closely related to declarative memory (Braver et al., 2001; Buckner et al., 1999; Simons & Spiers, 2003; Fletcher et al., 1998) and independent from non-declarative memory (Nemeth, Csabi, Janacsek, Varszegi & Mari, 2012). Implicit learning, on the other hand, is a subconscious process that is believed to be independent from general cognitive resources such as working memory (Janacsek & Nemeth, 2013). Although several studies over the past few years have tried to demonstrate the shared networks underlying the working memory and non-declarative systems, this is a question that will need to be studied in more depth in other investigations because many factors need to be taken into account to discover whether working memory interferes with the non-declarative memory (e.g., the type of non-declarative memory task and the explicitness of the sequence, the method for measuring working memory capacity, the online and offline stages of learning, etc.) (Janacsek & Nemeth, 2015) and these cannot be covered in this investigation.

Relationship between declarative memory and vocabulary knowledge

Based on prior work (Conti-Ramsden et al., 2015; Hsu & Bishop, 2015) and assuming the PDH approach about declarative memory is the memory used to acquire vocabulary, one of the hypotheses related to the role of declarative memory was that verbal declarative memory adds a significant amount of variance to vocabulary knowledge in children with and without SLI. To ascertain the role of declarative memory in vocabulary acquisition, participants' receptive and expressive vocabulary scores, assessed with standardized tests, were also used as complementary variables in carrying out a statistical regression analysis between the verbal declarative tasks and vocabulary knowledge. Our hypothesis was corroborated because the results demonstrated that verbal declarative memory scores were significant predictors of expressive and receptive vocabulary, thus supporting the assumption that declarative memory has an important role in the infant's ability to learn and recognize new words. However, although this hypothesis was confirmed, these results cannot be considered and interpreted in isolation since the results of the statistical learning tasks and their relationship with vocabulary knowledge should also be taken into account. Thus, while the PDH argues that vocabulary learning is supported by the declarative memory system and not by the procedural memory, the results presented above showed that although the correlations were not strong, statistical learning abilities accounted significantly for vocabulary acquisition. The fact that we found that verbal declarative memory was a stronger predictor of vocabulary scores than statistical learning tasks reveals that declarative memory carries more weight in vocabulary acquisition than statistical learning abilities. But these results also suggest that although statistical learning is not the core memory mechanism for acquiring vocabulary, it is one of the multiple components required.

9.3 Limitations and future directions

Future directions: individual differences and heterogeneity in children with SLI

Returning to the general results of the three statistical learning tasks, it is important to note that although the group mean showed that TD children had a better performance than children with SLI, there was some variability in the individual performance for both groups. Individual differences showed that some children with SLI were able to solve the tasks while some TD children were not. Thus, individual variability in statistical learning is an issue to consider in future studies because most research on statistical learning in developmental disabilities—including this study—has focused on group-level differences, comparing impaired with unimpaired groups, and few studies have examined individual differences between participants (Arciuli & Conway, 2018).

Furthermore, the fact that the group of children with SLI performed above chance in the three tasks but performed significantly worse than TD children might be associated with the language difficulties that children with SLI display: although they use an unstructured language, which is full of errors, limited in words and sometimes incomprehensible, they are still using it to communicate with others. It is important to mention that SLI is not a disorder defined as an absence of language but rather an impaired language. In this sense, it may be that statistical learning is an affected mechanism in children with SLI compared to TD children but not a non-existing mechanism in this population. Moreover, it is possible that they use different kinds of computations or mental processes that need to be assessed using different statistical learning tasks in future investigations.

Although the results point to the possibility that a more general non-declarative memory deficit may exist in this population, caution is needed when making general conclusions about the cognitive processes affected in children with SLI because this impairment is a heterogeneous spectrum covering grammar, phonological and word-learning difficulties. If we take a dimensional view of SLI, it can be explained by different causes (Leonard & Deevy, 2006). Some children with SLI have fairly good phonological abilities but struggle with lexical learning and other children have reasonably good grammar abilities but problems with word learning. Therefore, the heterogeneity that characterizes SLI may explain the variability in performance in these kinds of tasks.

Children with SLI that display problems managing vocabulary knowledge may be less accurate at solving tasks related to statistical word-learning processes (e.g., CSSL) and children who are grammatically more affected would show more difficulties in tasks involving procedural learning (e.g., SRT or VSL tasks). Past studies have shown that children with SLI that had preserved vocabulary abilities could perform the SRT task to a similar level than TD children. Conversely, those who were grammatically impaired could not (Tomblin et al., 2007). The conclusion of Tomblin's study was that children with SLI with preserved vocabulary did not show procedural memory deficits. The results of this dissertation can add one reflection to those conclusions: it may be the case that those children with preserved vocabulary abilities in Tomblin's study would show difficulties in solving a CSSL. Thus, they might show deficits in non-declarative memory but in tasks that involve other implicit computational mechanisms, such as the extraction of frequencies (i.e., word learning), instead of the transitional probabilities embedded in a sequence (i.e., grammar learning). Accordingly, the non-declarative memory deficit in children with SLI could be explained by the type of language difficulties children with SLI present. These language difficulties, in turn, could be related to a specific non-declarative mechanism that can be procedural or statistical.

The assumption that children with SLI can have one type of non-declarative memory compromised and another type preserved depending on the different language areas affected might be studied by doing big-sample studies with well-defined groups of children with SLI, taking into account their individual language difficulties and testing them with tasks that evaluate the different types of non-declarative mechanisms.

Furthermore, neuroimaging studies need to be carried out to classify children with SLI according to their language difficulties and see whether specific brain areas are activated when children with SLI with vocabulary or grammar impairments are performing tasks that require procedural or statistical learning. In this way, the conclusions about the impaired non-declarative memory deficit can be narrowed or better explained since they would take into account the particularities of each child with SLI. Neuroimaging studies are also required to study the overlapping brain regions that involve declarative and non-declarative memory. Krishnan, Watkins and Bishop (2018, p.705) argued that "no type of learning is purely declarative or procedural in nature, and the ways in which these distinctions apply to language learning in particular needs clarifications".

Finally, all the research conducted in this dissertation has been approached from a dimensional perspective of SLI (Sackett, Haynes, Guyatt & Tugwell, 1991), that is, that SLI assumes the potential for heterogeneity in symptoms, origins, and causal influences. Accordingly, we did not treat the non-declarative memory deficit in this population as a possible unique identifier of SLI and a categorical approach of this disorder. A recent study carried out supports the dimensional perspective of SLI considered in this dissertation: Lancaster and Camarata (2019) ran cluster analyses including the multivariable of language and cognitive measures with a big sample of children with SLI (n=505) to characterize and interpret the variability of SLI and understand its nature. They described and statistically examined three primary possible models for characterizing the variability in SLI: predictable subtypes; individual differences; and continuum/spectrum. The results showed non-random clustering coupled with a large number of noninterpretable subtypes and provided empirical support for the continuum/spectrum and an individual differences model to characterize children with SLI.

Although this dissertation adopted a theoretical model based on a dimensional perspective of SLI, the evidence of an impaired non-declarative memory system in children with SLI raises another major question for future study: is a non-declarative deficit a unique identifier of SLI? Taxonomic approaches, such as those adopted by Dollaghan (2004, 2011), are required for SLI to be conceptualized as a disorder with a discrete diagnostic category capable of clearly differentiating typical children from those who present the disorder. The problem of not finding a unique specifier of SLI is that the investigations cannot provide clear clinical guidelines for prevention and treatment because the existence of a well-delineated set of causal mechanisms creates the need for distinctive treatment strategies (Dollaghan, 2011). The results of this dissertation provide further evidence about the deficit in non-declarative memory in children with SLI and should encourage researchers in the field to investigate whether this memory impairment can be the identifier of SLI that enables typical children to be clearly differentiated from those who present this imprecise yet intriguing language disorder.

Limitations

The results of this dissertation also open up the possibility that more time may be needed to implicitly learn the linguistic regularities of language given that in this study children with SLI were able to solve the task significantly above chance. Thus, one of the clinical implications for children with SLI would be to increase the duration and exposure to the language input to give them more time to track all the implicit linguistic information. This assumption has to be taken with caution because the tasks performed in this dissertation were not designed to be run using different durations and exposure times. The results of our studies cannot therefore assure that increasing the duration of the stimulus presentation and exposure to it would result in children with SLI performing better in non-declarative learning tasks. However, the results can serve as an initial premise to support studies which showed that increasing duration and exposure benefitted children with SLI (Evans et al., 2009). In order to formulate more precise conclusions, further research must be carried out into the effects of duration and exposure on this kind of task.

The methodology used in this dissertation involved the use of just three task types to investigate non-declarative memory in children with SLI. Although one of our aims was to test a broader non-declarative memory system beyond the procedural memory, it was not possible to run more experiments. If we want to investigate a larger construct of non-declarative memory, we will need to run a greater number of different tasks and different variations of a given task. Hence, a greater variability in the tasks used to test the broad scope of non-declarative memory would help to explain the different behavioral outcomes and how they draw on particular underlying components of the non-declarative system.

Another issue regarding non-declarative memory is the role played by the particular developmental stage in which it is studied. Some studies that assessed non-declarative memory in different age groups suggested that it may not be invariant over the evolutionary development (e.g., Janacsek, Fiser & Nemeth, 2012; Arciuli & Simpson, 2011; Lum et al., 2014) but little research has been conducted on a typical population that focuses on the role of non-declarative memory through the different developmental stages. Although the age ranges in the studies performed in this dissertation are quite broad (from around 6 years old to 12 years old), the selected sample was not big enough to be able to compare the performance of smaller, age-specific groups and provide consistent results about the role that developmental stage plays in the non-declarative memory.

CONCLUSIONS

Catalan-Spanish children with SLI showed difficulties in automatically and spontaneously detecting implicit patterns from input in tasks requiring non-declarative learning. Specifically, they showed poorer results in comparison to the group of TD children in three statistical learning tasks in different domains. One auditory and one audio-visual SL task were designed to simulate two different processes required during word learning. The poor results of children with SLI in these tasks suggest that they may have a more general mechanism deficit in non-declarative memory in addition to the procedural learning deficit proposed in the PDH (Ullman, 2005). Children with SLI showed difficulties in both sequential and non-sequential statistical learning abilities in auditory, visual and audio-visual domains. Moreover, children with SLI showed no capacity for detecting the variability in the transitional probabilities and frequency variability embedded in the tasks. This behavior gives more evidence about a compromised statistical learning mechanism in children with SLI. These results are not intended to imply that all children with SLI have a broad non-declarative memory system. Instead, it can be assumed that children with SLI can show deficits in tasks related to procedural memory, statistical learning or both, regarding the type of language difficulties of each child (e.g., vocabulary or grammatical).

The importance of individual differences has been discussed, leading us to conclude that future studies need to focus on the specific and individual language difficulties that children with SLI have. At the very least, future studies must use samples that comprise more homogeneous groups selected according to the language difficulties of the participants. This would make it possible to give more specific answers about the underlying memory deficits in this population in order to establish further guidelines for speech and clinical intervention.

The results of the relationship between vocabulary knowledge and statistical learning showed that although the statistical learning tasks did not account for a high level of variance in vocabulary knowledge, they were significant predictors of vocabulary knowledge. These results suggest that the ability to implicitly extract regularities from the input contributes to vocabulary acquisition. Based on the studies conducted in this dissertation, it would therefore seem that non-declarative learning is a required mechanism for acquiring vocabulary as well as grammar.

Furthermore, children with SLI showed poorer results in the auditory and visual working memory tasks compared to the group of TD children. These results are in accordance with past research that suggested that children with SLI do not only have language difficulties but also have potential underlying memory deficits. The phonological working memory deficits in Catalan-Spanish children with SLI detected in this dissertation are along the same lines as those found in previous studies that showed that children with SLI present problems in storing phonological information and retaining it in a speech-based form. Moreover, the presented results support those studies that found deficits in the working memory and short-term memory abilities related to the visual domain in children with SLI. Clinical implications arise from these deficits: information regarding phonological and visual working memory must be available for speech language therapists and other professionals to diagnose children with SLI and design proper clinical interventions.

Equivalent results of declarative memory for the group of children with SLI and the group of TD children were found only after controlling for the working memory. These results confirm the findings of previous studies where declarative memory was seen to be affected by working memory deficits in children with SLI. Clinical implications have been proposed to consider the working memory deficits in this population as a key strategy when designing activities, programs and guidelines to help them improve their language skills by using intervention strategies to manage these deficits.

Moreover, the results showed that verbal declarative memory abilities are strong predictors of vocabulary knowledge in children with and without SLI. This finding suggests that the main memory mechanism for learning vocabulary is the declarative memory. Furthermore, these results also suggest that statistical learning is not the core memory mechanism for vocabulary acquisition but just one of the required mechanisms for learning new words. These results should be taken into account when designing language interventions to improve vocabulary knowledge in children with SLI.

In summary, the investigation reveals the need to extend the current theoretical models of non-declarative learning in children with SLI beyond the assumption that only procedural sequential learning is impaired in this population. In addition, the results of this research suggest that a more general non-declarative learning, including sequential and non-sequential statistical learning, is affected in children with SLI and shows that this deficit is related to grammar learning as well as vocabulary acquisition.

The evidence of an impaired non-declarative memory system in children with SLI raises another major question for future study: is the non-declarative deficit a unique identifier of SLI? In order to provide clear clinical recommendations for prevention and treatment, taxonomic approaches are required that would allow SLI to be conceptualized as a disorder with a discrete diagnostic category capable of clearly differentiating typical children from those who present the disorder.

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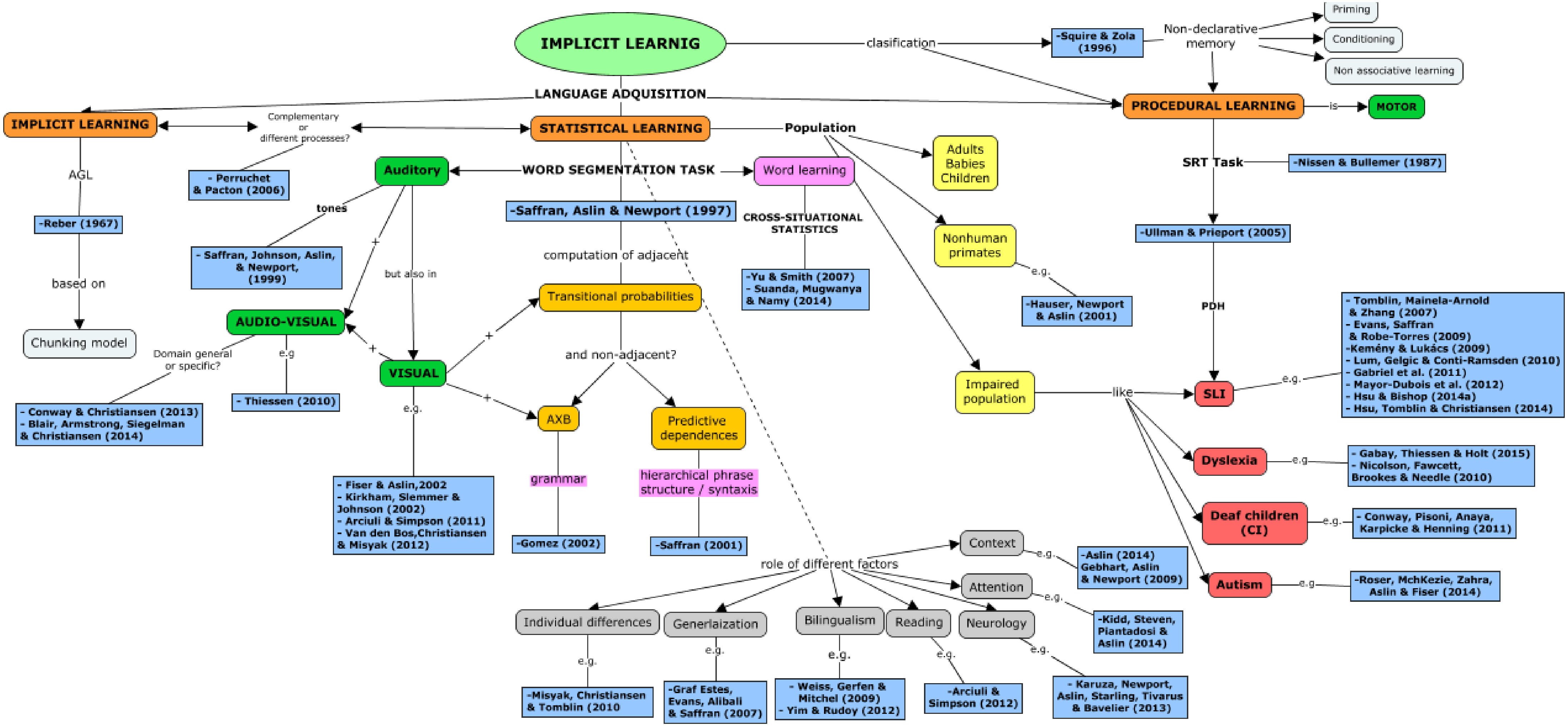
APPENDIX A

Research map: studies done to assess SL in different domains and different populations



IMPLICIT LEARNIG
clasification
-Squire & Zola (1996)
Non-declarative memory
Priming
Conditioning
Non associative learning
PROCEDURAL LEARNING
is
MOTOR
SRT Task
-Nissen & Bullemer (1987)
-Ullman & Prieport (2005)
PDH
SLI
e.g.
- Tomblin, Mainela-Arnold & Zhang (2007)
- Evans, Saffran & Robe-Torres (2009)
-Kemény & Lukács (2009)
- Lum, Gelgic & Conti-Ramsden (2010)
- Gabriel et al. (2011)
- Mayor-Dubois et al. (2012)
- Hsu & Bishop (2014a)
- Hsu, Tomblin & Christiansen (2014)
LANGUAGE ADQUISITION
IMPLICIT LEARNING
Complementary or different processes?
- Perruchet & Pacton (2006)
STATISTICAL LEARNING
Population
Adults Babies Children
Nonhuman primates
e.g.
-Hauser, Newport & Aslin (2001)
Impaired population
like
Dyslexia
e.g
- Gabay, Thiessen & Holt (2015)
- Nicolson, Fawcett, Brookes & Needle (2010)
Deaf children (CI)
e.g.
- Conway, Pisoni, Anaya, Karpicke & Henning (2011)
Autism
e.g
-Roser, MchKezie, Zahra, Aslin & Fiser (2014)
AGL
-Reber (1967)
based on
Chunking model
Auditory
WORD SEGMENTATION TASK
Word learning
CROSS-SITUATIONAL STATISTICS
-Yu & Smith (2007)
- Suanda, Mugwanya & Namy (2014)
-Saffran, Aslin & Newport (1997)
tones
- Saffran, Johnson, Aslin, & Newport, (1999)
+
but also in
AUDIO-VISUAL
Domain general or specific?
e.g
- Conway & Christiansen (2013)
- Blair, Armstrong, Siegelman & Christiansen (2014)
- Thiessen (2010)
VISUAL
e.g.
- Fiser & Aslin,2002
- Kirkham, Slemmer & Johnson (2002)
- Arciuli & Simpson (2011)
- Van den Bos,Christiansen & Misyak (2012)
computation of adjacent
Transitional probabilities
and non-adjacent?
AXB
grammar
-Gomez (2002)
Predictive dependences
hierarchical phrase structure / syntaxis
-Saffran (2001)
role of different factors
Context
e.g.
-Aslin (2014) Gebhart, Aslin & Newport (2009)
Attention
e.g.
-Kidd, Steven, Piantadosi & Aslin (2014)
Individual differences
e.g.
-Misyak, Christiansen & Tomblin (2010
Generlaization
e.g.
-Graf Estes, Evans, Alibali & Saffran (2007)
Bilingualism
e.g.
- Weiss, Gerfen & Mitchel (2009)
- Yim & Rudoy (2012)
Reading
e.g.
-Arciuli & Simpson (2012)
Neurology
e.g.
- Karuza, Newport, Aslin, Starling, Tivarus & Bavelier (2013)

APPENDIX B

Informed consent and family questionnaire

CONSENTIMIENT INFORMAT PER A LES FAMÍLIES

1. Nom del nen o nena que participarà en l'estudi:

____

2. Títol de la investigació

- *Memòria i aprenentatge implícit en infants amb Trastorn Específic del Llenguatge.*
- *Integració audiovisual de la parla en infants amb Trastorn Específic del Llenguatge.*

3. Objectiu de la investigació

El vostre fill/a és candidat a participar en un estudi per investigar el paper de la memòria i l'aprenentatge implícit i la percepció de la parla en infants amb Trastorn Específic del Llenguatge.

4. Procediment i duració de l'estudi

Es realitzaran quatre sessions d'una hora i mitja aproximadament on:

1. Es passaran test de llenguatge expressiu i receptiu i d' habilitats cognitives
2. Sis proves breus sobre l'aprenentatge de vocabulari i la integració audiovisual de la parla.

En algunes de les proves s'utilitza un aparell de registre de moviments oculars que és inòcul pel nen/a i que ens dóna idea de com processem el llenguatge mentre mirem imatges.

A més a més, demanarem a les famílies que emplenin un qüestionari amb dades personals que seran confidencials.

5. Riscs

Participar en aquest estudi no implica cap risc físic ni psicològic per als participants.

6. Beneficis

Els resultats d'aquest estudi contribuiran a la informació existent sobre el Trastorn Específic del Llenguatge (TEL) en benefici de totes les persones amb aquest tipus de trastorn, degut a que els científics, investigadors i doctors coneixeran amb major aspectes cognitius i d'aprenentatge relacionats amb aquest trastorn. Les famílies rebran els resultats de les proves que se li hagin administrat als seus fill(e)s.

7. Participació voluntària

La participació en aquest estudi és voluntària, podeu negar-vos a participar en l'estudi i el vostre fill/a pot deixar l'estudi en qualsevol moment.

8. Confidencialitat

El nostre grup de recerca guardarà totes les dades del vostre fill/a de manera confidencial. El nom del vostre fill/a no s'utilitzarà quan les dades d'aquest estudi es publiquin. La informació personal es tractarà de manera confidencial. Els resultats de l'estudi es mostraran sempre de manera global i mai es faran públiques dades personals dels participants. Teniu dret a demanar la retirada de qualsevol document que tingui les dades personals del vostre fill/a en qualsevol moment.

9. Contacte

Si teniu dubtes o preguntes sobre l'estudi podeu trucar a:

Nadia Ahufinger: 675134289 / nadiahufinger@uoc.edu

Laura Ferinu: 618033901/ lferinu@uoc.edu

10. Consentiment

Com a pare/mare o tutor/a legal, autoritzo (emplena amb el nom del seu fill/a): ____ a participar en l'estudi d'investigació descrit en aquest formulari i a que única i exclusivament l'equip de recerca tingui accés a les dades personals, resultats de proves i enregistraments audiovisuals com a finalitats de recerca.

____

Signatura del pare/mare/tutor legal

____

Signatura de l'investigador/a o persona que obté el consentiment

A, _____ de_________________ del ______ a, _____________________

QÜESTIONARI FAMÍLIES
(Recerca sobre el TEL 2017)

Benvolguts/des,

Us agrairíem que dediquéssiu un moment del vostre temps a respondre el següent qüestionari. Us informem de que el Grup de Recerca en Cognició i Llenguatge (GRECIL) guardarà i tractarà de forma confidencial totes les dades i la informació que ens faciliteu en aquest qüestionari. Els resultats de l'estudi es mostraran sempre de manera global i mai es faran públiques les dades personals dels participants.

Contesteu, sempre que sigui possible, totes les preguntes formulades.

Per qualsevol dubte o suggeriment ens podeu contactar enviant un correu a labgrecil@gmail.com.

MOLTES GRÀCIES PER LA VOSTRA COL·LABORACIÓ.

L' equip GRECIL

Dades de contacte

Data d'avui:_____________

Nom de la persona que contesta el qüestionari i relació que té amb el nen/a:

____

-Localitat: ____________________

-Telèfon de contacte 1:

____

-Telèfon de contacte 2:

____

-Correu electrònic 1

____

-Correu electrònic 2

____

Dades personals dels tutors legals

**Per tutors legals entenem les persones que es fan càrrec del nen o nena en el seu dia a dia (ex. pare, mare). Podeu introduir les dades de dos tutors legals.*

Tutor legal 1

-Nom i cognoms

____

-Relació parental amb el menor:

____

-Marqueu el nivell d'estudis més alt completat al que hagueu arribat:

☐ Educació Primària

☐ Graduat escolar/ graduat ESO.

☐ Batxillerat

☐ Cicle Formatiu de Grau Mitjà

☐ Cicle Formatiu de Grau Superior

☐ Grau universitari/Diplomatura universitària

☐ Llicenciatura//Màster

☐ Doctorat

☐ Altres: _______________________________________

-Professió: ____________________________________

-Llengua d'interacció amb el menor: ____________________________________

Tutor legal 2

-Nom i cognoms ____________________________

-Relació parental amb el menor: ________________________

-Marqueu el nivell d'estudis més alt completat al que hagueu arribat:

☐ Educació Primària

☐ Graduat escolar/ graduat ESO.

☐ Batxillerat

☐ Cicle Formatiu de Grau Mitjà

☐ Cicle Formatiu de Grau Superior

☐ Grau universitari/Diplomatura universitària

☐ Llicenciatura//Màster

☐ Doctorat

☐ Altres: ______________________________________

-Professió______________________________________

-Llengua d'interacció amb el menor______________________________________

Dades personals del nen/a

-Nom i cognoms :_____________________________________

-Gènere: ☐ Femení ☐ masculí ☐ Altres

-Data de naixement: ____/ ____/ ____ -Edat:______________

-Nacionalitat:__________________ -Lloc de naixement: __________________

-Lateralitat: ☐ Dretà/na ☐ Esquerrà/na ☐ Destre

Escolaritat

-Nom del centre d'estudis actual -Localització del centre d'estudis actual

_____________________________________ _____________________________________

-Curs escolar actual: ____________ -Ha repetit algun curs?. ☐ Sí ☐ No

En cas d'haver repetit curs, quin? _____________________________________

Rendiment acadèmic:

Quines notes (qualificacions) va obtenir el teu fill/filla a la seva última avaluació? (Marca una de les opcions):

☐ Diversos suspensos (3 o més).

☐ Algun suspens (1-2).

☐ Aprovat just.

☐ Aprovat i algun notable.

☐ Notable amb algun excel·lent.

☐ Excel·lent en gairebé tot.

Presenta dificultats en lectura? ☐ Sí ☐ No

-En cas afirmatiu, com descriuríeu les seves dificultats lectores?

____

Presenta dificultats d'escriptura?

☐ Sí ☐ No

En cas afirmatiu, com descriuríeu les seves dificultats d'escriptura?

____

- Té coneixements musicals? ☐ Sí ☐ No

En cas afirmatiu, especificar quins coneixements musicals i durant quant de temps:

____

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Capacitats, dificultats i relacions socials

Qüestionari sobre capacitats i dificultats (SDQ-Cas)

Si us plau, llegeix amb atenció les següents afirmacions i indica quina de les següents possibilitats (No estic d'acord, Estic bastant d'acord, Estic totalment d'acord) es correspon millor al comportament del seu fill/a durant els últims 6 mesos o durant aquest curs escolar:

	No estic d'acord (0)	Estic bastant d'acord (1)	Estic totalment d'acord (2)
1. Es queixa amb freqüència de mals de cap, d'estómac o nàusees.	○	○	○
2. És un/a nen/a més aviat solitari/a i tendeix a jugar sol/a.	○	○	○
3. Té moltes preocupacions, sovint està inquiet/a o preocupat/da.	○	○	○
4. Té com a mínim un bon/a amic o amiga.	○	○	○
5.Sovint es sent infeliç, desanimat o amb ganes de plorar.	○	○	○
6.Generalment, cau bé als altres nens/es.	○	○	○
7.Es posa nerviós/a o és depenent dels altres davant de situacions noves, fàcilment perd la confiança en sí mateix/a.	○	○	○
8.Els altres nens/es es porten malament amb ell/a o es burlen d'ell/a.	○	○	○
9.Té millor relació amb els adults que amb els altres nens/es.	○	○	○
10.Té moltes pors, s'espanta fàcilment.	○	○	○

Relacions Socials

Pensa en quina mesura el teu fill/a ha viscut les següents situacions i indica la opció que més s'aproximi a la seva realitat (marcar només una opció).

	No n'estic segur/a (0)	Mai (1)	Una vegada (2)	Poques vegades (3)	Diverses vegades (4)	Moltes vegades (5)	Sempre (6)
L'han exclòs d'algun grup expressament o l'han ignorat per complet.	○	○	○	○	○	○	○
Algú ha dit mentides o rumors falsos sobre ell/a.	○	○	○	○	○	○	○
Algun company l'ha agredit físicament.	○	○	○	○	○	○	○
Algú l'ha amenaçat o obligat a fer una cosa que ell/a no volia.	○	○	○	○	○	○	○
Algú s'ha burlat de la seva forma de parlar o expressar-se.	○	○	○	○	○	○	○
Algú s'ha portat malament amb ell/a per equivocar-se al parlar.	○	○	○	○	○	○	○
Algú s'ha portat malament amb ell/a per no entendre una broma.	○	○	○	○	○	○	○
Algú s'ha burlat d'ell/a per no entendre el que diuen els altres.	○	○	○	○	○	○	○

Llengua del nen/a

-Quina és la llengua dominant del menor? ___________________________________

- Quantes llengües parla?____________

-Quines llengües parla?: ____

% D'ús de Català i Castellà (Exemple: català 60% - castellà 40%) _____________________________

Informació econòmica i socioeconòmica

Informació econòmica

-Ingressos aproximats anuals a la llar:

☐ Menys de 12 000 € /any

☐ Entre 12 000€ - 15 000 € /any

☐ Entre 15 000 € - 25 000 €/any

☐ Entre 25 000 € - 35 000 €/any

☐ Entre 35 000 € - 45 000 €/any

☐ Més de 45 000 €/any

-Indica el número de persones que viuen en el domicili del menor (contant el menor):

____

-Quines persones viuen amb el menor? ___________________________________

Informació socioeconòmica

-Teniu vehicle propi a casa? :

☐ No ☐ Sí, en tenim 1. ☐ Sí, en tenim 2 o més.

-El vostre fill/a té una habitació per ell/ella sol?

☐ Sí ☐ No

-Durant els últims 12 mesos quantes vegades heu fet un viatge familiar per vacances?

☐ Cap vegada. ☐ Una vegada. ☐ Dues vegades. ☐ Més de dues vegades.

-Quants dispositius electrònics teniu a casa? (Només comptar ordinadors i tablets):

☐ Cap. ☐ Un. ☐ Entre 2 i 4. ☐ Més de 4.

Antecedents del/la menor

-A quina edat va començar a dir les primeres paraules?: ___________________________

-A quina edat va començar a caminar?: ___________________________

-A quina edat vau començar a pensar que podia tenir una dificultat en el llenguatge i per què?

____

____

-Pateix algun dèficit visual o auditiu (Per exemple: ceguera, sordesa, heminegligència, etc)?

☐ Sí ☐ No

En cas afirmatiu, especificar quin/s: ____

- Indiqueu les malalties que ha tingut el/la menor:

____

-Pren algun tipus de medicació actualment?

☐ Sí ☐ No

En cas afirmatiu, per quin motiu? ____

-Hi ha algú a la família directa que hagi presentat dificultats de llenguatge i/o d'aprenentatge?

☐ Sí ☐ No

En cas afirmatiu, indiqueu quin membre de la família i quin tipus de dificultat té o ha tingut

En cas d'haver respost SÍ en la pregunta anterior indica quines dificultats de l'aprenentatge van ser, si va haver-hi diagnòstic etc. Per exemple: TDAH, dislèxia, discalcúlia... O sense diagnòstic: dificultats del llenguatge oral, escrit, comprensió, en matemàtiques...

____

-Ha tingut otitis algun cop?

☐ Sí ☐ No

En cas afirmatiu, indiqueu de quin tipus: ____

- Li han fet alguna revisió bucofonatòria?

Òrgans bucofonatoris: Ens referim al tamany, la forma i la funció dels òrgans de la parla (llengua, llavis, mandíbula, paladar, dents...)

☐ Sí ☐ No

En cas afirmatiu, quins van ser els resultats d'aquesta exploració bucofonatòria?

____

- Li han fet una audiometria?

Una audiometria és una prova que avalua el funcionament del sistema auditiu i determina la capacitat d'una persona per escoltar sons.

☐ Sí ☐ No

En cas afirmatiu, quins van ser els resultats d'aquesta audiometria?

____

Proves diagnòstiques i altres exploracions

-El/la menor té diagnòstic de TEL (Trastorn Específic del llenguatge)? ☐ Sí ☐ No

En cas afirmatiu, quan li van diagnosticar? ______________________________________

- En quina mesura (del 1 al 4) penseu que té dificultats en els següents aspectes del llenguatge?

	Cap dificultat (1)	Poques dificultats (2)	Bastants dificultats (3)	Moltes dificultats (4)
Fonologia (la pronunciació de sons i de paraules)	○	○	○	○
Semàntica (la comprensió del significat de les paraules)	○	○	○	○
Morfosintaxis (ordre de les paraules, l'ús dels morfemes de passat/present, singular/plural, femení/masculí))	○	○	○	○
Lèxic (el vocabulari que presenta)	○	○	○	○
Pragmàtica (l'ús que fa del llenguatge segons el context)	○	○	○	○

-Té algun altre diagnòstic?

☐ Sí ☐ No

En cas afirmatiu, quin diagnòstic té? ____

-Ha rebut o rep intervenció o tractament per part d'algun professional?

☐ Sí, actualment.

☐ Sí, però actualment no.

☐ Mai ha rebut cap tipus d'intervenció.

Quin professional? Quin tipus d'intervenció? Per què i durant quan de temps?

____

____

____

Conducta i atenció - **Escala ADHD-Rating scale-IV ***

Escull la opció que descriu millor la conducta del seu fill/a en els últims 6 mesos.

	Mai/poc freqüent (0)	A vegades (1)	Sovint (2)	Amb molta freqüència (3)
1.No presta atenció suficient als detalls, o comet errors per descuits en tasques escolars o altres activitats.	○	○	○	○
2.Continuament mou les mans o peus o es mou a la cadira.	○	○	○	○
3.Té dificultats per mantenir l'atenció en tasques o jocs.	○	○	○	○
4.No román assegut a classe o a altres situacions.	○	○	○	○
5. Sembla que no escolti quan se li parla.	○	○	○	○
6.Corre i es mou en situacions que aquestes conductes no són apropiades.	○	○	○	○
7. No segueix instruccions i no aconsegueix acabar la feina.	○	○	○	○
8.Té dificultat per jugar en silenci en activitats d'oci o descans.	○	○	○	○
9.Té dificultats per organitzar les seves tasques o activitats.	○	○	○	○
10. Está sempre "amb presses" o actúa com si estigués "activat per un motor".	○	○	○	○
11.Evita tasques que requereixen un esforç mental continuat.	○	○	○	○
12.Parla de forma excessiva.	○	○	○	○
13.Perd coses que són necessàries per les seves tasques o activitats.	○	○	○	○
14. Respón impulsivament abans de que s'hagi acabat la pregunta que li fem.	○	○	○	○
15.Es distreu fàcilment.	○	○	○	○
16.Té dificultats per esperar el seu torn.	○	○	○	○
17.És oblidadís amb les seves activitats quotidianes.	○	○	○	○
18.Interromp o "es posa al mig" sense autorització dels altres.	○	○	○	○

APPENDIX C

Example of a language and cognitive assessment report

<u>1. CELF -4</u> (Spanish Clinical Evaluation of Language Fundamentals-4)

<u>RESULTATS ESCALES CENTRALS:</u>

	Puntuació	Descripció	Alteració llenguatge
- Núcleo del lenguaje	PT 45	Molt baixa	**Alteració severa***

- Conceptos y siguiendo direcciones
- Estructura de palabras
- Recordando oraciones
- Formulación de oraciones

- Lenguaje receptivo	PT 59	Molt baixa	**Alteració severa***

- Conceptos y siguiendo direcciones
- Clases de palabras-Receptivo
- Estructura de oraciones

- Lenguaje expresivo	PT 52	Molt baixa	**Alteració severa***

- Estructura de palabras
- Recordando oraciones
- Formulación de oraciones

CELF-4

Puntuació	Categoria descriptiva	Classificació de l'alteració del llenguatge
115 o més	Alta (per sobre de la mitjana)	---
86-114	Normalitat (Dins la mitjana)	---
78-85	Límit	Alteració lleu
71-77	Baixa	Alteració moderada
70 o menys	Molt baixa	Alteració severa

<u>1. Núcleo del lenguaje</u>

És una mesura de les habilitats generals del llenguatge que quantifica el rendiment total del llenguatge del nen(a). S'utilitza per prendre decisions sobre la presència (i la severitat) o l'absència d'un trastorn del llenguatge.

La puntuació de l'escala *Núcleo del lenguaje* de l'xxxxx és de 45 . Aquesta puntuació **és molt baixa (severament per sota de la mitjana) i indica que hi ha una alteració servera del llenguatge.**

2. Lenguaje receptivo y lenguaje expresivo

- L'índex de *Lenguaje receptivo* és una mesura de la comprensió oral.

- L'índex de *Lenguaje expresivo* és una mesura global de les habilitats expressives del llenguatge.

La puntuació referida al *Lenguaje receptivo* de l'xxxxx és de 59. **Aquesta puntuació es considera molt baixa i indica un rendiment severament per sota de la mitjana.**

La seva puntuació referida al *Lenguaje expresivo* és 52. **Aquesta puntuació es considera molt baixa i indica un rendiment severament per sota de la mitjana.**

La diferència de 7 punts entre el *Lenguaje receptivo* i *expresivo* no és significativa. Aquest perfil ocorre en un 29,9% de la població estandarditzada.

Aquestes puntuacions ens indiquen que l'xxxxx **presenta unes habilitats lingüístiques tan receptives i expressives per sota de la mitjana poblacional.**

RESULTATS ALTRES ESCALES DEL CELF-4

	Puntuació	Descripció
- Contenido del lenguaje	PT 70	**Molt baixa***
• Conceptos y siguiendo direcciones		
• Clases de palabras-Total		
• Vocabulario expresivo		
- Estructura del lenguaje	PT 41	**Molt baixa***
• Estructura de palabras		
• Recordando oraciones		
• Formulación de oraciones		
• Estructura de oraciones		

Contenido del lenguaje

L'índex referit al *Contenido del lenguaje* mesura diferents aspectes del desenvolupament semàntic incloent el vocabulari, conceptes i categories, comprensió d'associacions i relacions entre paraules i de l'habilitat de crear oracions correctes a nivell semàntic i sintàctic.

La puntuació referida al *Contenido del lenguaje* de l'xxxxx és de 70. **Aquesta puntuació es considera molt baixa i indica un rendiment severament per sota de la mitjana.**

Estrucura del lenguaje

L'índex referit a *Estructura del lenguaje* mesura de manera global components expressius i receptius per entendre i produir diferents tipus d'oracions així com l'habilitat de processar i produir el llenguatge d'acord amb les regles morfològiques i sintàctiques.

La puntuació referida a *Estructura del lenguaje* de l'xxxxx és de 41. **Aquesta puntuació es considera molt baixa i indica un rendiment severament per sota de la mitjana.**

NAME SURNAME
DN 15/02/2009 (8;00anys)
Avaluació: Febrer 2017

La diferència de 29 punts entre el *Contenido del lenguaje* i *Estructura del lenguaje* **és significativa**. Aquest perfil ocorre en un 2,1% de la població estandarditzada.

Aquestes puntuacions ens indiquen que l'xxxxx presenta **més dificultats en les habilitats lingüístiques referides a l'estructura en comparació a les referides al contingut del llenguatge**.

RESULTATS DELS SUBTESTS ADMINISTRATS (CELF-4)

	Puntuació	Categoria descriptiva
- Conceptos y siguiendo direcciones	PT 2	**Baixa***
- Estructura de palabras	PT 1	**Baixa***
- Recordando oraciones	PT 2	**Baixa***
- Formulación de oraciones	PT 2	**Baixa***
- Clases de palabras- Receptivo	PT 7	**Baixa***
- Clases de palabras-Total	PT 6	**Baixa***
- Estructura de oraciones	PT 1	**Baixa***
- Vocabulario expresivo	PT 7	Normal

BAIXA						NORMAL							ALTA					
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19

	Puntuació
- Conocimiento fonológico	**PD 28***

La puntuació del l'xxxxx de 28 **no coincideix** amb el criteri de puntuació de ≥38 per als nen(es) de la seva edat, indicant un processament fonològic inadequat amb dificultats potencials d'adquisició de la lectura.

Conocimiento fonológico

Edat	Criteri de puntuació
5;0 a 5;5	≥ 7
5:6 a 5:11	≥ 9
6;0 - 6;5	≥ 16
6;6 - 6;11	≥ 19
7;0 - 7;11	≥ 38
8;0 - 8;11	≥38
9;0 - 9;11	≥ 44
10;0 - 10:11	≥ 47
11;0 - 11;11	≥ 47
12;0 - 12;11	≥ 49

	Puntuació
- Asociación de palabras	PD 39

La puntuació de l'xxxxx de 39 coincideix amb el criteri de puntuació de ≥ 21 per als nen(es) de la seva edat. Per tant, compleix el criteri, indicant adequades estratègies de recuperació lèxica.

Asociación de palabras

Edat	Criteri de puntuació
5;0 a 5;5	≥14
5:6 a 5:11	≥16
6;0 - 6;5	≥17
6;6 - 6;11	≥ 18
7;0 - 7;11	≥ 20
8;0 - 8;11	≥ 21
9;0 - 9;11	≥ 22
10;0 - 10:11	≥ 23
11;0 - 11;11	≥ 25
12;0 - 12;11	≥ 27
13;0 - 14;11	≥ 30
15;0 - 16:11	≥ 31
17;0 - 21;11	≥ 33

2. K-BIT (Escala abreujada d'intel·ligència Kaufman)

	Puntuació	Descripció
- Expressió de vocabulari (Q.I verbal)	PT 68	**Molt baixa***
- **Raonament no verbal - Matrius (Q.I No verbal)**	PT 104	Mitja
- Resultat compost - Matrius + Voc (Q.I Compost)	PT 82	Mig baixa

K-BIT

Puntuació	Categoria descriptiva
130 o més	Molt alta
120 - 129	Alta
110 - 119	Mig alta
90 -109	Mitja
80 - 89	Mig baixa
70 - 79	Baixa
70 o menys	Molt baixa

3. PEABODY-III (Test de vocabulari en imatges)

	Puntuació	Descripció
- Comprensió de paraules	**PT 70**	**Moderadament baixa***

PEABODY

Puntuació	Categoria descriptiva
131 o més	Molt alta
115 -130	Moderadament alta
100 - 114	Mig-Alta
85 - 99	Mig-Baixa
70 - 84	Moderadament baixa
69 o menys	Molt baixa

4. TOMAL (Test de memòria i aprenentatge)

Resultats dels subtests administrats:

	Puntuació	Descripció
- Memoria de caras	PE 8	Normal
- Memoria de caras (demorado)	PE 9	Normal
- Memoria de pares	PE 9	Normal
- Repetición de números directo	PE 6	**Baixa***
- Repetición números inverso	PE 4	**Baixa***
- Recuerdo Selectivo Visual	PE 7	Normal

BAIXA						NORMAL							ALTA					
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19

5. ADHD RATING SCALE-IV (Escala per avaluar l'atenció i la hiperactiviat)

	Resultat	Descripció
- Inatenció	12	Normal
- Hiperactivitat	13	Normal
- Total	25	Normal

ADHD Rating Scale-IV

NENS			
Edat	Inatenció	Hiperactivitat -Impulsivitat	Puntuació total
5-7	13,6	14,9	27,5
8-10	14,6	13,4	26,9
11-13	16,1	13,1	28,5
14-18	13,7	10,2	22,8

NENES			
Edat	Inatenció	Hiperactivitat -Impulsivitat	Puntuació total
5-7	11,2	11,8	21,8
8-10	10,7	9,1	18,8
11-13	12,3	8,1	19,3
14-18	10,9	9,0	19,0

6. SDQ-Cas (Qüestionari de Capacitats i dificultats)

	Resultat	Descripció
- Puntuació símptomes emocionals	2	Normal
- Puntuació problemes amb els company(e)s	3	Normal

SDQ-Cas

	Normal	Límit	Alterat
Símptomes emocionals	0-3	4	5-10
Problemes companys/es	0-2	3	4-10

7. *SCREENING* AUDITIU

L'*screening* auditiu (o revisió de l'audició) s'utilitza per identificar persones que poden requerir una avaluació auditiva més àmplia o un control mèdic. Els *screenings* auditius es poden dur a terme en entorns de la primera infància, escoles, entorns comunitaris, clíniques d'audiologia etc.

L'ASHA (American Speech-Language-Hearing Association) estableix a la Guia d'Screening Auditiu (Guidelines for Audiologic Screening) que per presentar una audició dins dels paràmetres de normalitat cal que l'infant pugui escoltar tons purs a 500, 1000, 2000 i 4000 Hz a 20 dB i a 30 dB.

L'xxxxx mostra una audició adequada per als estímuls sonors presentats als nivells 20 i 30 dB per a les freqüències de 500, 1000, 2000 i 4000 Hz en ambues orelles.

8. CARAS-R. Test de Percepción de Diferencias-Revisado

El test CARAS-R avalua l'aptitud per a percebre ràpida i correctament semblances i diferències en patrons d'estimulació parcialment ordenats. Proporciona informació sobre el desenvolupament de les aptituds perceptives i atencionals de l'infant. La tasca consisteix en indicar quina de les cares, d'un conjunt de tres cares, és la diferent durant un temps limitat de 3 minuts.

En aquesta prova hem comptabilitzat els encerts nets que equivalen al total d'encerts menys el total d'errors que han realitzat. Per altra part, l'Índex de Control de la Impulsivitat (ICI) indica el nivell de control de la impulsivitat que ha manifestat l'infant a l'hora de realitzar la tasca.

	Puntuació	Descripció
- Encerts nets (Eficàcia)	PC 70	Mitja

Caras-R (Encerts nets)

Puntuació	Categoria descriptiva
96 o més	Molt alta
87 - 95	Alta
75 - 86	Mig alta
24 -74	Mitja
12 - 23	Mig baixa
4 - 11	Baixa
3 o menys	Molt baixa

La puntuació de l'xxxxx és mitja en encerts nets això reflecteix una adequada capacitat visuoperceptiva i atencional. L'xxxxx és capaç de prestar atenció a molts detalls i de realitzar judicis correctes, sense cometre gaires errors.

	Puntuació	Descripció
- Índex de control de la Impulsivitat (ICI)	PC 35	Mitja

Caras-R (Índex de control d'impulsivitat)

Puntuació	Categoria descriptiva
24-96 (o més)	Mitja
23 o menys	Baixa

Pel que fa al Índex de Control de la Impulsivitat (ICI), l'xxxxx obté una puntuació mitja això indica que presenta un adequat control de la impulsivitat, executant la tasca de forma reflexiva, cometent pocs errors.

TESTS DE REPETICIÓ DE PSEUDOPARAULES:

Les pseudoparaules són paraules inventades i que per tant no tenen significat. Es construeixen seguint les mateixes regles que les paraules amb significat. El que els diferencia és que no representen cap concepte.

La importància de la tasca de repetició de pseudoparaules per al diagnòstic del trastorn específic del llenguatge es basa, d'una banda, en què s'ha comprovat que és la millor manera de mesurar la capacitat de retenir la informació fonològica a la memòria de treball, ja que s'han de dur a terme tasques de discriminació i transformació de les senyals acústiques en els seus fonemes constituents. cal codificar la informació acústica en una representació fonològica i mantenir-la a la memòria de treball per després poder executar una resposta verbal (repetir la pseudoparaula).

Alguns estudis científics mostren que els nens i nenes amb trastorn específic del llenguatge mostren una limitació en capacitat de l'esmenta magatzem fonològic que afecta, en primer lloc, a l'adquisició de vocabulari, i, en segon lloc, al desenvolupament de la morfosintaxi.

9. TEST DE REPETICIÓ DE PSEUDOPARAULES EN ESPANYOL *(Aguado, 2006)*

L'xxxxx ha repetit correctament 23 pseudoparaules d'un total de 80.

10. TEST DE REPETICIÓ DE PSEUDOPARAULES EN CATALÀ (PseudoCAT)

**Aquest test ha estat creat pel Grup de Recerca en Cognició i Llenguatge (GRECIL). Encara no està baremat. La vostra participació en aquest estudi ens ajudarà a poder publicar aquest test de repetició de pseudoparaules per a contribuir en el diagnòstic dels nenes i nenes amb TEL a Catalunya.*

L'xxxxx ha repetit correctament 15 pseudoparaules d'un total de 40.

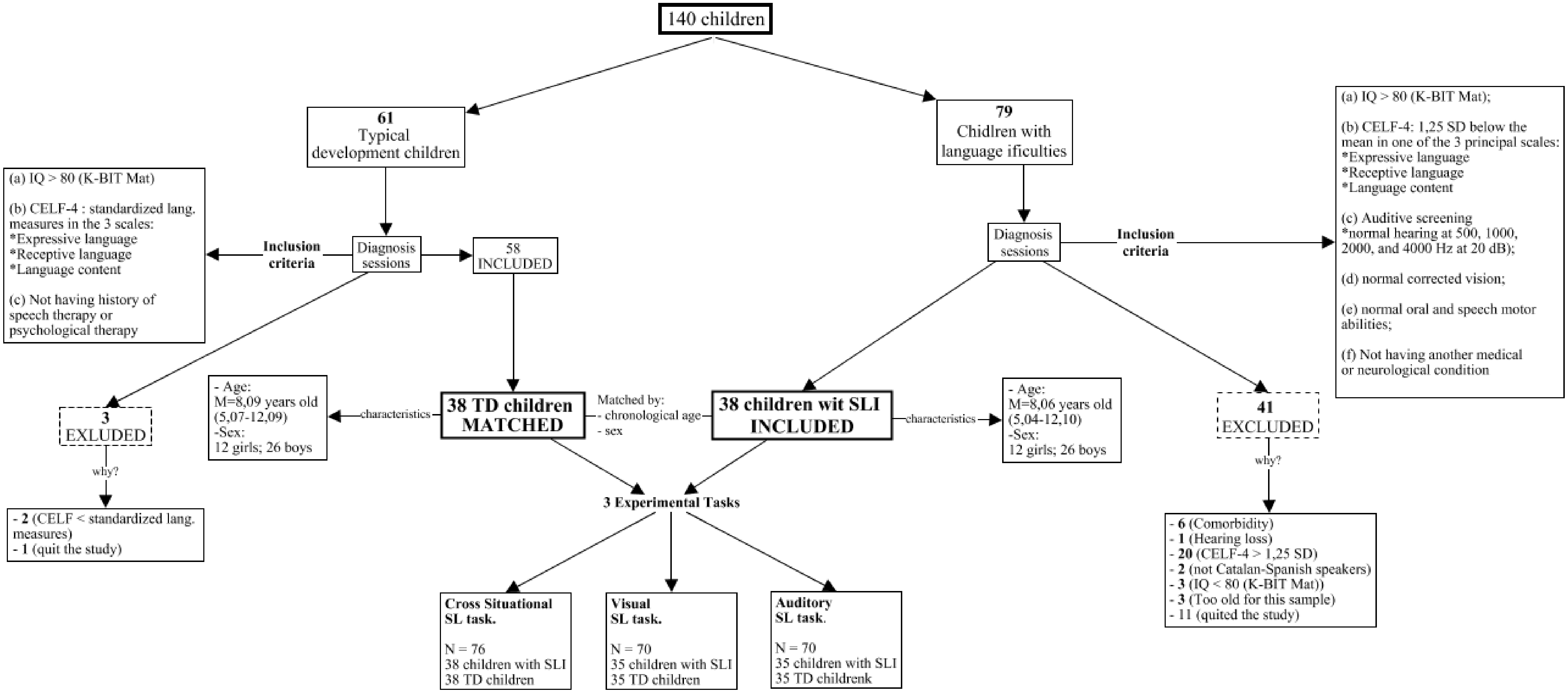
APPENDIX D

List of schools visited to collect the data for the group of children with SLI

1. Escola Pau Vila (Barcelona)
2. Escola Sant Jordi (Badalona)
3. Escola Santa Anna (Premià de Dalt)
4. Escola Ramón Llull (Barcelona)
5. Escola L'Olivera (Vallirana)
6. Escola Vaixell Burriac (Vilassar de Mar)
7. Escola Marià Manent (Premià de Mar)
8. Fundació Escolàpies – Escolàpies Masnou (El Masnou)
9. Escola El Sagrer (Barcelona)
10. Escola Aloc (Pineda de Mar)
11. Escola La Nova Electra (Terrassa)
12. Escola L'Olivera – Volpelleres (Sant Cugat del Vallès)
13. Escola el Casal (Castellar del Vallès)
14. Escola Tabor (Barcelona)
15. Escola Font Rosella (Sabadell)
16. Escola Turó de Can Mates (Sant Cugat del Vallès)
17. Escola Cavall Bernat (Barcelona)
18. Escola Els Pinetons (Ripollet)
19. Escola Pau Vilà i Dinarès (Terrassa)
20. Escola Tabor (Santa Perpètua de Mogoda)
21. Institut Thos i Codina (Mataró)
22. Institut Joan Boscà (Barcelona)
23. Escola Carles III (Sant Carles de la Ràpita)
24. Sant Josep de Tàrrega – Vedruna Tàrrega (Tàrrega)
25. Junts Autisme (Arenys de Mar)
26. Logocomunica (Sant Pol de Mar)
27. Centre Cívic Les Mallorquines (Montgat)
28. Centre de Logopèdia i Psicologia CLER (Mataró)

APPENDIX E

Inclusion criteria map for the group of children with SLI and TD children


140 children
61
Typical development children
79
Chidlren with language ificulties
(a) IQ > 80 (K-BIT Mat)
(b) CELF-4 : standardized lang. measures in the 3 scales:
*Expressive language
*Receptive language
*Language content
(c) Not having history of speech therapy or psychological therapy
Inclusion criteria
Diagnosis sessions
58 INCLUDED
Diagnosis sessions
Inclusion criteria
(a) IQ > 80 (K-BIT Mat);
(b) CELF-4: 1,25 SD below the mean in one of the 3 principal scales:
*Expressive language
*Receptive language
*Language content
(c) Auditive screening
*normal hearing at 500, 1000, 2000, and 4000 Hz at 20 dB);
(d) normal corrected vision;
(e) normal oral and speech motor abilities;
(f) Not having another medical or neurological condition
3 EXLUDED
why?
- 2 (CELF < standardized lang. measures)
- 1 (quit the study)
- Age:
M=8,09 years old
(5,07-12,09)
-Sex:
12 girls; 26 boys
characteristics
38 TD children MATCHED
Matched by:
- chronological age
- sex
38 children wit SLI INCLUDED
characteristics
- Age:
M=8,06 years old
(5,04-12,10)
-Sex:
12 girls; 26 boys
41 EXCLUDED
why?
- 6 (Comorbidity)
- 1 (Hearing loss)
- 20 (CELF-4 > 1,25 SD)
- 2 (not Catalan-Spanish speakers)
- 3 (IQ < 80 (K-BIT Mat))
- 3 (Too old for this sample)
- 11 (quited the study)
3 Experimental Tasks
Cross Situational SL task.
N = 76
38 children with SLI
38 TD children
Visual SL task.
N = 70
35 children with SLI
35 TD children
Auditory SL task.
N = 70
35 children with SLI
35 TD childrenk

APPENDIX F

Explanation about the creation of socioeconomic status as a quantity variable

Socioeconomic status was one of the variables controlled for in our analysis. The information was taken from the background information questionnaire.

To convert all the economic and social information from the background questionnaire to a unique SES quantity variable, we took into account two main scales of information:

1- The total family income in a year: families had to select their approximate income in a year from six options (1) less than €12,000, (2) from €12,000 to €15,000/year, (3) from €15,000 to €25,000/year, (4) from €25,000 to €35,000/year, (5) from €35,000 to €45,000/year and (6) over €45,000/year. Three different levels were created from these six options: low-income level for options 1 and 2, medium-income level from options 3 and 4 and high-income level for options 5 and 6.

2- Family affluence scale: families were asked about vehicles, rooms, holidays and devices at home:

   a. If they did not have any vehicle a score of 0 was given, if they had one vehicle a score of 1 was given and if they had two or more vehicles a score of 3 was given.
   b. If the child has her/his own bedroom, a score of 1 was given and if not, a score of 0 was given.
   c. If the family had not gone away for holidays in the last twelve months, a score of 0 was given, if they had been away once a score of 1 was given, if they had been away twice a score of 2 was given and if they had been away more than twice a score of 3 was given.
   d. Regarding the devices, if they did not have any device at home a score of 0 was given, if they had one device a score of 1 was given, if they had from 2 to

4 devices a score of 2 was given and if they had more than 4 a score of 3 was given.

After obtaining all the scores for the economic and social information, a specific weighting factor was given for each of the main scales: 50% of the total weighting for the to-be-created SES variable was given to the income information—value of 0.33 for the low-income level, value of 0.66 for the medium-income level and value of 1 for the high-income level out of a range from 0 to 1. The value for each participant was then multiplied by 0.5. The other 50% of the total weighting was given to the family affluence scale, adding together a weighting of 12.5% for each of the variables:

a. Vehicles: a value of 0.33 was given to the score of 0, a value of 0.66 to the score of 1 and a value of 1 to the score of 2. The value for each child was then multiplied by 0.125
b. Room: a value of 0.33 was given to the score of 0 and a value of 0.66 to the score of 1. The value for each child was then multiplied by 0.125
c. Holidays: a value of 0.25 was given to the score of 0, a value of 0.50 to the score of 1, a value of 0.75 to the score of 2 and a value of 1 to the score of 3. The value for each child was then multiplied by 0.125.
d. Devices: a value of 0.25 was given to the score of 0, a value of 0.50 to the score of 1, a value of 0.75 to the score of 2 and a value of 1 to the score of 3. The value for each child was then multiplied by 0.125.

We then added up the final values for each of the five variables (income, vehicles, room, holidays and devices), giving us the SES quantity variable for each participant. We then calculated the mean SES variable for each group.

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APPENDIX G

Template to collect the answers for the test phase in the ASL task

Name: Age: Date:
Age:
Group: Experimenter:

Practice Test Trial	Participant's answer	Answer key
1		*1*
2		*2*
3		*2*

Test Trial	Participant's answer	Answer key
1		*1*
2		*1*
3		*2*
4		*2*
5		*1*
6		*2*
7		*1*
8		*2*
9		*1*
10		*2*
11		*2*
12		*1*
13		*2*
14		*2*
15		*1*
16		*2*
17		*1*
18		*1*

Test Trial	Participant's answer	Answer key
19		*2*
20		*1*
21		*2*
22		*2*
23		*1*
24		*1*
25		*2*
26		*1*
27		*1*
28		*2*
29		*2*
30		*2*
31		*1*
32		*1*
33		*1*
34		*2*
35		*2*
36		*1*

TOTAL Nº =

APPENDIX H

List order of the tone-words the tone-nonwords presented in the test phase in the ASL task.

1	GG#A	F#G#E
2	FCF#	GCD#
3	AC#E	D#ED
4	F#G#E	FCF#
5	DFE	C#FD
6	F#G#E	DFE
7	ADB	C#FD
8	F#G#E	ADB
9	CC#D	G#BA
10	AC#E	GG#A
11	G#BA	DFE
12	GG#A	G#BA
13	C#BA	DFE
14	GCD#	GG#A
15	GG#A	C#BA
16	C#FD	GG#A
17	DFE	GCD#
18	ADB	AC#E
19	GCD#	CC#D
20	ADB	GCD#
21	G#BA	ADB
22	C#FD	CC#D
23	FCF#	AC#E
24	FCF#	C#FD
25	G#BA	FCF#
26	CC#D	C#BA
27	D#ED	F#G#E
28	AC#E	CC#D
29	C#BA	FCF#
30	C#FD	D#ED
31	D#ED	C#BA
32	CC#D	F#G#E
33	D#ED	G#BA
34	GCD#	D#ED
35	C#BA	ADB
36	DFE	AC#E

TONE-WORDS:
GG#A / FCF# / DFE / ADB / CC#D / D#ED

TONE NON-WORDS:
AC#E / F#G#E / G#BA / GCD# / C#FD / C#BA

APPENDIX I

List order of the triplets presented in the learning phase in the VSL task (list 1 and 2)

LIST 1

Trial	Triplet	Trial	Triplet	Trial	Triplet
1	DEF	33	ABC	65	GGHI
2	GHI	34	GHII	66	ABC
3	ABC	35	DEF	67	DEF
4	DEF	36	GHI	68	GHI
5	ABC	37	ABC	69	ABC
6	GHI	38	GHI	70	DEF
7	DEF	39	DEF	71	GHI
8	ABBC	40	ABCC	72	ABC
9	GHI	41	GHI	73	DEF
10	ABC	42	DEF	74	GHI
11	DDEF	43	ABC	75	ABC
12	GHI	44	GHI	76	DEF
13	DEF	45	AABC	77	ABC
14	ABC	46	DEFF	78	GHI
15	DEF	47	GHI	79	DEFF
16	GHI	48	ABC	80	GHI
17	DEEF	49	DEF	81	ABC
18	ABC	50	GHII	82	GHI
19	GHI	51	ABC	83	DEF
20	DEF	52	DEF	84	ABCC
21	ABC	53	ABC	85	DEF
22	DEF	54	GHI	86	GHHI
23	GHI	55	ABC	87	DEF
24	AABC	56	DEF	88	ABC
25	GHI	57	GHI	89	DEEF
26	DDEF	58	ABC	90	GHI
27	GHI	59	DEF	91	ABBC
28	ABC	60	ABC	92	DEF
29	GHI	61	DEF	93	GGHI
30	ABC	62	GHI	94	ABC
31	DEF	63	ABC	95	DEF
32	GHHI	64	DEF	96	GHI

LIST 2

Trial	Triplet	Trial	Triplet	Trial	Triplet
1	DEF	33	GHI	65	GHI
2	GHI	34	AABC	66	ABCC
3	ABC	35	GHI	67	GHI
4	GHI	36	ABC	68	DEF
5	ABC	37	DEFF	69	ABC
6	DEF	38	ABC	70	GHHI
7	ABC	39	GHI	71	DEF
8	GHI	40	DEF	72	GHI
9	ABC	41	GHI	73	DEF
10	GHI	42	DEEF	74	GHHI
11	DEF	43	ABCC	75	ABC
12	ABC	44	GHI	76	GGHI
13	GHI	45	DEFF	77	DEF
14	ABC	46	GGHI	78	GHII
15	DEF	47	ABC	79	ABC
16	GHI	48	GHI	80	DDEF
17	DEF	49	DEF	81	ABC
18	ABC	50	ABC	82	DEF
19	DEEF	51	DEF	83	GHI
20	GHI	52	ABBC	84	ABC
21	ABC	53	GHI	85	DEF
22	DEF	54	DEF	86	GHI
23	AABC	55	GHI	87	DEF
24	DEF	56	DEF	88	ABBC
25	ABC	57	ABC	89	GHI
26	GHI	58	GHII	90	ABC
27	ABC	59	DEF	91	DDEF
28	DEF	60	GHI	92	ABC
29	ABC	61	DEF	93	DEF
30	GHI	62	GHI	94	GHI
31	ABC	63	ABC	95	DEF
32	DEF	64	DEF	96	ABC

APPENDIX J

Template to collect the answers for the test phase in the VSL task

Name: Age: Date:
Age:
Group: Experimenter:

Test Trial	Participant's answer	Answer key
1		*1*
2		*2*
3		*2*
4		*1*
5		*1*
6		*2*
7		*2*
8		*2*
9		*1*
10		*2*
11		*1*
12		*1*
13		*1*
14		*2*
15		*1*
16		*1*
17		*2*
18		*2*

TOTAL Nº =

APPENDIX K

List order of the triplet and impossible triplets s presented in the test phase in the VSL task

Test trial	**Triplet 1**	**Triplet 2**
1	ABC	GBF
2	DHC	DEF
3	AEI	ABC
4	DEF	AEI
5	GHI	GBF
6	DHC	ABC
7	GBF	GHI
8	GBF	ABC
9	DEF	DHC
10	DHC	GHI
11	DEF	GBF
12	ABC	DHC
13	GHI	DHC
14	AEI	DEF
15	GHI	AEI
16	ABC	AEI
17	GBF	DEF
18	AEI	GHI

APPENDIX L

Trial order for the learning phase in the Cross situational Statistics task

LIST 1

Learning trials	Object order	Word order
1	HG	gh
2	GE	eg
3	GH	gh
4	DA	da
5	AC	ca
6	DB	bd
7	CD	dc
8	BA	ba
9	FG	gf
10	EF	fe
11	FH	hf
12	BC	bc
13	AB	ba
14	CD	cd
15	EF	ef
16	HE	he

LIST 2

Learning trials	Object order	Word order
1	HE	he
2	BC	bc
3	GH	gh
4	DA	da
5	AB	ba
6	CD	dc
7	CD	dc
8	FH	hf
9	GE	eg
10	BA	ba
11	EF	ef
12	HG	gh
13	AC	ca
14	EF	fe
15	DB	bd
16	FG	gf

APPENDIX M

Trial order and position of the visual objects for the test phase in the Cross situational Statistics task

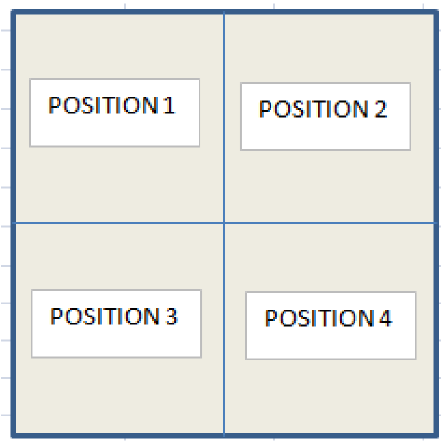
LIST 1

Trial	Word	Position 1	Position 2	Position 3	Position 4
1	e (DATU)	F2 (G)	T (E)	F3 (C)	F1 (F)
2	c (ZEPI)	F3 (F)	F1 (D)	F2 (A)	T (C)
3	h (RILE)	F3 (A)	T (H)	F2 (F)	F1 (G)
4	g (MEPO)	F3 (B)	F1 (H)	T (G)	F2 (E)
5	b (LASI)	F2 (D)	T (B)	F3 (G)	F1 (A)
6	e (DATU)	F2 (G)	F3 (A)	T (E)	F1 (F)
7	h (RILE)	T (H)	F3 (D)	F2 (F)	F1 (G)
8	c (ZEPI)	T (C)	F2 (A)	F3(G)	F1 (D)
9	f (TECO)	T (F)	F1 (E)	F2 (H)	F3(B)
10	a (PIMO)	F2 (C)	F1 (B)	T (A)	F3 (H)
11	d (BUNA)	F2 (B)	F1(C)	F3 (H)	T(D)
12	a (PIMO)	F3 (E)	T (A)	F2 (C)	F1(B)
13	d (BUNA)	T (D)	F3 (E)	F1 (C)	F2 (B)
14	f (TECO)	F3 (D)	F2 (H)	F1 (E)	T (F)
15	g (MEPO)	F2 (E)	F1(H)	F3 (C)	T(G)
16	b (LASI)	F3 (F)	F1 (A)	T (B)	F2 (D)

LIST 2

Trial	Word	Position 1	Position 2	Position 3	Position 4
1	(a) PIMO	F2 (C)	F1 (B)	T (A)	F3 (H)
2	(h) RILE	T (H)	F3 (D)	F2 (F)	F1 (G)
3	(a) PIMO	F3 (E)	T (A)	F2 (C)	F1(B)
4	(e) DATU	F2 (G)	T (E)	F3 (C)	F1 (F)
5	(b) LASI	F3(F)	F1 (A)	T (B)	F2 (D)
6	(e) DATU	F2 (G)	F3 (A)	T (E)	F1 (F)
7	(g) MEPO	F2 (E)	F1 (H)	F3 (C)	T (G)
8	(b) LASI	F2 (D)	T (B)	F3 (G)	F1 (A)
9	(c) ZEPI	F3 (F)	F1 (D)	F2 (A)	T (C)
10	(d) BUNA	F2 (B)	F1 (C)	F3 (H)	T (D)
11	(h) RILE	F3 (A)	T (H)	F2 (F)	F1 (G)
12	(f) TECO	F3 (D)	F2 (H)	F1 (E)	T (F)
13	(d) BUNA	T (D)	F3 (E)	F1 (C)	F2(B)
14	(c) ZEPI	T (C)	F2 (A)	F3 (G)	F1 (D)
15	(f) TECO	T (F)	F1 (E)	F2 (H)	F3 (B)
16	(g) MEPO	F3 (B)	F1 (H)	T (G)	F2 (E)

T= Target
F1= FOIL 1 / Strong competitor: foil that appears 2 times with the target in the learning phase.
F2= FOIL 2 / Weak competitor: foil that appears 1 time with the target in the learning phase.
F3= FOIL 3 / Distractor: foil that doesn't appear with the target in any trial during the learning phase.
A, B, C, D, E, F, G, H = visual objects (see image 1)



APPENDIX N

Template to collect the answers for the test phase in the CSSL task

CROSS SITUATIONAL STATISTICAL LEARNING - KEY ANSWER

Practice Test Trial	Participant's answer	Answer key
1		*4*
2		*2*

LIST 1

Test Trial	Participant's answer	Answer key	Name
1		*2*	*Datu*
2		*4*	*Zepi*
3		*2*	*Rile*
4		*3*	*Mepo*
5		*2*	*Lasi*
6		*3*	*Datu*
7		*1*	*Rile*
8		*1*	*Zepi*
9		*1*	*Teco*
10		*3*	*Pimo*
11		*4*	*Buna*
12		*2*	*Pimo*
13		*1*	*Buna*
14		*4*	*Teco*
15		*4*	*Mepo*
16		*3*	*Lasi*

LIST 2

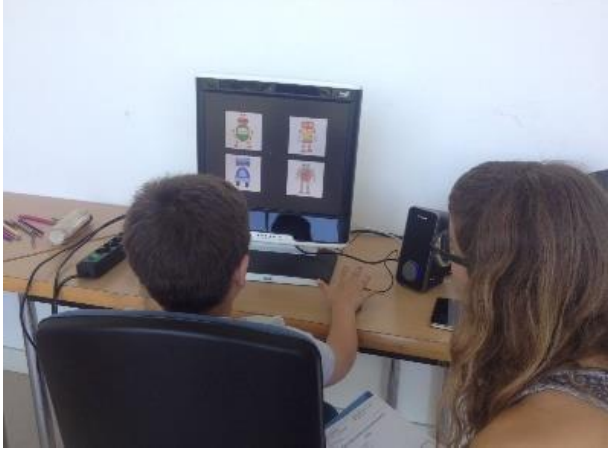
Test Trial	Participant's answer	Answer key	Name
1		*3*	*Pimo*
2		*1*	*Rile*
3		*2*	*Pimo*
4		*2*	*Datu*
5		*3*	*Lasi*
6		*3*	*Datu*
7		*4*	*Mepo*
8		*2*	*Lasi*
9		*4*	*Zepi*
10		*4*	*Buna*
11		*2*	*Rile*
12		*4*	*Teco*
13		*1*	*Buna*
14		*1*	*Zepi*
15		*1*	*Teco*
16		*3*	*Mepo*

APPENDIX O

Photographs of the moments when the experimental tasks where run with the participants

a) ASL

b) CSSL



c) VSL