Language-impaired children with Autism Spectrum Disorders and children with Specific Language Impairment: Similar language abilities but distinct memory profiles

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Dedication

To my parents, Abdulrazzak Bani Hani and Hanim Hamoudeh, who always taught me to dream big.

Baba, who I know is proudly smiling down on me from heaven. I have missed you all the time, and I miss you the most now.

Mama, whose love and support have been my light throughout my PhD years.

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Abstract

There is a long-standing debate in the literature about the extent of overlap between the language phenotype of the subgroup of children with ASD who have language impairment (language-impaired children with ASD) and children with specific-language impairment (SLI), as well as whether or not their language impairments arise from the same etiology (e.g., Kjelgaard & Tager-Flusberg, 2001; Leyfer, Tager-Flusberg, Dowd, Tomblin, & Folstein, 2008; Whitehouse, Barry, & Bishop, 2008; Williams, Botting, & Boucher, 2008). Procedural and declarative memory systems have been proposed to play a major role in typical language development, and have been hypothesized to contribute to language impairment in ASD (Romero-Munguía, 2008; Ullman, 2004) as well as in SLI (Ullman & Pierpont, 2005). Specifically, procedural memory involves learning and storing regularities and rule-based information such as those found in aspects of phonology and grammar. Declarative memory, which involves the learning and storing of facts and events, binds together the conceptual, phonological, and semantic representations of words (Ullman, 2004). The goal of this dissertation is to compare combined language and memory profiles in language-impaired ASD and in SLI, contributing novel evidence to the overlap debate, as well as insight into possible mechanisms of language impairment and targets for intervention.

This is the first direct comparison of language (i.e., phonology and vocabulary) and memory abilities (i.e., procedural memory using a simple visual sequence-learning task and declarative memory using intra- and cross-modality visual recognition tasks) in language-impaired children with ASD and children with SLI, as well as their age- and nonverbal intelligence-matched typically-developing (TD) peers. In addition, I explored potential relationships between procedural memory and phonology, declarative memory and vocabulary,

and both memory systems and sentence repetition. Results indicated distinct profiles in ASD vs. SLI: despite similar language difficulties in both clinical groups, the ASD group showed significantly poorer performance on procedural and declarative memory tasks, whereas the SLI group showed reductions only on a more challenging measure of declarative memory (e.g., cross-modality recognition). A trend toward a positive relationship was found between declarative memory and different measures of vocabulary in the ASD and SLI groups. These findings add to the evidence of distinct phenotypes in language-impaired ASD and SLI, despite similarities in structural language (Whitehouse et al., 2008; Williams et al., 2008). If the current findings are replicated, they may support different methods of language intervention for children with ASD and children with SLI related to their distinct memory profiles.

Résumé

Il existe un débat récurrent dans la littérature sur l'étendue du recoupement des phénotypes langagiers entre les enfants avec un trouble du spectre autistique avec des déficits langagiers (enfants TSA avec troubles langagiers) et les enfants avec un trouble spécifique du langage (TSL). En outre, la discussion reste ouverte sur le fait que ces déficits langagiers émergent de la même étiologie ou non (e.g., Kjelgaard & Tager-Flusberg, 2001; Leyfer, Tager-Flusberg, Dowd, Tomblin, & Folstein, 2008; Whitehouse, Barry, & Bishop, 2008; Williams, Botting, & Boucher, 2008). Il a été suggéré que les systèmes mnésiques procédural et déclaratif jouent un rôle considérable dans le développement du langage chez les individus à développement typique, et qu'ils contribueraient aux déficits langagiers présents dans le TSA (Romero-Munguía, 2008; Ullman, 2004) ainsi que dans le TSL (Ullman & Pierpont, 2005). De manière précise, la mémoire procédurale implique l'apprentissage et le stockage des invariants et des règles d'application telles que rencontrés en phonologie et en grammaire. La mémoire déclarative, quant à elle, implique l'apprentissage et le stockage des faits et événements, et relie les représentations conceptuelle, phonologique et sémantique des mots (Ullman, 2004). L'objectif de cette thèse est de comparer les profils de langage et de mémoire chez des enfants TSA avec troubles langagiers et chez des enfants avec un TSL. Ce travail approfondit nos connaissances des mécanismes possibles des déficits langagiers et apporte des pistes d'intervention clinique. Il introduit de surcroît un regard nouveau sur la question du chevauchement des phénotypes langagiers entre le TSA et le TSL.

Cette étude est la première à comparer directement les enfants TSA avec troubles langagiers, les enfants avec un TSL, et leurs pairs à développement typique, appariés en âge et en habilités intellectuelles (NVIQ). L'évaluation des capacités langagières comportait des tâches de phonologie et vocabulaire, celle de la mémoire procédurale consistait en une tâche simple d’apprentissage séquentiel et l’évaluation de la mémoire déclarative impliquait des tâches de reconnaissance visuelle uni-modale et multimodale. De plus, j’ai exploré les associations possibles entre la mémoire procédurale et la phonologie, entre la mémoire déclarative et le vocabulaire et enfin entre les deux systèmes mnésiques et la répétition de phrases. Les résultats révèlent des profils distincts pour le TSA et le TSL. Ainsi, malgré la présence de difficultés langagières similaires entre les deux groupes cliniques, le groupe TSA montrait des performances significativement moins bonnes dans les deux tâches de mémoire alors que le groupe TSL avait des performances réduites seulement sur la tâche la plus exigeante de mémoire déclarative (reconnaissance multimodale). Par ailleurs, une corrélation positive entre la mémoire déclarative et les différentes mesures de vocabulaire a été démontrée chez les deux groupes cliniques. L’ensemble des résultats suggère la présence de phénotypes distincts entre le TSA et le TSL, en dépit de similarités au niveau de la structure du langage (Whitehouse et al., 2008; Williams et al., 2008). Ces conclusions ouvrent des pistes prometteuses pour la mise en place de différentes méthodes d’intervention langagière pour les enfants TSA et pour les enfants TSL, en fonction de leur spécificités.

Preface

Prior work has compared language skills between children with ASD who have language impairment and children with SLI, often highlighting similar profiles. In addition to examining language skills, this dissertation is original in conducting the first direct comparison of procedural and declarative memory, which have been proposed as potential mechanisms of language learning, in the two clinical groups. Novel findings were revealed: despite similar language difficulties in both clinical groups, the ASD group showed significantly poorer performance on procedural and declarative memory tasks, whereas the SLI group showed reductions only on a more challenging measure of declarative memory. Furthermore, the relationship between procedural and declarative memory and aspects of language was explored. A trend toward a positive relationship was found between declarative memory and different measures of vocabulary in the ASD and SLI groups.

This dissertation is standard format and it consists of three behavioral studies. I (Hanady Bani Hani) developed the hypotheses and rationale for the studies described here with continuous assistance of my PhD advisor, Dr. Aparna Nadig. I was also fully responsible for writing the dissertation while receiving editorial suggestions and comments from my advisor. I collected the data reported in this dissertation with help from undergraduate and graduate student research assistants who helped with testing, data coding, and data entry. Some of the results contained in this dissertation were presented at the following conferences: 2014 Convention of the American Speech-Language-Hearing Association, 2015 Biennial Meeting of the Society for Research in Child Development, 2015 International Meeting for Autism Research.

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Chapter 1: General Introduction

Autism spectrum disorders (ASD) are defined by impairments in social interaction and communication as well as repetitive interests and behaviors (American Psychiatric Association [APA], 2013). It is now well recognized that language in ASD is extremely variable and that there are likely to be subgroups of individuals within the spectrum that have distinct language profiles, some of which are similar to those found in specific language impairment (SLI). SLI is another neurodevelopmental disorder that is defined entirely by language impairment (Rapin, Dunn, Allen, Stevens, & Fein, 2009; Tager-Flusberg, Paul, & Lord, 2005). The most common form of SLI is a "mixed receptive/expressive language disorder" that includes impaired expressive phonology (sounds of speech) and grammar (Rapin & Dunn, 2003). Although deficits in structural language components (i.e., phonology, grammar, vocabulary) are not core to ASD, 63% of preschool children with ASD demonstrate a mixed receptive/expressive language disorder (Rapin & Dunn, 2003) that is similar to SLI by virtue of deficits in these structural components of language. In addition, the prevalence of ASD in school-age children with SLI was found to be 3.9% (Conti-Ramsden, Simkin, & Botting, 2006).

The commonly reported similarities in language profiles in ASD and SLI have led some researchers to propose that there is a subtype of children with ASD with language impairment who show the same neurocognitive phenotype as that seen in children with SLI, reflecting a shared etiology (e.g., Kjelgaard & Tager-Flusberg, 2001; Leyfer, Tager-Flusberg, Dowd, Tomblin, & Folstein, 2008; Walenski, Tager-Flusberg, & Ullman, 2006). In contrast, other researchers have argued that although there are gross similarities in language between the two disorders, careful inspection of the data shows that these similarities are superficial and do not necessarily mean that the disorders have the same underlying causes (e.g., Whitehouse, Barry, &

Bishop, 2008; Williams, Botting, & Boucher, 2008; Williams, Payne & Marshall, 2013). These opposing positions have stimulated a heated debate as to whether these two disorders overlap, and whether the language impairment in the two developmental disorders arises from a shared etiology.

Language acquisition depends on the development of fundamental linguistic and cognitive processes that may contribute to variability in language abilities across typically-developing individuals as well as various clinical populations. Accordingly, it is theoretically and clinically informative to investigate the similarities and differences in language profiles as well as language-supporting cognitive abilities between individuals with ASD who have language impairment and individuals with SLI. In this area, two memory systems, namely procedural and declarative, have been suggested to play major roles in typical language development, and have been implicated in explanations for structural language impairment in ASD and SLI. Procedural memory underlies the implicit learning, storage, and retrieval of motor and cognitive skills especially those involving sequentially or probabilistically structured information (Conway & Pisoni, 2008; Karuza et al., 2013; Tulving, 1985; Willingham, 1998). Declarative memory involves the learning, storage, and retrieval of explicit knowledge related to factual information about the world and to contextual information surrounding personally experienced events (Squire, 2004; Squire & Dede, 2015; Tulving & Markowitsch, 1998). With respect to language learning, it has been proposed that procedural memory involves learning and storing regularities and rule-based information such as those found in phonology and grammar, whereas, declarative memory carries out the process of binding conceptual, phonological, and semantic representations of words (e.g., Ellis, 1994; Gupta & Cohen, 2002; Gupta & Dell, 1999; Ullman, 2004).

Although there is large body of research investigating these memory systems in different populations, the existing studies on ASD with language impairment have mostly investigated procedural and declarative memory systems separately and mostly apart from language. Moreover, none of the previous studies have compared individuals with ASD who have language impairment and individuals with SLI on procedural or declarative memory. Studies that examine whether cognitive characteristics commonly observed in individuals with ASD are found among individuals with SLI will further contribute to the 'etiological overlap' debate. In addition, studies that highlight similarities and differences in language and memory abilities in individuals with ASD and individuals with SLI are expected to help clinicians develop effective interventions for each group.

In the current dissertation, I directly compared language (i.e., phonology and receptive vocabulary) and cognitive abilities (i.e., procedural and declarative memory) in children with ASD who have language impairment and children with SLI as well as their typically-developing (TD) peers to address the overlap debate. Phonology, rather than grammar, and receptive vocabulary, rather than expressive vocabulary, were investigated in the current set of studies. This choice was made given that participants in both the ASD and SLI groups had language impairments and were anticipated to be minimally verbal, especially in the ASD group. This was expected to prevent the testing of their grammatical skills and expressive language. However, in the course of the study most of the children who were minimally verbal were not able to complete the study protocol and could not be included in analyses. Moreover, I explored relationships between procedural and declarative memory and performance on language measures in the three groups.

In the following sections, autism spectrum disorder and specific language impairment are introduced followed by a discussion on the overlap between the two disorders.

1.1 Autism Spectrum Disorder (ASD)

ASD is an umbrella term that encompasses disorders previously referred to as early infantile autism, childhood autism, Kanner's autism, high-functioning autism, atypical autism, pervasive developmental disorder not otherwise specified, childhood disintegrative disorder, and Asperger's disorder (APA, 2013). ASD is a neurodevelopmental disorder that is typically recognized during the second year of life and is defined by two main categories of criteria: social communication deficits and repetitive and stereotyped behaviors (APA, 2013). According to the most recent report by the Centers for Disease Control and Prevention (2014), the prevalence of ASD among children aged 8 years was estimated to be 1.47% in the United States in 2010, with higher prevalence rate in boys than girls, 2.38% to .35%, respectively.

Individuals with ASD represent a heterogeneous group that varies greatly in terms of cognitive, linguistic, and behavioral functioning. Therefore, it is quite likely that there are distinct subgroups within the disorder with different etiologies and behavioral characteristics (Boucher, 2012; Gerenser, 2009; Kjelgaard & Tager-Flusberg, 2001). Recently, the Diagnostic and Statistical Manual of Mental Disorders-Fifth edition has addressed this heterogeneity in ASD by demanding that the level of verbal and intellectual functioning be assessed and described for individuals with ASD as a severity specifier (APA, 2013).

Three general language profiles have been distinguished within the autism spectrum. At one end are verbally fluent individuals with ASD who acquire a full system of linguistic knowledge at the structural level similarly to typically-developing individuals (Walenski et al., 2006). In this group, language difficulties are primarily related to language use in social situations (Tager-Flusberg, Edelson, & Luyster, 2011). Children in this group are referred to as “language-normal children with ASD” in this dissertation. At the other end are minimally verbal individuals with ASD who fail to communicate beyond a basic level of single words or short phrases. It has been reported that 14% to 20% of individuals with ASD are minimally verbal (Lord, Risi, & Pickles, 2004). The majority of children with ASD fall into a third group that acquires language later, at slower rate, and without fully catching up to age expectations (Walenski et al., 2006). Children with ASD in the latter group are the focus of the current dissertation and from this point on are referred to as “language-impaired children with ASD”. It is important to note that the distinction between “language-normal and language-impaired children with ASD is artificial in that language abilities in ASD lie along a continuum (Boucher, 2012). For the purpose of this dissertation, Kjelgaard and Tager-Flusberg’s (2001) distinction between more and less linguistically able groups with ASD was adopted: The language-normal children with ASD were identified by scores within or above the normal range on standardized language tests, while scores of one standard deviation or more below the mean identify the language-impaired children with ASD.

1.2 Specific Language Impairment (SLI)

SLI involves persistent difficulties in the acquisition and use of language despite normal intelligence, vision and hearing, the absence of neurological impairment, and a supportive communicative environment (APA, 2013). Children with language impairment have been variously referred to as having language disorder (APA, 2013), specific language impairment (Gillam & Kamhi, 2010; Leonard, 2014), or primary language impairment that reflects the subtle non-linguistic processing weaknesses that exist alongside obvious lags in language (Kohnert, Windsor, & Ebert, 2009; Thordardottir et al., 2011). Deficits in non-linguistic domains include: attention (Spaulding, Plante, & Vance, 2008), executive functioning (Archibald & Gathercole, 2007; Bishop & Norbury, 2005; Leonard et al., 2007; Miller, Kail, Leonard, & Tomblin, 2001), and fine and gross motor function, such as cutting with scissors, finger tapping, and hopping (Hill, 2001). The term specific language impairment (SLI) is used in this dissertation given that it is the term most commonly used in the research literature.

SLI is a heterogeneous disorder and can be further classified into subgroups according to the language component that is impaired (Conti-Ramsden, Crutchley, & Botting, 1997; Friedmann & Novogrodsky, 2008). The most common subtypes are expressive language disorder (leaving comprehension relatively unimpaired), mixed receptive-expressive language disorder, and articulatory or phonological disorder (World Health Organization, 1992).

The criteria for identifying SLI are not universally standardized; nevertheless, in recent years, two principle inclusion criteria have been determined to identify children with SLI (Gillam & Kamhi, 2010; Tomblin & Zhang, 1999; World Health Organization, 1992): 1) performance within the normal range on a measure of non-verbal intelligence, and 2) performance below age on a standardized language measure. However, there is no conventional cut-off point to clearly identify poor language score in children with SLI (Paul, 2007). Commonly, researchers require one standard deviation or more below the mean on standardized language measures to determine language impairment in children (e.g., Kan & Windsor, 2010; Thordardottir et al., 2011; Tomblin & Zhang, 1999). In this dissertation, I used this conventional rule to identify language impairment in children diagnosed with ASD or SLI.

SLI affects approximately 7.4 % of monolingual English-speaking children at kindergarten with a slightly higher prevalence rate in boys than girls, 8% to 6%, respectively (Tomblin et al., 1997). Moreover, in a more recent study, Archibald and Gathercole (2006) estimated that among students with communication disorders who receive additional resource support in classroom units in the UK, around 13% had SLI, wherein 10% had receptive-expressive impairment and 3% had only expressive impairment.

1.3 Overlap between ASD with Language Impairment and SLI

The overlap between ASD and SLI was tested in landmark studies by Bartak, Rutter, and Cox (1975, 1977) but was not supported by their results. Nevertheless, recent behavioral, neurobiological, and genetic studies has revived interest in links between the two disorders, providing mixed evidence.

At the behavioral level, a growing body of research has investigated similarities in features of language impairment in individuals with ASD and individuals with SLI, leading to divergent conclusions on shared or distinct origins of these two disorders. In the first position, researchers have concluded that there is a subtype of children with ASD who show the same neurocognitive phenotype as that seen in children with SLI, reflecting a shared etiology (Kjelgaard & Tager-Flusberg, 2001; Leyfer et al., 2008; Tager-Flusberg & Joseph, 2003; Walenski et al., 2006). This position draws on evidence from studies in which some children with ASD showed structural linguistic difficulties that are highly reminiscent of a common profile in SLI including difficulties in: the receptive and expressive domains (Conti-Ramsden et al., 2006; Kjelgaard & Tager-Flusberg, 2001), non-word repetition and sentence repetition tasks (Bishop et al., 2004; Botting & Conti-Ramsden, 2003; Kjelgaard & Tager-Flusberg, 2001; Leyfer et al., 2008; Taylor, Maybery, Grayndler, & Whitehouse, 2014), grammar (Eigsti, Bennetto, & Dadlani, 2007; Kjelgaard & Tager-Flusberg, 2001; Roberts, Rice, & Tager-Flusberg, 2004; Williams et al., 2008), and word reading and spelling (Lindgren, Folstein, Tomblin, & Tager-Flusberg, 2009). In the second position, other researchers have argued that the similarities in the performance of children with ASD and those with SLI on language measures are superficial and do not necessarily reflect common underlying causes at the cognitive, neurobiological, or etiologic levels (Taylor, Maybery, & Whitehouse, 2012; Williams et al., 2008; Williams et al., 2013). This position relies on evidence showing that children with ASD and children with SLI who share some structural language difficulties make contrasting patterns of errors on nonword repetition tasks (a marker of SLI), which may indicate different underlying cognitive difficulties (Whitehouse et al., 2008; Williams et al., 2013).

On the neurobiological level, some neuroimaging studies have shown shared abnormalities in language-impaired children with ASD and children with SLI. These abnormalities are found in the development of fronto-corticocerebellar circuits that manage motor control and the processing of language, cognition, working memory, and attention (Hodge et al., 2010) as well as brain structure and functional abnormalities in inferior frontal gyrus language-association cortex, specifically Broca's area (De Fossé et al., 2004). Importantly, these abnormalities were not seen in language-normal children with ASD, suggesting that these anomalies are more closely related to language and cognitive deficits than to autism per se (Hodge et al., 2010), which in turn points to a shared source of language impairment in the language-impaired ASD group and the SLI group.

On the genetic level, ASD and SLI are complex genetic disorders that are thought to be caused by the interaction of many genes and have very high heritability estimates as documented in family and twin studies (Bishop, 2009; Bishop & Hayiou-Thomas, 2008; Hallmayer et al., 2011; Hallmayer et al., 2002). Several studies have described an increased prevalence of language delay and language-based learning difficulties in parents and siblings of individuals with ASD (e.g., Bailey, Palferman, Heavey, & Le Couteur, 1998; Fombonne, Bolton, Prior, Jordan, & Rutter, 1997; Piven, Palmer, Jacobi, Childress, & Arndt, 1997). Furthermore, studies of twins discordant for autism have reported language difficulties resembling what has been found in children with SLI in the non-affected twins (Folstein & Rutter, 1977; Le Couteur et al., 1996). Similarly, some family studies have found elevated levels of self-reported language difficulties in relatives of individuals with ASD (e.g., Folstein et al., 1999). Yet, these findings have not been replicated when relatives were tested with standardized language assessments. For instance, Whitehouse, Barry, and Bishop (2007) suggested that the weaknesses in grammar seen in children with SLI is highly heritable, but the otherwise similar grammatical weaknesses in ASD with variable language abilities may have a different basis such as poor social communication ability and be less heritable. In addition, Lindgren et al. (2009) demonstrated that although language-impaired children with ASD and children with SLI showed similar language and IQ performance, their first degree relatives had different results, with the relatives of language-impaired children with ASD performing better than relatives of the SLI children across language measures (i.e., receptive and expressive language and reading abilities).

Finally, although no specific gene has yet been identified as the cause of either autism or SLI, genetic studies have shown that at least one gene contributing to the common language phenotype observed in these disorders (Abrahams & Geschwind, 2008; Alarcón et al., 2008; Alarcón et al., 2002; Arking et al., 2008; Lai, Fisher, Hurst, Vargha-Khadem, & Monaco, 2001; Vernes et al., 2008). For example, the gene CNTNAP2 was identified as candidate gene for SLI, showing significant associations with nonword repetition performance (Vernes et al., 2008). It has also been implicated in ASD (Alarcón et al., 2008; Arking et al., 2008), especially in individuals who experienced language delay (Alarcón et al., 2008).

So far, evidence regarding the overlap between language-impaired children with ASD and children with SLI provided mixed results. On the behavioral level, most of evidence in this area has been provided in terms of language abilities. The current dissertation addressed the overlap debate by investigating structural language abilities as well as language-underlying cognitive abilities (i.e., procedural and declarative memory) in both groups. These two memory systems have been suggested to underlie typical language development and to explain structural language impairment in ASD and in SLI. Research on procedural and declarative memory in the two disorders has been limited. In the following sections, the two memory systems are presented, and their role in typical language development and in language impairment in ASD and SLI is discussed. Following Lum and Conti-Ramsden (2013), the term 'memory system' is used here to refer collectively to the learning, storage, and retrieval of information.

1.4 Procedural Memory

Procedural memory is one of multiple forms of memory that underlie the implicit (i.e., conscious awareness is not required) learning, storage, and retrieval of motor and cognitive skills and habits (Squire, & Dede, 2015; Tulving, 1985). Procedural memory underlies learning sequentially or probabilistically structured information including learning new motor and perceptual skills, such as riding a bike or producing your signature (Nissen & Bullemer, 1987). It also underlies learning rules (especially complex ones, or algorithms, that evolve for learning simple motor skills through experience and may not be easy to verbalize; Knowlton & Moody, 2008) and forming associations between pieces of verbal or visual information that are probabilistically or statistically structured, such as learning grammar, artificial language, or solving a Rubik's cube (Conway & Pisoni, 2008; Karuza et al., 2013; Knowlton & Moody, 2008; Knowlton, Squire, & Gluck, 1994). Learning via the procedural memory system is often slow and requires repeated exposure to information in order for a skill or knowledge to be learned (Packard & Knowlton, 2002). Once information has been acquired, new knowledge and skills may be used without awareness and sometimes only following the presence of a preceding stimulus (Lum & Conti-Ramsden, 2013). This memory system is composed of a network of several interconnected brain structures. It depends especially on left hemisphere structures and is rooted in neural circuits that encompass the frontal lobes and the basal ganglia (Packard & Knowlton, 2002; Parent & Hazrati, 1995).

A common paradigm that has been used to study procedural memory is the serial reaction time task (SRT; Nissen & Bullemer, 1987). In SRT tasks, participants are asked to press a button corresponding to a spatial location of a visual stimulus on a computer screen as quickly as possible. Unknown to participants, the stimuli follows a pattern on some blocks while it appears randomly on others. Faster responses during sequence trials relative to random trials are taken as evidence of sequence learning. An SRT task was used in this dissertation to assess procedural memory given that it is commonly used to test individuals with wide range abilities across ages, and is appropriate for children with impairments, as performance requires minimal language comprehension and motor skills.

1.5 Declarative Memory

This memory system supports the learning, storage, and retrieval of knowledge related to factual information about the world, referred to as *semantic memory*, and to contextual information surrounding personally experienced events, referred to as *episodic memory* (Squire, 2004; Squire & Dede, 2015; Tulving & Markowitsch, 1998). Semantic memory is responsible for general information acquired across different contexts and which can be applied in many novel situations (Baddeley, 2001), such as knowing that the word ‘dog’ corresponds to the object or concept of a dog. Episodic memory refers to the ability to retain information about a specific event and to locate it in time and space (Baddeley, 2001), such as knowing particular events that occurred at a dinner party. In this case, learning could follow witnessing which person told an anecdote at a dinner party (Lum & Conti-Ramsden, 2013).

Learning via the declarative memory system is achieved through binding arbitrarily related pieces of information together (Kurczek, Vanderveen, & Duff, 2014; Mayes, Montaldi, & Migo, 2007). This type of learning requires awareness (i.e., explicit) and can be achieved following a single exposure to the target stimulus (Squire & Dede, 2015). However, repeated exposure to the information increases the probability of learning as well as the speed of retrieving the acquired information. The learning and retrieval processes of this memory system are supported by the medial temporal lobes, in particular the hippocampus (Kurczek et al., 2014; Mayes et al., 2007; Packard & Knowlton, 2002; Tulving & Markowitsch, 1998).

Retrieval of information from the declarative memory system occurs through the processes of recognition and recall (Mayes et al., 2007). Accordingly, previous studies used explicit memory tests of recognition and recall to examine declarative memory processing (Boucher, Bigham, Mayes, & Muskett, 2008; Boucher, Mayes, & Bigham, 2012). Tests of recognition assess conscious feelings of familiarity with a stimulus without necessarily recalling any other information. Recognition is prompted by sensory cues; for example, when you see an object, this visual presentation triggers you to search your mind to match it with anything you have previously encountered. Recognition occurs when you find a match to that object (Bigham, Boucher, Mayes, & Anns, 2010). During recall, you have to first recognize the stimulus, which then triggers the retrieval of information from memory about that stimulus such as its name (Bigham et al., 2010). The present dissertation focused on recognition as a measure of declarative memory, since recognition can more easily be assessed in children with language impairments. Recognition could be tested on intra- or cross-modality tasks (Bushnell & Baxt, 1999), which are used in the current set of studies. In these tasks participants are required to visually identify a set of objects that they explored visually (intra-modality) or by hands without seeing them (cross-modality).

1.6 The Role of Procedural and Declarative Memory in Typical Language Development

For centuries, the importance of procedural and declarative memory processing for language acquisition and development has been echoed in the literature. However, the specific role of these memory systems in the acquisition of the different aspects of language remains controversial. Precisely, it is difficult and unnatural to isolate the processing of procedural and declarative memory systems and to separate aspects of language, such as phonology and semantic of lexical knowledge.

Comprehensive reviews of the literature on neurological disorders led Ullman (2001, 2004) to introduce the declarative/procedural model for the role of these two memory systems in language. According to this model, the fronto-basal ganglia circuits, which mediate the procedural memory system, underlie aspects of language learning. Specifically, Ullman proposed that procedural memory is involved in the learning and storage of sequential and hierarchical structure of phonology (i.e., the combination of sounds) and grammar including inflectional and derivational morphology – at least for default "regulars" and for irregulars that appear to be affixed. Regarding grammar, it has been found that grammatical operations that depend heavily on sequential properties of cognition such as inflectional morphology (e.g., the suffix-ed) that requires mandatory relations with other words in a sentence (e.g., the subject of the verb) would be more affected by sequencing skills and procedural memory than derivational morphology (e.g., harm - harmful) that does not involve relationships with other words in the sentence

(Sengottuvel & Rao, 2013). In addition, procedural memory possibly subserves the acquisition of non-lexical semantics (i.e., aspects of the composition of words into complex structures). Turning to declarative memory, Ullman proposed that the temporal lobe circuits that underlie declarative memory subserve the mental lexicon by binding conceptual, phonological, and semantic representations of word-specific knowledge.

Computational analyses of the fundamental properties of language have supported the hypothesized role of these two memory systems in language development. In this area, Gupta and colleagues hypothesized that; on the one hand, the learning of new distributed representations of phonological word forms can be accomplished by procedural learning (Gupta & Cohen, 2002; Gupta & Dell, 1999). For example learning that the syllable ba is followed by the syllables na and na in the word banana. On the other hand, the swift establishment of receptive and expressive language links (i.e., learning associations between distributed phonological and semantic representations) requires a fast learning rate such as that provided by the declarative learning system (for review see Gupta, 2012). Similarly, Ellis (1994) indicated that in terms of lexical knowledge representations, certain meaning-related aspects of word knowledge are inherently explicit whereas word form and usage related aspects could be best learned implicitly, but can also be learned explicitly depending on the presence or absence of awareness. Only one recent study (i.e., Mainela-Arnold & Evans, 2014) investigated these claims in children with SLI and TD children and confirmed different roles of procedural learning with respect to lexical knowledge. Procedural learning was tested with a well-known test of implicit learning. Specifically, the children's ability to segment 'words' from artificial language input on the basis of statistical regularities in phoneme sequences was measured (Saffran, Newport, Aslin, Tunick, & Barrueco, 1997). Two aspects of the children's pre-existing language knowledge were also tested: lexical-phonological knowledge and lexical-semantic knowledge. Lexical-phonological knowledge was measured using a forward gating task in which participants listened to acoustic chunks of words (i.e., gates), starting from the beginning and increasing in length. They guessed the word after each gate. Lexical-semantic knowledge was measured by a word definition task of familiar words. Performance on the laboratory measure of statistical learning was correlated with the children's lexical-phonological knowledge but not their lexical-semantic knowledge. These results are consistent with Ullman's (2004) claim of division in the role of the two memory systems under the declarative/procedural model. Specifically, this study provides evidence on the role of procedural memory in the acquisition of sequential structure of articulatory movements and auditory sounds in spoken language form (lexical-phonological knowledge), but not in word meaning knowledge.

Empirical evidence of the role of the procedural memory system in language has been documented in research on statistical learning. Implicit learning and statistical learning refer to the same underlying phenomenon: inducing structure and regularities from input following exposure to multiple exemplars (Conway, Bauernschmidt, Huang, & Pisoni, 2010; Perruchet & Pacton, 2006), leading researchers to use the terms statistical and implicit learning interchangeably (e.g., Conway et al., 2010). In this vein, during the first year of life, language acquisition seem to largely rely on infants' statistical abilities to extract the regularities of their native language with respect to vowel space, consonant categories, and phonological regularities (Jusczyk, 2000). Previous work on statistical learning has found this ability to be important for different aspects of language in infants, children, and adults including: word segmentation of auditory stimuli (Evans, Saffran, & Robe-Torres, 2009; Saffran, Aslin, & Newport, 1996; Saffran, Johnson, Aslin, & Newport, 1999; Saffran et al., 1997), knowledge of where sounds occur in syllables and words (Chambers, Onishi, & Fisher, 2003; Dell, Reed, Adams, & Meyer, 2000), word predictability in speech (Conway et al., 2010), and the acquisition of syntax such as using passive voice (Gómez & Gerken, 2000; Kidd, 2012). It is important to note that Kidd (2012) provided the first empirical demonstration of a direct association between procedural memory as measured on a visual sequence learning task and language acquisition (i.e., passive voice) in 4- to 6-year-old TD children. Kidd explained this relationship in terms of the similar implicit learning mechanism in spite of the different sensory domain. Specifically, visual sequence learning is gradual and requires repeated presentation of the stimuli; similarly, acquisition of grammar is gradual, particularly for non-canonical forms such as the passive voice, where children will hear hundreds of tokens of the structure before they master its use.

Implicit learning applies to semantic learning as well as phonological and grammatical learning. Statistical learning was found to facilitate the association of meanings with newly segmented words in infants (Estes, Evans, Alibali, & Saffran, 2007). Furthermore, recent studies have demonstrated that visual sequence response efficiency during infancy predicts later receptive and productive vocabulary size. One study showed that visual response efficiency at 8 months predicted vocabulary at 13 months (Shafto, Conway, Field, & Houston, 2012), and another study found that this ability at 6 months predicted vocabulary at 22-months (Ellis, Gonzalez, & Deák, 2014). Overall, the findings described above show that language processing is based on probabilistic knowledge and frequency of exposure to input, leading in turn to the conclusion that language learning is an implicit form of learning (Ellis, 2002).

Two major roles of declarative memory may help clarify its relation to language, given the hypothesis that language learning is fundamentally an implicit process dependent upon procedural learning mechanisms. First, the role of declarative memory in the creation of relational representations; second, the flexible expression of those representations (Squire, 2004; Squire & Dede, 2015). More specifically, declarative memory involves the creation of relational representations through the binding of the arbitrary co-occurrences of people, places, and events, thus establishing records of one's experience (Kurczek et al., 2014). Moreover, these relational representations are uniquely flexible, permitting integration with other types of representations as well being readily extended to use in novel contexts (Duff & Brown-Schmidt, 2012). The role of declarative memory has been proposed in the acquisition, representation, and use of vocabulary including word meaning and abstract representations such as word category (Duff & Brown-Schmidt, 2012; Ullman, 2004). The majority of the evidence for the relationship between declarative memory and vocabulary comes from studies on patients with amnesia (Duff & Brown-Schmidt, 2012; Gabrieli, Cohen, & Corkin, 1988; Kurczek et al., 2014), and recently in one study on TD children (Kidd & Kirjavainen, 2011).

Beyond vocabulary, research on patients with hippocampal amnesia suggests that declarative memory contributes to the online processing of language (Duff & Brown-Schmidt, 2012). More specifically, patients with hippocampal amnesia show difficulty in establishing, recovering, maintaining and using representations across the course of a conversation. For example, these patients show impairment in the flexible and creative use of language to reflect joint knowledge (Duff & Brown-Schmidt, 2012) including difficulties in verbal play (i.e., playing with the sounds and meanings of words through the use of puns, voices and sound effects, teasing, and telling funny stories; Duff & Brown-Schmidt, 2012; Duff, Hengst, Tranel, & Cohen, 2007), and representing ideas from other times or places (Duff et al., 2007).

In line with the role of procedural memory in early language acquisition, developmental studies indicated that procedural memory develops prior to declarative memory. Specifically, procedural memory is mediated by neural structures that emerge as early as birth (Nelson, 1995), while the neural structures that subserve declarative memory emerge by the end of the first year of life (Friedrich & Friederici, 2005, 2008). Accordingly, the role of declarative memory seems to be evident in language development in later stages in which the children can explicitly learn vocabulary, such as learning the arbitrary association between the sequential string of sounds and semantic meaning of a word. In addition, Gladfelter (2014) demonstrated that implicit and explicit learning show a differential time course during word learning in rich semantic context in TD children and children with ASD or SLI. Specifically, following the initial fast mapping phase of learning (during first session), implicit learning as indicated by phonetic accuracy and speech motor stability increased most dramatically for the words taught with rich semantic cues. Only following extended learning (over following two sessions) was the advantageous role of the rich semantic context evident on the explicit learning as measured by referent identification, confrontation naming, and definition tasks. These results are consistent with the view that learning lexical forms are primarily driven by children's ability to track frequencies of phonemes and syllable combinations (Coady & Aslin, 2003). Together, these findings suggest that procedural memory is involved in word learning in the first stage in which a label is associated to its referent, while with later experience of the label, declarative memory augment the word-referent pair with semantic information.

Although Ullman's declarative/procedural model (2001, 2004) separates the roles of the two memory systems along the lexicon and syntax, this does not preclude interaction between the two memory systems in language acquisition. Specifically, Ullman and colleagues (Ullman, 2004; Ullman & Pierpont, 2005; Ullman & Pullman, 2015) proposed that the procedural and declarative memory systems collaborate and, together, form a dynamically interacting network that yields both cooperative and competitive learning and processing. That is, the two systems can complement each other in acquiring the same or analogous knowledge, including knowledge of a sequence. Specifically, the declarative memory system may be expected to acquire knowledge initially given its rapid learning abilities, while the procedural system may gradually learn the same or analogous knowledge (Poldrack & Packard, 2003; Willingham, Salidis, & Gabrieli, 2002). Moreover, the two systems can interact competitively, leading to a "see-saw effect", such that a dysfunction of one system leads to enhanced learning in the other, or that learning in one system depresses functionality of the other (for review see Ullman, 2004; Ullman & Pullman, 2015).

Furthermore, it is important to keep in mind that different aspects of language also interact throughout development. In this vein, there is a strong relationship between phonology and vocabulary throughout language development (Claessen, Heath, Fletcher, Hogben, & Leitao, 2009; Storkel & Morrisette, 2002). For example, in the early stages of language development, it has been hypothesized that a child associates a holistic chunk of articulatory sounds with the meaning of a word. With the rapid growth of vocabulary, the stored "code" takes on a segmental nature, with progressively smaller units being stored until the representations contain phonemes. This process continues to develop up to 8 years of age (Claessen et al., 2009). Moreover, several studies indicated that procedural and declarative memory work together in our daily life and even in experimental settings; therefore, it is difficult to find tasks that test for one memory system completely in absence of the other (Destrebecqz & Cleeremans, 2001; Norman, Price, Duff, & Mentzoni, 2007; Rauch et al., 1995; Shanks & Johnstone, 1999; Sun, Slusarz, & Terry, 2005). Despite these obstacles to testing the declarative/procedural model, there has been an increasing interest in this model and its possible implications in clinical populations.

1.7 The Hypothesized Role of Procedural and Declarative Memory in Language Development in ASD with Language Impairment and in SLI

Ullman (2004) argued that autism is associated with cerebellar abnormalities and with difficulties of motor function, working memory, and procedural learning, especially of sequences, but not of declarative memory. On the surface, this conception is supported by the language profile in ASD, where morphology and syntax are often impaired whereas knowledge of words and concepts is not. However, Ullman's suggestion of procedural deficit in ASD draws on a limited literature review of studies on memory in autism that focused on language-normal children with ASD, rather than children with the language impairment the model aims to explain. Ullman's hypothesis has been espoused by other researchers (i.e., Klinger et al., 2007; Walenski et al., 2006) who further predicted that impaired procedural memory may be observed in the context of not only spared, but even enhanced declarative memory that could compensate for language and social difficulties in some children with ASD (for a review of declarative memory compensation in ASD see Ullman and Pullman, 2015). Walenski et al. (2006) applied this idea to explain the variability in language impairment in ASD. They proposed that since the procedural system involves a network of brain regions, heterogeneity across the autism spectrum might be explained by severity of impairment in the network subserving procedural memory, as well as compensatory systems, including declarative memory that may be activated. In the same vein, Romero-Munguía (2008) proposed the "mnesic imbalance" theory according to which an imbalance between procedural and declarative memory systems may explain the symptoms of ASD. Specifically, impaired procedural memory hinders the development of functions related to procedural learning and leads to an overuse of declarative memory as compensation, which results in conscious effort being required to perform actions that are normally automatic.

Boucher and colleagues provided an alternative hypothesis that is also founded on Ullman's (2004) declarative/procedural model to explain language profiles within the autism spectrum. They assumed a continuum of declarative memory impairment across the spectrum that could explain variability in language abilities among individuals with ASD (Boucher & Bowler, 2008; Boucher & Mayes, 2011; Boucher, Mayes, & Bigham, 2012). In the view of Boucher and colleagues this is shown in impaired episodic memory and predominantly spared semantic memory abilities in language-normal individuals with ASD while severity and pervasiveness of both episodic- and semantic-memory impairments increases in verbal language-impaired individuals with ASD, whereas minimally verbal individuals with ASD suffer from difficulties in most forms of memory. Accordingly, Boucher and Mayes et al. (2008) claim that diminished declarative memory in the verbal language-impaired children with ASD can explain the language profile in this group: diminished lexicon while phonology and grammar are relatively intact. However, the development of grammar in this group is not completely spared because it is partly dependent on linguistic meaning (Boucher, Mayes, & Bigham, 2008).

Turning to SLI, previous research suggested that this group has a deficit in sequential information processing which may underlie some of their linguistic difficulties such as identifying and discriminating successive phonetic elements (Tallal, 2000) and their non-linguistic difficulties such as those found in fine- and gross-motor skills ability, especially when sequential aspects are involved (Bishop, 2002; Hill, Bishop, & Nimmo-Smith, 1998). In addition, based upon an extensive review of research on SLI, Ullman and Pierpont (2005), under the procedural deficit hypothesis, suggested that language difficulties in SLI as well as poor motor abilities are consistent with neuropsychological data involving damage to one or more of the brain structures that support procedural memory (i.e., the basal ganglia and frontal cortex, especially the caudate nucleus and Broca's region). Furthermore, Ullman and colleagues argued that, although sequential learning is impaired in SLI, declarative memory function is intact and could compensate for the impaired procedural memory (Ullman, 2004; Ullman & Pierpont, 2005; Ullman & Pullman, 2015). Subsequently, they argue that while the rule-based aspects of language acquisition and use (e.g., phonology, grammar, and morphology) should be problematic for children with SLI, lexical-semantic knowledge hypothesized to be dependent on this memory system (e.g., recognition and comprehension in word learning tasks) should not be key areas of impairment in SLI. Against the procedural deficit hypothesis predictions, recent studies suggest that lexical semantic difficulties in SLI may have been underestimated in past research. Lexical semantic difficulties in some children with SLI include difficulties in word learning (Kan & Windsor, 2010), poor word definitions (Mainela-Arnold, Evans & Coady, 2010), and errors in semantic naming (McGregor, Newman, Reilly & Capone, 2002).

In conclusion, different hypotheses have been proposed on the role of procedural and declarative memory systems in language impairment in ASD and SLI. One account suggests that language deficits in both ASD (Klinger et al., 2007; Ullman, 2004; Walenski et al., 2006) and SLI (Ullman & Pierpont, 2005) are the result of impaired procedural memory. In addition, this position claims intact declarative memory that compensates for some of the impairment in both conditions (Ullman & Pullman, 2015). In another account, Boucher et al. (2008) hypothesized that in language-impaired children with ASD, language impairment can be explained by intact procedural memory and impaired declarative memory affecting the ability to form memories for personally experienced episodes and factual information. Currently, the validity of these hypotheses is still unclear due to the lack of studies on procedural and declarative memory in

ASD and in SLI. Previous studies on procedural and declarative memory in language-impaired children with ASD and children with SLI are discussed in Studies 1 and 2, respectively.

1.8 Research Aims

In the current dissertation, I directly compared specific aspects of language (phonology and vocabulary) and cognitive abilities (procedural and declarative memory) in language-impaired children with ASD and children with SLI to address the following objectives. In Studies 1 and 2, I describe language and memory profiles of language-impaired children with ASD and children with SLI, respectively, as compared to their TD peers. In Study 3, I clarify whether language-impaired children with ASD exhibit similar or different language and memory profiles as those observed in children with SLI, and I explore the role of procedural and declarative memory in performance on language measures in the three groups.

Chapter 2 : Study 1 - Language and Memory in ASD with Language Impairment

2.1 Introduction

Over the last two decades, most psychological and neuropsychological research into ASD has focused on individuals who possess age-appropriate language, that is individuals with Asperger syndrome or high-functioning autism, rather than individuals with marked language delay and intellectual impairment (APA, 2013). This is due to the fact that the core symptoms of autism (specifically, impairments in communication and social interaction, and the presence of restricted and repetitive behaviors) are observable in their "pure" form, without linguistic or intellectual impairments in language-normal individuals with ASD, and that language-normal individuals are easier to test. This led to a relative neglect of the impairments faced by language-impaired individuals with ASD.

There is an urgent need for more research into the characteristics and causes of language impairment in ASD to provide better understanding of the disorder that informs diagnosis and effective intervention. The current study investigates the profiles of language (phonology and vocabulary) and memory (procedural and declarative memory) in language-impaired children with ASD in comparison to TD children of similar age and nonverbal intelligence quotient (NVIQ).

In the following sections, the litreture on language abilities and procedural and declarative memory in langugе-impiared children with ASD is discussed. Given that research on language and memory profiles of language-impaired children with ASD is quite limited, in the folllowing sections I report on studies that either tested language-impaired children with ASD or tested *mixed groups* of children with ASD who varied in their language and intellectual abilities but included language-impaired participants with ASD.

2.1.1 Language characteristics in ASD with language impairment.

The following section provides a description of the structural language profile in language-impaired individuals with ASD with emphasis on two aspects of phonology; phonological awareness and articulation, and two aspects of vocabulary: receptive vocabulary and word learning, which are of the focus of the current dissertation.

2.1.1.1 *Phonological awareness.* Phonological awareness refers to the conscious ability to recognize, discriminate, and manipulate the speech sounds and other phonological units (e.g., words, syllables and sub-syllabic units such as onset and rime) in one's language (Anthony & Francis, 2005). There is abundant evidence that phonological awareness is important for the acquisition of oral language development, reading, and spelling in TD children as well as children with language and speech disorders (Rvachew, 2006, 2007; Snowling, Bishop, & Stothard, 2000; Stanovich, 2000). Few studies investigated phonological awareness in children with ASD and little is known about this area.

Phonological awareness is assessed by a wide variety of tasks measuring the ability to distinguish and manipulate speech sounds including phonemes and syllables. For example, phoneme segmentation and elision tasks require the participant to delete a phoneme or syllable from a word and point to the remaining word. Sound-blending tasks require participants to blend either syllables or phonemes into words.

Impaired phonological awareness in children with ASD and mixed language abilities was reported in early studies investigating multimedia computer intervention for language and reading skills (Heimann, Nelson, Tjus, & Gillberg, 1995; Tjus, Heimann, & Nelson, 1998). It was noted that children with the highest receptive language levels showed the most improvement in phonological awareness during training and follow-up periods (Tjus et al., 1998).

More recent studies found that phonological awareness skills vary among children with ASD. Some children were successful on multiple phonological tasks while others had difficulty with even the simplest tasks (Gabig, 2010; McGee, 2006; Newman et al., 2007). In a recent study, 5- to 7-year-old children with ASD were compared to their age-matched TD peers on two measures of phonological awareness: sound blending and elision (Gabig, 2010). In this study, although children with ASD as a group scored below the TD group, children with ASD varied in their performance. Six of 10 children with ASD scored within the average range on sound blending task, while 4 of 10 children scored within the average range on both measures. These results indicate that variance in phonological awareness abilities are related to the complexity of the task. It has also been suggested that language comprehension (Gabig, 2010; McGee, 2006) and phonological production (McGee, 2006) contribute most to the variance in phonological awareness in children with ASD. In addition, when testing individuals with ASD, Newman et al. (2007) found that a subgroup with hyperlexia performed significantly better than the subgroup without hyperlexia on phonological awareness measures; furthermore, the subgroup with hyperlexia performed similarly to a TD comparison group.

2.1.1.2 ***Articulation.*** Articulation refers to the expressive use of phonological knowledge in speech. Previous studies on articulation in children with ASD provided mixed evidence. For example, Kjelgaard and Tager-Flusberg (2001) concluded that phonology is the most spared aspect of language in 4- to 14-year-old children with ASD and mixed language abilities. Specifically, the children with ASD were divided into subgroups with- and without-language impairment on the basis of receptive vocabulary test scores. Performance on a single word articulation test was significantly worse for the language-impaired subgroup when compared to the subgroup without language impairment; yet, both subgroups achieved articulation test scores that were within the average range and elevated relative to other measures of speech-language function. However, when language-impaired and non-impaired ASD groups were matched on both receptive and expressive language scores, no difference between groups was found. On the basis of standardized measures of articulation at the single word level, several studies have reported delayed articulation skills in children with ASD with participant samples varying in age from 4 to 9 years (McGee, 2006; Rapin & Dunn, 2003; Rapin et al., 2009; Tager-Flusberg et al., 2005). These studies, including one large sample longitudinal study (Rapin & Dunn, 2003; Rapin et al., 2009), suggest a considerable drop in the prevalence of delayed articulation skills in children with ASD with age (63% in preschoolers vs. 24% in school age children).

Tager-Flusberg et al. (2005) proposed that one subgroup within minimally verbal children with ASD may experience verbal apraxia of speech, a neuro-motor deficit that affects the ability to produce speech sounds, sound sequences, and prosodic features (Darley, Aronson, & Brown, 1975). However, a recent study (Shriberg, Paul, Black, & van Santen, 2011) did not support the proposal of concomitant apraxia of speech in verbal ASD. Shriberg et al. (2011) found that 15.2% of 4- to 7-year-old children with ASD and intelligible speech had speech delay (as defined by reduced intelligibility due to age-inappropriate speech sound deletions, substitutions, and distortions) but did not display the core features of apraxia of speech including increased spatiotemporal vowel errors, increased uncommon phoneme distortions, and slow speech rate.

2.1.1.3 ***Receptive vocabulary.*** According to parent reports of early language development, most preschool children with ASD and mixed language abilities have delayed language comprehension and production onset and a slowed rate of language development (Charman, Drew, Baird, & Baird, 2003; Hudry et al., 2010; Luyster, Lopez, & Lord, 2007).

Direct assessment of language in children with ASD showed that they vary enormously in their word comprehension ability. For example, Kjelgaard and Tager-Flusberg (2001) found three subgroups within a group of verbal 4- to 14-year-old children with ASD that varied in their receptive and expressive language abilities. Precisely, one group included children who scored within the normal range on the receptive and expressive language measures, the second group included children whose scores were between one and two standard deviations below the mean, and children in the third group scored more than two standard deviations below the mean. Similar findings of varied receptive vocabulary at the single word and sentence levels were reported in preschool children with ASD (Rapin & Dunn, 2003) as well as school age children with ASD (Rapin et al., 2009).

2.1.1.4 ***Word learning.*** Language impairment found in some children with ASD may be related to difficulties in linking novel labels with novel referents in word learning episodes (Henderson, Powell, Gaskell, & Norbury, 2014). Most of previous studies focused on the ability of children with ASD to use social cues (such as gaze and gesture) in the process of learning a new word. Early studies in this area showed that children with ASD and severe language impairment were able to use non-verbal social cues to learn a novel label only when social and perceptual cues coincide, that is, when the intended object was already in the child's focus of attention (Baron-Cohen, Baldwin, & Crowson, 1997; Parish-Morris, Hennon, Hirsh-Pasek, Golinkoff, & Tager-Flusberg, 2007; Preissler & Carey, 2005). On the contrary, more recent studies have shown that some children with ASD can use social cues to learn novel words even when these cues conflict with perceptual salience (Bani Hani, Gonzalez-Barrero, & Nadig, 2013;

Luyster & Lord, 2009). Furthermore, it has been suggested that a number of factors facilitate successful word mapping in children with ASD including high receptive language and employing enhanced contextual supports such as additional repetitions of the novel word and multiple non-verbal social cues (Bani Hani et al., 2013; Luyster & Lord, 2009; McDuffie, Yoder, & Stone, 2006).

Beyond direct word mapping, children with ASD and mixed language abilities showed similar ability as younger TD children to generalize their knowledge of labels for novel 3D objects to 2D photographs of the object in color or in black and white (Bani Hani et al., 2013). In contrast, children with ASD and severe language delay were less successful in generalizing labels from 2D photographs to real 3D objects (Preissler, 2008) than younger TD children from a different study (Preissler & Carey 2004). In a more recent study, Hartley and Allen (2014) investigated whether 4- to 6-year old language-impaired children with ASD generalize labels from color photographs based on sameness of shape, color, or both to 3D real objects. Children with ASD mostly extended labels to items that matched depicted objects on shape and color, but also frequently generalized to items that matched on only shape or color. On the other hand, 2- to 5-year-old TD children, matched on expressive language to the ASD group, only generalized labels to items that matched the depicted referent's shape. These findings indicate that color has an important influence on pictorial understanding in ASD. However, unlike their TD peers who mostly generalize based on shape, language-impaired children with ASD often show an atypical pattern of generalization, based on incorrect dimension, color.

In conclusion, previous studies demonstrated that language-impaired children with ASD, as a group, show below average performance in terms of phonological awareness (Heimann et al., 1995; Tjus et al., 1998), articulation (McGee, 2006; Rapin et al., 2009; Tager-Flusberg et al., 2005), and receptive vocabulary (Hudry et al., 2010; Luyster et al., 2007). However, at the individual level, some children in this group acquire age-appropriate language abilities (Kjelgaard & Tager-Flusberg, 2001; Rapin et al., 2009). Turning to word learning, a number of factors may facilitate successful word mapping in children with ASD including high receptive language and employing enhanced contextual supports (Bani Hani et al., 2013; McDuffie et al., 2006). In addition, children with ASD show similar ability as younger TD children to generalize their knowledge of labels to different entities. However when compared to age-matched TD children, language-impaired children with ASD often show an atypical pattern of generalization, based on incorrect dimension, color rather than shape.

2.1.2 Procedural Memory.

Given that limited work has been done to investigate procedural and declarative memory processing in language-impaired individuals with ASD, the processing of both visual and verbal stimuli is discussed here, though only memory for visual stimuli was tested in the current dissertation.

Procedural memory in language-impaired children with ASD has been sparingly investigated, while a considerable number of studies examined this area in language-normal individuals with ASD. Most of the previous research on language-normal individuals with ASD demonstrated intact procedural memory as measured by different tasks that require implicit learning of a sequence or a category. For example, intact performance in this group was reported on diagrams that required learning of spatial context (Barnes et al., 2008; J. Brown, Aczel, Jiménez, Kaufman, & Grant, 2010; Kourkoulou, Leekam, & Findlay, 2012), learning transitional probabilities within artificial languages presented auditorily (Mayo & Eigsti, 2012) or visually (Klinger et al., 2007), and learning visual-motor sequences (Foti, De Crescenzo, Vivanti, Menghini, & Vicari, 2014; Mostofsky, Bunoski, Morton, Goldberg, & Bastian, 2004). For an extensive review on procedural memory in this group see Boucher et al. (2012).

To date, only two published studies investigated implicit learning or procedural memory in language-impaired children with ASD. First, Klinger and Dawson (2001) examined category formation for novel characters in a group of language-impaired children with ASD who were matched on receptive-vocabulary to a younger TD group and a group with intellectual impairments. Relative to the TD group, the clinical groups struggled with a more complex implicit learning task that required integration of information across experiences (prototype formation). However, they were able to learn the simple implicit learning task (rule based task) that required the processing of a single piece of information (e.g., all “mips” have long feet). In addition, all groups showed intact rule learning when they were told explicitly that there was a rule that defined category membership. The authors concluded that language-impaired children with ASD, as well as children who are intellectually disabled have difficulty abstracting a summary representation (a prototype) during category learning and, instead, may form categories by memorizing a list of rules.

Second, Gordon and Stark (2007) tested 6- to 14-year-old language-impaired boys with ASD (n = 7) and age-matched TD children. Overall, the ASD group had below-average IQs and limited language abilities. They tested children on a modified serial reaction time (SRT) task that is accessible to language-impaired children with ASD. Results showed that children with ASD can learn a visual-motor sequence with increased behavioral training (i.e., exposure to the sequence) and decreased memory load (i.e., shorter sequences). Procedural memory in the current dissertation was tested with an SRT task similar to the one used by Gordon and Stark; therefore, this task will be described in detail here. In a typical SRT paradigm (Nissen &

Bullemer, 1987), participants are seated in front of a computer screen, and then a visual stimulus appears in one of four designated spatial locations. On some blocks of the experiment, the visual stimulus follows a slowly repeating 10-item-sequence, known as deterministic sequence, and on others presentation is random. Participants are asked to respond as quickly as possible by pressing a button that corresponds to the location of the stimulus. Procedural learning of the sequence is indicated by participants' faster response to the repeating sequences in comparison to the random sequences. Gordon and Stark have modified the task for use with the ASD population. Specifically, participants were tested on an eight-item sequence followed by a four-item sequence, reducing the memory load from the 10-item sequence used in the original SRT paradigm. Furthermore, the participants with ASD were exposed to the sequence repeatedly over six sessions compared to only one session for participants in the TD group. In each session, the sequence was introduced in 12 blocks of 48 trials (i.e., 432 repetitions of the sequence in six days) followed by two random blocks. At the group level, the findings suggested a different pattern of learning for the four- versus eight-item sequences: learning of the four-item sequence emerged as early as the first session whereas learning of the eight-item sequence was not apparent until the final session. However, the reaction times of participants with ASD at both group and individual levels were significantly slower than the reaction time of the participants in the TD group for both sequences. Nonetheless, these results demonstrate that language-impaired children with ASD are capable of procedural sequence learning after intensive training when the sequence is short.

The procedural learning tasks have been criticized as testing declarative, not procedural memory (J. Brown et al., 2010). This criticism draws on studies that demonstrated that procedures involving slowly repeating deterministic sequences, such as the one used in Gordon and Stark's study, are more likely to encourage the development and use of explicit strategies to solve the task (Destrebecqz & Cleeremans, 2001; Norman et al., 2007; Rauch et al., 1995; Shanks & Johnstone, 1999; Sun et al., 2005). However, Sun et al. (2005) argued that in SRT tasks the acquired sequential knowledge at the implicit level could lead to the extraction of explicit knowledge. That is, at the implicit level, the initial extraction step creates a rule that corresponds to the current input and the output. Then at another level of processing, the explicit level, rule extraction, generalization, and specialization occur, which are determined by the amount of information gained about the rule. The generalization step adds more possible values (that may match new input) to the condition of the rule so that it may have more chances of matching new input, while the specialization step adds constraints to the rule (by removing possible matching values in the condition of the rule) to make it more specific and less likely to match new input (Sun et al., 2005). Accordingly, the debate should not be about the purity of the task in testing implicit learning; it should be on the role of explicit knowledge of the sequence, if occurred, in sequence learning. That is, whether the explicit knowledge of the sequence is another level of implicit learning (Sun et al., 2005) that enhances learning as seen in TD children (Thomas & Nelson, 2001), or does it play a compensatory role for impaired implicit learning as suggested for children with ASD (Klinger et al., 2007; Ullman & Pullman, 2015). In the current dissertation, the role of explicit knowledge in sequence learning was addressed by asking the participants to recreate the sequence they had learned.

2.1.3 Declarative memory.

Similar to procedural memory, declarative memory measured by recognition has been intensively investigated in language-normal individuals with ASD, while the existing methodologically robust studies in language-impaired individuals with ASD are limited, except for face stimuli. For the purpose of the present dissertation, the focus is on recognition of non-social stimuli given that those tasks assessing social stimuli such as faces are likely to be related to the pervasive social impairments in ASD (Behrmann, Thomas, & Humphreys, 2006) and to be mediated by dedicated brain structures not implicated in the present dissertation.

In brief, it has been shown that declarative memory processing in normal-language individuals with ASD remains largely intact, as tested by recognition (e.g., Bigham et al., 2010; Bowler, Gaigg, & Gardiner, 2010; Mostofsky, Goldberg, Landa, & Denckla, 2000).

Among the few studies that tested visual recognition of non-social stimuli in language-impaired individuals with ASD findings are inconsistent. Specifically, some studies reported intact immediate and delayed visual recognition of familiar objects in this group (Hauck, Fein, Maltby, Waterhouse, & Feinstein, 1998; Hill & Russell, 2002). Moreover, intact immediate visual recognition was reported of unfamiliar objects (Dawson, Osterling, Rinaldi, Carver, & McPartland, 2001) and pictures of unfamiliar buildings (Boucher & Lewis, 1992) in this group as compared to TD individuals. In contrast, other studies demonstrated poor immediate recognition of unfamiliar objects and shapes (Barth, Fein, & Waterhouse, 1995; Boucher, Bigham, et al., 2008; Dawson, Meltzoff, Osterling, Rinaldi, & Brown, 1998).

Dawson et al. (2001) found that language-impaired children with ASD show similar abilities to developmentally matched Down syndrome and TD children on a simple visual-paired comparison task that assessed visual recognition memory via novelty preference. In contrast, two studies (i.e., Barth et al., 1995; Dawson et al., 1998) reported poor visual recognition of unfamiliar stimuli in language-impaired children with ASD in comparison to TD children. However, these two studies were criticized for measuring stimulus-reward association in addition to recognition (Dawson et al., 2001). Poor visual recognition in language-impaired teenagers with ASD was also reported in a recent study by Boucher, Bigham, et al. (2008). In Boucher's, Bigham, et al. study, participants included four groups: 10- to 17-year-old language-impaired teenagers with ASD and below average verbal and nonverbal IQ scores, teenagers with intellectual-disability; and 5- to 11-year old language-normal children with ASD matched with TD children on chronological age, but of higher language and NVIQ ability. Participants were tested on two tasks that assess recognition of meaningless visual stimuli (i.e., patterns and shapes recognition tasks). Results showed that the language-normal ASD group did not significantly differ from the TD group on both of the measures, although numerically they did worse on the pattern task than the TD group. In contrast, results showed poorer recognition on the two tasks in the language-impaired ASD group in comparison to the TD group with similar language and NVIQ. Comparisons between the two ASD groups showed similar recognition in the language-impaired ASD group and the language-normal ASD group on only one of the recognition measures (pattern recognition which is more difficult), suggesting impaired recognition with less severity in the language-normal ASD group. Interestingly, similar recognition ability was found in the language-impaired ASD group and the intellectually disabled group matched on age, language, and NVIQ. The authors proposed that their results of poor recognition in the language-impaired ASD group and the intellectually disabled group might be an artifact of using language scores as a covariate but not NVIQ scores, and thereby advantaging the language-impaired ASD group in terms of their nonverbal abilities. This conclusion was drawn because performance on nonverbal IQ subtests was found to contribute to recognition performance more consistently in the autism groups than in the non-autism groups (Boucher, Bigham, et al., 2008). This discrepancy in results might be related to differences in the stimuli used in the recognition task (e.g. real novel objects; Dawson et al., 2001 vs. images of shapes; Boucher, Bigham, et al., 2008) or the difficulty of the task.

Studies that reported poor visual recognition in language-impaired children with ASD (i.e., Barth et al., 1995; Dawson et al., 1998) highlighted the importance of controlling for NVIQ differences between groups when testing for declarative memory. For example, Boucher, Bigham, et al. (2008) found that performance on nonverbal intelligence subtests contributed to recognition performance more consistently in the ASD groups than in the non-ASD groups. In addition, studies indicated a positive strong correlation between performance on declarative memory and NVIQ (McGeorge, Crawford, & Kelly, 1997; Reber, Walkenfeld, & Hernstadt, 1991).

Regarding recall in language-impaired children with ASD, findings on free recall demonstrated intact immediate recall of lists of unrelated words (Boucher, 1981a; Summers & Craik, 1994), while impaired immediate recall of semantically related words (Summers & Craik, 1994; Tager-Flusberg, 1991) as well as impaired delayed recall (Boucher, 1981b; Boucher & Lewis, 1989). Findings on cued recall (e.g., semantic and rhyme cues) indicated largely intact ability in language-impaired ASD (Boucher & Lewis, 1989; Tager-Flusberg, 1991).

2.1.4 Purpose of Study 1.

The purpose of the current study was to provide a broad survey of different aspects of language and both procedural and declarative memory in language-impaired children with ASD in comparison to TD children similar in age and NVIQ. More precisely, I aimed to answer two general questions: first, whether language-impaired children with ASD show similar or different performance on language measures including phonological awareness, articulation, receptive vocabulary, and word learning in comparison to their TD peers. Based on previous findings, I predict poorer performance of the language-impaired ASD group in comparison to the TD group on all language measures: phonological awareness as measured on phoneme/syllable deletion task (Gabig, 2010; Newman et al., 2007), articulation (Masterson & Bernhardt, 2001; Rapin, 2007; Rapin & Dunn, 1997; Rapin & Dunn, 2003; Rapin et al., 2009), receptive vocabulary (Kjelgaard & Tager-Flusberg, 2001; Rapin & Dunn, 2003; Rapin et al., 2009), and word learning given that the current word learning paradigm was demanding.

A second goal was to assess whether language-impaired children with ASD show similar or different performance on measures of procedural and declarative memory in comparison to their TD peers. I predict similar procedural learning on a simple-sequence learning task in the language-impaired ASD group and the TD group in line with the finding of the only study on this group using the same simple paradigm but with intensive training over six days (Gordon & Stark, 2007). Turning to declarative memory, although previous studies mostly used tasks that required visual recognition of previously seen novel objects (also referred to as intra-modality recognition in the current dissertation) to assess declarative memory, pilot testing showed that TD children are at ceiling in the intra-modality recognition task used in the current study. Therefore a more complex form of this task, cross-modality recognition, was also used. Cross-modality recognition involves visual identifying of objects that were explored by hands, without being seen. Previous studies indicated positive strong correlation between performance on declarative memory and NVIQ in TD children (McGeorge et al., 1997; Reber et al., 1991) and in children with ASD (Boucher, Bigham, et al, 2008), I predict that when groups are matched on NVIQ, performance of the language-impaired ASD group will be similar to the TD comparison group in the intra-modality recognition task. On the other hand, no speculations could be made on performance on the cross-modality task, given the lack of evidence in this area.

2.2 Study 1 Method

2.2.1 Participants. Two groups of 6- to 10-year-old children were enrolled in this study: 23 children with autism spectrum disorder (ASD), who were reported to have *language impairment* by their parents at study entry and 45 typically-developing (TD) children. Details on confirmation of language impairment are given in section 2.2.1.1.

Participants were recruited in Montreal, Quebec, Canada and came from homes where either English or French was spoken as the first language. More specifically, language dominance was determined based on parent report of their child's exposure to either English or French for at least 65% of the week at home, averaged over the course of the child's life. Using this definition the ASD group included 15 English-speaking participants and 8 French-speaking participants. The TD group included 25 English-speaking participants and 20 French-speaking participants. Participants with ASD were recruited through a pool of prior study participants, advertising at autism events and on social media websites, as well through community contacts in the field of autism. The TD participants were recruited through a university research database as well as by advertising on social media websites targeting families.

This research project received ethics approval from McGill University Faculty of Medicine. Parental consent was obtained prior to participation.

2.2.1.1 Identification of language impairment in participants with ASD. Language impairment was determined by participants' scores on the Recalling Sentences subtest of the Clinical Evaluation of Language Fundamentals, Fourth Edition (CELF-IV; Semel, Wiig, & Secord, 2003) or on the standardized French adaptation of this subtest: Répétition de phrases, L'Évaluation clinique des notions langagières fondamentales-Version pour francophones du Canada (Wiig, Secord, Semel, Boulianne, & Labelle, 2009). The Recalling Sentences subtest evaluates participant's ability to recall and reproduce sentences of varying length and syntactic complexity by imitating sentences presented by the examiner. This task has been found to be an effective psycholinguistic marker of specific language impairment with high levels of sensitivity (90%), specificity (85%), and overall accuracy (88%) (Conti-Ramsden, Botting, & Faragher, 2001). Responses on this subtest are scored in relation to the number of errors made in each sentence and scores are scaled to a mean of 10 and standard deviation (SD) of 3.

For the purposes of the study language impairment was defined as having scores at least 1 *SD* below the mean on the Recalling Sentences subtest. The cutoff of 1 *SD* was chosen because previous research using this subtest (Conti-Ramsden et al., 2001) and work using other language measures found it to be useful in identifying language impairment in children with ASD (Kjelgaard & Tager-Flusberg, 2001) and children with SLI (Thordardottir et al., 2011).

Only ASD participants who could complete the study procedures and who met the language impairment criterion were included in analyses. Three participants were minimally verbal and could not be tested on most tasks and an additional two participants scored within the normal range on the Recalling Sentences subtest. This resulted in a sample of 18 language-impaired participants with ASD, 12 English-speaking and 6 French-speaking. Eight participants (five English-speaking and three French-speaking) scored 1 *SD* below the mean, five (three English-speaking and two French-speaking) scored 2 SD below the mean, and five (four English-speaking and one French-speaking) scored 3 SD below the mean. It is also important to note that all participants in the language-impaired ASD group had language impairment but were verbal aside from one child who was minimally verbal (i.e., did not use functional words spontaneously).

Participants in the TD group did not meet the criteria for language impairment as indicated by scores within or above the average range on the Recalling Sentences subtest.

2.2.1.2 Identification of participants. For participants with ASD who met criteria for language impairment (*n* = 18), confirmation of diagnosis was obtained via records of the child's diagnosis, which in Quebec is given by a multidisciplinary team or M.D. Sixteen of the 18 participants with ASD received the Autism Diagnostic Observation Schedule (ADOS; Lord, Rutter, Dilavore & Risi, 1999) as part of their evaluation. For 12 participants a specific ADOS classification was available from records; nine met ADOS criteria for Autism and three met criteria for ASD. For the remaining six participants, five had an overall clinical diagnosis of Autistic Disorder (DSM-IV-TR criteria, APA, 2000), and one had a diagnosis of ASD (DSM-V criteria, APA, 2013).

In addition, within this study all participants were screened for ASD symptoms using the Social Communication Questionnaire (SCQ; Rutter, Bailey, & Lord, 2003). This is a brief parent-report questionnaire, which was completed by parents in its English format or in French using a translation developed for use in our lab by a licensed speech language pathologist and a master's student in speech language pathology who were both native speakers of Quebec French. All participants in the ASD group scored in the ASD range (scores of 15 or above) while TD participants scored below this cutoff.

TD participants had no developmental, learning, or behavioral disorders, and did not have first-or second-degree relatives with an ASD per parent report.

2.2.1.3 Nonverbal intelligence quotient (NVIQ). The TD sample was selected by pairing each participant with ASD who met the language impairment criteria (*n* = 18) with a TD participant of the same dominant language who had a similar NVIQ as measured by the Leiter

International Performance Scale 3 (Leiter-3; Roid, Miller, Pomplun, & Koch, 2013). Matching on NVIQ allows for the comparison of language level between groups who are at the same cognitive level. Leiter-3 was chosen as a NVIQ measure because it does not require verbal responses, and therefore is appropriate for children with communication disabilities. Leiter-3 standard scores have a mean of 100 and standard deviation of 15. Participants had NVIQs within or above the average range except one ASD participant who obtained a standard score of 83 on the Test of Nonverbal Intelligence Third edition (TONI–3; L. Brown, Sherbenou, & Johnsen, 1997), which assesses fluid intelligence, abstract reasoning, and problem solving. This participant was assessed by a psychologist on the TONI-3 around the time of study participation. Therefore, it was not appropriate to retest the child using Leiter-3.

Finally, for an estimate of socioeconomic status we asked parents for information on their highest level of education. Participant characteristics are given in Table 2.1. As shown participants in the language-impaired ASD and TD groups did not differ significantly in NVIQ, chronological age, gender, or parent level of education, although there was a trend for TD participants to be younger. Since equal numbers of English-speaking and French-speaking participants of similar NVIQ and chronological age were represented in each of the groups, data was collapsed over dominant language for all analyses.

2.2.2 Procedure.

The study involved one session in a quiet room either in our university lab or at the participant's home, if it was more convenient for the participant's family. The session lasted for approximately 2 and a half hours. If needed, testing was administered across 2 days. This was the case for six ASD participants. Each child participated in tasks examining performance on phonology (phonological awareness and articulation), vocabulary (receptive vocabulary and word learning), procedural memory, and declarative memory. Table 2.2 provides a summary of the session protocol. The entire session was conducted by trained examiners in either English or French according to the participant's dominant language.

Table 2.1.

Participant Characteristics

	Language impaired-ASD (n = 18)		Typically developing (n = 18)		
	M (SD)	*Range*	*M (SD)*	*Range*	*p-value
Dominant language (English, French)	12, 6		12, 6		1.00
[a] NVIQ (Leiter-3)	100.84 (11.09)	83 - 123	105.27 (7.23)	95 - 123	.10
Chronological age (Y; M)	8 (1; 2)	6 - 10	7; 5 (0; 6)	6; 4 – 8; 6	.07
Gender (M, F)	14, 4		9, 9		.08
[b] Parent education: University degree	9		12		.46
SCQ	21.94 (6.59)	15-34	3.50 (2.99)	0 - 12	< .001
Recalling Sentences (CELF-IV)	3.61 (2.17)	1 - 7	11.11 (2.54)	8 - 16	< .001

Note. [a] One ASD participant had score from the Test of Nonverbal Intelligence Third edition (TONI–3; L. Brown et al., 1997). [b] Information on parent education was not available for three ASD and three TD participants. * An alpha level of .05 was used for all statistical comparisons.

Table 2.2.

Order of Task Administration

1. Word learning **with brief-delay**
2. Phonology (phonological awareness): Auditory Analysis Test (English) or Test d'Analyse Auditive en Français (French)
3. Procedural memory: Serial Reaction Time task
4. Receptive vocabulary: Peabody Picture Vocabulary Test, Fourth edition (English) or Les Échelle de Vocabulaire Image Peabody (French)
5. Recalling Sentences subtest of the Clinical Evaluation of Language Fundamentals, Fourth Edition (English) or Répétition de phrases, L'Évaluation clinique des notions langagières fondamentales-Version pour francophones du Canada (French)
6. Nonverbal IQ: Leiter International Performance Scale 3
7. Phonology (articulation): Goldman-Fristoe test of Articulation (English) or Test de Dépistage Francophone de Phonologie (French)
8. Declarative memory: Intra- and cross-modality-recognition tasks
9. Word learning **with longer-delay**

2.2.2.1 ***Phonology.*** To evaluate phonological comprehension and production, two measures of phonology were administered: phonological awareness and articulation. These two measures were chosen given that the performance on each of them was speculated to depend on procedural memory (declarative/procedural model; Ullman, 2004). Specifically, the phonological awareness task requires deleting a phoneme or syllable from a spoken word then saying the remaining word, and the articulation task involves producing the sequence of sounds that form the name of a picture. Such phonological abilities require knowledge of the structured rules that govern sound sequencing. These abilities are hypothesized to be subserved by the procedural memory system and implicit learning mechanisms that extract regularities and patterns distributed across a set of exemplars, such as those found in phonology (Conway & Pisoni, 2008). In addition, these measures were chosen given the limited number of standardized measures of phonology in both English and French.

a. Phonological awareness was assessed using the Auditory Analysis Test (AAT; Rosner & Simon, 1971) for English-speaking participants or its validated French version, Test d'Analyse Auditive en Français (TAAF; Cormier et al., 1995) for French-speaking participants. Participants were instructed to repeat a word (e.g., "Say *birthday*"), and then repeat it again but to delete certain phoneme or syllable (e.g. "Now say it again without /day/"). Deletions were located at the beginning, middle, or end of words that varied in length from one to four syllables. In the English version, words (with three exceptions) were selected such that the elimination of a phoneme, phoneme cluster, or syllable that would result in another English word when pronounced. This was not the case for the French version, e.g., "Dit *pantalon*." "Dis-le encore, mais sans le /ta/."

The administration procedure described in the original AAT test (Rosner & Simon, 1971) was followed with two modifications to the training phase only to make the French and English versions as similar as possible. Firstly, training items were presented verbally as well as orthographically in both languages, on a computer screen; the training items in the French standardized version of the AAT couldn't be depicted pictorially, as they did not form words after the omission was done. Secondly, two additional English training items (i.e., rain/bow/ and

/slide/show) were added to the two in the original version so that both the English and French versions presented four opportunities to train on this task.

Participants were seated comfortably in front of a laptop computer and instructed to respond according to the instructions they heard: “We will play a game now. The computer will ask you to say a word. Listen carefully then say the word.” The four training items were recorded by a female native speaker and were presented one at a time via a PowerPoint presentation. The participant heard a word on external/built-in speaker and saw it written on the screen. The examiner provided verbal reinforcement for correct responses. If a participant did not respond or did not repeat a word correctly, that item was replayed for up to two times. This high number of training opportunities was meant to provide adequate training for participant with language impairment. Following the original guidelines, all participants proceeded to testing regardless of their performance on training.

During testing, each participant was told that they would need to repeat more words while removing one part of each word, but would no longer read the word on the screen. All the items of AAT (40 items) and FAAT (42 items) were recorded by a female English- or French-native speaker, respectively (provided by Rvachew, Chiang, & Evans, 2007). The PowerPoint slide presented an audio file as well as visual information about the number of items completed and the number remaining. When a participant did not respond to an item or asked for a repetition, that item was repeated once. During testing, the examiner provided verbal encouragement for responding to encourage participants but no information about the accuracy of the responses.

During training and testing, responses were transcribed by the examiner and recorded with a digital audio recorder (TASCAM, Teac Professional-DR 100) for scoring purposes.

Speech articulation problems were noted by the examiner at the first repetition of the full word and were taken into consideration; a mistake in omission that involved misarticulating sounds was not counted as an error. If a participant did not repeat the word with the deleted phoneme/syllable correctly or did not respond after one repetition of the item, a score of zero was recorded and the next item was presented. Testing was discontinued after four consecutive zeros. The final score indicated the total number of correct deletions with a maximum score of 40 on the AAT and 42 on the TAAF.

b. Articulation was assessed using the sounds-in-words subtest of the Goldman-Fristoe Test of Articulation, Second Edition (GFTA-II; Goldman & Fristoe, 2000) for English-speaking participants. This test measures the accuracy of producing the consonant sounds in individuals between the ages of 2 and 21 years at the single word level. During the administration of this test, each participant was presented with a series of 34 colored pictures on a computer screen and was asked to name them. This test elicited 53 single-word responses that targeted 77 consonants and consonant clusters in the initial, medial, and final position of words. If a participant did not respond or named the picture incorrectly, the examiner named that picture once and prompted the participant to repeat the name, e.g., “This is a tree. It has green leaves. What is this? ”

For Francophone participants, articulation was assessed using the Test de Dépistage Francophone de Phonologie (TDFP; Rvachew, Brosseau-Lapré, & Paul, 2012) that targeted 94 consonants and vowels in initial, medial, and final positions of words. This test involves picture naming using 10 photographs to elicit 30 single words spontaneously or by imitation using a procedure similar to the GFTA-II.

Responses were recorded with a digital audio recorder (TASCAM, Teac Professional-DR 100) for scoring purposes. Responses on only the consonant sounds were transcribed on-line by trained students and were subsequently verified by listening to the audio recording by another student. If there was a discrepancy in the obtained scores, the audio recording was checked again to determine the correct score.

2.2.2.2 Vocabulary was assessed using two measures, a standardized test of receptive vocabulary and a behavioral task assessing novel word learning.

a. Receptive vocabulary was examined using the Peabody Picture Vocabulary Test; Fourth Edition (PPVT-IV; Dunn & Dunn, 2007) or its French standardized version; adapted and normed for Canadian speakers of French (i.e., Les Échelle de Vocabulaire Image Peabody-ÉVIP; Dunn, Thériault-Whalen, & Dunn, 1993). These are standardized (*M* = 100, *SD* = 15) measures of lexical comprehension where the participant is asked to select a named item from an array of four pictures. The PPVT included 228 items and the ÉVIP included 170 items.

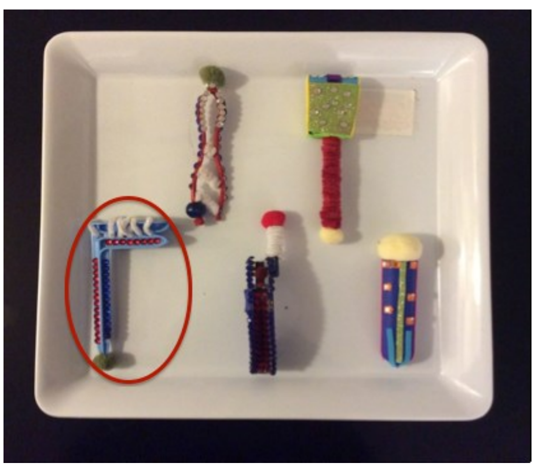
b. Word-learning was explored with a task that assessed the extension of a novel label to another object of the same kind (differing in color) with both a *brief-delay* (just after two objects were labeled) and a *longer delay* of approximately 2 hours.

Materials.

- *Familiar objects*. Four familiar objects commonly found in young children's repertoire (e.g., pen, book, spoon, and block) were used in *exposure phase*.

- *Novel objects. In exposure phase***,** three novel objects were used, a target (labeled object) and two foils (unlabeled objects). *During brief-delay test phase,* five objects were presented: the target and the two foils from the exposure phase that were the same kind of object but differed in color, and two novel distracters that had not been seen in the exposure phase. Novel objects were real-world objects (e.g., paint brush, key holder) that were modified to look novel by changing their texture, shape, and decorating them. Foil and distractor objects were chosen to be visually more interesting than the target object in terms of color and decorations. However, all the novel objects in a set were chosen to be similar in size. Object novelty was confirmed by asking parents whether the child had seen the objects before. If parents indicated their child's familiarity with any of the objects, substitute objects were provided. Figure 2.1 displays the two sets of novel objects used in brief-delay test phase. In *longer-delay test phase,* the five novel objects of the brief-delay test phase of trial A and B (*N* = 10) were used.

- *Novel label.* The novel words *remope* and *fental were* used to label the target object in trial A and B, respectively. These novel labels were obtained via parallel norming in both English (/riˈmop/; /ˈfɛntəl/) and French (/Riˈmop/; /fɑ̃ˈtɑl/) in a previous study conducted in our lab (Bani Hani et al., 2013). The presentation of the two trials was counterbalanced among participants.



Trial A

Trial B

Figure 2.1. Object sets used in the testing phase of the word-learning task. Target objects, which were labeled during the exposure phase, are indicated by circles.

- *Exposure phase.* The examiner placed the objects in two rows on a square tray in front of the participant. The two familiar objects placed in the first row and the novel objects in the second row so they were all equally visible to the participant. After placing the objects, the examiner directed the participant's attention by calling her name and then looking and pointing at the target object while labeling it as follows: "Participant's name, look, this is a *remope.*" The examiner then held a bucket centrally in front of the participant and asked the participant to "Put the (*familiar object label)* in the bucket, now put the Y in the bucket." No help or feedback was provided. The examiner then asked the participant to "Put the *remope* in the bucket." After the participant put the target in the bucket, the examiner looked and pointed at the foil object, and said "Put *this* in the bucket", which was followed by the second foil object. The last two steps were added to have the participant touch the three novel objects during exposure, which made the novel objects equally salient to the participant and accordingly picking out the target object harder during the test phase. When a participant failed to identify the target (e.g., did not respond or chose unlabeled object), the examiner instructed the participant while pointing at the target, "This is a *remope*, put it in the bucket." If the participant still failed to identify the target, the examiner helped put the target in the bucket while labeling the target again by moving the participant's hand toward it and if needed putting it in the bucket. Similarly, when a participant failed any of the two foil objects, the examiner assisted the participant identify the object in the same manner used with the target object. The exposure phase of trial B was administered directly after trial A. Participants proceeded to the two testing phases if they (i) were able to identify all the familiar objects, indicating that they were able to accomplish the task, or (ii) if they had adequate exposure to the novel label (even if they did not identify the novel target independently).

- *Brief-delay test phase.* After about 5 minutes of labeling the target, the examiner placed the five objects of trial A in two rows on a square-shaped tray in front of the participant. The examiner then held the bucket centrally in front of the participant and asked the participant to put the target object in the bucket, "Put the *remope* in the bucket." The position of the target object (left or right) in the testing phase was chosen to be opposite to its position in the exposure phase. For example, if the target object was placed on the right side of the tray during the exposure phase, it was placed on the left side during the testing phase.

Testing of brief-delay for trial A was directly followed by testing for trial B in the same manner. Figure 2.1 displays the two sets of novel objects used in brief-delay test phase; trial A and trial B. Note that identifying the correct object during testing involved extending the label to an object of the same kind that differed in color, providing a stronger test of word learning than simply mapping the label to the original object.

- *Longer-delay test phase.* At the end of the session, approximately 2 hours after presenting the brief-delay phase, the examiner placed the 10 novel objects from the testing phases of brief-delay of both trials-A and-B in two rows in front of the participant. The object locations were varied to ensure that each row contained objects from both trials. All participants were administered this testing phase in the same way even if they needed help to identify the target in one or two of the brief-delay test phase given that they had adequate exposure to the labels. The order of presenting the labels in testing with longer-delay was reversed of that during the exposure phases. That is, the participants who were exposed to the label from trial A (i.e., *remope*) first were asked to identify the label from trial B (i.e., *fental*) first in testing with longer-delay phase and vice versa.

In sum, the longer-delay test phase was designed to be more complex and demanding than the brief-delay phase in multiple ways: 1) the testing took place about 2 hours after exposure to the labels, 2) both of the targets from trial A and B were introduced together, 3) target objects were presented in a reverse order relative exposure order, and 4) the child had to choose the targets from among all 10 novel objects introduced in the brief-delay phase.

For each of trial A and B, the total possible score for testing with brief-delay or longer-delay was 2, with 1 point gained for identifying the target object (i.e., put the target in the bucket) on each of the two trials.

2.2.2.3 Procedural memory. A modified version of the serial reaction time (SRT) task (Nissen & Bullemer, 1987), as adapted by Thomas and Nelson (2001) for 7- and 10-year-old children, was used to assess procedural memory. The primary modification involved testing the learning of a four-item, rather than 10-item *deterministic* visual sequence. This modification was done based on Gordon and Stark's (2007) study showing that such modification enables language-impaired children with ASD learn the sequence. This is important to avoid floor performance in the language-impaired ASD group. Gordon and Stark also included intensive training over six days. This modification was not followed in the current study given that the results of their study showed that language-impaired children with ASD learned the 4-item sequence from the first session and because of time restrictions in the current set of studies.

In the present study, each participant was told that she will play a computer game in where she needs to "catch" a dog as quickly as possible by pressing the button that corresponds to the dog's spatial location on a computer screen. Stimulus presentation and data recordings were controlled by E-Prime 2 software by Psychology Software Tools (PST, 2002). On each experimental trial, an image of a dog was presented in one of four boxes arranged in a horizontal line on a blue background in the middle of the computer screen (Figure 2.2). Participants used a four-button serial response box (PST, 2002) with their dominant hand to respond; reaction time (RT) and accuracy were recorded. Hand dominance was determined at study entry by parent report. Thomas and Nelson's (2001) pilot testing revealed that a significant number of 7-year-olds were unable to coordinate using different fingers on one hand to access each of the four buttons. Therefore, in the current task participants were allowed to use any finger combination of their dominant hand to respond. The serial response box was positioned on the table in front of the participant's dominant hand. Buttons were arranged in the same spatial arrangement (a horizontal line) as the boxes in the visual display (Figure 2.2). Each button measured 1cm x 1 cm, with 7 mm separation between adjacent buttons.

Prior to testing, each participant was trained to map each visual position on the screen to the corresponding response button in two steps: demonstration by the examiner and practice by the participant. During demonstration, a star appeared in one of the four boxes and the examiner showed the participant how to catch it by demonstrating the process on eight trials. When the star was caught, it glowed then disappeared and another star appeared in a different location. If an incorrect response was made, the star remained present until the correct key was pressed. Then the participant was told, "It's your turn now; catch the star as fast as you can." Testing began when the participant successfully caught the star eight consecutive times. This criterion was specified to ensure that all participants received adequate training to complete the testing phase.

Figure 2.2. The stimulus display and the serial response box.

In the testing phase, the examiner instructed the participant: “Now you will see a dog. Catch the dog as fast as you can just like you did with the star. Remember you should be really fast.” Following the procedure of Thomas and Nelson (2001), each participant completed five blocks of 40 trials with short breaks (approximately 2 min) between blocks. Participants initiated each block with a key press, and once the block started no breaks were taken within that block. The location of the dog was randomly determined on blocks 1 and 4. On blocks 2, 3, and 5 however the location of the dog followed a four-item sequence consisting of 10 repetitions following the pattern C, A, B, D, where A represents the left-most position and D represents the right-most position. Neither the boxes on the screen nor the buttons of the serial response box were labeled for participants. On each trial, the dog remained on the screen until the corresponding key was pressed. After the correct key was pressed, the dog disappeared and the next one appeared following a 500-milliseconds delay. The end of one 4-item sequence and beginning of the next was not marked in any manner. Thus, in the absence of knowledge of the sequence, each block would seem to be a continuous series of 40 trials. No feedback was given regarding correct or incorrect responses in the testing phase. In sum, this was a deterministic four-choice task with a total of 200 trials (i.e., 5 blocks, each with 40 trials) where the response-to-stimulus interval was 500 milliseconds.

Upon completing the task, each participant was asked if she had noticed a pattern that helped her “catch the dog” and to replicate it on the button box, providing a measure of explicit knowledge of the sequence. In other words, the participant was asked to press the buttons of the response box to indicate the sequence (C, A, B, D). Explicit knowledge was determined when children showed the sequence correctly. The SRT task lasted for 10–15 minutes.

Performance on the SRT task was analyzed based on two factors: (i) the accuracy of first response, and (ii) a comparison of RT between sequence and random blocks for correct responses only. The key comparison of interest was whether there was a significant decrease between the RT in fourth (final random block) and the fifth block (final sequence block), indicating that the participant had learned the sequence and was anticipating the stimuli position in the fifth block (Thomas & Nelson, 2001). For this comparison, a median RT of correct responses was calculated for each participant over sets of eight trials of block 4 and 5, resulting in five medians for each block. Medians were used because RT distributions were highly skewed - any RTs longer than 10 seconds were excluded from this calculation. The mean of these medians was then calculated for each of the two blocks. Given that differences in motor speed may lead to differences on the SRT task, Thomas and Nelson’s (2001) method to control for baseline RT differences was used. A *sequence learning score* was calculated using a proportional measure of magnitude comparing the difference between the RT means of random and sequence trials to overall RT means for each participant (i.e., [Block 4 - Block 5] ÷ [Block 4 + Block 5]). To ensure that the *sequence learning score* as introduced by Thomas and Nelson reflects sequence learning in a shorter sequence, the performance of the full TD sample ($N = 45$) on the SRT task was evaluated. Results confirmed that comparing block 4 and 5 indicates sequence learning.

2.2.2.4 Declarative memory. The intra- and cross-modality recognition tasks developed by Bushnell and Baxt (1999) were used to assess the declarative memory. Previous studies have commonly used standardized and computerized visual recognition tasks to assess declarative memory. In the current set of studies, I choose to use this intra-modality recognition task given that it involved natural interaction with participants and it required short administration time which provided variation in the types of assessments administered, and it assisted in maintaining children's attention and participation throughout the session. In addition, pilot testing showed that TD children were at ceiling on the intra-modality recognition task. Therefore a more complex form of this task, cross-modality recognition, was also used. Cross-modality recognition involves visual identifying of objects that were explored by hands, without being seen.

a. Intra-modality recognition task: Visual-visual.

Materials.

- *Familiar objects.* Four familiar objects (e.g., cup, plate, bowl, and crayon) were used. Two of the familiar objects (i.e., cup, plate) were identified as the familiar targets and the other two (bowl, crayon) were familiar distracters. In addition, a second identical exemplar of each of the two targets was used.

- *Novel objects.* Twelve novel objects made of clay were used (see Figure 2.3). Six of these objects were identified as novel target objects and the other six were novel distracters. All

12 novel objects were similar in size and some of them were similar in color. In addition, this task included using three gift boxes with lids that were different in color to place the target and distractor objects in during training and testing phases as explained shortly.

Procedure.

- *Training phase-Exposure.* The examiner placed the two boxes next to each other on the table in front of the participant. The examiner said, “We will play a matching game, which box do you want to be yours?” After the participant chose a box, “This is your box and this is my box.” The examiner then held the familiar target item and slowly rotated it to display the full range of its properties for 10 seconds, while saying, “Look at this. You need to remember so that you will know it later when you see it." The participant was not permitted to touch any of the items. Then, the examiner put the familiar target object in the participant’s box and covered it while saying, “I will put it in your box”. The second familiar target item was presented following the same procedure.

- *Training phase- Test.* The examiner held up a familiar distracter, which had not been seen in exposure, and asked “Was this in the box?” This was followed by testing for familiar target, familiar distracter, and then the other familiar target. If the participant indicated a familiar target by saying “yes” or nodding, the examiner gave her feedback “You are right,” and took the other familiar target from the participant’s box while saying, “See, here it is”, placing the object back in the participant’s box saying, “They go in your box.” If the participant indicated that a familiar distracter was not in her box by saying “no” or shaking her head, the examiner provided feedback “Yes, you are right,” and put it in the examiner’s box while saying, “It goes in my box.” If the participant did not correctly identify a familiar target item, the examiner got the other identical target from the participant’s box and told her, “Yes, it was in your box.” If the participant did not identify a distracter item, the examiner corrected her by saying "No, this was not in the box, it goes in my box."

In the case that a participant said "yes" or "no" to all of the four training objects, additional phases of training (i.e., second training and third training) were completed. The second training involved a forced-choice paradigm in which during the test the examiner showed one familiar target and one familiar distracter together and asked, "Which one was in your box?" If the participant failed either of the pairs, the examiner corrected her as before. In the third training, the original training exposure and test phases were carried out once more to ensure that the participant could make the correct choice when she saw only one object at a time. If the participant still answered with "yes" or "no" to all training objects, testing was discontinued and the administration of the cross-modality recognition task started. Each participant had to correctly recognize at least 1 of the 2 familiar target objects at some point in training to proceed to the testing phase.

- *Testing phase- Exposure.* The examiner held the novel target item and slowly rotated it to display the full range of its properties for 10 seconds while saying, "Look at this; you need to remember so that you will know it later when you see it." The participant was not permitted to touch any of the objects. After 10 seconds, the examiner put the target in the participant's box while saying, "It goes in your box." For the next five novel target items, the examiner displayed each for 10 seconds and said, "*Look at this one*" before placing it in the participant's box.


Figure 2.3. Novel object sets used in the testing phase of the intra-modality recognition task. They included six target objects (left picture), which were seen during the exposure phase, and six distractor objects (right picture).

- *Testing phase – Test.* The examiner emptied the six objects from the participant's box into a bigger box located on her lap, which included six novel distracter items not been seen during exposure. Each target or a distracter item was held up and rotated, one-by-one, for the participant to visually inspect, and again she was asked, "Was this in your box?" The items that the participant indicated as targets were put in her box and the ones she identified as a distracter were put in the examiner's box. No feedback on the participant's performance was provided by the examiner during testing.

The total possible score for intra-modality testing was 12, 1 point was gained for correctly identifying a target object as being seen before, and 1 point was gained for identifying distractor as being novel. If a participant said "yes" or "no" to all of the novel objects tested, her data was excluded from the analysis.

b. Cross-modality recognition: Haptic-visual

Materials.

- *Familiar objects.* Four familiar objects were used, of which, two were identified as targets, and the other two were identified as distracters. The target familiar objects were duplicated and were selected to be tactilely prominent, such as a golf ball.

- *Novel objects.* Twelve novel objects created of real-world objects (e.g., kitchen tools) were used. Six of these objects were identified as targets and the other six were distracters. Novel objects in this task were selected to be things participants were not likely to have handled frequently, that probably had little meaning for them, and for which they probably did not have conventional verbal labels (Bushnel & Baxt, 1999). To confirm object novelty, parents were asked if their child had seen them before at the beginning of the session. Alternate novel objects were provided if parents reported their child was familiar with an object. The novel target objects were selected to have special features in terms of shape or texture to help participants learn them with their hands. The novel distracters were selected to have some features similar to those of the targets such as their shape or texture. The novel objects are shown in Figure 2.4.

- *A tactile exploration box and a piece of cloth.* To present objects for haptic exploration without visual access, a box with two holes in the sides was used for the participant to put her hands and forearms into (Figure 2.5). A piece of cloth was draped over their arms to prevent them from seeing inside the box. In addition, there was a hole in the side that faces the examiner to enable her to insert objects and to help the participant hold the object with her two hands inside the box, if needed.

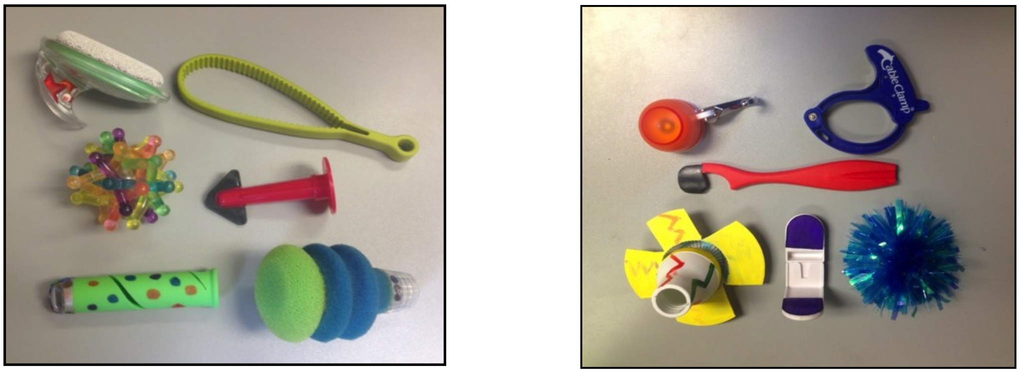


Figure 2.4. Novel object sets used in the testing phase of the cross-modality recognition task. They included six target objects (left picture), which were explored with hands (without being seen) inside a box during the exposure phase, and six distractor objects (right picture)

Figure 2.5. The box used in the cross-modality recognition task. Participants placed their hands inside the box to touch a novel object during the tactile exposure phase. They later had to visually identify the object they touched.

Procedure.

- *Training phase-Exposure.* The examiner placed the box on the table and said, “We will play another matching game.” The examiner asked the participant to put her hands in the side holes. Then the examiner said, “I am going to put something inside the box and then I want you to feel it to get an idea of what it is so you will know it when you see it later," and placed the first familiar target object inside the box, without it being seen by the participant. After the participant had explored the familiar target object for 10 seconds with her two hands, the examiner took the object from the participant’s hands (inside the box). Following the same procedure, the examiner gave the participant the second familiar target object saying, “I will give you another one.”

- *Training phase-Test.* The examiner held a familiar distracter object that had not been touched inside the box, up in front of the participant while asking, “Was this in the box?” This was followed by a familiar target, familiar distracter, and then the other familiar target. If the participant indicated a target correctly by saying, “yes” or nodding, the examiner took the other identical familiar target outside of the box and told the participant, “Yes, you are right, it was in the box.” When the participant indicated a distracter by saying “no” or shaking her head, the examiner assured her correct response “you are right, this was not in the box.” When the participant did not indicate a familiar target, the examiner took the other identical familiar target out of the box and told the participant, “Look, it was in the box, I have two.” If the participant did not indicate a distracter, the examiner corrected her by saying, “No, this was not in the box.” For a participant who said “yes” or “no” to all training objects, the additional training was administered as for the intra-modality recognition task above but in exposure the participant touched the objects instead of seeing them. Each participant had to correctly recognize at least 1 of the 2 familiar target objects at some point in training to proceed to the testing phase.

- *Testing phase.* The test phase also involved exposure followed by the test but no feedback on performance was provided. The examiner informed the participant "Let's do more. Remember, you need to feel each thing in the box and try to learn it with your hands, so that you will know it if you see it later." During exposure, each participant was given a series of six novel target objects one at a time to explore with both hands for 10 seconds inside the box. After that, the examiner intermixed the six novel target objects with six novel distracters that had not been presented during the exposure phase in a box located on her lap. During testing, a target or a distracter object was held up above the box one at a time for the participant to visually inspect, and again the participant was asked to indicate whether each item was one she had felt during exposure or not, "Was this in the box?"

The total possible score for intra-modality testing was 12 in which 1 point was gained for correctly identifying a target object that was previously encountered haptically, and 1 point was gained for identifying distractors as being novel. If a participant said "yes" or "no" to all of the novel objects tested, her data was excluded from the analysis.

The order of presentation of the two recognition tasks, intra- and cross-modality, was counterbalanced across participants.

2.3 Study 1 Results

All results below are reported based on the following procedures. Kolmogorov-Smirnov tests of normality and histograms were inspected for all measures to determine data distribution in order to use appropriate parametric or nonparametric statistical analyses. For normally distributed data, parametric tests were conducted. Specifically, to compare performance between groups, independent *t*-tests were used for continuous variables, and Pearson's $\chi 2$ (chi-square) tests for categorical variables (e.g. scores on the word learning task). However, in cases where more than 20% of the expected frequencies in a chi-square test were less than 5, Fisher's exact tests are reported (Field, 2009). For within-group comparisons, dependent *t*-tests were conducted for continuous variables. The standard error of the mean (*SE*) is reported to indicate the standard deviation of sample means as recommended by Field (2009) for reporting *t-t*est results.

Nonparametric tests were conducted to analyze the data that were not normally distributed. Specifically, for continuous variables, Mann-Whitney *U*-tests and Wilcoxon signed-rank were conducted to compare between groups and within groups, respectively. Median scores were reported in the text as is conventional for non-parametric tests; however, means and standard deviations of variables were provided in tables and figures for ease of interpretation.

Effect size was reported with Pearson's correlation coefficient *r* for all comparisons but when chi-square tests were used, Cramer's *V* value was reported for the effect size (Field, 2009). Values of *r* and Cramer's *V* of .1 are considered small effects, .3 medium effects, and .5 large effects (Field, 2009). An alpha level of .05 was used for all statistical comparisons.

2.3.1 Phonological awareness. The Auditory Analysis Test (Rosner & Simon, 1971) or its validated French version was used to assess phonological awareness. The dependent variable was the total number of correct phoneme/syllable deletions from spoken words. The minimum score on this task is zero, which was obtained if training or the first four words of the list were failed. The maximum possible score on the English version is 40 and on the French version is 42.

Given that the auditory analysis task does not provide normalized scores for either language, *z*-scores were calculated on the raw scores of correct answers within each language group based on the mean and standard deviation of the full sample of the TD participants in the respective language (English speaking $n = 25$, French speaking $n = 20$).

Mann-Whitney *U*- tests were conducted to compare *z*-scores between the groups. The scores of the ASD group (*Mdn* = -.79) were significantly lower than the scores of the TD group (*Mdn* = .10), *U* = 102.5, *z* = -2.04, *p* = .04, *r* = -.34, indicating that the participants in the ASD group made significantly more errors than participants in the TD group on this task. Figure 2.6 represents performance on the phonological awareness task.

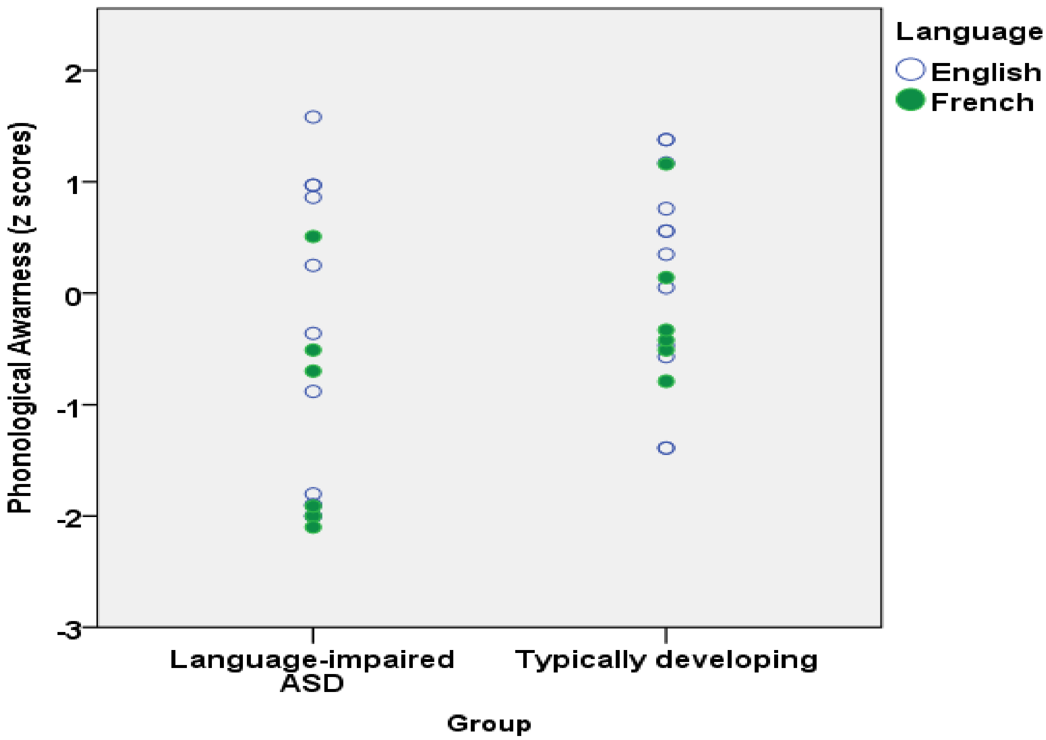


Figure 2.6. Performance on the phonological awareness task by group and language. Phonological awareness was assessed by the Auditory Analysis Test (Rosner & Simon, 1971) in its English (open circles) or French (closed circles) version.

2.3.2 Articulation. Articulation was assessed using the sounds-in-words subtest of the Goldman-Fristoe Test of Articulation; Second Edition (Goldman & Fristoe, 2000) or Test de Dépistage Francophone de Phonologie (Rvachew et al., 2012). The dependent variable was the percent of correct consonants, PCC = (total number of consonant targets + number of correct consonants)/ total number of consonants targets; Shriberg & Kwiatkowski, 1982). One participant in the ASD group was excluded from the analysis because she was minimally verbal with unintelligible speech and could not be tested on this task.

To compare the groups on articulation, the PCC score for each participant was converted into a z score using the mean and standard deviation of the full sample of the TD participants in the respective language (English speaking $n = 25$, French speaking $n = 20$). Results on the Mann-Whitney U- tests showed that the ASD group (*Mdn* = 0) made more errors in articulation of consonants than the TD group (*Mdn* = .24), a marginally significant difference with medium effect size, $U = 96$, z = -1.89, $p = .05$, $r = -.31$.

2.3.3 Receptive Vocabulary. An independent t-test was conducted to compare the standard scores on receptive vocabulary between groups as measured by the Peabody Picture Vocabulary Test, Fourth Edition (Dunn & Dunn, 2007) in its English or French version. Results demonstrated that the standard scores of the participants in the ASD group ($M = 83.22$, $SE = 2.94$, range = 59 - 113) were significantly lower than the standard scores of the participants in the TD group ($M = 111.66$, $SE = 3.72$, range = 86 - 144); $t(34) = -5.99$, $p < .001$, $r = .72$. Figure 2.7 represents performance on the receptive vocabulary task.

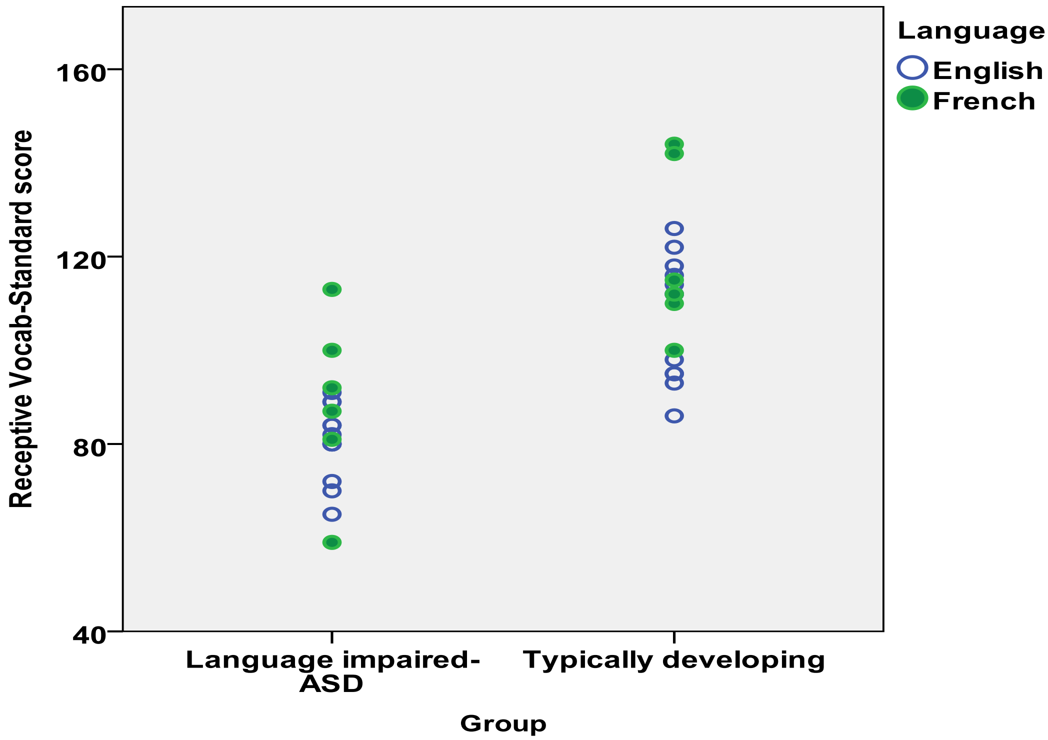


Figure 2.7. Performance on the receptive vocabulary task by group and language. Receptive vocabulary was assessed by the Peabody Picture Vocabulary Test in its English (open circles) or French (closed circles) version. The data points represent the standard score of each participant on this test.

2.3.4 Word learning. The dependent variable in the word-learning task was the number of trials where a participant selected the correct object, with scores ranging from 0 to 2 for each testing phase (i.e., brief- and longer-delay).

The order of presentation of the two labels and stimulus sets, A and B, was counterbalanced among participants. Chi-square tests showed that order had no influence on performance. That is, in the ASD group, similar proportions of participants who received trial A or trial B first showed no learning, 1 word learning, and 2 word learning in the brief- delay phase; p = .10, *Fisher's Exact Test,* as well as the longer-delay phase, p = 1.00, *Fisher's Exact Test*. Similar results were found in the TD group in the brief-delay phase, x^2 (1, N = 18) = .05, p = .83, as well as the longer-delay phase, p = .15, *Fisher's Exact Test*.

a. Brief-delay phase. There was a trend for learning of fewer words by participants with ASD than TD participants. However, a chi-square test revealed that this difference was not statistically significant, p = .12, *Fisher's exact test*, with a medium effect size, Cramer's V = .35. Table 2.3 displays performance on word learning with brief delay.

Table 2.3.

Word Learning Task: Brief Delay Performance: Number of Participants in each Group Who Learned 0, 1, or 2 Words

Number of words learned	Group		Total
	Language–impaired ASD	Typically developing	
0	3	0	3
1	5	3	8
2	10	15	25
Total	18	18	36

b. Longer-delay phase. A chi-square test revealed that fewer participants with ASD were able to learn words in comparison to the TD participants in the longer-delay phase, a marginal significant difference, p = .05, *Fisher's exact test,* with a medium effect size, Cramer's V = .41, indicating that over half of the participants with ASD were unable to learn a novel word under these conditions. Moreover, it is important to point out that fewer participants in both groups were able to identify the two labels and more participants showed no learning of either label, in comparison to the brief-delay phase, demonstrating the higher demands of this phase. Table 2.4 shows performance on word learning with longer delay.

Table 2.4.

Word Learning Task: Longer Delay Performance: Number of Participants in each Group Who Learned 0, 1, or 2 Words

Number of words learned	Group		Total
	Language–impaired ASD	Typically developing	
0	10	4	14
1	4	3	7
2	4	11	15
Total	18	18	36

2.3.5 Procedural memory. This memory system was assessed via the serial reaction time (SRT) task. The key comparisons of interest in this task were 1) whether *sequence learning scores (i.e.,* [Block 4 - Block 5] ÷ [Block 4 + Block 5]) differed between groups and 2) whether the RTs were significantly decreased on the fifth block (final sequence block) relative to the fourth (final random block) block.

Handedness was similar in the ASD group (right handed = 13, left handed = 5) and TD group (right handed = 15, left handed = 3), $\chi 2$ (1, N = 36) = .64, p = .42, Cramer's $V = .13$. Mann-Whitney U-tests showed that although the ASD group (Mdn = 5, range = 0 - 23) made more errors than the TD group (*Mdn* = 2, range = 0 - 10) in blocks 4 and 5, the difference was not significant, $U = 122$, $z = -1.28$, $p = .20$, $r = -.21$, indicating similar ability to perform the SRT task.

The *sequence learning score* in the ASD group *(M* = .09, *SE* = .04) was significantly lower than in the TD group (*M* = .21, *SE* = .02), $t\,(34) = -2.39$, $p = .02$, $r = .38$, demonstrating a larger difference in response to sequence vs. random blocks in the TD group. To further investigate sequence learning within groups, repeated *t*-tests were conducted between responses in block 4 vs. 5 in each group. No significant difference was found between block 5 (*M = 951.85, SE* = 110.62) and block 4 (*M* = 1063.56, *SE* = 86.43) in the ASD group, $t(17) = 1.95$, $p = .07$, $r = .42$, while the TD group showed significantly faster responding in block 5 (*M* = 617.30, *SE* = 32.17) than 4 (*M* = 925.87, *SE* = 28.39), $t(17) = 9.81$, $p < .001$, $r = .92$. Taken together, these results indicated that the ASD group did not learn the sequence while the TD group did. Figure 2.8 represents the mean RT of each group over the five blocks.

After completing the SRT task, participants were asked to show the pattern on the serial response box providing a measure of explicit knowledge of the sequence. A chi-square test revealed that reliably fewer participants with ASD (6 of 18) than TD participants (15 of 18) showed explicit knowledge of the sequence and were able to recreate the sequence they had learned, $\chi2\ (1) = 9.26$, $p < .01$, Cramer's $V = .51$. Furthermore, Mann-Whitney *U*- tests were conducted to assess potential differences in an implicit measure (*sequence learning score*) for participants who showed or did not show explicit knowledge of the sequence by the end of the task. In the ASD group, participants who demonstrated explicit knowledge of the sequence had significantly higher *sequence learning scores* (*Mdn* = .15) than participants who did not (*Mdn* = .02), $U = 11.5$, $z = 2.29$, $p = .02$, $r = .54$. Similarly, in the TD group, participants who demonstrated explicit knowledge of the sequence (*Mdn* = .24) had higher *sequence learning scores* than participants who did not (*Mdn* = .10), a marginally significant difference with medium effect size $U = 6$, $z = 1.96$, $p = .05$, $r = .46$. Figure 2.9 shows the *sequence learning scores* of participants who had explicit knowledge of the sequence as well as the participants who did not in each group. These results are elaborated on in the discussion section.

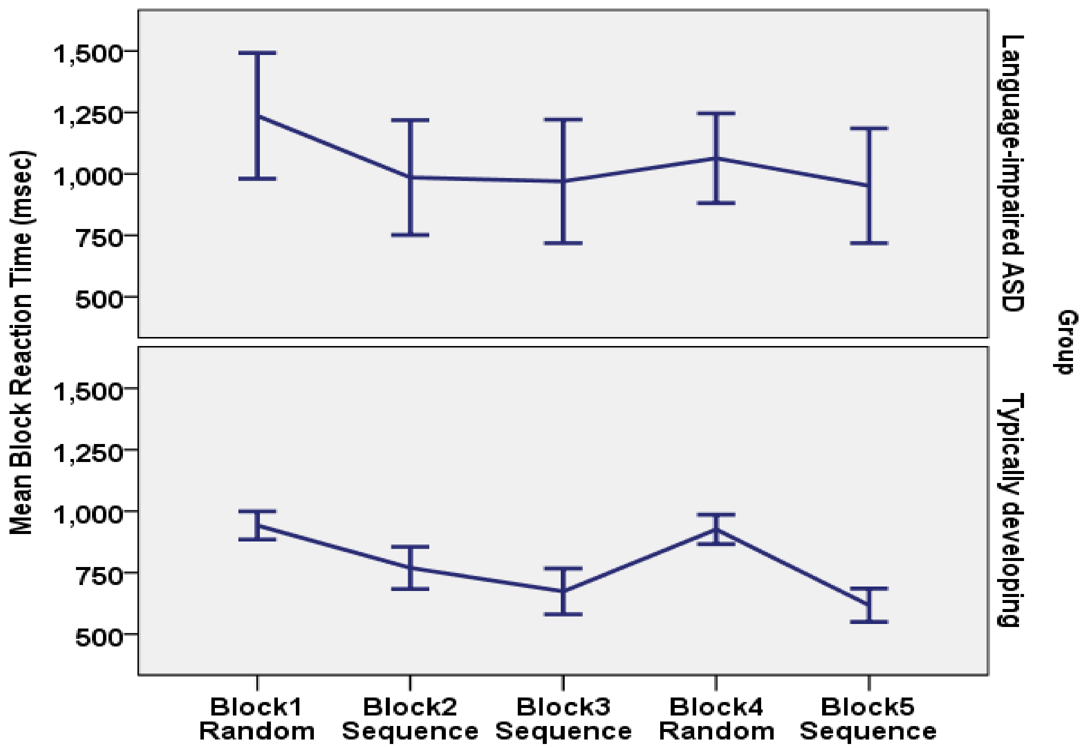


Figure 2.8. Performance of groups on the SRT task. Data points indicate the mean reaction time per block of 40 trials. Error bars represent standard error of the mean. Sequence learning is indicated by significantly faster responses on block 5 (sequence) than block 4 (random).

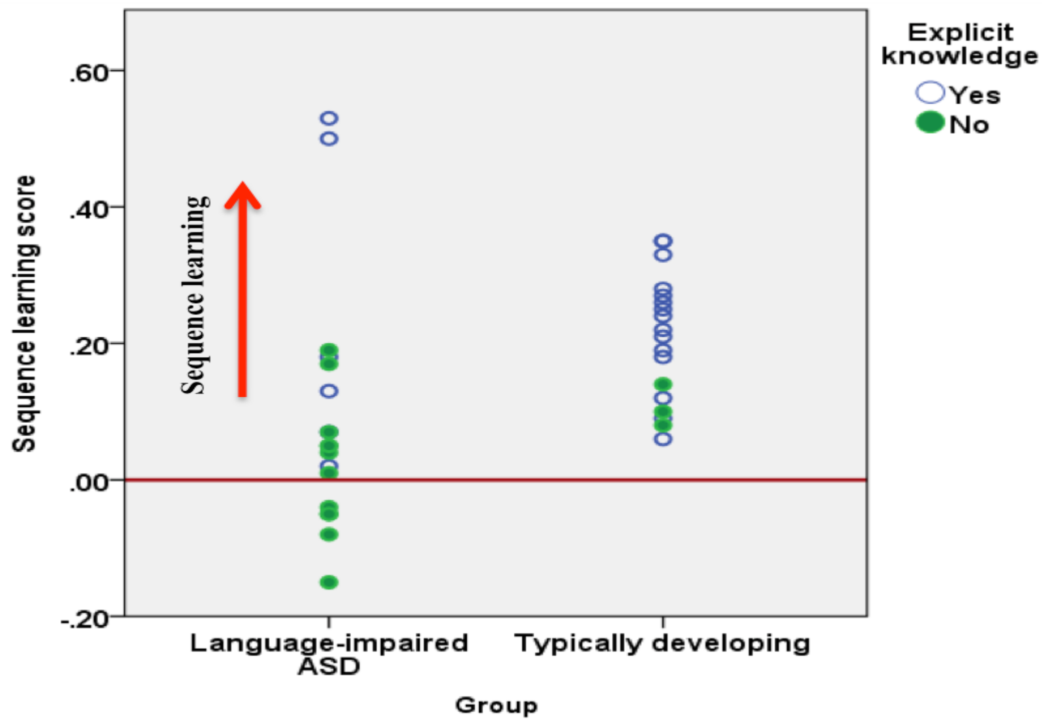


Figure 2.9. Sequence learning scores for language-impaired ASD and TD groups who showed explicit knowledge (open circles) and those who did not (closed circles). Sequence learning scores above 0, indicated by the red line, demonstrate implicit learning of the sequence. Results showed that only participants who showed a high degree of implicit learning also showed explicit knowledge of the sequence at the end of the task.

2.3.6 Declarative memory. Intra-modality and cross-modality recognition tasks were used to assess declarative memory. The order of presentation of the two recognition tasks was counterbalanced across participants. Mann-Whitney *U*- tests were conducted to investigate the effect of task order on performance. In the ASD group, no significant difference in scores was found on intra-modality task, $U = 41.5$, $z = -.21$, $p = -.84$, $r = -.09$, or cross-modality task, $U = 34.5$, $z = -.37$, $p = .72$, $r = -.09$, between participants who received the intra-modality task first and participants who received cross-modality task first. Similarly, in the TD group, scores did not differ by presentation order for the intra-modality, $U = 33.5$, $z = -1.14$, $p = .4$, $r = -.26$ or cross-modality tasks, $U = 33.5$, $z = -.9$, $p = .4$, $r = -.21$.

a. Intra-modality recognition. Participants were required to visually identify at least 3 out of 4 familiar objects in training to proceed to the testing phase of novel objects. Five of eighteen participants in the ASD group required additional training to pass the training criteria because they either said "yes" or "no" to all presented familiar objects. None of the participants in the TD group required additional training. All participants eventually passed the training criteria and completed the testing phase.

The total possible score for intra-modality testing was 12, in which 1 score was gained for identifying a target object as being seen before or a distracter as being novel.

Mann-Whitney *U*-tests were conducted to compare performance between groups. The scores of the ASD group ($Mdn = 9.50$) were significantly lower than the scores of the TD group ($Mdn = 12$), $U = 74$, $z = -3.02$, $p < .01$, $r = -.50$.

b. Cross-modality recognition. Participants were required to visually identify at least 3 out of 4 familiar objects in training to proceed to the testing phase of novel objects. Five participants with ASD out of eighteen required additional training to pass the training criteria because they either said "yes" or "no" to all presented familiar objects in testing. All participants eventually passed the training criteria and completed the testing phase of novel objects. However, one participant with ASD was excluded from the analysis given that she said, "yes" to all testing novel objects indicating a lack of the ability to distinguish between previously encountered and novel objects.

The total possible score for cross-modality testing was 12, in which 1 point was gained for correctly identifying a target object that was previously encountered haptically or identifying distractors as being novel. Results on Mann-Whitney *U*-tests demonstrated that the scores of the ASD group (*Mdn* = 9) were lower than the scores of the TD group (*Mdn* = 11), a marginally significant difference with medium effect size, $U = 94.50$, $z = -1.97$, $p = .05$, $r = -.32$. Figure 2.10 shows the performance of participants in each group on the declarative memory tasks.

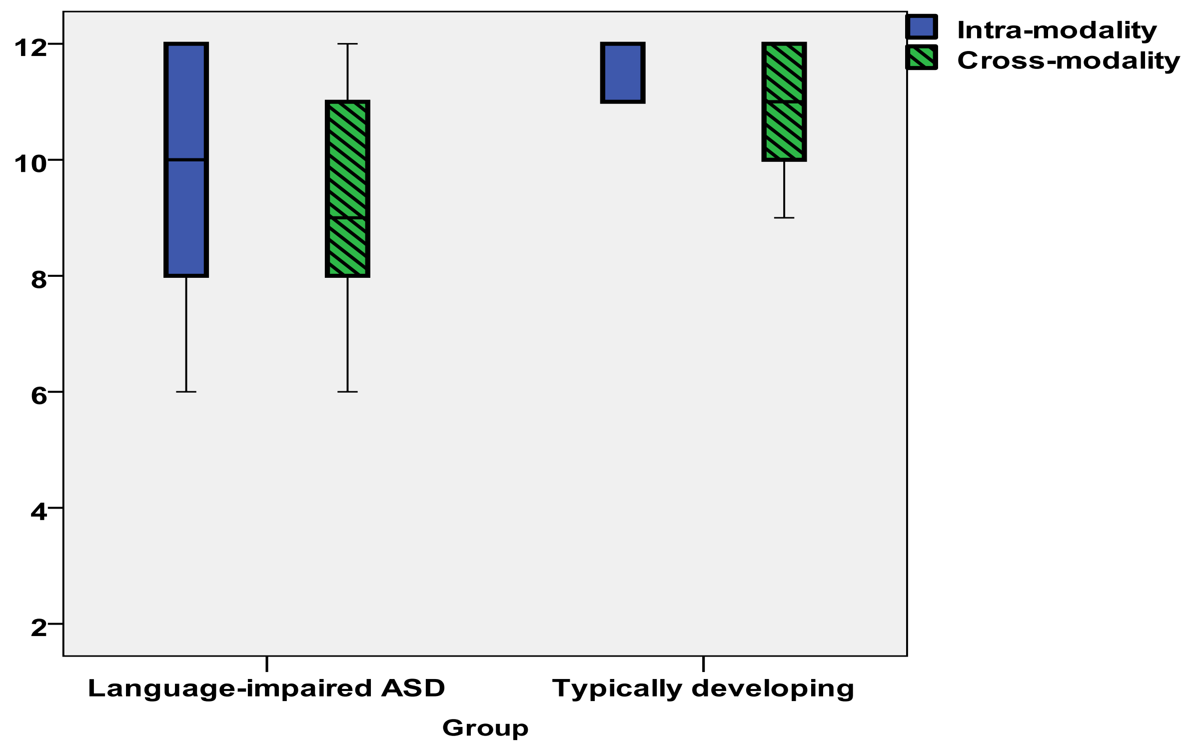


Figure 2.10. Performance of groups on the declarative memory tasks. Clear bars demonstrate performance on the intra-modality recognition task and lined bars show performance on the cross-modality recognition task. Error bars represent the minimum and maximum scores of correctly identified novel objects in each group (score range: 0 - 12).

2.4 Study 1 Discussion

The present study aimed to investigate language and memory profiles in language-impaired children with ASD as compared to TD children. In this study, groups were comparable in terms of their NVIQ scores, age, gender, and their parent's education level. However, all children with ASD were at least 1*SD* below the mean on a recalling sentences subtest while all children in the TD group were within or above the normal range. A language profile was established by two measures of phonology (phonological awareness and articulation) and two measures of vocabulary (receptive vocabulary and word learning). A memory profile was established using tasks that assessed both procedural and declarative memory processing.

2.4.1 Phonological awareness. As expected, the language-impaired ASD group had significantly poorer phonological awareness than the TD group as measured on a task that required phoneme or syllable deletion from spoken words. This finding is aligned with previous studies that also showed that children with ASD and mixed language abilities had poor phonological awareness on different tasks (Heimann et al., 1995; Tjus et al., 1998) including ones that require phoneme deletion from spoken words (Gabig, 2010; Newman et al., 2007).

It is important to note that the phoneme or syllable deletion tasks, such as the one used in the current study, are relatively difficult given that the child needs to remember the word, isolate the sound, and then rearrange the sounds of the word into a new word with or without meaning. In this vein, Gabig (2010) found that isolating and manipulating the phonemes within words during a phoneme deletion task was significantly difficult for children with autism. Similarly, McGee (2006) showed that although some children with ASD performed poorly on difficult phonological tasks such as phoneme deletion, they were successful on elementary phonological awareness tasks such as word initial sound identification, which were not tested here.

2.4.2 Articulation. The language-impaired ASD group had poorer articulation abilities than the TD group as indicated by significantly more errors in producing consonants in single words. This finding is in agreement with recent studies that reported poor articulation in some language-impaired children with ASD (Masterson & Bernhardt, 2001; Rapin, 2007; Rapin & Dunn, 2003; Rapin et al., 2009). However, it has been suggested that difficulties in phonology including articulation disappear with age in children with ASD (Boucher, 2012; Tager-Flusberg et al., 2005). The current finding of poor articulation abilities in school-age children with ASD was also reported in a study by Rapin et al. (2009) who reported the persistence of articulation deficits at school age in a substantial minority of children with autism.

Age appropriate articulation in children with ASD and mixed language abilities was reported in Kjelgaard and Tager-Flusberg's (2001) study. This disparity in findings might be explained by sampling difference and the fact that Kjelgaard and Tager-Flusberg made comparisons with test norms rather than a TD comparison group. In addition, Kjelgaard and Tager-Flusberg found that the average of scores in all ASD subgroups was within the normal range, yet they reported significantly lower scores in the language-impaired group. Thus, the authors' conclusion of intact articulation in children with ASD appears to be based on children with higher language abilities than those tested in the current study.

2.4.3 Receptive vocabulary. The language-impaired ASD group had poorer receptive vocabulary than the TD group as indicated by their significantly lower standard scores on the Peabody Picture Vocabulary Test. The scores of TD children were within or 1 to 3 *SD* above the normal range on this test. The scores of children with ASD were within the normal range or 1 to 2 *SD* below the normal range: seven children were within the normal range, nine were 1 *SD* below the mean, and two were 2 *SD* below the mean. Such variability in receptive vocabulary scores in language-impaired children with ASD was also reported in studies that investigated the language profiles of children with ASD who had mixed language abilities (Kjelgaard & Tager-Flusberg, 2001) or had evident language delay (Rapin & Dunn, 2003; Rapin et al., 2009) using the same measure. However, the previous studies did not directly compare the ASD group to a TD group as the current study did. Such an addition is important because it provides a more stringent comparison since participants were matched on NVIQ and were similar in age.

2.4.4 Word learning. Word learning was tested with a brief-delay where a child was asked to identify a labeled object in different color shortly after seeing an examiner labels one of three novel objects. It was also assessed at a longer delay after about 2 hours of exposure to the label when the identification task was made more complex. Results indicated that the language-impaired ASD group was as successful as the TD group in learning the novel labels in the brief-delay condition. In contrast, the ASD group was significantly less successful than the TD group in retaining the learned labels in the longer delay phase.

Previous research on the use of social cues for word mapping provided evidence on the ability of young children with ASD and severe-language impairment to map a novel label to a novel object when the object they were interested in was the labeled object, but not when the labeled object was not of the child's interest (Baron-Cohen et al., 1997; Parish-Morris et al., 2007; Preissler & Carey, 2005). However, in line with the current finding in the brief-delay phase, more recent studies showed that similar to younger TD children closely matched on language, children with ASD can map novel words by following the speakers' social cues whether the labeled object was of their interest or not (Bani Hani et al., 2013; McDuffie et al., 2006; Parish-Morris et al., 2007). These findings were reported when enhanced contextual supports are presented, including additional repetitions of the novel word and multiple nonverbal social cues. The current study did not target social cues per se, however, adequate social cues were provided to children in a semi-natural manner, which may have facilitated learning of words in children with ASD.

Although the ASD group was similar to the TD group in their ability to learn novel words in the brief delay phase, there was a trend in the ASD group toward learning fewer words than the TD group. The study of Hartley and Allen (2014) could touch directly on the reason of this trend in the ASD group. They showed that language-impaired children with ASD understand that words paired with color photographs relate to independently existing referents. However, unlike their TD peers, they often generalize based on color not shape (Hartley & Allen, 2014). If children use the color of the object to map and generalize the new words, then asking the child in the current study to identify the real object in a different color could have complicated the task for some children in the ASD group.

Finally, the current findings of enhanced word learning ability in the ASD group in the brief-delay phase, while poor ability in the longer delay could be explained by difficulties in the longer-term integration of new and existing lexical knowledge. These speculations draw on the findings of Henderson et al. (2014) who examined whether individual differences in vocabulary knowledge in ASD might be partly explained by a difficulty consolidating newly learned spoken words or integrating them with existing knowledge. Their findings suggested that word learning in ASD is characterized by both skill and deficit; specifically, enhanced sensitivity to phonological competitors early in the time course of word learning but impairments in the longer-term integration of new and existing lexical knowledge. The current study did not evaluate phonological competition effects on word learning; therefore, these speculations require further investigation.

2.4.5 Procedural memory. Although the ASD group showed a comparable ability to respond to the SRT task to the TD group, the group of ASD group did not learn the sequence while the TD group did. The current finding of poor sequence learning in the ASD group is against my predictions. However, this finding corroborates the findings of the only previous study by Gordon and Stark (2007) that tested procedural learning using SRT task in language-impaired children with ASD. Gordon and Stark suggested that children with ASD can learn a sequence with increased behavioral training (i.e., exposure to the sequence) and decreased memory load (i.e., shorter sequences of 4- and 8- items). Similar to Gordon and Stark's paradigm, the current SRT task used 4-item sequence, however, the exposure to the sequence (sequence repeated 30 times) was not as intensive as in Gordon and Stark's study in which the sequence was consecutively repeated 72 times over six sessions only for the ASD children. Together, these findings highlight the importance of the intensive exposure to the sequence, even in a short sequence of 4-items, in successful sequence learning of language-impaired children with ASD.

It has been demonstrated that procedures involving slowly repeating "deterministic sequences", such as the one used in the current study and in Gordon and Stark's (2007) study, are more likely to encourage the development and use of explicit strategies to solve the task (Destrebecqz & Cleeremans, 2001, 2003; Norman et al., 2007). Gordon and Stark did not test explicit knowledge in their participants, preventing any conclusions in this area. In the current study, immediately after the SRT task, children were told about the sequence and were asked to reproduce the sequence on the response box. Considerably fewer children in the ASD group (only 6 out of 18) showed explicit knowledge of the sequence than in the TD group (15 out of 18). Results showed that in both ASD and TD groups, the group of children who demonstrated explicit knowledge showed larger differences in responses on sequence vs. random blocks than the group that had no explicit knowledge of the pattern. A similar finding was reported by Thomas and Nelson (2001) for TD children learning a 10–item sequence. Together, these findings suggest that children who developed explicit knowledge of the underlying sequence in SRT tasks usually show additional reaction-time improvement than children who did not develop explicit knowledge.

In the current study, all TD children showed sequence learning (as indicated by their above zero scores) regardless of the presence of explicit knowledge. On the other hand, in the ASD group, most of the children who did not have explicit knowledge did not learn the sequence (as indicated by their below zero sequence learning scores) while the children who had explicit knowledge of the sequence showed the highest sequence learning scores. These findings could suggest adequate sequence learning in some children with ASD, which was developed into explicit knowledge with training; helping children become faster in their responses in the sequence blocks.

In summary, these results indicated that as a group, language-impaired children with ASD show poor procedural learning of a simple sequence in comparison to age- and NVIQ-matched TD group. However, some children in the language-impaired ASD group can learn the sequence, especially those who showed explicit knowledge of the sequence.

2.4.6 Declarative memory. Declarative memory was measured on two tasks that require visual recognition of previously seen (intra-modality recognition) or explored by hands (cross-modality recognition) novel objects. Results indicated poor visual recognition in the ASD group on the intra-modality and cross-modality recognition tasks. The current finding on the intra-modality corroborate previous findings showing difficulties in visual recognition in language-impaired ASD group using different visual recognition tasks (Boucher, Bigham, et al., 2008).

The current results are at odds with those that found intact visual-to-visual recognition of familiar and unfamiliar objects (Boucher & Lewis, 1992; Dawson et al., 2001; Hauck et al., 1998). However, this conflict could be explained by methodological differences that might have facilitated recognition in the above metntioned studies. For instance, in Dawson's et al. (2001) study that showed intact recognition in language-impaired children with ASD, the children were given each object to explore before testing which might have enhanced the children's ability to identify the object and pay more attention to its features. In this area, it has been shown that recognition, although impaired in language-impaired ASD groups, was better for stimuli the child had handled than for those handled or named only by the experimenter (Lind & Bowler, 2008; Summers & Craik, 1994). In addition, Dawson et al., tested participants using a forced choice task in which the target object was paired with a distractor, whereas in the current study targets and distractors were mixed and shown one-by-one, making the recognition task more difficult. Prior work appealed to lower intellectual abilities to explain difficulties in visual recognition (Barth et al., 1995; Dawson et al., 1998), the current study found poor recognition in the ASD group even when NVIQ was within the normal range and similar between groups.

The current study also showed that the ASD group had difficulties in visual recognition of objects explored by hands (haptic-visual modality). Haptic-to-visual recognition was investigated in few studies that tested language-normal individuals with ASD. Results demonstrated normal or even superior haptic recognition ability in this group (Nakano, Kato, & Kitazawa, 2012). Accordingly, the current study provides a pioneer investigation of haptic-to-visual recognition in language-impaired children with ASD.

It may be argued that the difficulty in the cross-modality task was not due to impairments in integrating information about the features of the explored by hands object, but due to deficits in the perception of the object features before integration such as tactile hypersensitivity that might cause some difficulty in processing the tactile information (Nakano et al., 2012). It has been indicated that 69% of individuals with ASD show sensory-perceptual anomalies including hypo-or hypersensitivity in both social and non-social contexts (Baranek, David, Poe, Stone, & Watson, 2006). However, experimental studies of tactile perception in ASD are scarce. So far, findings suggest normal tactile perception (O'Riordan & Passetti, 2006) along with certain areas of enhanced perception in language-normal individuals with ASD (Blakemore et al., 2006; Cascio et al., 2008). Studies that included a group of individuals with ASD and mixed language abilities indicated that children with ASD have sensory processing deficits in a variety of areas that are related to tactile sensitivity (Tomchek & Dunn, 2007; Wiggins, Robins, Bakeman, & Adamson, 2009). In the current study, this aspect was not tested and generalization from the normal-language ASD group to language-impaired ASD group is not possible.

In conclusion, the current study showed that the language-impaired ASD group and the TD group significantly differed on most of language and memory measures despite group matching for age and NVIQ. Regarding language, the ASD group had significantly lower scores than the TD group on phonological awareness as measured by a phoneme or syllable deletion task and on a single word picture naming measure of consonant articulation skills. Furthermore, the ASD group had significantly lower scores than the TD group on receptive vocabulary and on a word-learning task that required identifying a labeled object in different color with a long delay. Groups were similar only on the word learning task with brief delay. Turning to memory, groups showed different performance on the procedural memory task that required learning a deterministic 4-item sequence: the ASD group did not learn the sequence while the TD group did. As for declarative memory, the ASD group was not as successful as the TD group in their ability to visually recognize previously seen or explored-by-hands novel objects.

The current findings on language and memory do not support the two hypotheses that explain language impairment in ASD by deficits in either procedural or declarative memory. One hypothesis (Klinger et al., 2007; Ullman, 2004; Walenski et al., 2006) claims that ASD is associated with difficulties in procedural memory, especially of sequences, but not of declarative memory. Based on this hypothesis, the language profile in ASD includes difficulties in phonology and grammar, but not in knowledge of words and concepts. In another hypothesis, Boucher, Mayes, and Bigham (2008) claims that diminished declarative memory and intact procedural memory in the verbal language-impaired children with ASD can explain the language profile in this group: diminished lexicon while phonology and grammar are relatively intact. The current study revealed that children with ASD had significantly lower scores on all phonology and vocabulary measures than the TD group, and they showed difficulties in both procedural and declarative memory. In Study 3, the hypothesized role of procedural and declarative memory in language impairment in children with ASD is investigated.

Chapter 3 : Study 2 - Language and Memory in SLI

3.1 Introduction

Language is one of the major milestones that most children acquire rapidly and effortlessly in early childhood. However, children with specific language impairment (SLI) are exceptions to this and exhibit a significant deficit in language ability that cannot be attributed to hearing, intellectual, or neurological difficulties (APA, 2013). Generally speaking, two broad competing theories have been proposed to explain the core impairment in SLI. The first approach focuses on the linguistic aspect of SLI, in particular on specific grammatical structures that might be affected (Ullman & Gopnik, 1999). The second, more recent approach explains the difficulties in SLI as cognitive and perceptual processing limitations that impact language learning (for a review see Leonard & Weber-Fox, 2012). Proposed processing limitations include slower temporal processing of verbal information (Tallal et al., 1996), slower general speed of processing (Archibald & Gathercole, 2007; Miller et al., 2001), limited verbal or phonological working memory capacity (Gathercole & Baddeley, 1990; Weismer, Evans, & Hesketh, 1999), or deficits in procedural memory that could be compensated for by intact declarative memory (Ullman & Pierpont, 2005).

The current study investigated the language profile (i.e., phonology and vocabulary) in children with SLI as well as the status of cognitive mechanisms: procedural and declarative memory. These memory systems are thought to play a major role in typical language development (Gupta, 2012; Kidd, 2012; Kidd & Kirjavainen, 2011; Ullman, 2004) and have been hypothesized to explain structural language deficits in SLI (Mainela-Arnold & Evans, 2014; Ullman & Pierpont, 2005). In the following sections, the literature on language characteristics and procedural and declarative memory systems in SLI is discussed. Although a considerable number of studies on language in children with SLI have focused on morpho-syntax and grammar (e.g., Goffman & Leonard, 2000; Leonard, 2014; Rice, 2004b; Sengottuvel & Rao, 2013), the review in the following section is limited to phonological awareness, articulation, receptive vocabulary, and word learning as they were the aspects of language assessed in the current study.

3.1.1 Language characteristics in SLI.

Language difficulties that children with SLI experience often affect some or all of the areas of language including phonology, semantics, morphology, and syntax. Although children with SLI show heterogeneous language profiles that vary in the aspects and severity of language affected (Conti-Ramsden et al., 1997; Friedmann & Novogrodsky, 2008; Rapin & Allen, 1987), some common patterns have been revealed. This section reports the profile of children with SLI with an emphasis on phonological awareness, articulation, receptive vocabulary, and word learning which represent the aspects of language assessed in the current study.

Phonology. Among the areas of language adversely affected in many children with SLI is phonology (Bortolini & Leonard, 2000). For example, in studies aimed at identifying subgroups of children with SLI, children with marked phonological difficulties emerge as the largest subgroup, approximately 34% of the sample (Conti-Ramsden et al., 1997; Friedmann & Novogrodsky, 2008). Phonological difficulties in SLI include difficulties in phonological awareness (Claessen & Leitão, 2012; McArthur & Castles, 2013) and articulation (Conti-Ramsden et al., 1997).

3.1.1.1 *Phonological awareness.* A significant delay in phonological awareness has often been reported in children with SLI in comparison to their TD peers (Kamhi, Lee, & Nelson, 1985; Warrick, Rubin, & Rowe-Walsh, 1993; Zens, Gillon, & Moran, 2009) even with the absence of expressive phonological deficits (Leitato, Hogben, & Fletcher, 1997). Longitudinal studies in SLI showed that early phonological awareness deficits are present in kindergarten and up to second grade in both children with SLI who do and do not go on to demonstrate reading difficulties (Bishop, McDonald, Bird, & Hayiou-Thomas, 2009; Catts, Adlof, Hogan, & Weismer, 2005; Catts, Fey, Tomblin, & Zhang, 2002). However phonological awareness difficulties become milder or diminish over time, as found in grade 4 (Bishop et al., 2009; Catts et al., 2002) and grade 9 (Catts et al., 2005), especially in children who develop normal reading (Bishop et al., 2009; Catts et al., 2002) and literacy skills (Vandewalle, Boets, Ghesquière, & Zink, 2012). Finally, it has been suggested that phonological awareness deficits are more apparent in children with SLI when they are tested on higher-order linguistic, more demanding, or less familiar tasks (Vandewalle et al., 2012).

3.1.1.2 ***Articulation.*** There is considerable evidence showing that children with SLI make more articulation errors than their age-matched TD peers (Bortolini & Leonard, 2000; Fee, 1995; Maillart & Parisse, 2006; Parisse & Maillart, 2007; Plante, Bahl, Vance, & Gerken, 2011). In addition, children with SLI are less consistent than younger TD preschoolers in using the consonants in their inventory (Bortolini & Leonard, 2000; Leonard, Sabbadini, Leonard, & Volterra, 1987). Furthermore, some unusual processes were detected in the speech of children with SLI including omissions of word-initial stops, consonants added to initial position, and frequent vowel errors (Aguilar-Mediavilla, Sanz-Torrent, & Serra-Raventós, 2002; Beers, 1995; Kunnari, Saaristo-Helin, & Savinainen-Makkonen, 2012). A comorbidity study of children with SLI and children with speech delay (characterized by age-inappropriate speech sound deletions and substitutions, typically affecting speech intelligibility) in the USA revealed that at 6 years of age, approximately 11–15% of children with persisting speech delay had SLI and approximately

5–8% of children with persisting SLI had speech delay (Shriberg, Tomblin, & McSweeny, 1999).

Although impairment in articulation has been repeatedly documented, it is not evident in all children with SLI. For example, Conti-Ramsden et al. (1997) reported that 21.5% of 7- year-old children with SLI (*N* = 242) showed very good performance (79th percentile) on a standardized articulation test that requires naming pictures. Similarly, Friedmann and Novogrodsky (2008) described reported that 62% of school-age children with SLI (*N* = 36) did not show phonological deficits as measured on articulation and phonological awareness.

3.1.1.3 ***Receptive vocabulary***. Previous research has shown that children with SLI perform below age-matched TD children, but similarly to younger children, on receptive and expressive vocabulary measures, indicating a delayed lexical system (e.g., Buschmann et al., 2008; Leonard, 1998; McGregor, Oleson, Bahnsen, & Duff, 2013; Paul, 1996; Rice Warren, & Betz, 2005). Delays in receptive vocabulary were reported in children with SLI in the acquisition of their first words (Trauner, Wulfeck, Tallal, & Hesselink, 2000) and during early school years up to the age of 8 years with their receptive vocabulary growth being 2 years behind expected levels (Rice, 2004a). Limited semantic knowledge was reported in children with SLI as indicated by semantic naming errors (e.g., foot for shoe) on word definition and drawing tasks (McGregor et al., 2002).

With age, when children begin to produce multiword utterances, limitations in vocabulary in children with SLI include reduced vocabulary diversity, difficulties in extending new words to a variety of exemplars (Goffman & Leonard, 2000; Rice & Bode, 1993; Watkins, Rice, & Molz, 1993), and shallower knowledge of word definitions that are in their vocabularies compared to their TD peers (Mainela-Arnold et al., 2010; McGregor et al., 2013).

3.1.1.4 ***Word learning.*** There is considerable evidence of poor word learning in children with SLI as compared with age-matched TD children on both receptive and expressive tasks (Alt & Plante, 2006; Alt, Plante, & Creusere, 2004; Rice, 2004a; Rice & Bode, 1993; Rice, Cleave, & Oetting, 2000; Zens et al., 2009). However, some studies revealed that children with SLI show adequate word learning ability on the comprehension level (Eyer et al., 2002; Schwartz, Leonard, Messick, & Chapman, 1987), but not on the production level (Dollaghan, 1987; Gray, 2003; Kiernan & Gray, 1998). They often require more exposure to words to reach learning criteria (Rice et al., 2000; Rice, Oetting, Marquis, & Bode, 1994; Weismer & Hesketh, 1998).

A recent meta-analysis by Kan and Windsor (2010) investigated 28 word-learning studies of children with SLI and provided possible explanations of the variable findings. Kan and Windsor indicated that group differences were larger when: 1) the children were younger; under 6 years of age (Gray, 2003) vs. 6 years of age and older (Gray, 2006), 2) the SLI group had lower NVIQ score, although participants had normal NVIQ ability (Alt & Plante, 2006; Beverly & Estis, 2003), and 3) a sizable difference between groups in their receptive language score was present (Horohov & Oetting, 2004). However, group differences were evident even when groups had comparable NVIQ (Weismer & Hesketh, 1998), or smaller difference in receptive language (Gray, 2004). In addition, a fewer number of labels, direct instructions, and less demanding tasks were involved when comparable performance was found between children with SLI and their TD peers, suggesting that decreased processing demands allow children with SLI to perform similarly to their TD peers. Specifically, studies that reported similar performance in groups required children to fast-map three or four words in a direct labeling interactive setting (Dollaghan, 1987; Gray, 2003). In contrast, in the studies in which group differences were found, more labels were included in more demanding tasks. For example, Rice et al. (1994) required children to fast-map 20 novel words representing four different syntactic categories in a quick incidental-learning paradigm that involved introducing the labels through a story narration in a storybook or video without explicitly referring to the target words.

In conclusion, previous studies showed that language impairment in children with SLI is demonstrated in poor phonological awareness abilities (e.g., Bishop et al., 2009; Catts et al., 2005), which are more apparent in higher-order linguistic, more demanding, or less familiar tasks (Vandewalle et al., 2012), difficulties in articulation (Conti-Ramsden et al., 1997; Friedmann & Novogrodsky, 2008), and delayed receptive vocabulary (e.g., Buschmann et al., 2008; McGregor et al., 2013). Turning to word learning, multiple factors may facilitate word learning in children with SLI including few number of labels and direct instructions (Kan & Windsor, 2010).

3.1.2 Procedural memory.

A growing body of research has investigated procedural learning and memory for both visual and verbal information in SLI. For the purpose of the present study, the focus is on studies that investigated visual information using the serial reaction time (SRT) task. For simplicity, below we refer to procedural memory for visual information as visual procedural memory and that for verbal information as verbal procedural memory.

3.1.2.1 *Visual procedural memory*. In SRT tasks (Nissen & Bullemer, 1987), participants are asked to press a button corresponding to a spatial location of a visual stimulus on a computer screen as quickly as possible. Unknown to participants, this task included two types of blocks: “random blocks” of trials in which the spatial location occurs in a random order or “sequence blocks” of trials in which the order is either deterministic (i.e., a set pattern is established and repeated for a number of trials, e.g., 1-2-3-4-1-2-3-4), or probabilistic (i.e., a pattern is likely but not certain to appear because deviations in stimulus order are permitted during sequenced blocks). Another modification of the SRT task is the presentation of alternating predictable and random stimuli throughout the task, e.g., 1-r-2-r-4-r-3 (where the numbers correspond to locations on the screen and r stands for random locations among the determined positions). Regardless of the specific procedure, decreased response time during predictable trials relative to random trials are taken as evidence of learning as the participants learn to anticipate where the next stimulus will appear.

Research investigating procedural memory in individuals with SLI using SRT tasks has produced varied results that were related to different factors including the difficulty of the task. Some studies showed poor initial procedural learning in children with SLI in comparison to their age-matched TD peers as indicated by the SLI group slower responses (Mayor-Dubois, Zesiger, Van der Linden, & Roulet-Perez, 2012; Tomblin, Mainela-Arnold, & Zhang, 2007) or smaller difference in responses between random and sequence blocks of 10-item-determined SRT task (Hsu & Bishop, 2014; Lum, Conti-Ramsden, Page, & Ullman, 2012; Lum, Gelgic, & Conti-Ramsden, 2010).

In a recent study, Mayor-Dubois et al. (2012) showed that despite longer reaction times in a SLI group (age range: 8-14 years), the group learned 10-item alternating sequence as displayed by significant learning effect for the repeated versus random sequences. However, more fine-grained analysis revealed that some children (8 out of 18) in the SLI group did not show significant learning effects and they all had an associated Developmental Coordination Disorder. The other children, who were able to learn, showed slower and less efficient motor learning compared to the TD group. These findings suggest that poor sequence learning may be linked to motor coordination difficulties rather than SLI per se. However, poor sequence learning in SLI has also been reported in studies that controlled for group differences in motor speed (Lum et al., 2010; Sengottuvel & Rao, 2013), visual working memory (Lum et al., 2012), or visuo-motor attention (Sengottuvel & Rao, 2013).

Other studies reported a similar pattern of sequence learning in children with SLI as compared to age-matched TD children on SRT tasks involving deterministic 10-item sequence (Lum & Bleses, 2012), deterministic- (Gabriel, Meulemans, Parisse, & Maillart , 2015), or probabilistic- 8-item sequence (Gabriel, Maillart, Guillaume, Stefaniak, & Meulemans, 2011). However, the SLI children made more errors than the TD children (Gabriel et al., 2015; Lum and Bleses; 2012). The studies by Gabriel and colleagues (Gabriel et al., 2011; Gabriel et al., 2015) provided extensive exposure to the 8-item sequence, specifically 6-consecutive blocks of deterministic sequence (Gabriel et al., 2015) or 12-consecutive blocks of probabilistic sequence (Gabriel et al., 2011) followed by a pseudo-random block. In another study, Gabriel et al. (2013) showed that the task complexity could explain the differences in findings between studies that investigated sequence learning on SRT tasks. That is, they examined the performance of 7- to 11-year-old children with SLI and age-matched TD children on a probabilistic 12-item visual sequence, which was longer and more complex than those used in previous studies. The SRT task included six sequence blocks followed by a transitional block that consisted of a different pattern. Results showed poorer procedural memory in SLI, as evidenced by both longer reaction times and no sign of sequence-specific learning in comparison to the TD children.

Together, these findings suggest that children with SLI show poor procedural memory for challenging sequences characterized by long and complex statistical structures, such as with a 12-item probabilistic sequence in which the transitions within the sequence were harder to reveal (Gabriel et al., 2013). However, they are able to learn simpler sequences (8-item-deterministic or-probabilistic) with intensive exposure to the sequence (Gabriel et al., 2011; Gabriel et al., 2015).

Hsu and Bishop (2014) tested 7- to 11-year-old children with SLI on three procedural memory tasks. They used an SRT task (10-item deterministic sequence), pursuit rotor task (motor procedural learning task that did not involve learning sequential relationships between discrete elements), and the Hebb effect task (involved implicit learning of word sequences in a verbal memory task). Results showed poor performance on the SRT task and the Hebb effect task in the children with SLI in comparison to their TD peers. However, children with SLI performed comparably with their TD peers on the pursuit rotor task. These findings suggest that SLI might be characterized by deficits in learning sequence-specific information, rather than generally weak procedural learning.

Finally, Lum, Conti-Ramsden, Morgan, and Ullman (2014) used meta-analysis and meta-regression to investigate and evaluate available evidence regarding procedural learning abilities in SLI, as indexed by SRT task performance. They examined eight studies that collectively examined 186 participants with SLI and 203 TD peers between the ages of 7- and 15-years. Overall, the results indicated a significant difference between participants with and without SLI on the SRT tasks. Specifically, the average mean effect size was .33, 95% *CI* [.07, .58], and was significant, suggesting that the difference in RTs between sequenced and random blocks is around .33 *SD* larger in TD participants than in participants with SLI. These results suggest poor procedural learning in children with SLI. In addition, they investigated the sources of heterogeneity among study findings. Both the age of participants and the number of exposures to the sequence were found to predict variability across the studies (i.e., study effect sizes). That is, older participants and increased exposure to the sequence were significant predictors of small effect sizes, indicating smaller difference between groups. Moreover, group differences between children with SLI and their age-matched TD peers was larger when the SLI group had lower NVIQ scores (Alt & Plante, 2006) and when there was a sizable difference between groups in their receptive language score (Horohov & Oetting, 2004). However, group differences were evident even when groups had comparable NVIQ (Weismer & Hesketh, 1998), or smaller difference in receptive language (Gray, 2004).

3.1.2.2 ***Verbal procedural memory.*** Poor sequence learning in individuals with SLI has also been demonstrated in studies on implicitly learned verbal information. In two studies (Evans et al., 2009; Mayor-Dubois et al., 2012) children with SLI and age-matched TD peers listened to a continuous stream of artificial language (i.e., nonwords) or tones. The stimuli were constructed so that the adjacent probabilities between specific phonemes/tones within nonwords/phrases are higher than those between nonwords/phrases. During exposure, stimuli were presented while the children were engaged in another activity, to ensure that children were not actively attending to the verbal information and that any learning that took place was implicit. At test, knowledge of the artificial language or tones was assessed using a recognition task in which participants were told about the rules and then are instructed that they will be introduced with new strings and will have to decide whether or not strings confirm the rule. The results from the two studies (i.e., Evans et al., 2009; Mayor-Dubois et al., 2012) showed significantly poorer recognition of implicitly learned verbal information in children with SLI than TD children. However, Evans et al. (2009) also found that children with SLI did learn embedded regularities in the artificial language with longer exposure to the stimuli. That is, children with SLI showed statistical learning after 48 minutes, but not 24 minutes, of exposure to artificial language and tones, while children in the TD group showed statistical learning after both exposures. Similar to the findings for visual sequence learning (Lum et al., 2014), these results suggest that implicit learning occurs in SLI, but these individuals require increased exposure to the target information.

In conclusion, previous studies suggest poor visual (Hsu & Bishop, 2014; Lum et al., 2012; Lum et al., 2010; Tomblin et al., 2007) and verbal procedural memory (Evans et al., 2009; Mayor-Dubois et al., 2012) in children with SLI, which is suggested to be related to deficits in learning sequence-specific information, rather than generally weak procedural learning (Hsu & Bishop, 2014). However, one trend that is emerging from this literature is that children with SLI show adequate procedural memory under some conditions including more exposure to information (Evans et al., 2009; Tomblin et al., 2007), shorter sequences, and simpler statistical structure (Gabriel et al., 2013).

3.1.3 Declarative memory.

As stated earlier, the focus of this dissertation is on studies that investigated recognition of visual stimuli as a measure of declarative memory. For simplicity, below I refer to declarative memory for visual information as visual declarative memory, and likewise for verbal declarative memory.

3.1.3.1 ***Visual declarative memory.*** A limited number of studies have tested visual declarative memory in SLI. Overall, results showed no differences between SLI and age-matched TD groups on standardized memory tests that assess the ability to identify a previously presented picture that cannot be verbalized easily, or recognize elements of that picture from a set of distractor pictures (Lum et al., 2012; Riccio, Cash, & Cohen, 2007) or to learn the spatial location of an abstract object over a number of trials (Baird, Dworzynski, Slonims, & Simonoff, 2010; Lum & Bleses, 2012; Lum et al., 2010). However, it has been suggested that difficulties on declarative memory in SLI could be evident in tasks that have more processing demands (Bavin, Wilson, Maruff, & Sleeman, 2005). For example, while toddlers with SLI were as accurate as TD toddlers on visual recall of locations, they were significantly less accurate in harder tasks involving recalling patterns and associating a particular pattern with a particular location (Bavin et al., 2005). In general, the studies presented above used memory tasks that presented the exposure and test items within the same modality: visual-to-visual. This modality is referred to as intra-modality (Bushnell & Baxt, 1999).

Few studies used a different recognition paradigm, haptic-modality (Bushnell & Baxt, 1999), with children with SLI. These studies were specifically interested in investigating motor difficulties in children with SLI through their haptic recognition abilities. Haptic recognition is a complex ability that requires adequate cutaneous and kinesthetic information, hand-movement patterns, and cross-modal haptic-visual transfer (Bushnell & Baxt, 1999). In those studies, children were asked to touch familiar (e.g., Müürsepp, Aibast, Gapeyeva, & Pääsuke, 2012, 2014) or unfamiliar geometric shapes (e.g., Kamhi, Catts, Koenig, & Lewis, 1984; Montgomery, 1993) and then visually identify the picture of the touched object from an array of distractors (up to six pictures) in a forced-choice task. Results consistently indicated significantly poorer haptic-visual recognition of familiar and unfamiliar objects in 5- to 7-year-old children with SLI in comparison to their age- and NVIQ-matched TD peers (Kamhi, 1981; Kamhi et al., 1984; Montgomery, 1993; Müürsepp et al., 2012, 2014; Müürsepp, Aibast, & Pääsuke, 2011).

Some studies have suggested that the ability of children with SLI to recognize objects in a haptic-visual condition is related to the nature of stimuli presented. Specifically, some children with SLI showed comparable ability to age-matched TD children in visually recognizing familiar geometric shapes explored by hands but not unfamiliar ones (Kamhi, 1981; Montgomery, 1993) and they had less difficulty recognizing simple shapes than complex shapes (Kamhi, 1981). In addition to the haptic-visual recognition task, Montgomery (1993) also investigated the performance of children with SLI on similar haptic to-haptic recognition task. Results suggested that the impairment in SLI is related to the high demands on short-term memory and the cross-modality transfer, not sensory difficulties per se. That is, although children with SLI were significantly less accurate than the TD group on a haptic-visual task, children were similar in haptic-haptic recognition task that had minimal demands on short term memory (i.e., testing included one object at a time) but not when the demands increased (i.e., testing included six objects to choose from). Together, these studies provide evidence of difficulties in children with SLI on cross-modality recognition tasks that require haptic-visual transfer (Kamhi, 1981; Montgomery, 1993; Müürsepp et al., 2012, 2014; Müürsepp et al., 2011). These difficulties may be related to difficulties in cross-modality transfer per se as well as the high demands on short-term memory.

3.1.3.2 ***Verbal declarative memory***. A common measure that has been used to test this area is the list-learning paradigms. In this paradigm participants are presented with a list of words or word pairs for certain number of times, and are asked to verbally recall the items immediately after each presentation, as well as following a short or long delay (Lum & Conti-Ramsden, 2013). Studies of list-learning tasks have often found recognition to be impaired in SLI (Lum et al., 2010; Nichols et al., 2004), yet normal performance has also been reported in other studies (Lum & Bleses, 2012; Lum et al., 2012; Riccio et al., 2007).

Recently, Lum and Conti-Ramsden (2013) in a meta-analysis review of 11 studies in this area found that most of those studies reported that the SLI group recalled significantly fewer words during the learning trials than age-matched control group. The average effect size computed using all studies of the meta-analysis was found to be 0.89 and statistically significant.

Thus, Lum and Conti-Ramsden (2013) concluded that on average, the literature shows significantly poorer verbal learning in children with SLI than in TD children of the same age. In addition, Baird et al. (2010) found impaired immediate recall, but largely normal performance after a delay in children with SLI, suggesting that it is the immediate processing and short-term storage memory that is more of a problem in this group.

It is important to note that most verbal declarative memory task paradigms have task demands including verbal working memory and language demands that may obscure declarative memory abilities in SLI (Lum et al., 2012). In support of this, studies that controlled for verbal working memory and language deficits in previous studies (Lum & Bleses, 2012; Lum et al., 2012; Lum et al., 2010) mainly report no deficits in declarative memory (Lum & Bleses, 2012; Lum et al., 2012). More recently, Lum, Ullman, and Conti-Ramsden (2015) examined verbal declarative memory functioning in SLI and its relationship to verbal working memory. Their study demonstrated that verbal declarative memory deficits in SLI only occur when verbal working memory is impaired. Accordingly, verbal declarative memory in SLI seems to be largely intact and deficits are likely to be related to working memory impairments.

In summary, previous studies revealed inconsistent findings regarding the declarative memory abilities in children with SLI that appeared to depend on the type of stimulus. Specifically, children with SLI show intact visual recognition of previously seen stimuli (e.g., Baird et al., 2010; Lum & Bleses, 2012), however, they show difficulties in tasks that require visual recognition of explored novel objects by hands without being seen (e.g., Kamhi et al., 1984; Montgomery, 1993). Poor recognition and recall of verbal information was reported in SLI (Baird et al., 2010; Lum et al., 2010), yet, the difficulties observed in this area may be due to verbal working memory and language problems, and not declarative memory deficits (Leonard

& Weber-Fox, 2012; Lum & Bleses, 2012; Lum et al., 2015).

3.1.4 Purpose of Study 2.

The primary goal of this dissertation was to address the gap in the literature on the role of procedural and declarative memory systems in language impairment in children with ASD, and to address the question of overlap with SLI. Accordingly, Study 2 provides a broad survey of language abilities and memory processing in children with SLI in comparison to age- and NVIQ-matched TD children using the same language and memory measures employed in Study 1. This study aimed to answer two specific questions: the first is whether children with SLI show similar or different performance on language measures including phonological awareness, articulation, receptive vocabulary, and word learning. In line with previous studies, it is expected that the SLI group will perform significantly worse than the TD group on all language measures: phonological awareness as measured on task required phoneme/syllable deletion of spoken words (e.g., Catts et al., 2005; Vandewalle et al., 2012), articulation (e.g., Bortolini & Leonard, 2000; Plante et al., 2011), receptive vocabulary (e.g., Buschmann et al., 2008; Rice et al., 2005; Zens et al., 2009), and word learning (e.g., Rice, Buhr, & Oetting, 1992; Rice et al., 1994).

The second question of the current study is whether children with SLI show similar or different performance on measures of procedural and declarative memory in comparison to their TD peers. For procedural memory, it is expected that the SLI group will show the same pattern of sequence learning as the TD group. This prediction draws on the simplicity of the current serial reaction task (i.e., deterministic 4-item sequence), a factor that has been demonstrated to enable SLI children to learn sequences (Gabriel et al., 2015; Lum et al., 2014). As for declarative memory, the SLI group is predicted to show adequate visual recognition of previously seen stimuli in agreement with previous results using standardized measures (e.g., Lum et al., 2012;

Riccio et al., 2007). In line with previous studies (e.g., Kamhi, 1981; Kamhi et al., 1984; Montgomery, 1993), significantly poorer haptic-visual recognition is expected in the SLI group compared to their TD peers, especially since the current task required high memory demands and involved unfamiliar objects with complex shapes.

3.2 Study 2 Method

3.2.1 Participants. Sixteen children with SLI without-autism and 45 typically-developing (TD) children participated in this study. The full TD sample (n = 45) was described in Study 1-section 2.2.1. However, a TD subgroup in this study was selected from the full TD sample to match the SLI participants who met the language impairment criteria, described in the following section, in terms of NVIQ. For this reason, the TD sample in this study is not the same as that in Study 1.

Participants were recruited in Montreal, Quebec, Canada and came from homes where English or French was spoken as the first language. Language dominance was determined based on parent report of their child's exposure to either English or French for at least 65% of the week at home, averaged over the course of the child's life. The SLI group included nine English-speaking participants and seven French-speaking participants. Participants with SLI were recruited through centers for interdisciplinary research in rehabilitation of greater Montreal and community contacts in the field of SLI. As described in study 1-section 2.2.1, the TD group included 25 English-speaking participants and 20 French-speaking participants. The TD participants were recruited through a university research database as well as by advertising on social media websites targeting families.

This research project received ethics approval from McGill University Faculty of Medicine and centers for interdisciplinary research in rehabilitation of greater Montreal where participants with SLI were recruited. Parental consent was obtained prior to participation.

3.2.1.1 Identification of language impairment in participants with SLI. Potential positive psycholinguistic markers for specific language impairment include third person singular tasks, past tense tasks, nonword repetition tasks, and sentence repetition tasks. However, there is growing evidence showing that these markers vary in accuracy, with sentence repetition proving to be the most useful measure that can be used alone to identify language impairment (Conti-Ramsden, Botting, & Faragher, 2001, Stokes, Wong, Fletcher, & Leonard, 2006; Thordardottir et al., 2011). In addition, comparable nonword repetition tasks are not available in both English and French. Therefore, sentence repetition was chosen to confirm language impairment in the current set of studies. Specifically, language impairment was determined by participants' scores on the Recalling Sentences subtest of the Clinical Evaluation of Language Fundamentals, Fourth Edition (CELF-IV; Semel et al., 2003) or on its standardized French adaptations: Répétition de phrases, *L'Évaluation clinique des notions langagières fondamentales-Version pour francophones du Canada;* Wiig et al., 2009). This sentence recalling task has been found to be an effective psycholinguistic marker of SLI with high levels of sensitivity (90%), specificity (85%), and overall accuracy (88%) (Conti-Ramsden et al., 2001). Responses on this subtest are scored in relation to the number of errors made in each sentence and scores are scaled to a mean of 10 and *SD* of 3.

Language impairment was defined as having scores of at least 1 *SD* below the mean on the Recalling Sentences subtest. This cutoff was chosen because previous research using this subtest (Conti-Ramsden et al., 2001) or other recalling sentences tests (Thordardottir et al., 2011) found it to be useful in identifying SLI. Two French-speaking participants with SLI were excluded from the analysis given that they had scores within the average range on the Recalling Sentences subtest. This resulted in a sample of 14 SLI participants, nine English-speaking and five French-speaking. Eight SLI participants (four English-speaking and four French-speaking) scored 1 *SD* below the mean; four (three English-speaking and one French-speaking) scored 2 *SD* below the mean, and two English-speaking participants scored 3 *SD* below the mean.

TD participants did not meet the criteria for language impairment as indicated by scores within or above the average range on the Recalling Sentences subtest.

3.2.1.2 Identification of participants. Confirmation of a diagnosis of specific language impairment or primary language impairment was obtained for all SLI participants via prior clinical diagnostic reports. Participants with SLI did not have a diagnosis of other developmental disorders such as autism or Down syndrome and TD participants had no developmental, learning, or behavioral disorders. In addition, SLI and TD participants did not have first-or second-degree relatives with an ASD per parent report.

Within this study, all participants were screened for ASD symptoms using the Social Communication Questionnaire (SCQ; Rutter et al., 2003), which was completed by parents in its English or French translation. All Participants in the TD group scored below the ASD cutoff (scores below 15). All but two participants in the SLI group (with scores of 16 and 20) scored below the ASD cutoff. These two participants were included in analyses given that ASD was never raised as a concern in their developmental history and they were attending a school specifically for children with non-ASD language difficulties.

3.2.1.3 ***Nonverbal intelligence quotient.*** The TD sample was selected by pairing each participant with SLI (n = 14) with a TD participant of the same dominant language who had a similar NVIQ as measured by the Leiter International Performance Scale-3 (Leiter-3; Roid, et al., 2013). Participants had NVIQs within or above the average range (M = 100, SD = 15).

For an estimate of socioeconomic status we asked parents for information on their highest level of education. Participant characteristics are given in Table 3.1. As shown participants in the SLI and TD groups did not differ significantly in NVIQ, chronological age, gender, or parent level of education. Since equal numbers of English-speaking and French-speaking participants, of similar NVIQ and chronological age were represented in each of the groups, data was collapsed over dominant language for all analyses.

Table 3.1.

Participant Characteristics

	Specific language impairment (n = 14)		Typically developing (n = 14)		
	M (SD)	*Range*	*M (SD)*	*Range*	*p-value
Dominant language (English, French)	9, 5		9, 5		1.00
Chronological age (Y; M)	7; 4 (1; 2)	5; 4 – 9; 1	7; 4 (0; 9)	6 – 8; 7	.98
NVIQ (Leiter-3)	105.14 (7.67)	93 - 125	105.21 (6.74)	95 - 120	.98
Gender (M, F)	10, 4		7, 7		.44
[a] Parent education: University degree	7		9		.97
SCQ	10.43 (4.47)	6 - 20	4.29 (3.63)	0 - 12	< .001
Recalling Sentences (CELF-IV)	4.57 (2.17)	1 - 7	10.86 (2.05)	8 - 14	< .001

Note. [a] Information on parent education was not available for four participant with SLI and one TD participant. *An alpha level of .05 was used for all statistical comparisons.

3.2.2 Procedure.

The procedures of Study 1 were followed in testing SLI and TD participants. Briefly, each child participated in tasks examining performance on phonology (phonological awareness and articulation), vocabulary (receptive vocabulary and word learning), procedural memory (Serial Reaction Time task), and declarative memory (intra- and cross-modality-recognition tasks). See procedure section (2.2.2) in Study 1 for details.

3.3 Study 2 Results

Similar to Study 1, Kolmogorov-Smirnov test of normality and histograms were inspected for all measures to determine data distribution and accordingly the suitable parametric or nonparametric tests were conducted. Refer to the Result section (2.3) of Study 1 for details.

3.3.1 Phonological awareness. The Auditory Analysis Test (Rosner & Simon, 1971) or its validated French version, Test d'Analyse Auditive en Français (Cormier et al., 1995) was used to test phonological awareness. The dependent variable was the total number of correct deletions of phonemes or syllables from spoken words. The minimum score on this task was zero and the maximum score on the English version is 40 and on the French version is 42.

To compare the groups, *z*-scores were calculated on the raw scores of correct answers within each language group based on the mean and standard deviation of the full sample of the TD participants in the respective language (English speaking n = 25, French speaking n = 20).

An independent *t*-test was conducted to compare the *z*-scores between the groups. Results showed that the scores of the SLI group (M = -1.12, SE = .24) were significantly lower than the scores of the TD group (M = .01, SE = .22), $t(26)$ = -3.73, p < .001, r = .59 (Figure 3.1).

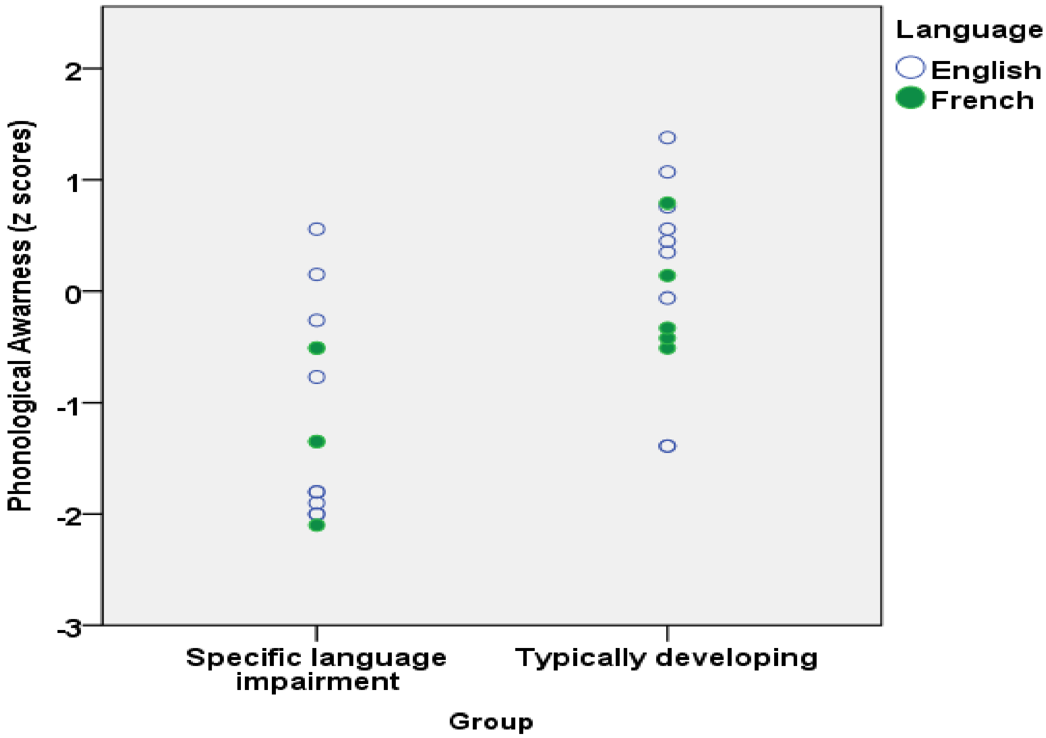


Figure 3.1. Performance on the phonological awareness task by group and language. Phonological awareness was assessed by the Auditory Analysis Test (Rosner & Simon, 1971) in its English (open circles) or French (closed circles) version.

3.3.2 Articulation. Articulation was assessed using the sounds-in-words subtest of the Goldman-Fristoe Test of Articulation; Second Edition (GFTA-II; Goldman & Fristoe, 2000) or Test de Dépistage Francophone de Phonologie (TDFP; Rvachew, Brosseau-Lapré, & Paul, 2012). The dependent variable was the percent of correct consonants (PCC; Shriberg & Kwiatkowski, 1982). To compare the groups on articulation, the PCC score for each participant was converted into a *z* score using the mean and standard deviation of the full sample of TD participants in the respective language (English speaking n = 25, French speaking n = 20).

Results on the Mann-Whitney *U*-tests showed similar articulation performance in the SLI group (*Mdn* = -.17) and the TD group (*Mdn* = .45), $U = 66$, $z = -1.48$, $p = .14$, $r = -.28$.

3.3.3 Vocabulary. An independent *t*-test was conducted to compare the standard scores receptive vocabulary between groups as measured by the Peabody Picture Vocabulary Test (Dunn & Dunn, 2007) in its standardized English or French version. Results showed that standard scores of the participants in the SLI group ($M = 94.36$, $SE = 3.77$, range = 76 - 124) were significantly lower than the standard scores of participants in the TD group ($M = 109.36$, $SE = 3.54$, range = 86 - 142), $t(26) = -2.90$, $p <.01$, $r = .49$ (Figure 3.2).

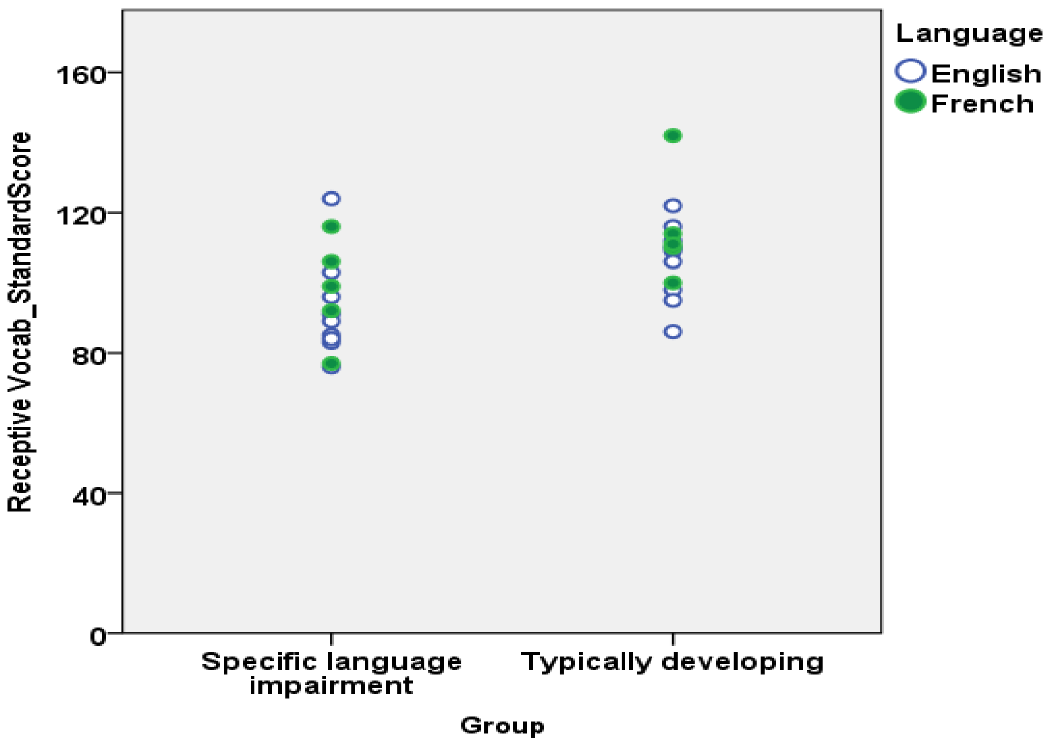


Figure 3.2. Performance on the receptive vocabulary task by group and language. Receptive vocabulary was assessed by the Peabody Picture Vocabulary Test in its English (open circles) or French (closed circles) version. The data points represent the standard score of each participant on this test.

3.3.4 Word learning. The dependent measure in each testing phase (i.e., brief- and longer-delay) of the word learning task was the number of trials where a participant selected the correct object, with a score range of 0 to 2 for each testing phase (i.e., brief- and longer-delay).

The order of presentation of the two labels and stimulus sets, A and B, was counterbalanced among participants. Chi-square tests showed that order had no influence on performance. Specifically, in the SLI group, similar proportions of participants who received trial A or trial B first showed no learning, 1 word learning, and 2 word learning in the brief-delay phase, $p = .10$, *Fisher's Exact Test*, as well as in the longer-delay phase, $p = .51$, *Fisher's Exact Test*. Similar results were found in the TD group in the brief-delay phase, $p = .46$, *Fisher's Exact Test*, as well as in the longer-delay phase, $p = .94$, *Fisher's Exact Test*.

a. Brief-delay phase. A chi-square test revealed that word learning in the brief-delay phase was similar in groups, $p = .59$, *Fisher's exact test, Cramer's V* = .27. Table 3.2 displays performance on word learning with brief delay.

Table 3.2.

Word Learning Task: Brief Delay Performance: Number of Participants in each Group Who Learned 0, 1, or 2 Words

Number of words learned	Group		Total
	Specific language impairment	Typically developing	
0	0	1	1
1	3	1	4
2	11	12	23
Total	14	14	28

b. Longer-delay phase. Although there was a trend for learning fewer words by participants with SLI than TD participant, a chi-square test showed that this difference was not statistically significant with medium effect size, *p* = .17, *Fisher's exact test, Cramer's V= .36*. Moreover, fewer participants in both groups were able to identify the two labels and more participants showed no learning of either label, in comparison to the brief-delay phase, demonstrating the higher demands of this phase. Table 3.3 shows performance on word learning with longer delay.

Table 3.3.

Word Learning Task: Longer Delay Performance: Number of Participants in each Group Who Learned 0, 1, or 2 Words

Number of words learned	Group		Total
	Specific language impairment	Typically developing	
0	7	3	10
1	3	2	5
2	4	9	13
Total	14	14	28

3.3.5 Procedural memory. The serial reaction time (SRT) task was used to assess procedural memory. The key comparisons of interest in this task were 1) whether *sequence learning scores (i.e.,* [Block 4 - Block 5] ÷ [Block 4 + Block 5]) differed between groups and 2) whether the response times (RTs) were significantly decreased on the fifth block (final sequence block) relative to the fourth block (final random block).

Handedness was similar in the SLI group (right handed = 11, left handed = 3) and the TD group (right handed = 13, left handed = 1), $p = .60$, *Fisher's Exact Test*, *Cramer's V* = .20. Independent *t*-tests showed that the SLI group ($M = 6.43$, $SE = 1.52$) made significantly more errors in block 4 and 5 than the TD group ($M = 2$, $SE =. 43$), $t(15.08) = -2.80$, $p = .01$, $r = .58$.

An independent *t*-test showed that the *sequence learning score* in the SLI group ($M = .17$, $SE = .03$) did not significantly differ from the TD group ($M = .19$, $SE = .03$), $t(26) = .58$, $p = .57$, $r = .11$, indicating that the difference in response to sequence vs. random blocks was similar in groups. Furthermore, repeated *t*-tests showed that the SLI group showed significantly faster responding in block 5 ($M = 732.45$, $SE = 64.93$) than block 4 ($M = 1017$, $SE = 83.95$), $t(13) = 16.31$, p < .001, $r = .98$. Similarly, the TD group showed the same trend with significantly faster responding in block 5 ($M = 653.71$, $SE = 50.67$) than block 4 ($M = 935.59$, $SE = 32.06$), $t(13) = 8.65$, $p < .001$, $r =.85$. These results indicate that the SLI group and the TD group learned the sequence. Figure 3.3 represents the mean RT of each group over the five blocks.

After completing the SRT task, participants were asked to show the pattern on the serial response box providing a measure of explicit knowledge of the sequence. A chi-square test was performed to compare the number of participants who demonstrated explicit knowledge of the sequence in the two groups. Results indicated that similar proportion of participants in the SLI group (4 of 14) and the TD group (7 of 14) showed explicit knowledge of the sequence, *x2* (1, *N* = 28) = 1.17, $p = .28$, *Cramer's V* = 21.

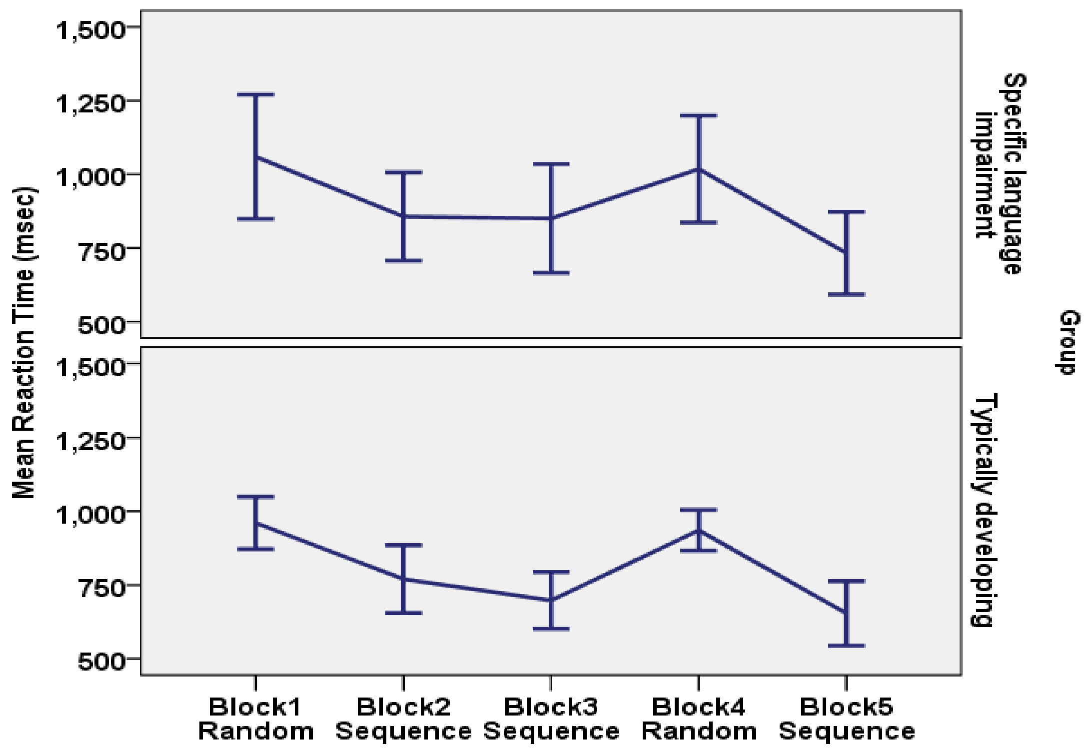


Figure 3.3. Performance of groups on the SRT task. Data points indicate the mean reaction time per block of 40 trials. Error bars represent standard error of the mean. Sequence learning is indicated by significantly faster responses on block 5 (sequence) than block 4 (random).

Moreover, Mann-Whitney *U*- tests were conducted to assess potential differences in an implicit measure (*sequence learning score*) for participants who showed or did not show explicit knowledge of the sequence by the end of the task. In the SLI group, participants who showed explicit knowledge of the sequence had significantly higher *sequence learning score* (Mdn = .24) than participants who did not indicate the explicit knowledge of the sequence (Mdn = .12), U = 3, z = 2.41, p = .02, r = .64. Similarly, in the TD group, participants who showed the explicit knowledge of the sequence had significantly higher *sequence learning score* (Mdn = .25) than participants who did not (Mdn = .14), U = 2, z = 2.88, $p < .001$, r = .77. Figure 3.4 displays the *sequence learning scores* of participants who had explicit knowledge of the sequence as well as the participants who did not in each group.

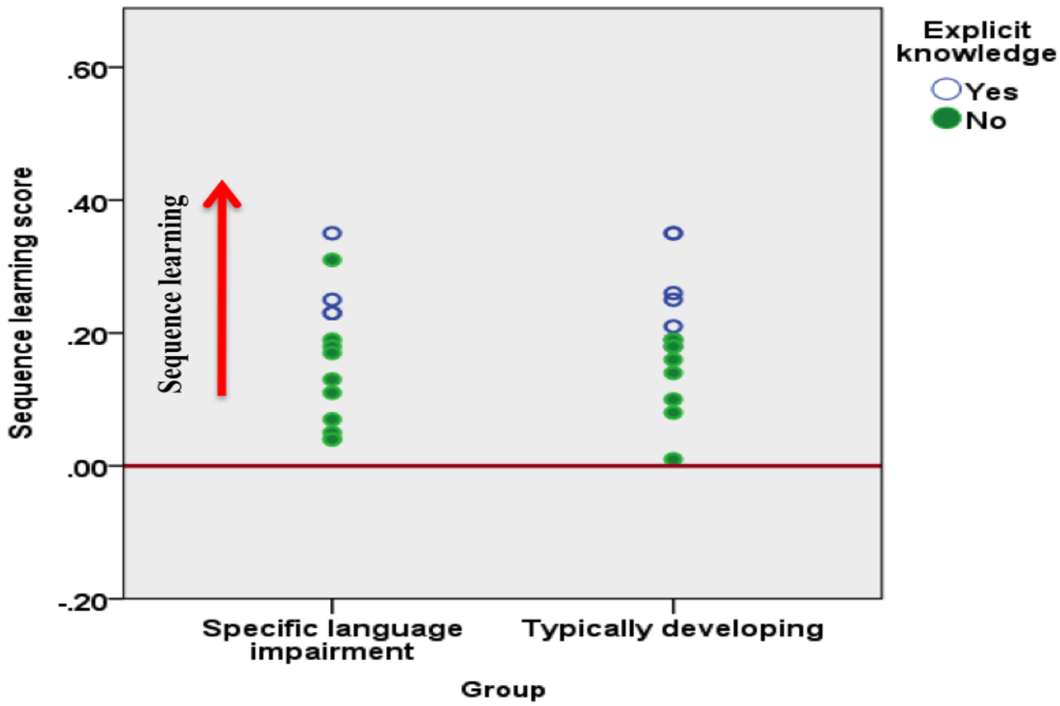


Figure 3.4. Sequence learning scores for SLI and TD groups who showed explicit knowledge (open circles) and those who did not (closed circles). Sequence learning scores above 0, indicated by the red line, demonstrate implicit learning of the sequence. Results demonstrated that only participants who showed a high degree of implicit learning also showed explicit knowledge of the sequence at the end of the task.

3.3.6 Declarative memory. Intra- and cross-modality recognition tasks were used to assess this memory system. The presentation order of the two recognition tasks, intra- and cross-modality, was counterbalanced across participants. Mann-Whitney *U*-tests showed no significant difference in scores on intra-modality task, *U* = 24.5, *z* = .3, *p* = 1, *r* = .08, or cross-modality task, *U* = 15, *z* = -.88, *p* = .38, *r* = -.24, between participants who received the intra-modality task first and participant who received cross-modality task first in the SLI group. Likewise, in the TD group, scores did not differ by presentation order for the intra-modality, *U* = 22, *z* = -.36, *p* = .72, *r* = -.10 or the cross-modality tasks, *U* = 21, *z* = -.40, *p* = .69, *r* = -.11.

a. Intra-modality recognition. Participants were required to visually identify at least 3 out of 4 familiar objects in training to proceed to the testing phase. None of the participants required additional training.

The total possible score for intra-modality testing was 12, in which 1 score was gained for identifying a target object as being seen before or a distracter as being novel. Mann-Whitney *U*-tests showed that similar scores in the SLI group (*Mdn* = 12) and the TD group (*Mdn* = 12), *U* = 86.5, *z* = -.7, *p* = .47, *r* = -.13.

b. Cross-modality recognition. Four participants with SLI required additional training before proceeding to the testing phase of novel objects. However, the data of one participant with SLI was excluded from the analysis given that she said "yes" to all testing novel objects.

The total score for cross-modality testing was 12, in which 1 point was gained for correctly identifying a target object as being previously encountered haptically or identifying distractors as being novel. Mann-Whitney *U*-tests demonstrated that scores of the SLI group (*Mdn* = 9) were significantly lower than the scores of the TD group (*Mdn* = 11), *U* = 44.5, *z* = -2.51, *p* = .01, *r* = -.47. Figure 3.5 shows the performance of participants in each group on the intra- and cross-modality recognition tasks.

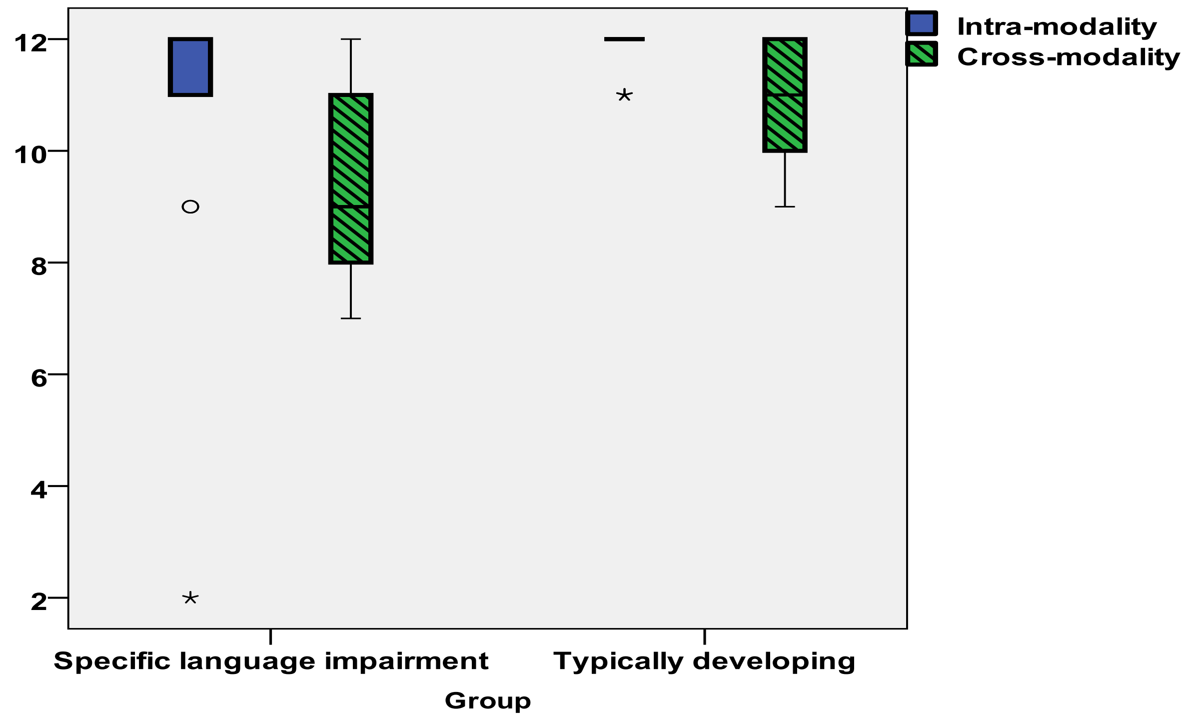


Figure 3.5. Performance of SLI and TD groups on the declarative memory tasks. Clear bars demonstrate performance on the intra-modality recognition task and lined bars show performance on the cross-modality recognition task. Error bars represent the minimum and maximum scores of correctly identified novel objects in each group (score range: 0 - 12).

3.4 Study 2 Discussion

The present study investigated language and memory profiles in children with SLI as compared to TD children. Groups were similar in terms of their NVIQ scores, age, gender, and their parent's education level. However, all children with SLI had language impairment, defined as performing at least 1*SD* below the mean on the recalling sentences subtest (CELF-IV; Semel, et al., 2003), while all children in the TD group were within or above the normal range.

3.4.1 Phonological awareness. The SLI group made significantly more errors than the TD group on a phonological awareness task that required phoneme or syllable deletion of spoken words. This finding supports previous findings of impaired phonological awareness in children with SLI (Bishop et al., 2009; Kamhi et al., 1985; Warrick et al., 1993) including similar phoneme deletion tasks (Catts et al., 2005; Vandewalle et al., 2012).

3.4.2 Articulation. Results showed comparable articulation skills in the SLI and TD groups. This finding is contrary to my prediction and previous studies that showed poor articulation in children with SLI (Bortolini & Leonard, 2000; Fee, 1995; Plante et al., 2011). However, it supports the view that SLI consists of subgroups with different language profiles including subgroups with age appropriate articulation (Conti-Ramsden et al., 1997; Friedmann & Novogrodsky, 2008; Shriberg et al., 1999).

The current finding could be influenced by the simple task used to assess articulation in which children were required to label the names of pictures of common words. Yet, on the same test of articulation, Conti-Ramsden et al. (1997) showed that 34% of school-age children with SLI show impaired ability. The deficits in articulation in children with SLI might be more apparent in more difficult tasks that involve phonologically complex words and nonwords (Friedmann & Novogrodsky, 2008) or in continuous speech (Maillart & Parisse, 2006; Parisse & Maillart, 2007). Moreover, given that children were tested at a developmental point when all the speech sounds of a language are already acquired, any potential difficulties might be found in more specific comparisons that target unusual processes detected in the speech of children with SLI (Aguilar-Mediavilla et al., 2002; Kunnari et al., 2012) rather than comparison of the overall percentage of consonants correct as in the current study.

3.4.3 Receptive vocabulary. Although most of the children with SLI had age appropriate receptive vocabulary levels, as a group, children with SLI performed significantly worse than their TD peers, indicating receptive vocabulary deficits in this group. Specifically, while all the children in the TD group had scores within or above the normal range on the receptive vocabulary standardized test, 4 of 14 children in the SLI group had scores below the normal range, and the others had scores within (8 of 14 children) or above (2 of 14 children) the normal range. This variability in performance on the receptive vocabulary measure is not surprising given the heterogeneity in the language profiles in SLI reported in the literature (Conti-Ramsden et al., 1997; Rapin & Allen, 1987). This result confirmed previous findings of deficits in vocabulary knowledge in children with SLI, specifically on tasks that required identifying the picture of a spoken word from a number of pictures, similar to the test used in this study (Buschmann et al., 2008; Leonard, 1998; Paul, 1996; Rice, 2004b; Rice et al., 2005; Zens et al., 2009).

3.4.4 Word learning. Contrary to my prediction, the present study showed that children with SLI can learn novel words similarly to their TD peers in both the brief-delay and longer-delay phases of the word learning task employed. The current finding is consistent with a number of previous studies (Dollaghan, 1987; Gray, 2003) but different from those that found that children with SLI learned significantly fewer words than an age-matched TD group in an indirect narrative context (Rice et al., 1992, 1994). A number of differences in methodological and participant characteristics between studies could explain these divergent results. First, similar to the studies that reported no differences between SLI and age-matched TD groups, the present word learning task presented explicit labeling, interaction between the examiner and the child in a game based task, and less contextual information than that provided in studies in which labeling was indirectly done in the context of a narrative (Rice et al., 1992, 1994, 2000). Second, the number of words presented to be learned might also explain the difference in findings. That is, the studies that reported adequate word learning in children with SLI presented fewer labels to be mapped (e.g., three labels; Dollaghan, 1987, four labels; Gray, 2003, and two labels in the current study) than those that reported difficulties in this group (8 labels; Rice et al., 1994, 16 labels; Rice et al., 2000).

The characteristics of participants in the SLI group in the current study might also play a role in the diminished difference between groups. Specifically, all participants but one were older than 6 years, had NVIQs comparable to the TD group, and most children had receptive vocabulary scores within the normal range. Together, these findings are in line with the previous observations by Kan and Windsor (2010) in their meta-analysis: children with SLI are more comparable to their age-matched TD peers on word learning tasks when they are older than 6 years, when they have comparable NVIQ to the TD group, when receptive language delays are minimal (i.e., less than 1.25 *SD* below the mean), when comprehension (rather than production) is assessed, fewer labels are taught, and when explicit instructions are provided – all of these conditions held for the current study.

3.4.5 Procedural memory. In this study, procedural memory processing was examined with an SRT task that required sequence learning of a deterministic 4-item pattern. Results showed similar learning patterns across the five blocks of the SRT task with the SLI and TD groups learning the sequence as indicated by their significantly faster responses in sequence block 5 in comparison to random block 4.

Gabriel et al. (2013) showed that sequence complexity in terms of length and statistical structure play a major role in visual sequence learning in children with SLI. In line with this finding, previous studies reported that children with SLI were able to learn 8-item-deterministic (Gabriel et al., 2011) and probabilistic-sequences (Gabriel et al., 2013) but not 10-item deterministic sequence (Lum et al., 2010, Lum et al., 2012) or 12-item probabilistic sequence

(Gabriel et al., 2013). Similarly, the findings of this study confirm the ability of children with SLI to learn simple sequences (deterministic 4-item sequence), which according to prior findings is well within the length and complexity range of their procedural learning ability.

The number of times participants are exposed to the sequence in an SRT task is also likely to impact study findings since learning by the procedural memory system requires repeated exposure to information. Specifically, in previous studies, the number of times participants were exposed to the sequence ranged from 20 (impaired learning of 10-item sequence; Lum et al., 2010) to 108 exposures (intact learning of 8-item sequence; Gabriel et al., 2011). The current study provided 30 exposures to the short 4-item sequence, which could also have enabled the children in the SLI group to learn the sequence. This pattern of results suggests that procedural learning can occur in SLI, but they may require increased exposure to the information. Thus, it is possible that the differences between this study and the previous ones that also used deterministic sequence structure (Lum et al., 2010; Tomblin et al., 2007) could be related to differences in the speed to acquire procedural knowledge between children with SLI and TD children rather than in the ultimate ability to learn the sequence or not.

Finally, explicit knowledge of the sequence was tested in the current study. Similar numbers of SLI children (4 of 14) and TD children (7 of 14) showed explicit knowledge of the sequence and were able to recreate the sequence they had learned. Regardless of explicit knowledge, all children in both groups, but one in the TD group with no explicit knowledge, showed successful learning of the sequence as shown by their faster responses on the last sequence vs. random blocks. However those children with explicit knowledge showed a greater difference in their response times to the sequence vs. random block than those who did not. These results indicate that children in the two groups learned the sequence implicitly, and then with repetitions they became more aware of the sequence that enabled them to anticipate the sequence at faster rate. In the few previous studies that assessed explicit knowledge of sequences in SRT tasks, participants did not show explicit knowledge (Hedenius et al., 2011; Lum et al., 2012; Lum et al., 2010). This could be due to the complexity of the SRT tasks used in these studies (e.g., alternating 8-item sequence repeated 40 times; Hedenius et al., 2011, deterministic 10-item sequence repeated 36 times; Lum et al., 2010) that did not lead to explicit knowledge. In the current study, the simple task employed was very easy to learn explicitly over training. Thus, it appears that children with SLI were able to learn this simple 4-item sequence procedurally and developed explicit knowledge of it to a similar degree as age- and NVIQ- matched TD children.

3.4.6 Declarative memory. Children with SLI were able to visually recognize the previously seen novel objects (intra-modality recognition) similarly to the TD children, but they were significantly poorer in their ability to visually recognize the objects explored by hands (cross-modality recognition).

Intact visual recognition has generally been reported in individuals with SLI using standardized tasks (Baird et al., 2010; Lum & Bleses, 2012; Lum et al., 2010), which was confirmed in the current study using a different paradigm. However, it is important to note that the task used in this study included natural interaction between the child and the examiner during a game in which the demands were minimal in comparison to previous studies.

The current finding of poorer performance of children with SLI than TD children in cross-modality recognition is consistent with previous research showing that children with SLI are poorer than TD children at recognizing pictorial representations of novel shapes they had previously manipulated with their hands (Kamhi, 1981; Kamhi et al., 1984; Montgomery, 1993). In addition, the current finding is consistent with previous reports showing that difficulty in cross-modality recognition tasks in children with SLI were related to methodological factors. For example, Kamhi (1981) showed that children with SLI are more successful in recognizing simple shapes than complex ones. In this study, the novel objects were all made of real objects and had prominent features that were expected to help children identify them by touch, yet some objects had complex shapes, which could have made the task difficult for children with SLI. Furthermore, Montgomery (1993) found that children with SLI show less difficulty on tasks that had minimal demands on the short-term memory but not when the demands increased (i.e., testing included six objects to choose from). In the present study, the presentation of stimulus included six novel objects, one-by-one, followed by testing of visual recognition for all of those objects with another six distractors. This kind of presentation imposes high short term memory load given that children are required to maintain the knowledge they acquired about each of the six object at once to be able to recognize those objects from a set of 12 novel objects.

Another possible explanation is that the poorer haptic performance of the children with SLI was due in part to motor deficits. It has been reported that, as a group, children with SLI perform poorly on a range of fine and gross motor tasks such as object manipulation, finger movement, and grasping (Brumbach & Goffman, 2014; Hill, 2001). Accordingly, it could be suggested that the SLI group was not successful in the haptic recognition task due to motor deficits rather than recognition. Although fine motor skills were not directly assessed in the present study, during the haptic recognition task the examiner made sure that children used both hands to explore each object for 10 seconds and made sure that they explored the object and didn’t simply hold it still inside the box. In addition, the adequate visual-motor ability of the SLI group as measured on the SRT task suggests that the participants with SLI had adequate motor ability to do well on tasks requiring a motor response. These observations however do not exclude the possibility that fine motor skills contribute to exploring objects in the haptic recognition task.

Finally, the current finding of divided profile of declarative memory in SLI based on the modality used for recognition; adequate visual-visual recognition but poor haptic-visual recognition was also found in previous studies in younger TD children (Bushnell & Baxt, 1999; Kalagher & Jones, 2010). A valid explanation for these findings is that representations formed entirely from haptic exploration differ importantly from visual exploration (Bushnell & Baxt, 1999; James, James, Humphrey, & Goodale, 2006). That is, attention during haptic exploration might be focused on material-based properties (e.g., texture, mass), whereas in vision attention is focused more on shape and color. Accordingly, these differences in perceptual focus would likely lead to qualitatively different representations and therefore poorer performance in cross-modality tasks as compared to intra-modality tasks (James et al., 2006). Another possible explanation is that haptic exploration may require considerable time, especially when compared with vision (James et al., 2006). The longer it takes to gather the necessary sensory information to create a whole percept; the more demand is placed on other cognitive resources such as spatial and temporal integration, working memory, and attention. When presentation time is limited, these demands may become too high and recognition may fail. However, with enough time for thorough exploration, haptic inputs contain enough information to construct robust three-dimensional object representations, representations that are quite similar to those used by vision (James et al., 2006). In the current study, children were given 10 seconds to explore each object, a period that was adequate for the TD children to recognize the objects. Considering this time factor directs the attention to previous findings on procedural memory in which some studies reported that children with SLI learned the sequence when the exposure to the sequence was doubled (Evans et al., 2009; Tomblin et al., 2007). This could be the case in cross-modality recognition as well, whereas some children with SLI require more time to explore the objects with their hands to be able to visually recognize them.

In conclusion, the current study showed that the SLI group performed similarly to the TD group on a single word picture naming measure of consonant articulation skills and on a word-learning task with a short and long delay. In contrast, significant group differences were found in receptive vocabulary and phonological awareness as measured by a phoneme or syllable deletion task despite group matching for age and NVIQ. Turning to memory, the SLI group showed similar performance to the TD group on the procedural memory task that required learning deterministic 4-item sequence. Results on declarative memory as measured by recognition showed a divided profile. Specifically, the SLI group and the TD group were similar in their ability to visually recognize previously seen novel objects, while they significantly differed in their ability to visually recognize novel objects explored by hands.

The current result of the ability of children with SLI to learn a simple sequence similarly to their TD peers contradicts with the procedural deficit hypothesis (Ullman & Pierpont, 2005). That is, Ullman and Pierpont claim that language difficulties in SLI can be explained by deficits in procedural memory. However, previous studies indicated poor performance on procedural memory tasks that involve complex sequence learning (e.g., Lum et al., 2010; Tomblin et al., 2007), which is in line with the procedural deficit hypothesis. The hypothesized role of procedural and declarative memory in language impairment in children with SLI is investigated in Study 3.

Chapter 4 : Study 3 - Language and Memory Profiles in ASD with Language Impairment and in SLI

4.1 Introduction

A growing body of research has investigated similarities in language impairment in individuals with ASD and individuals with SLI, leading to divergent conclusions on shared or distinct origins of these two disorders. In one position, researchers have concluded that there is a subtype of children with ASD who show the same neurocognitive phenotype as that seen in children with SLI, reflecting a shared etiology (e.g., Kjelgaard & Tager-Flusberg, 2001; Leyfer, Tager-Flusberg, Dowd, Tomblin, & Folstein, 2008; Tager-Flusberg & Joseph, 2003; Walenski et al., 2006). This position draws on evidence from studies in which some children with ASD showed structural linguistic difficulties that are highly reminiscent of a common profile in SLI including difficulties in phonology, grammar, or vocabulary (e.g., Bishop et al., 2004; Botting & Conti-Ramsden, 2003; Kjelgaard & Tager-Flusberg, 2001; Eigsti, Bennetto, & Dadlani, 2007).

In a second position, researchers have argued that similarities in the performance of children with ASD and those with SLI on language measures are superficial and do not necessarily reflect common underlying causes at the cognitive, neurobiological, or etiologic levels (e.g., Taylor, Maybery, & Whitehouse, 2012; Whitehouse, Barry, & Bishop, 2008; Williams et al., 2008; Williams et al., 2013). This position relies on evidence showing that children with ASD and SLI who share some structural language difficulties make contrasting patterns of errors on nonword repetition tasks, which may indicate different underlying cognitive difficulties (Whitehouse et al., 2008; Williams et al., 2013). In addition, in a comprehensive review of the empirical literature, Williams et al. (2008) concluded that similar or different phenotypic language profiles in language-impaired ASD and SLI could depend to some degree, on the age at which assessment is done. That is, the typical profiles of linguistic impairments overlap are found in preschool children in each disorder, while at school age the typical profile in each disorder is predominantly different despite some areas of overlap. Precisely, the majority of preschool language-impaired children with ASD, like preschool and school-aged children with SLI, show difficulties at all levels of structural language and are best classified as having mixed receptive and expressive difficulties (Williams, et al., 2008). At school age, the majority of children with ASDs do not have evident “structural” language deficits, provided the child is not with severe autism or cognitive impairment. The language difficulties experienced by school-age children with ASD are best characterized as higher order processing deficits involving major impairments in comprehension and production of discourse but relatively intact phonology and mild to moderate impairments of grammar (Rapin, 2007; Rapin et al., 2009). On the contrary, language difficulties in school-aged children with SLI are predominantly of a mixed receptive–expressive form, affecting all levels of comprehension and production (e.g., Conti-Ramsden & Botting, 1999).

To date, a considerable number of studies has focused on linguistic and behavioral overlap of language-impaired ASD and SLI, yet relatively little research has been done on the overlap in cognitive functions. Studies that examine whether cognitive characteristics commonly observed in ASD are found among individuals with SLI will contribute to the ‘etiological overlap’ debate (Taylor et al., 2014). In this area, recent hypothesized explanations of language impairment in individuals with ASD and individuals with SLI are based on the role of procedural and declarative memory in typical language development. Specifically, some researchers hypothesized that structural language impairment in phonology and grammar in ASD (Klinger et al., 2007; Romero-Munguía, 2008; Ullman, 2004) and in SLI (Ullman & Pierpont, 2005) can be explained by impaired procedural memory that involves learning and storing regularities and rule-based information. In addition, they hypothesized that the relatively intact vocabulary in these disorders can be explained by intact declarative memory that is involved in binding conceptual, phonological, and semantic representations of words. In another hypothesis, Boucher et al. claim that language deficits in language-impaired individuals with ASD are consequent to their impaired declarative memory processing (Boucher & Bowler, 2008; Boucher, Mayes, & Bigham, 2008; Boucher et al., 2012). Although there has been broad interest in these hypotheses, few studies have investigated procedural and declarative memory in language-impaired children with ASD and children with SLI, separately, and using different methods. In addition, scarce research has investigated the relationship between procedural and declarative memory and language impairment in these disorders.

The current study is the first to directly compare the two disorders to examine whether language-impaired children with ASD show similar or different profiles of language (phonology and vocabulary) and memory (procedural and declarative) to that found in their SLI peers. In addition, this study provides a preliminary investigation of possible relationships between performance on procedural and declarative memory tasks and language abilities in the two groups. Including a subgroup of children with ASD who have concomitant language impairment in the current study sheds light on the profile of this relatively understudied population. This is essential because if impaired memory processing contributes to language impairment it should be most apparent in language-impaired children with ASD rather than individuals with ASD who have age-appropriate structural language abilities.

In the following sections, studies that directly compared language in language-impaired ASD and SLI groups are reviewed followed by an overview of the findings on the relationship between procedural or declarative memory systems and aspects of language in the two disorders.

4.1.1 Direct comparisons of language profiles across groups.

In Studies 1 and 2, language profiles in language-impaired ASD and SLI groups were reviewed in comparison to a TD group. In the current section, the focus is on studies that directly compared language profiles in the two disorders. Surprisingly, similarities in language profiles of language-impaired children with ASD and children with SLI have not been extensively investigated in studies directly comparing the two disorders.

4.1.1.1 Phonology. Similar difficulties were reported in children with ASD and children with SLI in phonological processing/memory span as indexed by nonword repetition tasks (Botting & Conti-Ramsden, 2003; Taylor et al., 2014) and deficits in recalling sentences (Botting & Conti-Ramsden, 2003; Riches, Loucas, Baird, Charman, & Simonoff, 2010; Taylor et al., 2014; Williams et al., 2013).

4.1.1.2 Vocabulary. Parent reports on language development of 4- to 7-year-old children with ASD and children with SLI indicated delayed receptive and expressive language development in both groups (Geurts & Embrechts, 2008). Evidence of similarities between language-impaired ASD and SLI groups include similar difficulties in receptive and expressive vocabulary across different ages at the single word level (Cantwell, Baker, Rutter, & Mawhood, 1989; Mawhood, Howlin, & Rutter, 2000; McGregor et al., 2012) and the general language level as measured on standardized tests (Whitehouse et al., 2008; Williams et al., 2013). In addition, at school age, shallow lexical knowledge is evident in the two clinical groups in comparison to TD comparison groups as shown by partial knowledge of word meaning and immature knowledge of word to word relationships (McGregor et al., 2012), severe difficulties in interpreting compound words (Riches, Loucas, Baird, Charman, & Simonoff, 2012), and poorer ability to use semantic context to identify ambiguous word meanings (Norbury, 2005).

In contrast, some studies indicated different patterns of language difficulties between the two disorders (e.g., Lloyd, Paintin, & Botting, 2006; Manolitsi & Botting, 2011). For example, Lloyd et al. (2006) found that although language-impaired ASD and SLI groups had similar receptive language scores, the group with SLI scored significantly worse on expressive language than the ASD group. In addition, the SLI group showed non-significantly higher receptive scores compared to expressive scores, while the ASD group showed the reverse pattern; non-significantly higher expressive scores compared to receptive scores.

4.1.1.3 Word learning. Few studies compared word learning in children with ASD and children in SLI. In one study, Shulman and Guberman (2007) investigated whether 3- to 7-year-old language-impaired children with ASD and children with SLI could use their grammatical knowledge of transitive and intransitive frames in order to acquire the meaning of a novel verb. Results showed that children with ASD and TD children learned novel verbs using the syntactic cues in the sentences in which they were presented, whereas children with SLI experienced more difficulty, learning only that which would be expected from chance.

In another study, Gladfelter (2014) tested children with ASD and mixed language abilities and children with SLI with the aim of understanding how novel words should best be taught to these children. Participants included 12 children with ASD (age range: 4-11 years), 12 children with SLI (age range: 5-8 years), and 12 TD children (age range: 4-7 years) matched on expressive vocabulary. Children were taught novel words with different amounts of semantic information. Results showed that children with ASD and SLI benefit from semantically rich learning context in much the same way as their TD peers to fast map novel nouns to their referent picture and retrieve semantic knowledge of the learned word (e.g., definition task).

The following sections present the findings on the relationship between procedural or declarative memory systems and aspects of language in the two disorders. None of the previous studies directly compared both of ASD with language impairment and SLI in terms of the status of procedural and declarative memory processing, as was done in the current study.

4.1.2 Relationships between procedural memory and language in ASD with language impairment.

As presented in study 1, so far only two studies investigated the status of procedural memory in language-impaired children with ASD using different measures of implicit learning. Findings demonstrated that children with ASD show adequate procedural learning under certain conditions including increased training requirements and decreased memory load (Gordon & Stark, 2007; Klinger & Dawson, 2001). These findings do not imply global intact procedural memory in this group given that on more difficult tasks the ASD children are not as successful as on simpler tasks (e.g., 4 vs. 8 item sequence learning task; Gordon & Stark, 2007).

Klinger and Dawson (2001) investigated the relationship between procedural learning of category membership for novel figures and receptive language in 5- to 21-year-olds with ASD and language impairment, intellectual disability, or typical development. Results showed that across the three groups, rule learning was related to receptive language mental age as measured on the Peabody Picture Vocabulary test. Specifically, in all groups, participants with a higher receptive-language mental age were more likely to show rule learning than participants with a lower receptive-language mental age. These results suggest that, similar to TD children, children with ASD and children with intellectual disability become more proficient at using a rule to learn a new category as their ability level increases. To my knowledge, no other study investigated the relationship between performance on procedural memory and language measures in language-impaired individuals with ASD.

4.1.3 Relationships between declarative memory and language in ASD with language impairment.

The few studies that tested visual recognition in language-impaired individuals with ASD provided inconsistent results. Some studies reported intact immediate recognition of unfamiliar objects and buildings (Boucher & Lewis, 1992; Dawson, Osterling, Rinaldi, Carver, & McPartland, 2001), while others demonstrated poor recognition of unfamiliar stimuli such as patterns and shapes in this group (e.g., Barth et al., 1995; Boucher, Bigham, et al., 2008; Dawson et al., 1998). This discrepancy in results might be related to differences in stimuli used in the recognition task (e.g. real world unfamiliar objects; Dawson et al., 2001 vs. images of unfamiliar shapes; Boucher, Bigham, et al., 2008) or the difficulty of the task.

So far, only Boucher, Bigham, et al. (2008) investigated the relationship between declarative memory as measured by recognition and language measures in a language-impaired ASD group. They tested recognition on two tasks of non-representational shapes and patterns (computer-generated dot patterns with straight lines drawn in black to connect the dots so as to make an enclosed shape) in four groups: language-impaired ASD, language-normal ASD, intellectually disabled, and TD. Recognition in the two tasks was measured by the number of correct identifications of stimuli as seen before. In addition, language (conceptual-lexical knowledge) was tested on four standardized measures: the pyramids and palm trees test (Howard & Patterson 1992), the vocabulary and similarities subtests of the Wechsler Abbreviated Scales of Intelligence (Wechsler 1999), and the British Picture Vocabulary scales (Dunn, Dunn, Whetton, & Burley, 1997). Results showed impaired recognition in both the language-impaired ASD and intellectually disabled groups on both recognition tasks, and impaired recognition only on the pattern task in the language-normal ASD group. To assess possible relations between recognition and conceptual–lexical scores in the four groups, scores on the two recognition tests were combined, and scores on the four tests of language were also combined. The authors reported a significant correlation between visual recognition and conceptual–lexical knowledge in the language-impaired ASD group ($n = 28$, $r = .42$, $p < .05$) and a strong trend towards correlation with medium effect size in the language-normal ASD group ($n = 26$, $r = .37$, $p = .06$), while no correlation was found in either the TD or intellectually disabled groups. As a result, the authors concluded that the ASD groups may depend on declarative memory to an unusual extent to learn language while the intellectually disabled group may depend less on declarative memory. Their findings on correlations between recognition and language confirmed Boucher's hypothesis (Boucher & Mayes, 2011) stating that impaired declarative memory contributes to language deficits found in language-impaired individuals with ASD. Nevertheless, findings also suggest that memory impairments affect language acquisition across the spectrum not only the language-impaired group. It is important to note that the language-impaired ASD group consistently had the lowest scores on language and recognition measures while the language-normal ASD group had the highest scores, which most likely biased the findings. In addition, the authors reported more floor effects in the language-impaired ASD group and more ceiling effects in the TD group, raising the question of whether the recognition tasks used were appropriate or too difficult for the language-impaired ASD group. Moreover, given the relatively small sample size and the variability of scores in groups, it would have been informative to include scatter plots that might better reflect the possible relationship, if any, while showing the possible outliers and variability within and between groups.

Boucher, Bigham, et al. (2008) investigated the relationship between performance on declarative memory and lexical knowledge. However, this study touched on what was already stored in the lexicon but did not investigate the relation between declarative memory and the acquisition of new words. Using a word-learning task would help us understand the role (if any) of declarative memory in vocabulary acquisition, a critical area of impairment in language-impaired children with ASD that was addressed in the present dissertation.

4.1.4 Relationships between procedural and declarative memory and language in SLI.

Unlike the case for ASD, there is growing evidence of the roles of procedural and declarative memory in language in SLI, and a number of studies have investigated both memory systems in combination. Accordingly, in this section, after providing a brief summary on the status of procedural and declarative memory in SLI, evidence on the relationship between the two memory systems and language measures is introduced together.

Previous studies suggest poor visual- (Hsu & Bishop, 2014; Lum et al., 2012; Lum et al., 2010; Tomblin et al., 2007) and-verbal procedural memory (Evans et al., 2009; Mayor-Dubois et al., 2012) in children with SLI. However, one trend that is emerging from this literature is that children with SLI show adequate procedural memory under some conditions including more exposure to information (Evans et al., 2009; Tomblin et al., 2007), shorter sequences, and simpler statistical structure (Gabriel et al., 2013).

Findings on declarative memory in children with SLI appear to depend on the type of stimulus and task demands. Specifically, children with SLI show intact visual recognition of previously seen stimuli (e.g., Baird et al., 2010; Lum & Bleses, 2012); however, they show difficulties in tasks that require visual recognition of explored novel objects by hands without being seen (e.g., Kamhi et al., 1984; Montgomery, 1993). Although children with SLI seem to struggle to learn and retrieve verbal information (Baird et al., 2010; Lum et al., 201; Lum & Conti-Ramsden, 2013), the difficulty observed in this area may be due to verbal working memory and language problems, and not declarative memory deficits (Leonard & Weber-Fox, 2012; Lum & Bleses, 2012; Lum et al., 2015).

There is growing evidence on the relationship between procedural memory and phonology and grammar in SLI that supports the procedural deficit hypothesis (Ullman & Pierpont, 2005) by implying that sequence learning deficits in children with SLI could account for most of phonological and grammatical deficits seen in this group. In this vein, Mayor-Dubois et al. (2012) found that compared with a TD group (n = 65, age range 8-12 years), children with SLI (n = 18, age range: 8-14 years) were able to learn alternating 10-item sequence but were less efficient. Moreover, for the SLI group, the scores on the sequence-learning task correlated with the performance on phonological awareness task ($r = .48$, $p < .05$) and rapid automatized naming task ($r = .65$, $p < .01$), but not a grammatical sentence generation task in French. Correlations were not conducted for the TD group. These findings partially congruent with Ullman's (2004) declarative/procedural model: phonological and lexical retrieval were associated with a procedural learning; yet, this association was not found for grammatical impairments.

In a recent study, Mainela-Arnold and Evans (2014) investigated whether statistical sequential learning abilities are associated with the proposed aspects of the acquisition and use of the mental lexicon that rely on procedural memory, such as lexical-phonological access, but not on those aspects of the mental lexicon that are proposed to rely on declarative memory, such as lexical-semantic knowledge. They tested children with SLI and age-matched TD children using artificial language learning task as a measure of implicit procedural learning. Lexical-phonological access was measured using a forward gating task, and lexical-semantic abilities were measured using a word definition task. The gating task investigates children's lexical activations by manipulating the temporal aspect of acoustic-phonetic information children hear. On this task, children hear acoustic chunks (i.e., gates) of words, starting from the beginning and increasing in length and they must guess the word after each gate. Similar ability to learn the artificial language was found in both groups. Children who were poor at learning the artificial language were also poor at managing excess activation of lexical-phonological competitors during the lexical access task (i.e., they had high lexical-phonological accounts). In contrast, learning the artificial language was not a significant predictor of the ability to provide semantically rich word definitions (i.e., high lexical- semantics scores). These findings indicate that procedural sequential memory appears to be crucial to the acquisition of phonological, but not semantic, aspects of the lexicon in children with and without SLI. These findings are consistent with the notion that different brain networks with different learning properties may be associated with the two types of lexical learning: phonology and semantic (Ullman, 2004).

Turning to grammar, Tomblin et al. (2007) investigated the correlation between language (receptive and expressive vocabulary and grammar) and procedural memory as measured on an SRT task in 15-year-old children with SLI (n = 38) in comparison to age-matched TD children (n = 47). *All* participants from SLI and TD groups (N = 85) were organized into two groups based on language scores that were obtained earlier, when participants were in kindergarten. Specifically, in one analysis, two groups were formed based on those who scored either high or low on vocabulary tests (composite score of receptive and expressive vocabulary at a single word level) from both the SLI and TD groups. In the second analysis, two groups were formed based on whether they scored high or low on standardized tests of grammatical ability (i.e., composite score of expressive and receptive grammar). Significant group differences in the rate of learning on the SRT task were found between high and low grammar groups but not high and low vocabulary groups. These results provide evidence linking grammatical (but not lexical) abilities to procedural memory, consistent with the procedural deficit hypothesis (Ullman & Pierpont, 2005). However, a number of methodological artifacts of this study raise questions about the validity of results. First, language scores were taken from the kindergarten phase and correlated to sequence learning after about 10 years, which might not be a realistic comparison and may not represent the role of procedural memory in these children at the stage when they were tested. Second, for correlations between language measures and procedural memory processing, combining the two groups (SLI and TD) who had different abilities in language and memory processing does not provide information on whether the same relationship stands for the SLI group. Similarly, Hedenius et al. (2011) found that poor visual procedural learning as measured on SRT task is specifically associated with concurrent grammatical difficulties in a *combined* sample of school age-children with SLI (n = 31) and TD children (n = 31).

Sengottuvel and Rao (2013) reported a positive correlation between performance on inflectional aspects of grammar (i.e., prepositions and marking tense) and sequence learning performance in a SLI group (n = 17, age range: 8–13 years) but not in age-matched TD group (n = 23). Specifically, the performance on inflectional aspects of language for the SLI group worsened as procedural difficulties increased. However, no correlation was found between derivational aspects of grammar or sentence complexity and sequence learning measure in either the TD or SLI group. The authors interpreted these results as suggesting that procedural deficits affect dependent grammatical operations: non-adjacent operations that require relationships outside the word boundary, such as inflections, make greater demands on sequencing skills.

The relationship between procedural memory and language was not found in other studies. Gabriel and colleagues (Gabriel et al., 2011; Gabriel et al., 2015) reported intact procedural learning as measured on SRT task in 7- to 13-year-old children with SLI in comparison to age-matched TD children, and no correlations were found in the SLI or TD group for any of the language measures (receptive and expressive grammar, phonology, vocabulary as measured by standardized tests). However, as highlighted by the authors, given the small sample (i.e., 16 participants in each group), the results must be treated with caution.

Relationships between declarative memory and language measures were also reported in SLI. For example, Kamhi et al. (1984) investigated the relationship between language measures (expressive and receptive vocabulary and grammar) and performance on haptic-recognition task in 10 children with SLI matched on mental age to 10 TD children. Results showed that children with SLI were significantly poorer than their TD peers on the haptic recognition task. Correlational analyses revealed a particularly strong positive relationship between performance on receptive vocabulary measure (Peabody Picture Vocabulary Test; Dunn, 1965) and the haptic recognition task in the SLI group. For the TD group, the correlation was not conducted because there was very little variability in the children's scores on the haptic recognition task. It was speculated that this relationship was motivated by the symbolic demands of these tasks, implying that a symbolic representational deficit might better explain the receptive language deficit than the expressive one (Kamhi et al., 1984). Once more, the small sample size of groups in this study requires caution in inferring the results.

Finally, Lum et al. (2012) investigated the relationship between visual and verbal declarative memory with receptive and expressive grammar in 10-year-old children with SLI (n = 51) and TD children. Results showed that verbal but not visual declarative memory correlated with vocabulary (composite score of receptive and expressive) in both SLI group ($r = .39$, $p < .05$) and TD group ($r = .48$, $p < .001$), and with grammatical abilities (composite score of receptive and expressive) for only the SLI group ($r =. 31$, $p < .05$). The authors suggested that this correlation could be explained by an increased dependency of children with SLI on their intact declarative memory system, given the found impairment in procedural memory, which is consistent with the procedural deficit hypothesis (Ullman, Pierpont, 2005). These findings suggest that, unlike TD individuals, individuals with SLI may rely on lexical/semantic processing and declarative memory to compensate for impairments at syntactic processing and procedural memory, and that an increased dependence on declarative memory in SLI does not occur for functions that already depend on this system in TD individuals (Ullman & Pullman, 2015).

So far, procedural memory appeared to correlate with performance on phonological-lexical (Mainela-Arnold & Evans, 2014; Mayor-Dubois et al., 2012), grammatical (Hedenius et al., 2011; Tomblin et al., 2007), or vocabulary tests (Evans et al., 2009; Mayor-Dubois et al., 2012). Furthermore, in some reports, when no correlation was found between procedural memory and grammatical measures in SLI (Gabriel et al., 2011; Gabriel et al., 2015; Mayor-Dubois et al., 2012), a correlation rather with declarative memory was reported (Lum et al., 2012). In line with the procedural deficit hypothesis, Lum et al. (2014) suggests that one interpretation of this association between declarative memory and grammar in SLI is that the results reflect compensatory processes of the declarative memory system due to increased involvement of this memory system during childhood. Although the declarative/procedural model of Ullman (2001, 2004) is supported by the findings of a positive relationship between declarative memory and vocabulary (Kamhi et al., 1984), phonology (Mainela-Arnold & Evans, 2014; Mayor-Dubois et al., 2012), or grammar (Hedenius et al., 2011; Tomblin et al., 2007) in children with SLI, it is not supported by the reported relationship between procedural memory and vocabulary in this group (e.g., Evans et al., 2009; Mayor-Dubois et al., 2012).

4.1.5 Purpose of Study 3.

The major purpose of this study was to provide a broad survey of different aspects of language and both procedural and declarative memory in language-impaired children with ASD and children with SLI which directly addresses the etiological overlap debate. Accordingly, the present study had two aims. The first was to identify whether language-impaired children with ASD share similar or different language and memory profiles as their SLI peers who are similar in age and NVIQ. The second aim was exploratory given the sample size restrictions and the language measures used in this study. Specifically, the second aim was to evaluate the possible relationships between language measures and procedural and declarative memory in all groups. Based on the declarative/procedural model (Ullman, 2001, 2004) and previous findings in this area, if the procedural memory plays a role in phonology, a positive relationship between procedural memory and phonology is expected (Boucher & Bowler, 2008; Mayor-Dubois et al., 2012; Ullman, 2004; Ullman & Pierpont, 2005). In addition, if the declarative memory plays a role in receptive vocabulary, a positive relationship between declarative memory and vocabulary is expected (Boucher, Mayes, & Bigham, 2008; Kamhi et al., 1984). Finally, the relationship between the two memory systems and performance on a sentence repetition task, the Recalling Sentences subtest (CELF-IV; Semel et al., 2003) was investigated. Sentence repetition tests are complex linguistic measures that reflect the integrity of language processing systems at many different levels including grammatical skills, speech perception, vocabulary knowledge, and speech production (Klem et al., 2015). In addition, these tasks tap memory processes, specifically the capacity of the episodic memory buffer, which mediates transfer of information from working memory to long-term memory (Repovš & Baddeley, 2006), and to a lesser extent the phonological loop (Alloway, Gathercole, Willis & Adams, 2004).

4.2 Study 3 Method

4.2.1 Participants. The full sample of participant with ASD (*n* = 23) and the participant with SLI (*n* = 16) was described in Study 1-section 2.2.1 and Study 2-section 3.2.1, respectively. However, while the sample of SLI (n = 14) in this study was identical to the sample in Study 2, 14 participants of the ASD sample were selected to match SLI participants on NVIQ, therefore the ASD group is not the same as that in Study 1.

4.2.1.1 Identification of language impairment in participants. As described in Studies 1 and 2, language impairment was determined by scores of at least 1 *SD* below the mean (Conti-Ramsden et al., 2001) on the Recalling Sentences subtest of the Clinical Evaluation of Language Fundamentals, Fourth Edition (CELF-IV; Semel et al., 2003) or on the standardized French adaptation of this subtest: Répétition de phrases, L'Évaluation clinique des notions langagières fondamentales-Version pour francophones du Canada (Wiig et al., 2009).

In the full ASD group (*n* = 23), five children were excluded from the analysis, three participants were minimally verbal and could not be tested on most tasks, and an additional two participants had scores within the normal range on the Recalling Sentences subtest. In addition, two participants with SLI were excluded from the analysis given that they had scores within the average range on the Recalling Sentences subtest. This resulted in a sample of 18 *language-*

impaired participants with ASD (12 English-speaking and 6 French-speaking). Eight participants (five English-speaking and three French-speaking) scored 1 *SD* below the mean, five (three English-speaking and two French-speaking) scored 2 *SD* below the mean, and five (four English-speaking and one French-speaking) scored 3 *SD* below the mean. Moreover, the SLI sample included 14 SLI participants (nine English-speaking and five French-speaking). Eight participants (four English-speaking and four French-speaking) scored 1 *SD* below the mean, four (three English-speaking and one French-speaking) scored 2 *SD* below the mean, and two English-speaking participants scored 3 *SD* below the mean.

4.2.1.2 Identification of participants. For participants with ASD who met criteria for language impairment (n = 18), confirmation of diagnosis was obtained via records of the child's diagnosis, which in Quebec is given by a multidisciplinary team or M.D. See Study 1 section 2.2.1.2 for specific details. For SLI participants, confirmation of a diagnosis of SLI or primary language impairment was obtained via prior clinical diagnostic reports. Participants with SLI did not have a diagnosis of other developmental disorders such as autism or Down syndrome, and they did not have first-or second-degree relatives with an ASD per parent report.

Additionally, screening for ASD symptoms within the study using the Social Communication Questionnaire (SCQ; Rutter et al., 2003) showed that participants in the ASD group met the ASD criteria (scores of 15 or above), while participants in the SLI group, excluding two, did not meet this criterion. These two participants were included in analyses given that ASD was never raised as a concern in their developmental history and they were attending a school specifically for children with non-ASD language difficulties. Participants with SLI did not have a diagnosis of other developmental disorders such as autism or Down syndrome, and they had no first-or second-degree relatives with an ASD via parent report.

4.2.1.3 ***Nonverbal intelligence quotient.*** The language-impaired ASD sample was selected by pairing each ASD participant with a participant with SLI (*n* = 14) of the same dominant language who had a similar NVIQ as measured on the Leiter-3 (Roid, et al., 2013). Participants had NVIQs within or above the average range (*M* = 100, *SD* = 15).

Finally, for an estimate of socioeconomic status we asked parents for information on their highest level of education. Participant characteristics are given in Table 4.1. As shown participants in the ASD and SLI groups did not differ significantly in NVIQ, chronological age, gender, parent level of education, or performance on the recalling sentences task.

Since equal numbers of English-speaking and French-speaking participants of similar NVIQ and chronological age were represented in each of the groups, data was collapsed over dominant language for all analyses.

4.2.2 Procedure.

Language-impaired participants with ASD and participants with SLI were tested on the same tasks described in Studies 1 and 2. The study involved one session that lasted for approximately 2 and half hours in a quiet room either in our university lab or at the participant's home. If needed, testing was administered across 2 days. This was the case for five participants with ASD. All participants were tested on tasks of phonology (phonological awareness and articulation), vocabulary (word learning and receptive vocabulary), procedural memory (serial reaction time task), and declarative memory (intra- and cross-modality recognition tasks).

Table 4.1

Participant Characteristics

	Language-impaired ASD (n = 14)		SLI (n = 14)		
	M (SD)	*Range*	*M (SD)*	*Range*	*p-value
Dominant language (English, French)	9, 5		9, 5		1.00
Chronological age (Y; M)	8 (1; 2)	6 – 9; 9	7; 4 (1; 2)	5; 4 – 9; 1	.16
NVIQ (Leiter-3)	102.86 (9.83)	91 - 123	105.14 (7.67)	93 - 125	.50
Gender (M, F)	11, 3		10, 4		.66
[a] Parent education: University degree	8		7		1.00
SCQ	21.71 (6.41)	15 - 32	10.43 (4.47)	6 - 20	< .001
Recalling Sentences (CELF-IV)	3.71 (2.13)	1 - 6	4.57 (2.17)	1 - 7	.30

Note. [a] Information on parent education was not available for two ASD and three SLI participants. * An alpha level of .05 was used for all statistical comparisons.

4.3 Study 3 Results

Kolmogorov-Smirnov test of normality and histograms were inspected for all measures to determine data distribution and the suitable parametric or nonparametric tests were conducted. Refer to the Result section (2.3) of Study 1 for details.

In this study, error analyses were conducted for articulation given that participants completed all the test items. Error analyses was not conducted for phonological awareness or recalling sentences, given that participants finished different number of test items with a number of participants scoring at floor on these tests, preventing comparable error analyses.

4.3.1 Phonological awareness. The Auditory Analysis Test (Rosner & Simon, 1971) or its validated French version, Test d'Analyse Auditive en Français (Cormier et al., 1995) was used to test phonological awareness. The dependent measure was the total number of correct deletions of phonemes or syllables from spoken words. The minimum score on this task is zero and the maximum possible score is 40 or 42 on the English and the French versions, respectively. Given that the auditory analysis task does not provide normalized scores and the language differences between the English and French participants, *z*-scores were calculated of the raw scores of correct phoneme/syllable omission for participants in each language group (English vs. French) based on the mean and standard deviation of the full sample of the TD participant (N = 45) in that language (English speaking n = 25, French speaking n = 20).

Although children with ASD (M = -.57, SE = .34) had higher correct phoneme or syllable deletion scores than children with SLI (M = -1.12, SE = .24), results on independent *t*-test showed that the difference was not significant, $t(26)$ = 1.33, p = .2, r = .25 (Figure 4.1).

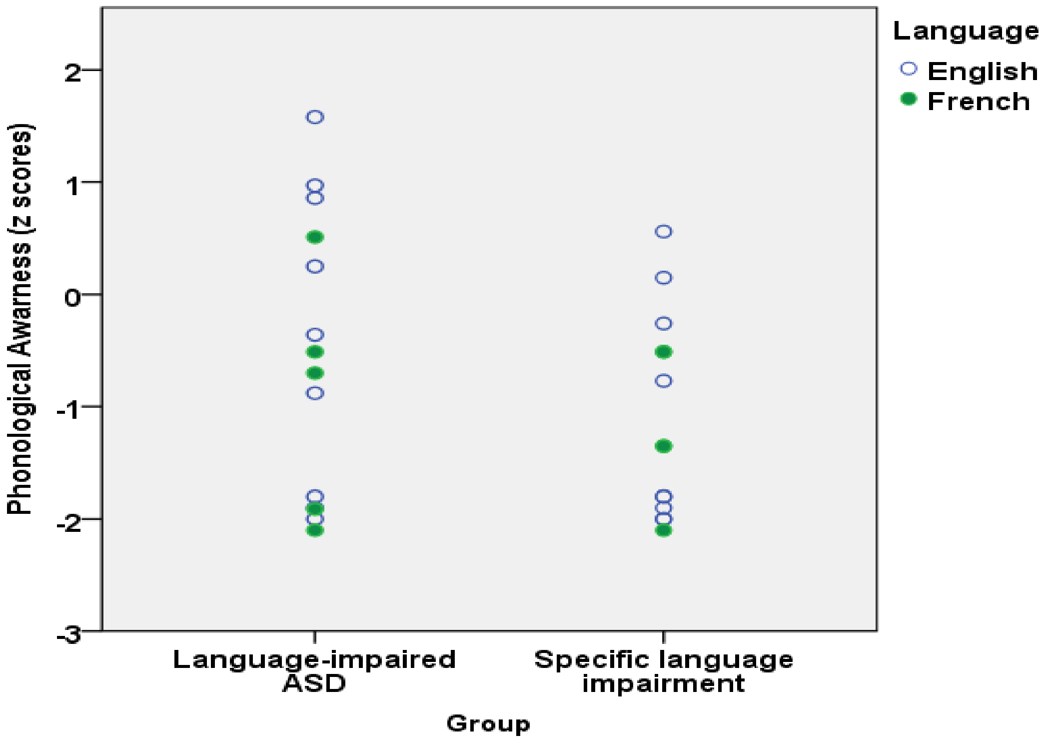


Figure 4.1. Performance on the phonological awareness task by group and language. Phonological awareness was assessed by the Auditory Analysis Test (Rosner & Simon, 1971) in its English (open circles) or French (closed circles) version.

4.3.2 Articulation. Articulation was assessed using the sounds-in-words subtest of the Goldman-Fristoe Test of Articulation; Second Edition (Goldman & Fristoe, 2000) or Test de Dépistage Francophone de Phonologie (Rvachew et al., 2012). The dependent measure was the percent of correct consonants (PCC; Shriberg & Kwiatkowski, 1982). One participant in the ASD group was excluded from the analysis because she was minimally verbal with unintelligible speech and could not be tested on this task.

To compare the groups, the PCC score for each participant was converted into a *z* score using the mean and standard deviation of the full sample of the TD participants in the respective language (English speaking *n* = 25, French speaking *n* = 20). Mann-Whitney *U*-test showed that the ASD group (*Mdn* = 0) and SLI group (*Mdn* = -.17) were not significantly different in their performance on the articulation measure, $U = 86.5$, $z = -.22$, $p = .83$, $r = -.04$.

In addition, the errors on all the consonant sounds were reported and divided into three types in each group, as directed in Goldman-Fristoe Test of Articulation (Goldman & Fristoe, 2000): substitution, deletion, and distortion. Two participants with ASD and two participants with SLI had no errors and were excluded from the analysis leaving a subgroup of 12 participants in each group. Mann-Whitney *U*-tests showed that groups did not significantly differ on any of the articulation errors types, see Table 4.2.

Table 4.2.

Articulation Errors Comparisons between Groups

	Language-impaired ASD (n = 12)	Specific language impairment (n = 12)	
Type of errors	Mean (*SD*)	Mean (*SD*)	*p*-value (*r*)
Substitution	.51 (.35)	.50 (.34)	.91 (.02)
Deletion	.27 (.28)	.33 (.34)	.77 (.06)
Distortion	.22 (.31)	.18 (.20)	.88 (.01)

4.3.3 Receptive Vocabulary. The dependent measure was the standard score of the Peabody Picture Vocabulary Test (Dunn &Dunn, 2007) in its English or French standardized version. The standard scores of the ASD group (*Mdn* = 84, range = 59 - 113) were lower than the standard scores of the SLI group (*Mdn* = 91.5, range = 76 - 124). However, the Mann-Whitney

U-test demonstrated that the difference was not statistically significant, $U = 58.5$, $z = -1.82$, $p = .07$, $r = -.34$. Figure 4.2 represents performance per language on the receptive vocabulary task.

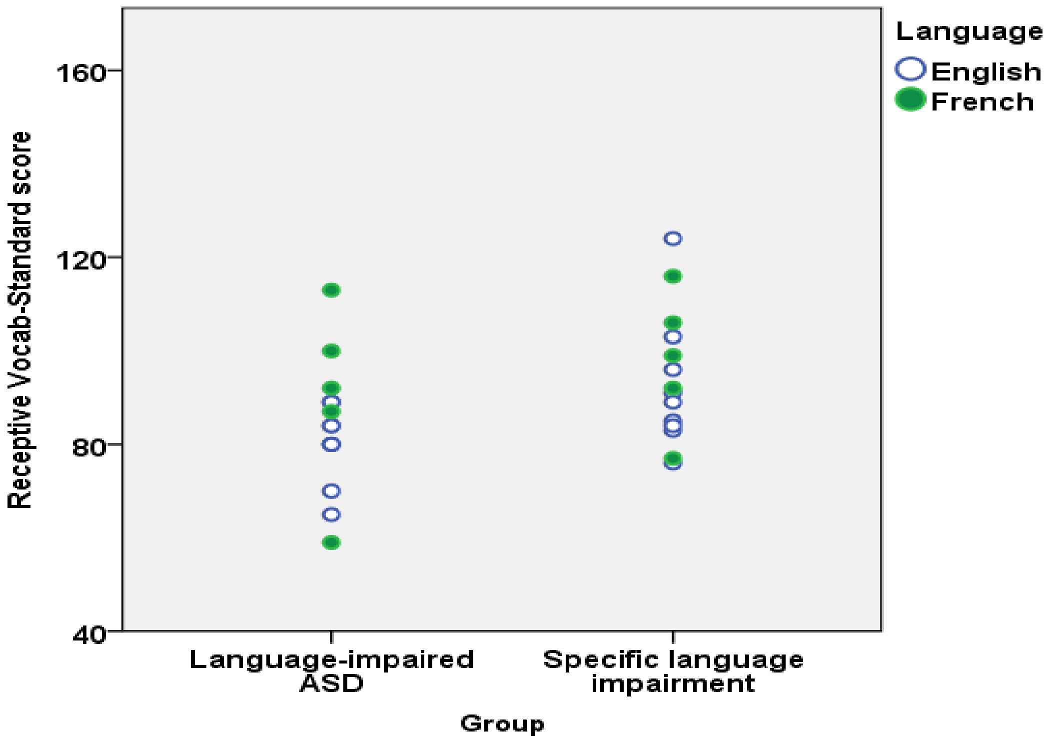


Figure 4.2. Performance on the receptive vocabulary task by group and language. Receptive vocabulary was assessed by the Peabody Picture Vocabulary Test in its English (open circles) or French (closed circles) version. The data points represent the standard score of each participant on this test.

4.3.4 Word learning. The dependent variable in the word-learning task was the number of trials where a participant selected the correct object, with scores ranging from 0 to 2 for each testing phase (i.e., brief- and longer-delay).

The order of presentation of the two labels and stimulus sets, A and B, was counterbalanced among participants. Chi-square tests showed that order had no influence on performance. Precisely, in the ASD group, similar proportions of participants who received trial A or trial B first showed no learning, 1 word learning, and 2 word learning in the brief- delay phase, $p = .10$, *Fisher's Exact Test*, as well as the longer-delay phase, $p = 1.00$, *Fisher's Exact Test*. Similar results were found in the SLI group in the brief-delay phase, $p = 1.00$, *Fisher's Exact Test*, as well as the longer-delay phase, $p = .50$, *Fisher's Exact Test*.

a. Brief-delay phase. A chi-square test revealed that performance on the word learning with brief-delay phase was similar in groups, $p = .36$, *Fisher's exact test, Cramer's V=. 31*. Table 4.3 displays performance on word learning with brief delay.

Table 4.3.

Word Learning Task: Brief Delay Performance: Number of Participants in each Group Who Learned 0, 1, or 2 Words

Number of words learned	Group		Total
	Language–impaired ASD	Specific language impairment	
0	2	0	2
1	4	3	7
2	8	11	19
Total	14	14	28

b. Longer-delay phase. A chi-square test showed that groups were similar in their performance on word learning with longer delay, $p = 1.00$, *Fisher's exact test, Cramer's V*= .10. In addition, fewer participants in both groups were able to identify the two labels and more participants showed no learning of either label in comparison to the brief-delay phase. Table 4.4 demonstrates performance on word learning with longer delay.

Table 4.4.

Word Learning Task: Longer Delay Performance: Number of Participants in each Group Who Learned 0, 1, or 2 Words

Number of words learned	Group		Total
	Language–impaired ASD	Specific language impairment	
0	7	7	14
1	4	3	7
2	3	4	7
Total	14	14	28

4.3.5 Procedural memory. This memory system was assessed on the serial reaction time (SRT) task. The key comparisons of interest in this task were 1) whether *sequence learning scores (i.e.,* [Block 4 - Block 5] ÷ [Block 4 + Block 5]) differed between groups and 2) whether the RTs were significantly decreased on the fifth block (final sequence block) relative to the fourth (final random block) block.

Handedness was similar in the ASD group (right handed = 11, left handed = 3) and the SLI group (right handed = 11, left handed = 3), $p = 1.00$, *Fisher's exact test*, Cramer's $V = 1.00$. In addition, Mann-Whitney *U*-tests demonstrated that the number of errors in block 4 and 5 in the ASD group (*Mdn* = 3.5, range = 0 - 22) and the SLI group (*Mdn* = 4.5, range = 0 - 20) were not significantly different, $U = 82$, $z = -.74$, $p = .47$, $r = -.14$.

Results of Mann-Whitney *U*-tests showed that the *sequence learning score* in the ASD group *(Mdn* = .05) was significantly lower than in the SLI group (*Mdn* = .18), $U = 52.5$, $z = -2.09$, $p = .04$, $r = -0.4$, demonstrating a larger difference in response to sequence vs. random blocks in the SLI group than the ASD group. Furthermore, Wilcoxon signed-rank tests showed no significant difference in responses between block 5 (*Mdn* = 935.80) and block 4 (*Mdn* = 886.25) in the ASD group, $T = 30$, $p = .17$, $r = -.27$, while the SLI group showed significantly faster responding in block 5 (*Mdn* = 669.3) than block 4 (*Mdn* = 959.85), $T = 0$, $p < .001$, $r = .88$. These results indicate that the ASD group did not learn the sequence while the SLI group did. Figure 4.3 represents the mean of responses of each group on the five blocks.

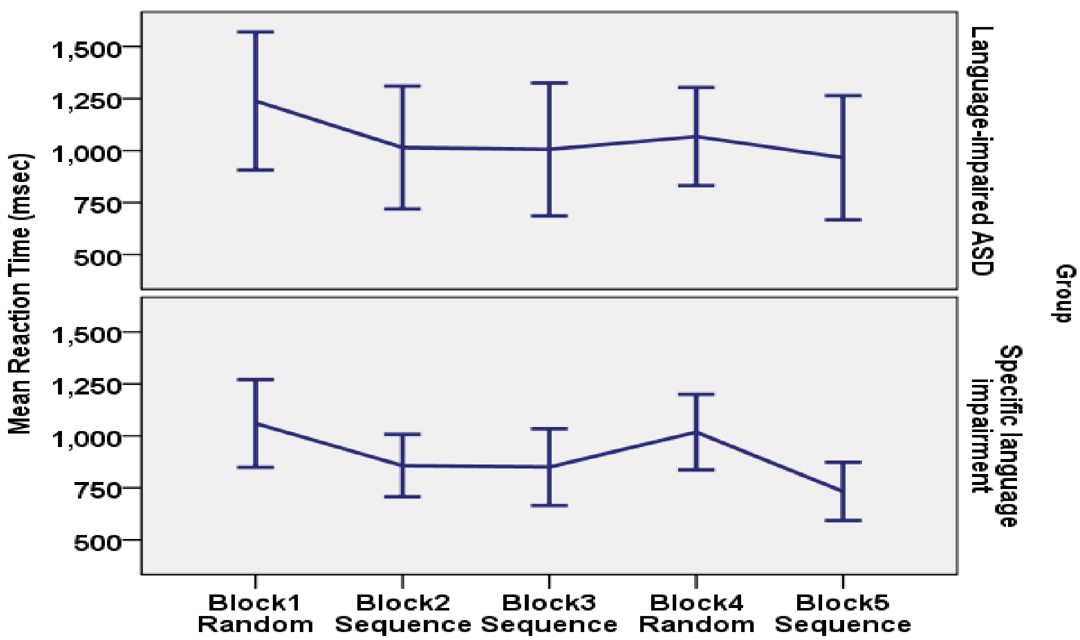


Figure 4.3. Performance of groups on the SRT task. Data points indicate the mean reaction time per block of 40 trials. Error bars represent standard error of the mean. Sequence learning is indicated by significantly faster responses on block 5 than block 4.

After completing the SRT task, participants were asked to show the pattern on the serial response box providing a measure of explicit knowledge of the sequence. Similar proportions of participant with ASD (5 of 14) and participants with SLI (4 of 14) showed explicit knowledge of the sequence and were able to recreate the sequence they had learned, p = 1.00, *Fisher's Exact Test*, Cramer's V = .08. In addition, Mann-Whitney U-tests showed that in the ASD group, participants who demonstrated explicit knowledge of the sequence (*Mdn* = .13) had significantly higher *sequence learning scores* than participants who did not (*Mdn* = .01), U = 6.5, z = 2.13, p = .03, r = .57. Similarly, in the SLI group, participants who indicated explicit knowledge of the sequence (*Mdn* = .24) had significantly higher *sequence learning score* than participants who did not indicate the explicit knowledge of the sequence (*Mdn* = .12), U = 3, z = 2.41, p = .02, r = .64. Figure 4.4 demonstrates the *sequence learning scores* of participants who had explicit knowledge of the sequence as well as the participants who did not in each group.

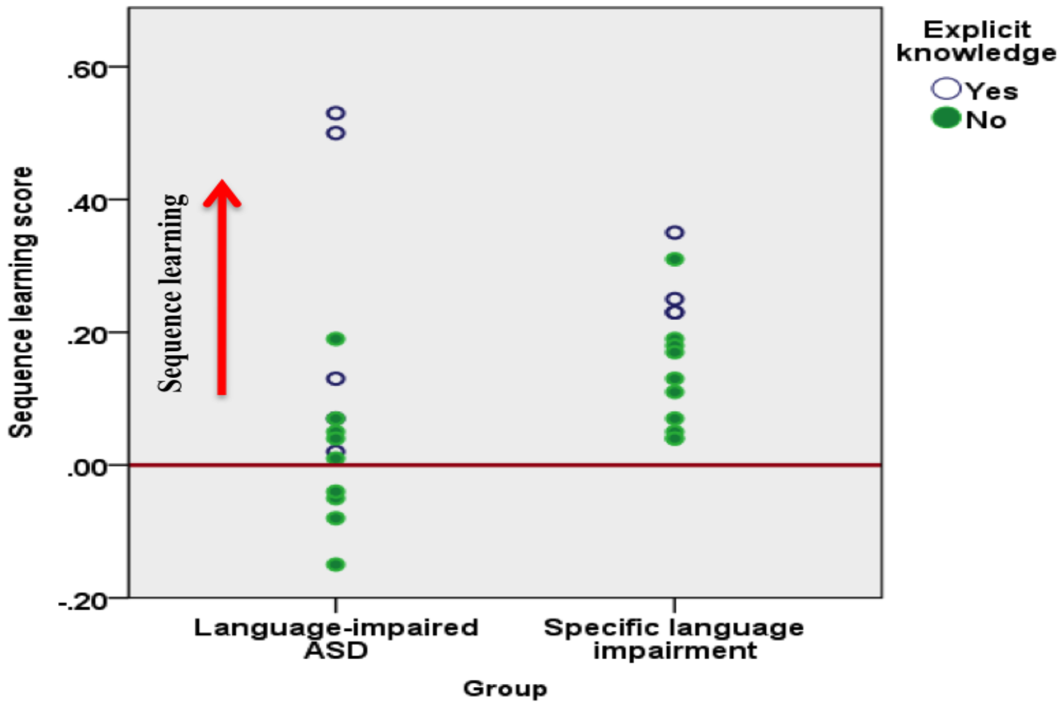


Figure 4.4. Sequence learning scores for language-impaired ASD and SLI groups who showed explicit knowledge (open circles) and those who did not (closed circles). Sequence learning scores above 0, indicated by the red line, demonstrate implicit learning of the sequence. Results indicated that only participants who showed a high degree of implicit learning also showed explicit knowledge of the sequence at the end of the task.

4.3.6 Declarative memory. Declarative memory was measured on two tasks of visual recognition, the intra- and cross-modality recognition tasks. The presentation order of the two recognition tasks was counterbalanced among participants. Mann-Whitney *U*-tests demonstrated that in the ASD group, no significant difference in scores on the intra-modality task, $U = 22.5$, $z = -.2$, $p = .84$, $r = -.05$, or cross-modality task, $U = 12$, $z = -1.58$, $p = .11$, $r = -.42$, between participant who received the intra-modality task first and participant who received cross-modality task first. Similarly, in the SLI group, scores did not differ by presentation order for the intra-modality, $U = 24$, $z = 0$, $p = 1$, or cross-modality task, $U = 15$, $z = -.88$, $p = .38$, $r = -.24$.

a. Intra-modality recognition. Participants were required to visually identify at least 3 out of 4 familiar objects in training to proceed to the testing phase. Three out of 14 participants in the ASD group required additional training because they either said "yes" or "no" to all presented objects in the testing phase, while none of the participants in the SLI group required additional training.

The total possible score for intra-modality testing was 12, in which 1 score was gained for identifying a target object as being seen before or a distracter as being novel. Mann-Whitney *U*-tests showed that the difference in scores of the ASD group (*Mdn* = 9) and the SLI group (*Mdn* = 12) was marginally significant with medium effect size, $U = 58.5$, z = -1.98, $p = .05$, $r = -.37$.

b. Cross-modality recognition. Three participants with ASD and four participants with SLI required additional training with familiar objects to proceed to testing of novel objects. However, one participant with SLI was excluded from the analysis given that she said "yes" to all testing novel objects in the testing phase.

The maximum score for cross-modality testing was 12, in which 1 point was gained for correctly identifying a target object as being previously encountered haptically or identifying distractors as being novel. Results on independent *t* test demonstrated that the scores of the ASD group ($M = 9.43$, $SE = .57$) and the SLI group ($M = 9.38$, $SE = .42$) were not significantly different, $t(25) = .06$, $p = .95$, $r = .01$. Figure 4.5 shows the performance in each group on the intra- and cross-modality-recognition tasks.

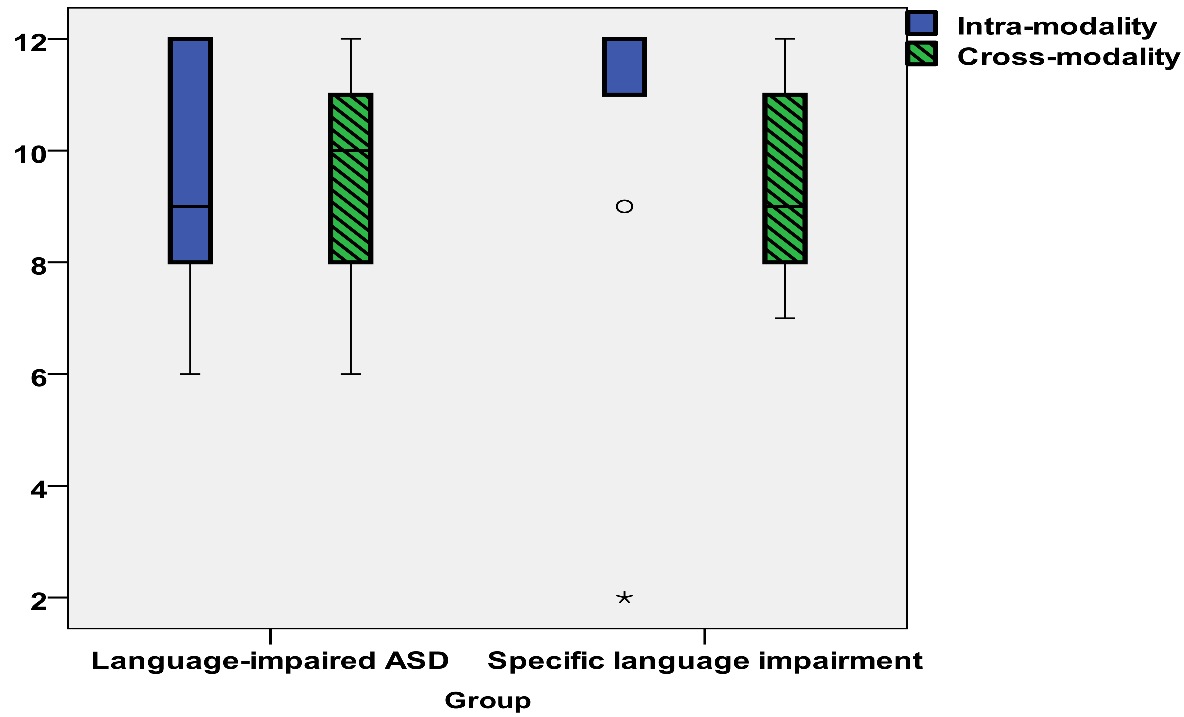


Figure 4.5. Performance of groups on the declarative memory tasks. Clear bars demonstrate performance on the intra-modality recognition task and lined bars show performance on the cross-modality recognition task. Error bars represent the minimum and maximum scores of correctly identified novel objects in each group (score range: 0 - 12).

4.3.7 Relationships between procedural and declarative memory and language.

The next set of analysis evaluated the hypothesized relationships between procedural memory and phonology (Gupta, 2011; Mainela-Arnold, 2014; Ullman, 2004) on the one hand and declarative memory and vocabulary (Duff & Brown-Schmidt, 2012; Ellis; Gupta, 2011, Ullman, 2004) on the other. Analyses included the data of participants from the three groups described in detail in the previous set of studies: 45 TD participants (6 to 9; 10 years old), 18 language-impaired children with ASD (6 to10 years old) and 14 children with SLI (5; 4 to 9; 1

years old). Given the relatively small sample size in the ASD and SLI groups, nonparametric correlations were conducted to assess the relationship between memory systems and language abilities. Specifically, Kendall's tau-b tests (*T*) were reported for correlations between continuous variables and Kruskal-Wallis tests (*H*) for correlations between categorical independent variables and continuous dependent variables (Field, 2009).

a. Procedural memory and phonology.

The *sequence learning score* was used to reflect procedural memory processing. For phonological abilities, a composite score was calculated by adding the *z* score on the phonological awareness measure (number of correct deletions of phonemes or syllables) and the *z* score on the articulation measure (percent of consonants correct) for each participant. *Z* scores for the three groups were calculated based on the mean and standard deviation of the full sample of the TD group in the respective language (English speaking $n = 25$, French speaking $n = 20$). As seen in Figure 4.6, there was no relationship between the *sequence learning scores and* composite phonology score in any of the groups. These results were confirmed by non-parametric correlations (Kendall's tau-b): TD $T = -.03$, $p = .81$, ASD $T = -.064$, $p = .93$, SLI $r = -.13$, $p = .51$.

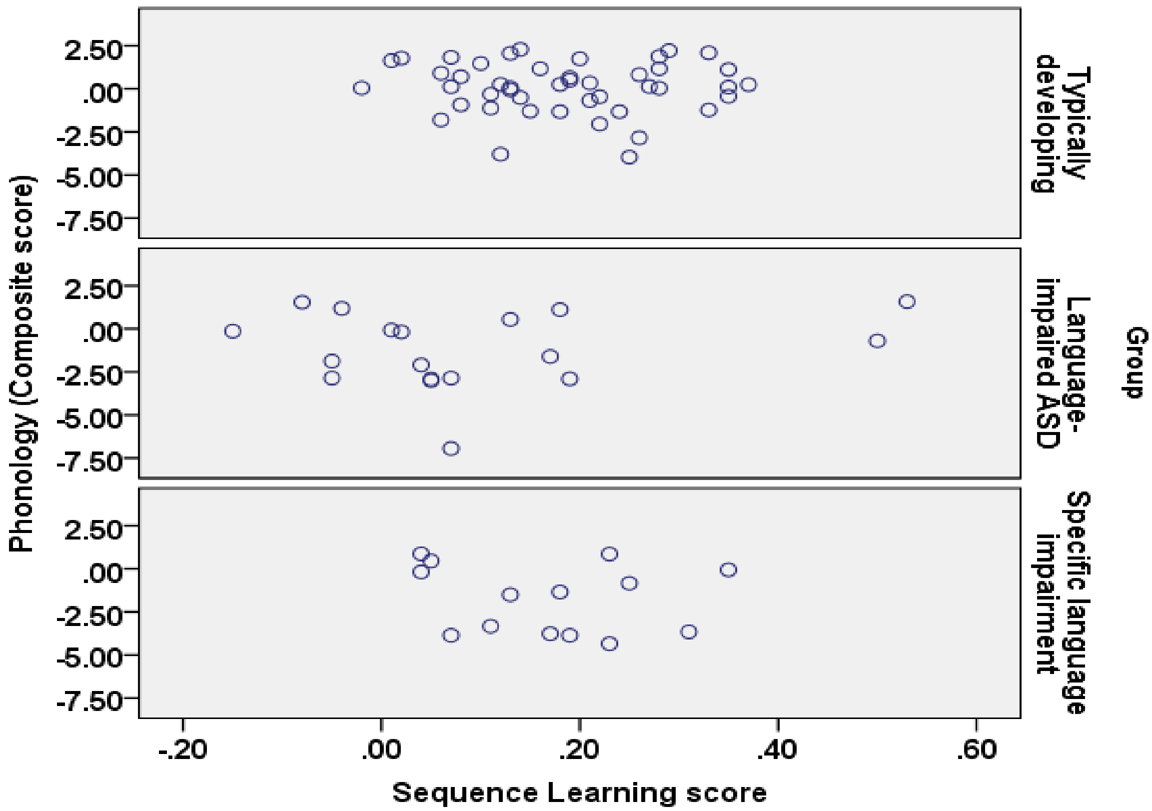


Figure 4.6. Relationship between procedural memory and phonology in groups. Sequence learning score was used as a measure of procedural memory. Higher sequence learning scores reflect faster responses to the sequence block 5 in comparison to the random block 4.

b. Declarative memory and vocabulary.

First, the relationship between performance on declarative memory and receptive vocabulary test (PPVT-IV; Dunn & Dunn, 2007) was examined using scatter plots for each group. For declarative memory, a composite score was computed by adding the score of intra- and cross-modality tasks of each participant resulting in a possible score range between 0 and 24. The raw scores on the receptive vocabulary test in its English or French version were used to demonstrate the variability in scores. Figure 4.7 demonstrates a trend toward a positive relationship between declarative memory and receptive vocabulary in the SLI group but not the other two groups. That is, in the SLI group, children who had higher ability to visually recognize the novel objects tended to have higher scores on receptive vocabulary. Nonparametric correlations confirmed these results. Precisely, no correlation was found between declarative memory and receptive vocabulary in the TD group, $T = .01$, $p = .94$, or the ASD group, $T = .27$, $p = .13$, while a trend toward a positive correlation was found in the SLI group, $T = .34$, $p = .09$.

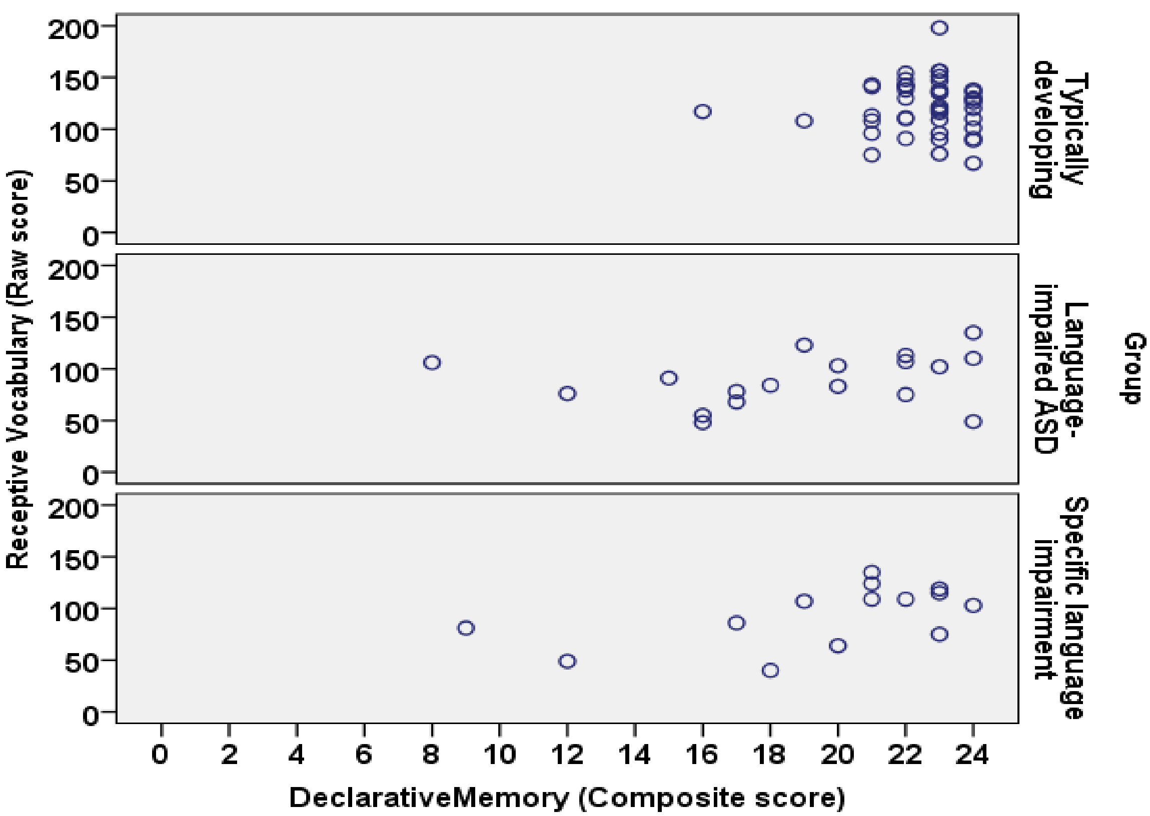


Figure 4.7. Relationship between declarative memory and receptive vocabulary in groups.

Second, the relationship between declarative memory and word learning was examined. Scores from the longer-delay phase of the word-learning task were used because variability in performance was more apparent in this phase than in the brief-delay phase. Possible scores ranged between 0 and 2. Five participants in the TD group had missing data given that they were administered a different version of the word learning task, resulting in a sample of 40 participants in the TD group.

Mean composite scores from the declarative memory task were compared for participants responding in each of the three word learning response categories as shown in table 4.5. In the TD group, the mean scores of declarative memory were similar among children with different scores on the word-learning task. In contrast, there was a trend toward a positive relationship between performance on declarative memory and the word-learning task in the ASD group: participants who had higher scores on declarative memory learned 2 words, while those who had lower scores did not learn any of the words. Finally, in the SLI group, there was an unexpected pattern that differed from the TD and ASD groups. That is, children who had the highest scores on declarative memory showed no word learning, those who had the 2nd highest scores learned 2 words, while those who had lowest scores learned 1 word. Kruskal-Wallis Tests showed no effect of declarative memory on word learning in the TD group, $H(2) = 3.07$, $p = .22$, while a trend toward a significant effect in both the ASD group, $H(2) = 4.91$, $p = .09$, and SLI group $H(2) = 4.69$, $p = .09$.

Table 4.5.

Relationship between Declarative Memory and Word Learning

	Typically developing (N = 40)		ASD (N = 18)		SLI (N = 14)	
	Declarative memory composite score					
	Mean (SD)	Range	Mean (SD)	Range	Mean (SD)	Range
No word learned	22.27 (1.19)	19 - 23	17.2 (4.73)	8 - 23	21.57 (1.13)	20 - 23
1 word learned	22.4 (1.14)	21 - 24	19.6 (3.2)	16 - 24	15 (5.29)	9 - 19
2 words learned	22.92 (1.18)	21 - 24	22.5 (22.5)	20 - 24	19.25 (5.5)	12 - 24

c. Procedural and declarative memory and recalling sentences.

No relationship was found between the *sequence learning scores* and the raw scores on the Recalling Sentences subtest (CELF-IV; Semel et al., 2003), in its English or French version, in any of the groups, as shown in figure 4.6. Nonparametric correlations confirmed these results: TD $T = .05$, $p = .63$, ASD $T = .01$, $p = .93$, SLI $T = .07$, $p = .74$.

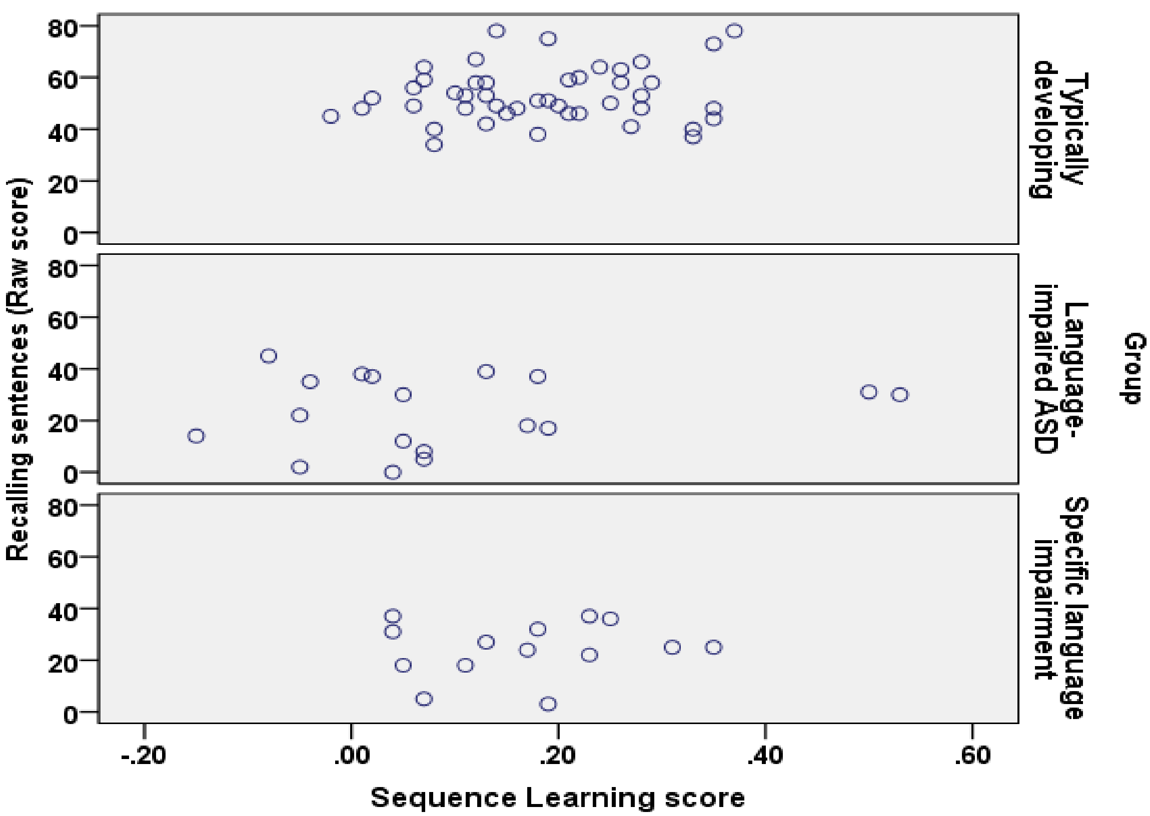


Figure 4.8. Relationship between procedural memory and recalling sentences in groups. Sequence learning score was used as a measure of procedural memory. Higher sequence learning scores reflect faster responses to the sequence block 5 in comparison to the random block 4.

There was a trend toward a positive relationship between declarative memory composite scores and raw scores on the recalling sentences in the ASD group but not the other two groups (figure 4.7). In the ASD group, children who had higher ability to visually recognize the novel objects tended to have higher scores on recalling sentences. Nonparametric correlations confirmed these results. Specifically, significant positive correlation was found between the two measures in the ASD group, $T = .39$, $p = .03$, while no correlation was found in the TD group, $T = .01$, $p = .93$, or the SLI group, $T = .12$, $p = .58$.

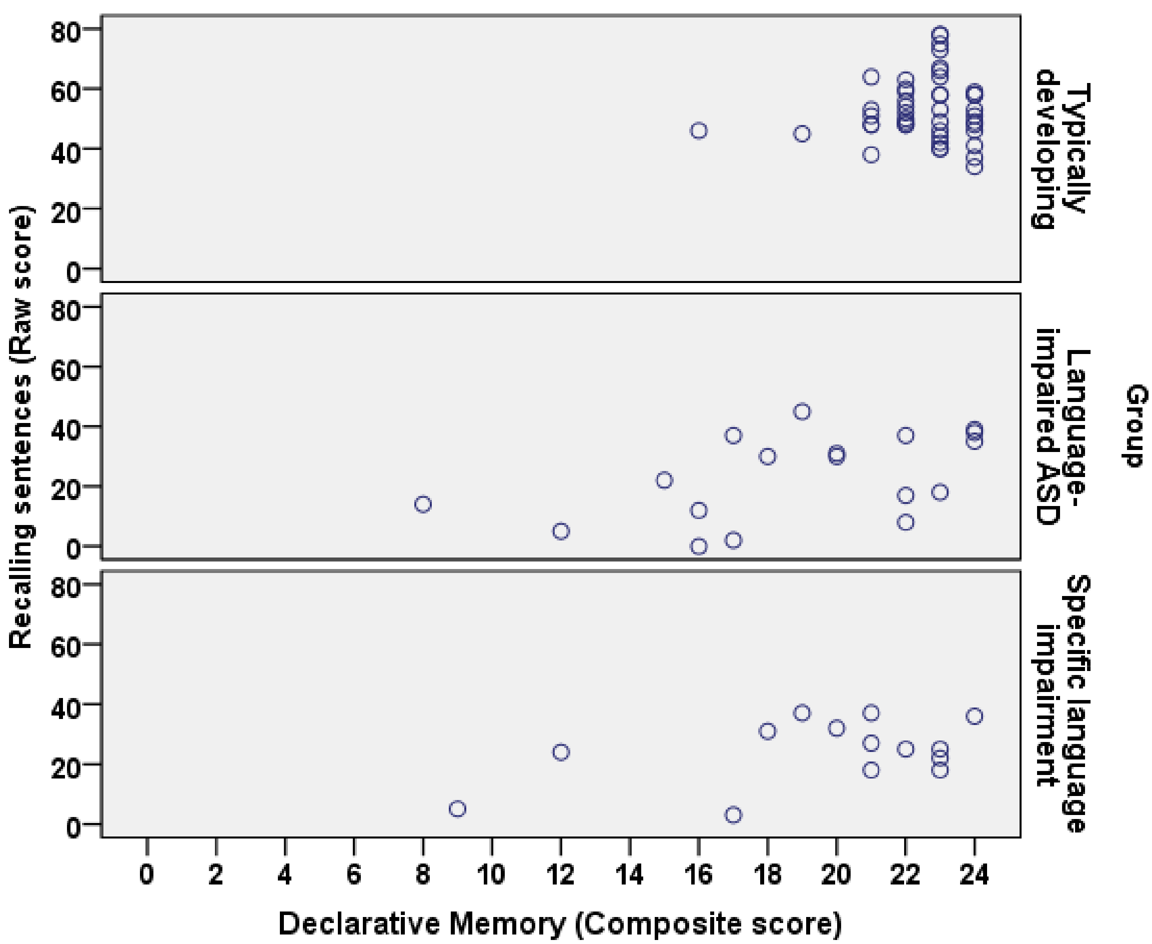


Figure 4.9. Relationship between declarative memory and recalling sentences in groups. A composite score was computed for declarative memory by adding the score of intra- and cross - modality tasks of each participant.

4.4 Study 3 Discussion

The present study had two major aims. First, to investigate language and memory profiles in language-impaired children with ASD as compared to SLI children. Second, to investigate possible relationships between language measures and procedural and declarative memory in each group. Groups were similar in terms of their age, NVIQ scores, gender, their parent's education level, and presence of language impairment as defined by scores at least 1*SD* below the mean on the Recalling Sentences subtest of the CELF-IV (Semel et al., 2003).

4.4.1 Phonology. The current study demonstrated that the ASD and SLI groups were similar in their phonological abilities. Specifically, groups showed similar performance on the phonological awareness test that required phoneme or syllable deletion and on the articulation test that examined consonant articulation skills at a single word level.

Among the studies that directly investigated language in these two disorders, phonological processing has been investigated on nonword repetition tasks and there has been agreement on similar overall performance in language-impaired children with ASD and children with SLI (Botting & Conti-Ramsden, 2003; Taylor et al., 2014). However, some researchers showed that there are differences between the two disorders in the errors made on nonword repetition tasks (Williams et al., 2008). Accordingly, in addition to the overall performance on the articulation measures, the current study examined the articulation errors in the two groups. Specifically, the errors on all the consonant sounds were reported and divided into three types in each group: substitution, deletion, and distortion. Results showed that children with ASD and children with SLI did not show different patterns of articulation errors.

Some researchers proposed that articulation deficits in a subgroup of children with ASD (Rapin et al., 2009; Tager-Flusberg et al., 2005) and children with SLI (Goffman, Maassen, &

Van Lieshout, 2010) can be explained by apraxia of speech. Although in the present study no information on whether the children in the ASD group and the SLI group were diagnosed with apraxia of speech or speech motor difficulties, the results highlight the importance of further investigation of the possible causes of articulation impairment in the two disorders and whether they stem from accompanying disorders.

4.4.2 Vocabulary. Overall, the children with ASD had lower receptive vocabulary scores in comparison to their peers with SLI. However, the difference was not statistically significant with small effect size, indicating similar difficulties in receptive vocabulary in groups. Moreover, groups were similar in their performance on the word-learning task that involved identifying a labeled novel object in different color after brief and long delay.

Comparable to the current finding on receptive vocabulary, previous studies reported that, as a group, language-impaired children with ASD and children with SLI were not different in their receptive language impairment on multiple measures (Lloyd et al., 2006; McGregor et al., 2012; Whitehouse et al., 2008; Williams et al., 2014) including the Peabody Picture Vocabulary Test (PPVT) used in the current study (e.g., McGregor et al., 2012). However, Mawhood et al. (2000) reported that although impaired receptive vocabulary on the PPVT was found in both language-impaired adults with ASD and adults with SLI, it was more apparent in the ASD group. Specifically, in adulthood, over two thirds still had a level of language comprehension that was below a 10-year level, as compared to just fifth of the SLI group. In the current study, although differences in receptive vocabulary were not significant between groups, similar observations were found in younger children. Specifically, 6 of 14 children in the ASD group scored within the normal range and the other 8 scored below the normal range in 1 or 2 *SDs*, while in the SLI group, 10 of 14 children were within or above the normal range and 4 were

1 *SD* below the range. Together, the current study and previous studies on ASD (Kjelgaard & Tager-Flusberg, 2001; Rapin & Dunn, 2003; Rapin et al., 2009) and SLI (Conti-Ramsden et al., 1997; Rapin & Allen, 1987; World Health Organization, 1992) indicate that delayed receptive vocabulary is not a universal characteristic of language impairment in children with ASD or children with SLI.

In the only previous study that investigated novel noun learning in these disorders, Gladfelter (2014) found that children with ASD and mixed language abilities and children with SLI were similar to TD children in their ability to fast-map novel nouns to a referent picture after the picture was labeled seven times, regardless of the semantic cues presented. The present study confirms the similar ability to learn novel words in language-impaired children with ASD and age- and NVIQ-matched children with SLI using different stimuli.

Finally, it has been suggested that similarities in structural language across these two disorders are more apparent during preschool, while at school age the typical profile in each disorder is predominantly different, despite some areas of overlap (Williams et al., 2008). The current findings diverge with this suggestion by showing that school-age language-impaired children with ASD and age- and NVIQ-matched children with SLI have similar language profiles. Specifically, groups showed similar performance on recalling sentences, phonological awareness, articulation, receptive vocabulary, and word learning. These results could be due to sampling differences between the current study and previous studies. Longitudinal studies that directly compare multiple aspects of language in children with ASD and children with SLI are required to provide an accurate picture on similarities in the two disorders over time. In addition, to address the argument that language similarities in language-impaired children with ASD and children with SLI are superficial (Williams et al., 2013), future studies should compare the two disorders on specific tasks of linguistic knowledge with the focus on the fine details of types of errors and language complexity (e.g., inflection, derivation, syntactic structures, or comprehension versus production), in which differences might be observed between the two disorders.

4.4.3 Procedural memory. This is the first study to examine language-impaired ASD group and SLI group on procedural memory. Although the groups showed similar ability to perform the SRT task as indicated by the similar number of errors made in block 4 and 5 in groups, the ASD group did not show sequence learning, while the SLI group did. It is important to note that all children with SLI showed sequence learning. In addition, similar proportion of children in both groups (ASD: 5 of 14 children; SLI: 4 of 14 children) showed explicit knowledge of the sequence as indicated by their ability to correctly reproduce the sequence on the response box. In both groups, the children with explicit knowledge of the sequence had the highest sequence learning scores. In the ASD group, a pattern occurred in which the children who showed no learning of the sequence as indicated by their negative sequence learning score (i.e., they were faster on random block than on sequence block) had no explicit knowledge of the sequence while those with the highest sequence learning scores were the ones who showed explicit knowledge. However, it is not a definite relationship between sequence learning and explicit knowledge, given that some children who did not show explicit knowledge still showed sequence learning in the two groups. Accordingly, it seems that children learned the sequence implicitly and with more exposure to the sequence, some of them acquire sequence knowledge that enables them to be faster in anticipating the sequence. These results are elaborated on under General Discussion.

4.4.4 Declarative memory. The ASD group showed poorer ability to recognize previously seen novel objects (intra-modality recognition) in comparison to their SLI peers, yet the groups were similar in their poor recognition of explored-by-hands novel objects (cross-modality recognition).

The current results on intra-modality recognition resemble previous findings of studies that investigated visual recognition in each of these disorders separately in comparison to TD children. Those studies showed deficits in visual recognition in language-impaired children with ASD as compared to TD children using different tasks that involved visual-to-visual recognition (i.e., Barth et al., 1995; Boucher, Bigham, et al., 2008; Dawson et al., 1998). Regarding SLI, intact visual recognition has generally been reported in this group using standardized tasks (Baird et al., 2010; Lum & Bleses, 2012; Lum et al., 2010), which was also confirmed in the current study.

Haptic-visual recognition has not been previously investigated in language-impaired children with ASD. Although many individuals with ASD show hyper- or hypo-reactivity to sensory input or unusual interest in sensory aspects of the environment (APA, 2013), experimental studies of tactile perception in ASD are scarce. The few studies that have investigated haptic recognition in language-normal individuals with ASD have demonstrated normal or even superior ability in comparison to TD individuals. In line with current findings, previous studies on SLI showed poorer recognition of pictorial representations of novel shapes explored by hands in this group in comparison to a TD group (Kamhi, 1981; Kamhi et al., 1984; Montgomery, 1993). Difficulties in haptic-visual recognition could be due to deficits in the perception of local features, perhaps due to tactile hypersensitivity (Nakano et al., 2012) or fine and gross motor difficulties that limit children's ability to explore the novel objects in children with ASD (Baird et al., 2006; Ming, Brimacombe, & Wagner, 2007) or children with SLI (Hill, 2001). Given that motor skills were not examined in the current dissertation, this remains open to investigation. Finally, It is likewise possible to argue that Haptic-visual recognition task could have been solved to some degree through linguistic mediation by attaching a verbal label or description to each object, which may have placed the children in both groups at a disadvantage. However, similar approach was employed in the intra- and cross-modality recognition tasks. Accordingly if language has a role, then children with SLI should have shown impairment on both of the recognition tasks, not only the one that required haptic-visual recognition.

In conclusion, the current study was innovative in comparing language-impaired children with ASD and children with SLI in terms of their performance on both language and memory measures. The current results indicate that the children with ASD shared the language profile observed in age- and NVIQ- matched children with SLI, yet, the two groups differed in their memory profiles. Specifically, the ASD group performed similarly to the SLI group on phonological awareness as measured by a phoneme or syllable deletion task and word picture naming measure of consonant articulation skills. In addition, groups were similar on receptive vocabulary and a word-learning task that required identifying a labeled object in different color with a short and long delay. Turning to memory, compared to the SLI group, the ASD group had poorer procedural memory as measured on a simple sequence learning task and poorer declarative memory as measured on a visual recognition task of previously seen objects. Groups did not significantly differ on the more difficult declarative memory task that involved visual recognition of novel objects explored by hands.

4.4.5 Relationships between procedural and declarative memory processing and language measures. The current study is the first to investigate the relationship between procedural and declarative memory and language ability in language-impaired ASD (*n* = 18), SLI (*n* = 14), and TD (*n* = 45) groups.

First, the relationship between procedural memory (*sequence learning score*) and phonology (composite score of phonological awareness and articulation *z* scores) was investigated. No relationship was found between procedural memory and phonology in any of the groups. Previous studies that reported a relationship between procedural memory and language used linguistic tasks that involved learning a new skill or a measure of grammar. For example, a positive relationship was found between procedural memory and language acquisition (i.e., passive voice) in 4- to 6-year -old TD children (Kidd, 2012). Moreover, Mainela-Arnold and Evans (2014) indicated that procedural learning as measured on artificial language learning task predicted lexical-phonological abilities (i.e., forward gating task) but not lexical-semantic knowledge (i.e., word definition task) in children with and without SLI. Mayor-Dubois et al. (2012) indicated a relationship between procedural memory and phonological awareness in 8-to 14-year-old children with SLI; however, the specific phonological awareness task used in analyses was not described. Most of the previous studies that demonstrated the role of procedural memory as measured by SRT tasks in language in SLI involved both receptive and expressive grammar on standardized tests (Hedenius et al., 2011; Tomblin et al., 2007), yet other studies failed to replicate this finding using standardized receptive or production tasks of grammar (Gabriel et al., 2011; Gabriel et al., 2015; Mayor-Dubois et al., 2012). Methodological differences can probably explain the differences between these results. That is, the studies that found a relationship used a composite score of both receptive and expressive language (Hedenius et al., 2011; Tomblin et al., 2007) and they combined the SLI and TD group in one group in correlation analysis. In contrast, the studies that did not report a relationship used either receptive or expressive language, separated the group in analysis, and used simple SRT task (e.g., 8- item probabilistic sequence; Gabriel et al. 2011; Gabriel et al. 2015), which may not have been the most sensitive test of procedural learning. Changes to the paradigm (length and type of sequence) may result in a better measure of procedural memory, without the involvement of declarative memory.

Second, the relationship between declarative memory (composite score of intra- and cross-modality recognition) and vocabulary (receptive vocabulary or word learning with delay) were examined in groups. First, the current results showed that there was a trend with medium effect size toward a positive relationship between receptive vocabulary and recognition scores in the SLI group but not the other two groups. That is, in the SLI group, children who had higher ability to visually recognize the novel objects tended to have higher standard scores on receptive vocabulary, suggesting a role of declarative memory in acquiring vocabulary in children with SLI. The current finding of a trend toward a positive relationship between declarative memory and receptive vocabulary in the SLI group replicates Kamhi's et al. (1984) findings. They reported a strong positive relationship between performance on a haptic recognition task and receptive vocabulary (i.e., Peabody Picture Vocabulary Test) in their SLI sample.

Second, in the current study, a trend toward a positive relationship was found between performance on the declarative memory tasks and word learning with delay in the ASD group, reflecting that the children who had higher recognition scores are the ones who were able to learn the two novel labels in this group. In contrast, performance on recognition tasks did not affect word learning in the SLI or TD group. These results might be related to the different performance on the intra- and cross-modality recognition tasks in the ASD and SLI groups, with the intra-modality task appears to be more related to learning words as shown in the ASD group.

That is, the variability in performance was shown in both recognition measures in the ASD group, but only on cross-modality in the SLI group. Accordingly, the lack of variability in scores on the intra-modality recognition task in the SLI group may have resulted in not finding a relationship.

Two prior studies investigated the relationship between declarative memory and language measures in language-impaired individuals with ASD and reported a strong positive relationship. Similar to the current study, these studies included a receptive vocabulary measure but they used different recognition tasks than the one used in this study. First, Klinger and Dawson (2001) reported a strong correlation between receptive vocabulary and visual explicit rule learning of categories in 5- to 21- year old language-impaired ASD group, intellectually disabled group, and TD group. Unlike the current study, groups were combined for correlations. Second, Boucher, Bigham, et al. (2008) found strong correlations between lexical knowledge and recognition in language-impaired ASD but not in intellectually disabled and TD groups. Language was used on multiple measures, therefore, it is not clear whether the relationship found was directly related to performance on receptive vocabulary itself or not. The authors predicted the correlation in the language-impaired ASD group and explained the absence of a correlation in the intellectually disabled group, who also showed impaired recognition. That is, unlike the children in the language-impaired ASD group, the children with intellectual disability rely less on declarative learning to learn language. However, they did not explain their assumption of no correlation between recognition and the language scores in the TD group.

The current finding of no relationship in the TD group between language measures and recognition could be due to the lack of variability in scores on the recognition tasks in this group given that mostly their scores were at ceiling.

Finally, the relationship between procedural memory and declarative memory and performance on the recalling sentences subtest was explored in this study. The only relationship found was between declarative memory and performance on the recalling sentences subtest in the ASD group. This finding might suggest that the ASD group processed the recalling sentence task differently than the other groups. That is, they memorized the sentences as chucks and therefore their declarative memory was involved.

In conclusion, the current study did not find a relationship in any group between procedural memory and phonology. Nonword repetition tasks or forward gating tasks could provide a more appropriate measure of phonology that is less reliable on lexical knowledge and could reflect the role of procedural memory in phonology. Furthermore, the role of procedural memory could be evident in learning grammar, such as tasks that involves learning a new skill that requires hearing hundreds of tokens of the structure before mastering its use such as in artificial language and passive voice. In addition, more difficult SRT tasks than the one used in the current set of studies may be a better measure of procedural memory with minimal interference of declarative memory. A trend toward a positive relationship was found between declarative memory as measured by visual recognition and word learning with delay in the language-impaired ASD group, on the one hand, and with receptive vocabulary in the SLI group, on the other. These results support the hypothesized role of declarative memory in lexical abilities (Ullman, 2001, 2004). The link between the current findings and previous hypotheses on the role of procedural and declarative memory in language impairment in ASD and SLI is elaborated on in the next Chapter “General discussion”.

Chapter 5 : General Discussion

There is a long-standing debate in the literature about the extent of overlap between the language phenotype of a subgroup of children with ASD who have language impairment and children with SLI, as well as whether or not their language impairments arise from the same etiology (Kjelgaard & Tager-Flusberg, 2001; Leyfer et al., 2008; Whitehouse et al., 2008; Williams et al., 2008). Previous behavioral studies focused on comparing language-impaired children with ASD and children with SLI on structural language (i.e., phonology, vocabulary, and grammar) to address the question of overlap in language processing. Nevertheless, it is also important to investigate whether a shared language profile in the two disorders can be explained by shared cognitive processing. Procedural and declarative memory systems have been proposed to play a major role in typical language development, and have been hypothesized to contribute to language impairment in ASD (Romero-Munguía, 2008; Ullman, 2004) and in SLI (Ullman & Pierpont, 2005). Specifically, procedural memory involves learning and storing regularities and rule-based information such as those found in aspects of phonology and grammar. Declarative memory, which involves learning and storing facts and events, binds conceptual, phonological, and semantic representations of words (Ullman, 2004). Although there has been broad interest in the role of procedural and declarative memory systems in language impairment, few studies have investigated them alongside the structural language in language-impaired children with ASD and children with SLI. This dissertation represents the first direct comparison of both language (i.e., phonology and vocabulary) and memory abilities (i.e., procedural and declarative memory) in language-impaired children with ASD and children with SLI as well as their age- and NVIQ-matched TD peers. The main aim of the current dissertation was to provide a broad survey on the similarities and differences in aspects of language and procedural and declarative memory systems in language-impaired children with ASD and children with SLI. Accordingly, the language and memory measures used in this dissertation were chosen to serve this aim and to be suitable for children with limited language abilities especially in the ASD group. Testing children with language impairment required selecting tasks with minimal language requirements that were quickly administered and enjoyable, given the number of tasks included in this dissertation. In addition, the choice of language measures was limited by the availability of both English and French versions of language-standardized tests. Phonology was assessed with a phonological awareness task that involved phoneme or syllable deletion of spoken words and an articulation test. Vocabulary was assessed with a receptive vocabulary test and a word learning task that required identifying a labeled novel object in a different color with short and long delay. Turning to memory, procedural memory was examined using a visual sequence-learning task that was selected to be simple to ensure that the ASD group would not perform at floor (Gordon & Stark, 2007). Declarative memory was tested using intra- and cross-modality visual recognition tasks.

Studies 1 and 2 aimed to identify language and memory profiles of language-impaired children with ASD and those of children with SLI, in comparison to NVIQ- and chronological age (5; 4- to 10-years-old)-matched TD children. Study 3 had two aims: (1) to directly compare the language and memory profiles in language-impaired children with ASD and age- and – NVIQ-matched children with SLI, and (2) to explore relationships between procedural and declarative memory and language measures in each of the three populations tested. Results indicated distinct profiles in ASD vs. SLI.

5.1 Language Profile

Studies 1 and 2 revealed the language profiles in each of the clinical groups in comparison to a TD group to be as follows. The ASD group showed significantly poorer performance on phonological awareness, articulation, receptive vocabulary, and word learning when tested after a 2-hour delay compared to the TD group. Groups showed similar performance on the word learning task with brief delay. The language profile of the SLI group consisted of significantly poorer performance on phonological awareness and receptive vocabulary relative to the TD group, while groups showed similar performance on articulation and word learning. In Study 3, the ASD group and age- and NVIQ-matched SLI group showed similar performance on all language measures: recalling sentences, phonological awareness, articulation, receptive vocabulary, and word learning.

Interestingly, in comparison to the TD group, the ASD group made significantly more articulation errors and was not as successful in word learning with delay, while the SLI group performed similarly to the TD group. However, when the ASD and SLI groups were compared, they showed similar abilities on the articulation and word learning with longer delay tasks. One likely explanation for this discrepancy rests in the different language characteristics of the TD comparison groups in Studies 1 and 2. Specifically, the ASD group was compared to a TD group that generally had higher language scores on all measures than the TD group that was compared to the SLI group. Another possible explanation is that the four children in the ASD group not included in Study 3, to be matched to the 14 SLI children on NVIQ, had lower articulation and vocabulary skills. This was not the case; however, this discrepancy in findings provides an example of the challenge inherent in matching comparison groups in profiling studies, one also evident when comparing the results between studies.

Difficulties in phonological awareness were consistently found in both language-impaired ASD and SLI groups across the three studies. Two factors could contribute to the reduced phonological awareness skills across these conditions: lower vocabulary levels and reduced word decoding ability. Previous studies have suggested that reduced vocabulary size may hinder the development of more cognitively demanding phonological analysis skills in children with ASD (Gabig, 2010; McGee, 2006; Tjus et al., 1998) and in children with language and speech disorders (Rvachew, 2006, 2007; Snowling et al., 2000; Stanovich, 2000). That is, as children acquire more vocabulary, the structure of spoken word representations gradually become increasingly segmentalized and more robust, making these representations more suitable for tasks of phonological awareness (Gabig, 2010). When the clinical groups were compared to their TD peers in Studies 1 and 2 on phonological awareness abilities, they showed an impaired ability that could have been partially affected by their lower receptive vocabulary scores. However, this relationship was not reflected when the clinical groups were compared to each other on the phonological awareness task in Study 3. In particular, although the children with SLI had higher receptive vocabulary than children with ASD, they performed more poorly on the phonological awareness task. Furthermore, the significant difference between groups in their phonological awareness is in part due to the difference in reading levels between children in the clinical groups and the TD group. Anecdotally, all parents of children in the TD group reported class-appropriate reading levels, while those of children in the ASD and SLI groups absent or delayed reading skills; one child with ASD was reported to have hyperlexia. Research has shown a strong and predictive relationship between phonological awareness and word reading ability in young TD children (Nithart et al., 2011; Stahl & Murray, 1998; Stahl & Murray, 1994) and in SLI (Vandewalle et al., 2012). Accordingly, it could be argued that difficulties in phonological awareness in the clinical groups is negatively impacted by poor reading abilities, preventing adequate development.

5.2 Memory Profile

Studies 1 and 2 revealed the memory profiles in each of the clinical groups in comparison to age- and NVIQ-matched TD group to be as follows. Relative to the comparison TD group, the ASD group showed reductions in procedural memory as measured with a simple 4-item sequence-learning task, and reductions in declarative memory as measured with two visual recognition tasks. The memory profile of the SLI group was similar to the TD comparison group on the procedural memory task and on declarative memory as measured on a visual recognition task of previously seen objects. Significantly poorer performance in the SLI group was found with respect to the more complex declarative memory task that involved visual recognition of objects explored by hands. The memory profile found in Studies 1 and 2 was confirmed when the clinical groups were compared in Study 3. Specifically, the ASD group demonstrated difficulties in procedural and declarative memory, while the SLI group showed difficulties only on the more difficult declarative memory task that required visual recognition of objects explored by hands. These results suggest relatively intact declarative memory in children with SLI.

A major finding of this dissertation is the reduction of procedural memory, as measured on a simple deterministic 4-item sequence learning task (serial reaction time, SRT) in the ASD but not the SLI group. The current dissertation included two measures of sequence learning: 1) implicit sequence learning as indicated by faster responses on sequence vs. random blocks (i.e., *sequence learning score*), 2) explicit knowledge of the sequence as indicated by reproducing the sequence on the serial response box. Explicit knowledge was measured given that simple sequences, such as the one used in the current dissertation, are more likely to encourage the development and use of explicit strategies to solve the task (Destrebecqz & Cleeremans, 2001, 2003; Norman et al., 2007).

Previous studies on procedural memory suggested that children in both clinical groups can implicitly learn a sequence under facilitative conditions including, simplicity of the sequence and intensive exposure to the sequence (e.g., Gordon & Stark, 2007; Gabriel et al., 2013). Only one previous study (i.e., Gordon & Stark, 2007) investigated sequence learning in language-impaired children with ASD in deterministic 4- and 8-item sequence learning tasks that involved extensive exposure to the sequence over six sessions. They found that children with ASD learned the 4-item sequence on the individual level, while they showed sequence learning of the 6-item sequence on the group level only by the sixth session. Similarly, previous studies using SRT tasks in children with SLI showed relatively intact sequence learning ability during simpler SRT tasks. For example, children with SLI showed difficulties leaning deterministic 10-item sequences (Lum et al., 2012; Lum et al., 2010), but not 8-item sequences (Gabriel et al., 2011). Furthermore, some studies showed that procedural learning can occur in SLI, but they may require increased exposure to the information (Evans et al., 2009). Together, previous findings and the current findings suggest that while children with ASD can learn a sequence that is both very simple and intensively repeated, sequence learning in children with SLI seems to be more related to the simplicity of the task, relative to times of exposure. Specifically, the current results showed that while simplicity of the task enabled children with SLI learn the sequence, it did not in children with ASD, suggesting difficulties in procedural memory to a larger degree in the ASD group than the SLI group.

Explicit knowledge of the sequence was found in most of the TD children, while in few children in the ASD (n = 5) and SLI groups (n = 4). Results demonstrated that, in all groups, children with explicit knowledge showed faster response on the sequence vs. random blocks. Children with ASD who did not have explicit knowledge of the sequence did not show implicit sequence learning, while all children in the SLI and TD children showed implicit learning regardless of their explicit knowledge. These results can be interpreted by two proposals on the role of explicit knowledge in sequence learning. First, sequence learning of simple tasks start unconsciously (implicit learning) then with practice could become conscious (explicit knowledge), resulting in earlier anticipation of the sequence and faster responses (Perruchet & Pacton, 2006). This proposal explains the current findings of higher *sequence learning score* (implicit learning) in children with explicit knowledge than in children with no explicit knowledge in all groups. In addition, this proposal is in line with the finding of no explicit knowledge in the children who did not show implicit learning of the sequence in the ASD group. The second proposal suggests that explicit learning of the sequence (i.e., the formation of chunks) is the only effective process in learning the sequence in simple tasks (Perruchet & Pacton, 2006). This proposal, if proved, provides support to the hypothesized compensatory role of declarative memory in learning sequences (e.g., Boucher & Mayes, 2011; Ullman, 2004; Ullman & Pierpont, 2005; Ullman & Pullman, 2015). The current results do not support this proposal. However, three participants with ASD showed explicit knowledge of the sequence but did not have high sequence learning scores, which might be related to this proposal, an assumption that cannot be confirmed. Future studies are needed to investigate the proposal of compensatory declarative memory in clinical groups via longitudinal studies using both simple and complex sequence learning tasks.

The ASD and SLI groups in the current dissertation showed similar poor performance in declarative memory when they were asked to visually recognize explored-by-hands novel objects (cross-modality recognition). These difficulties in haptic-visual recognition could be due to deficits in the perception of local features, perhaps due to tactile hypersensitivity (Nakano et al., 2012) or fine and gross motor difficulties that limit children's ability to explore the novel objects in children with ASD (Baird et al., 2006; Ming, Brimacombe, & Wagner, 2007) or children with SLI (Hill, 2001). Given that motor skills were not examined in the current dissertation, this remains open to investigation. Future work should investigate if difficulties on cross-modality recognition tasks in the two disorders are related to impaired recognition per se or motor difficulties. In addition, future work should investigate if motor difficulties are shared between the two disorders or subgroups thereof.

Different hypotheses have been proposed on the role of procedural and declarative memory systems in language impairment in ASD and SLI. Some researchers hypothesized that language impairment is the result of deficits in procedural memory in ASD (Klinger et al., 2007; Romero-Munguía, 2008; Ullman, 2004; Walenski et al., 2006) and in SLI (Ullman & Pierpont, 2005), and that intact declarative memory compensates for some of the impairment in both conditions (Ullman & Pullman, 2015). This hypothesis is referred to as the procedural deficit hypothesis in SLI (Ullman & Pierpont, 2005). There is no other competing hypothesis related to procedural and declarative memory in SLI. In another hypothesis on ASD, Boucher et al. (Boucher & Bowler, 2008; Boucher, Mayes, & Bigham, 2008) proposed that language impairment in children with ASD can be explained by impaired declarative memory while procedural memory remains intact. This dissertation provides evidence of poor procedural learning in children with ASD even on a simple sequence while this ability was intact in the SLI group. Furthermore, it provides evidence on difficulties in declarative memory on both intra- and cross-modality recognition tasks in the ASD group, while only on the cross-modality recognition task in the SLI group. Accordingly, the current findings do not support the previous hypothesis of impairment in either procedural (e.g., Klinger et al., 2007; Romero-Munguía, 2008; Ullman, 2004; Walenski et al., 2006) or declarative memory in language-impaired children with ASD (Boucher & Bowler, 2008; Boucher, Mayes, & Bigham, 2008). Specifically, the current findings suggest that language-impaired children with ASD have difficulty in both procedural and declarative memory processing. Moreover, the current results do not support the procedural deficit hypothesis in the SLI group (Ullman & Pierpont, 2005). However, previous studies indicated difficulties in children with SLI in more complex sequence learning tasks. Ullman and Pierpont (2005) in the procedural deficit hypothesis allow for differences in the degree of procedural memory deficits in individuals with developmental disorders based on the neurological area affected. Accordingly, difficulties in procedural memory on more difficult tasks as seen in previous studies, while intact ability reported in studies using easier tasks might reflect the variability of neurological impairment of the areas responsible for the procedural memory system in SLI. Based on the current findings, speculations on possible differences between the two disorders on the neurocognitive level include abnormalities in the brain areas related to both procedural and declarative memory in language-impaired children with ASD. In children with SLI, abnormalities are expected in brain structures related to procedural memory but to a lesser degree than in ASD, leaving the brain structures related to declarative memory relatively intact.

The language and memory profiles described in the current dissertation reflect decrements at the group level in the clinical groups. However, it is important to note that performance was variable and not all children showed poor performance on language and memory measures. For example, on the standardized test of receptive vocabulary (Peabody Picture Vocabulary test; Dunn & Dunn, 2007) both clinical groups scored significantly below the scores of the TD groups, yet some children in ASD group (7 of 18) and the SLI group (10 of 14) showed within or above the normal range standard scores. Similarly, although on the group level, children with ASD did not show sequence learning, some children were able to learn the sequence and developed explicit knowledge of the pattern. These findings highlight variability even in well-defined subgroups of children with developmental disorders. In addition, these findings underscore the need for more comprehensive profiling studies of these populations involving larger sample size, using wider range of language measures that allow for fine analyses of differences beyond the overall performance, and using procedural and declarative memory tasks that examine performance in different modalities (visual as well as auditory) with varying levels of complexity. Such studies should help explain inconsistent findings of similarities between language-impaired ASD and SLI groups (e.g., Kjelgaard & Tager-Flusberg, 2001; Lindgren et al., 2009; Whitehouse et al., 2008; Williams et al., 2008), resulting in divergent conclusions regarding the "overlap" debate.

5.3 Relationships between Memory and Language

Relationships between the two memory systems and language measures were explored for language-impaired ASD, SLI, and TD groups. This explanation was a preliminary one given the restrictions on language measures and sample size given the goals of the current dissertation. Specific language abilities were compared with performance on procedural and declarative memory tasks employing visual rather than verbal stimuli. This was done for both logistical reasons, testing memory in nonverbal tasks where the task demands would not interfere with performance for children with language impairment, and for theoretical reasons, to test how a domain-general cognitive mechanism would relate to aspects of language learning. This represents a more conservative test, as it may be less likely to find this cross-modality relationship rather than one between verbal learning and memory task stimuli (e.g., artificial grammars studies) and language learning. Domain-general implicit learning contributes to language acquisition in the typical development (Kidd, 2012; Shafto et al., 2012) and may contribute to the language impairment in ASD (Ullman, 2004). If implicit learning contributes to language impairment in individuals with SLI, it appears to be in a more subtle way than for language-impaired children with ASD.

No relationship was found between procedural memory and phonology in any of the groups in the current dissertation. Previous studies found a relationship between procedural memory and phonology and grammar (Hedenius et al., 2011; Mainela-Arnold & Evans, 2014; Mayor-Dubois et al., 2012; Tomblin et al., 2007). The following possible suggestions could explain the current results of no relationship between procedural memory and phonology. First, overall, the developmental level of children in the three groups was advanced for the language measures used. Specifically, children had already acquired the phonological representations whereas previous studies that found a relationship between procedural memory and language measures used tasks that involved learning a new skill by extracting statistical information from the environment (passive voice in 4-6 year olds; Kidd, 2012) or that required online processing (forward gating task; Mainela-Arnold & Evans, 2014). Second, procedural memory was assessed on a simple sequence-learning task in the current study, in contrast previous studies that found a relationship between phonology and procedural memory used complex sequences (e.g., alternating or probabilistic 10-item sequence; Mainela-Arnold & Evans, 2014; Mayor-Dubois et al., 2012). Third, the current study had relativly small sample size per group and limited variability in performance within groups. Previous studies that found a relationship between procedural memory and language measures combined the SLI and TD group (Hedenius et al., 2011;Tomblin et al., 2007; Mainela-Arnold & Evans; 2014) or had a large sample size (e.g., 100 children; Kidd, 2012). In this vein, correlations were explored in the current study after combining the ASD, SLI and TD groups in one sample (N = 77). Significant positive relationships were found between procedural memory and receptive vocabulary and recalling sentences on the one hand, and declarative memory and phonologcal composite socre, receptive vocabulary, and recalling sentences on the other. However, this type of correlation does not serve the purpose of exploring the specific role of these memory systems in language impairment in each of the clinical groups. See appendix B for the correlation results.

The current dissertation provides support for the predictions of the role of declarative learning and memory and vocabulary (Boucher, Mayes, & Bigham, 2008; Gupta, 2012; Ullman, 2004). Specifically, a trend toward a positive relationship was found between declarative memory and word learning scores in the ASD group, and with receptive vocabulary in the SLI group. In line with the current findings, the relationship between declarative memory and vocabulary has been reported in few studies on ASD (Boucher, Bigham, et al., 2008) and SLI (Kamhi et al.,1984; Lum et al., 2012). In addition, a positive relationship was found in the current dissertation between declarative memory and recalling sentences in the ASD group. This finding might reflect that the recalling sentences task is more related to vocabulary than other language aspects (e.g., grammar), which is processed by declarative memory, or that children with ASD memorized the sentences as chunks.

As discussed extensively in Study 3, the literature on the relationship between procedural and declarative memory and aspects of language in language-impaired children with ASD or in children with SLI, including the current dissertation, has garnered mixed findings. The following suggestions may provide an explanation for the mixed findings and demonstrate that the original goal of dividing procedural from declarative memory in hopes of identifying distinct relationships with aspects of language may be misguided. First, many of the behavioral, neuroanatomical, and neurophysiological findings in the literature are not easily categorized as being either procedural or declarative (e.g., Norman et al., 2007; Sun et al., 2005). Therefore, although one can manipulate experimental conditions to solicit one type of memory over the other, both learning systems are involved to varying degrees in most situations (Destrebecqz & Cleeremans, 2001; Norman et al., 2007; Rauch et al., 1995; Shanks & Johnstone, 1999; Sun et al., 2005). In line with this observation, in the current dissertation, explicit knowledge of the sequence was evident as a second step of sequence learning in the SRT task. Second, different aspects of language learning are also not cleanly dissociable. There is interaction between different aspects of language over development that challenges attempts to disentangle them, such as the strong relationship between vocabulary and phonology throughout language development (Claessen et al., 2009, Storkel & Morrisette, 2002). In the current dissertation, both of the phonological awareness and the articulation tasks rely on both lexical-phonological knowledge and lexical–sematic knowledge. Specifically, in the articulation task, the child had to recall the name of a familiar picture and then articulate it. Similarly, unlike the French version, the phonological awareness task in the English version includes a number of compound words or words that even after omitting a phoneme, the words still had a meaning, which required both semantic knowledge of the words and knowledge of the sounds of those words. Accordingly, the current results of no relationship between these two phonological measures and procedural memory may be due to the fact that they implicated both phonology and lexicon and did not require procedural learning per se. These observations highlight the difficulty of conducting studies that can divide memory systems on the one hand and specific aspects of language on the other. These challenges affect the ability of researchers to make firm conclusions on the status of procedural and declarative memory and their role in language acquisition.

Finally, the current findings of no relationship between memory and language measures in the TD group may be related to the small variability on memory and language measures in this group. That is, correlations are more likely to be observed if there is more variability in the independent variable rather than a restricted range on it (Bates, Zhang, Dufek, & Chen, 1996). Another possible explanation could be that at this age and level of language development, TD children do not relay on one memory system to process the language tasks. Therefore, neither procedural nor declarative memory showed a prominent role in this group.

In conclusion, the current results provide evidence of a trend toward a positive relationship between declarative memory as measured by visual recognition and word learning and recalling sentences in the language-impaired ASD group, and with receptive vocabulary in the SLI group. These results support the hypothesized role of declarative memory in lexical abilities in children with ASD (Boucher & Bowler, 2008; Klinger et al., 2007; Ullman, 2004) and in children with SLI (Ullman, 2004; Ullman & Pierpont, 2005).

5.4 Study Limitations

One limitation of this dissertation is the restricted number of language measures used to identify language profiles in children with ASD and children with SLI. It was expected that the participants in the language impairment groups would have limited language, preventing the examination of their language at the sentence level and in terms of grammar. However, in the end children with very low language abilities were excluded from analyses given that they could not complete many of the tasks successfully. Consequently, a measure of receptive/expressive grammar would have been feasible to administer to the final sample. In addition, the language measures used in the current set of studies did not allow for a detailed analysis of linguistic competence beyond passing test items, except for articulation. Nevertheless, the current dissertation still provided informative findings on the similarities and differences in two measures of phonology and two measures of vocabulary between the two clinical groups.

Similarly, the memory measures used in this dissertation were limited, given time constraints, and affected the memory profile found in the SLI group. Specifically, although the current memory measures allowed finding an area of poor performance in declarative memory in SLI, the use of short sequence in the procedural memory task did not.

Another limitation involves generalization of findings to individuals in other linguistic settings. In this dissertation, both English-speaking and French-speaking children who were not fully monolingual were included in one sample, given the dual or multiple language exposure common in Montreal. To address this diversity children in each comparison were matched on their dominant language (English or French) and were similar in NVIQ and chronological age. The dual language exposure of our sample also narrowed the options for language measures given that any selected measure had to have both English and French versions, or, if not available, a similar test should be used such as in the case of the articulation measure. However, though including both English- and French-speakers made the dissertation more methodologically complicated, it adds unique and important information to the literature on language in children with developmental disorders learning a language other than English.

Although the total sample was reasonably large with 77 children tested, the final samples who met all research criteria in the ASD group (n = 18) and SLI group (n = 14) was modest though similar or even larger to samples in many studies of language and memory profiles in clinical populations (e.g., Gabriel et al., 2015; Gordon & Stark, 2007; Lloyd et al., 2006; McGee, 2006).

5.5 Future Directions

This dissertation demonstrated for the first time that procedural and declarative memory difficulties are more prominent in language-impaired children with ASD than in children with SLI matched on age and NVIQ, despite having similar language profiles with respect to phonological awareness, articulation, receptive vocabulary, and word learning. Further research is needed to replicate and extend the findings reported in this dissertation.

Future studies should include a wider range of language skills than those reported in this paper on both standardized language measures and natural language samples to provide more comprehensive language profiles in both children with ASD and children with SLI. In addition, language comparisons should include careful inspection of the data beyond the overall performance on language measures including the use of spontaneous speech samples. Similarly, more work is warranted on the status of procedural and declarative memory in these populations to further refine current hypotheses on the role of these memory systems in language learning and impairment with the focus on how the two systems work together.

Individual differences within well-defined subgroups of language-impaired children with ASD and children with SLI deserve attention in future research to shed light on the accompanying disorders of ASD and SLI such as hyperlexia, apraxia, and motor difficulties that could play role in the similarities and differences in language and memory abilities in groups. Moreover, conducting studies that include subgroups of children with SLI (e.g., expressive language disorder or mixed receptive-expressive disorder) is expected to be informative for the overlap debate between the two disorders.

It would also be interesting to understand individual differences in term of implicit and explicit learning. That is, some people might be relying more on implicit processing to learn language while others are more explicit and accordingly require explicit instructions to learn. In addition, a further step is needed to draw individual language profiles for the ASD children and SLI children and to see if deficits in one memory system in these children provide different profile than when they have deficits in the two memory systems. Such investigation would address the see-saw effect in which one memory system can compensate for the impairment in the other system (Ullman, 2004).

One major finding that requires further investigation is the underlying cause of language impairment in the SLI although they showed intact procedural and declarative memory except for declarative memory on the cross-modality recognition task. To address this issue, there is a need for longitudinal studies including cross-lagged models that directly investigate the development of language profiles as well as procedural and declarative memory processing over time in individuals with ASD and individuals with SLI. This need stems from the suggestion that similar or different phenotypic language profiles in language-impaired ASD and SLI depends to some degree, on the age at which assessment is done (Bennett et al., 2008; Geurts & Embrechts, 2008; Rapin et al., 2009; Williams et al., 2008). In addition, future cross-sectional and longitudinal studies are needed to determine if the relationship between procedural and declarative learning deficits and language impairment is in fact causal. These studies are required to carefully choose language and memory measures that could reflect the impairment in the clinical populations and to assess the proposed relationships. For example, it would be beneficial to test children with SLI on longer sequence as a measure of procedural memory, which could reveal the difficulties and might explain their language impairment. Moreover, examining language using spontaneous sample could provide a natural measure of different aspects of grammar, phonology, and vocabulary, which might better reflect the possible relationship and interaction between language abilities and memory systems as it occurs in real life.

5.6 Clinical Implications

To provide evidence based intervention, speech and language therapists need to better understand the nature of developmental language impairments as well as the nature of the underlying deficits involved in each disorder. The lack of recent research on the nature of language impairment in ASD is striking, given that of nearly 1,000 individuals on the spectrum between the age of 4 and 52 years, approximately half of the sample show delays in language acquisition by parent report (Hus, Pickles, Cook, Risi, & Lord, 2007). In addition, 15.2% of 4-to 7-year-old children with ASD have speech delay (Shriberg et al., 2011), 55% (Leyfer et al., 2008) to 63% (Rapin & Dunn, 2003) meet the criteria for specific language impairment, and 14% to 20 % of individuals with ASD are minimally verbal through adulthood (Lord et al., 2004). Accordingly, there is an urgent need to develop targeted interventions and more studies to investigate the characteristics and immediate causes of language impairments in this group.

In a pioneering step, the current dissertation showed similar language abilities but different procedural and declarative memory profile in language-impaired children with ASD and children with SLI. If replicated in younger samples, these results may further assist in differentiating between the two disorders in early childhood based on memory profiles. Specifically, the replication of intact ability in simple sequence learning tasks in SLI would differentiate them from language-impaired children with ASD who are impaired even on simple tasks. However, to achieve this step, further understanding of the see-sew effect between the two memory systems should be achieved given that it could lead to compensation for the impairment in some children.

Research into procedural and declarative memory systems is still growing. More experimental work on the role of these two memory systems in language impairment and randomized controlled trials of intervention are required before interpreting the findings into treatments. Nevertheless, if the current findings are confirmed in future studies, they may suggest different methods of intervention for language impairment in children with ASD and children with SLI. Specifically, interventions should directly target cognitive rehabilitation in both disorders, "a systematic intervention designed to improve cognitive or behavioral difficulties following a pathological process in order to improve daily functioning", including restoration and compensation (Schaffer & Geva, 2015, p. 4). Given that the ASD group showed poor performance in both procedural and declarative memory in Studies 1 and 3, intervention should aim to restore the lost functions which can be accomplished implicitly by employing training or explicitly by teaching specific strategies (Schaffer & Geva, 2015). Moreover, if future studies in children with ASD show that difficulties in procedural memory tasks reflect simply slower learning, then increasing the salience and frequency of target information should be effective. Children with SLI show relatively less deficits in sequence learning and intact declarative memory of visual stimuli. Therefore, intervention for this group should target restoring the impaired abilities as well as building upon preserved functions to support performance.

The findings of the current set of studies as well as Gordon and Stark's (2007) suggest that language-impaired children with ASD show difficulties in sequence learning that they may overcome by both intensive exposure to the stimuli and using simple tasks. Accordingly, clinicians need to simplify and extensively repeat the information to be learned in interventions for children with ASD. In this area, intensive discrete trial training (Lovaas, 1987) has been widely used in language intervention in ASD (Vismara & Rogers, 2010) and has been found to help develop functional language skills in minimally verbal children with ASD (Paul, Campbell, Gilbert, & Tsiouri, 2013). Discrete trial training makes use of the Skinnerian principles of operant learning (Skinner, 1957) and "involves breaking down complex skills and teaching each sub-skill through a series of highly adult-structured, massed teaching trials" (Vismara & Rogers, 2010, p. 449). In contrast, it seems that children with SLI, although benefit from simplification and repetition of information, require these modifications to a less degree than children with ASD.

5.7 Conclusion

To understand the nature of language impairment in ASD and children with SLI, it is important to identify not only their language skills but also cognitive profiles that may underlie language impairment. This dissertation is the first to directly compare language-impaired children with ASD and children with SLI with respect to language and memory profiles, revealing a novel finding. Specifically, despite similar difficulties in structural language in both groups, children with ASD were found to have poor procedural and declarative memory, whereas SLI only showed reductions in a more complex declarative memory task. These findings suggest that ASD and SLI are best viewed as distinct disorders. Accordingly, these findings provide support to the argument that the similarities in the language profile of children with ASD and children with SLI do not necessarily indicate shared underlying cognitive causes (Whitehouse et al., 2008; Williams et al., 2008; Williams et al., 2013). The relationship between procedural and declarative memory and language impairment in these populations is still unclear. The current dissertation provides evidence for a relationship between declarative memory and word learning, as well as between declarative memory and recalling sentences in the ASD group. A relationship was also found between declarative memory and receptive vocabulary in the SLI group. In ASD, language impairment may be explained by underlying difficulties in both procedural and declarative memory. In SLI, language impairment does not appear to follow from difficulties in procedural and declarative memory to the same degree.

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Appendix A

Performance on the Serial Reaction Time Task in Depth

To better understand the typical performance on the serial reaction time (SRT) task, additional analyses were conducted on the *full sample* of the typically developing (TD) participants. Participant characteristics are provided in Table A1.

Table A1

Participant Characteristics

	Typically developing group ($N = 45$)	
	M (SD)	*Range*
[a] Nonverbal IQ	110.4 (9.18)	95 - 143
Chronological age (Y; M)	7; 6 (1; 0)	6 – 9; 10
[b] Recalling Sentences	11.33 (2.35)	8 - 16
[c] Receptive language	117.06 (16.02)	86 - 150
Handedness (Right, Left)	38, 7	

Note. [a] Leiter International Performance Scale 3 (Leiter-3; Roid et al., 2013). [b] Recalling Sentences subtest of the Clinical Evaluation of Language Fundamentals, Fourth Edition (Semel et al., 2003) or the French standardized adaptation of this subtest. [c] Peabody Picture Vocabulary Test-IV (Dunn & Dunn, 2007) or its French standardized adaptation.

In this section, the key comparisons of interest were in three areas: accuracy, learning the sequence, and explicit knowledge of the sequence. Based on the distribution of data the suitable parametric or nonparametric tests were conducted.

Accuracy

As shown in Figure A1, the TD participants generally made few errors with the mean of errors being less than 2 throughout the five blocks of the experiment. The maximum number of errors was observed in block 4, which is random.

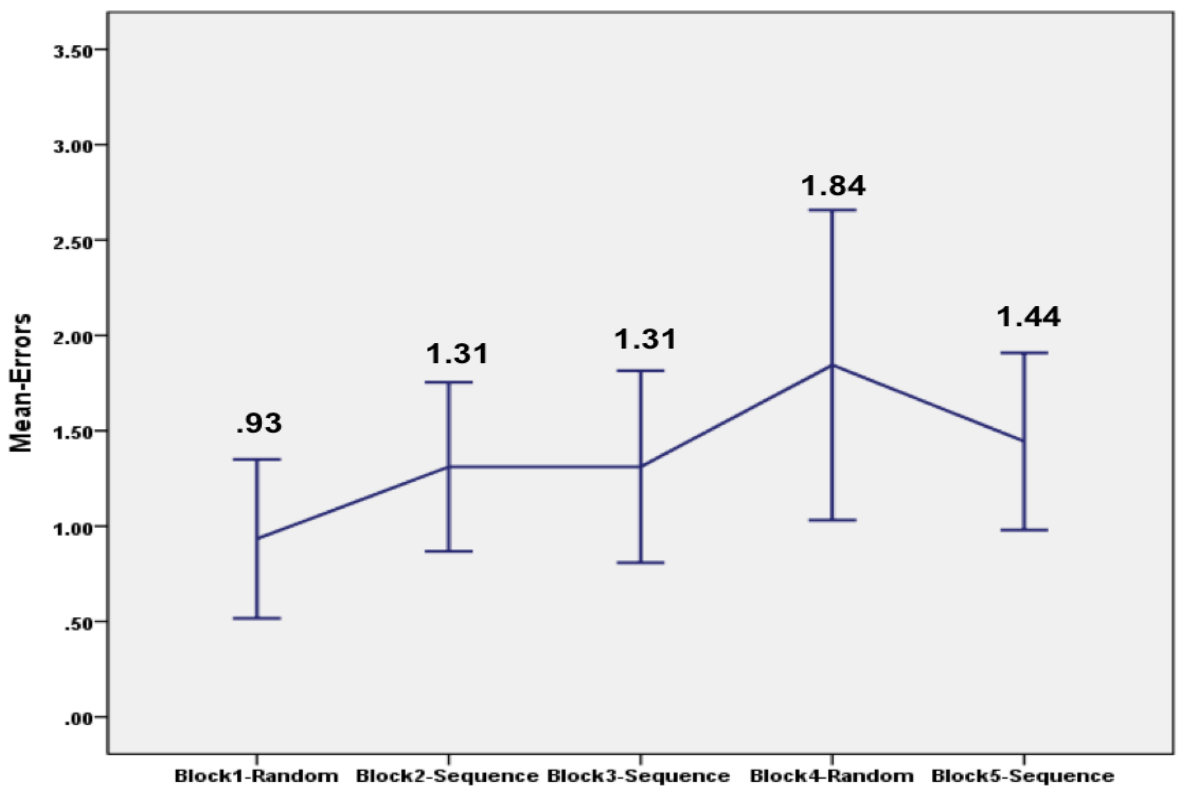

Figure A1. Mean of errors in the SRT task of the typically developing group.

The number of errors in the random blocks (i.e., block 1 and 4) was compared to investigate the role of fatigue on performance in this task. Results showed that the number of errors were significantly lower in block 1 (*M* = .93, *SE* = .20) than block 4 (*M* = 1.84, *SE* = .40), $t(44) = -2.60$, $p = .01$, $r = .36$. These results suggest that participants tended to make more errors toward the end of the SRT task, which could be due to fatigue. Another possible explanation for the increase in the number of errors in block 4 could be that participants were looking for a pattern in this random block and accordingly anticipating the sequence and making more errors, especially that they were shown the sequence in the two sequence blocks (block 2 and 3) that preceded.

Learning the sequence

For each participant, a median Reaction Time (RT) was calculated for sets of 8 trials of the 40 trials of each block, resulting in five medians for each block. Medians excluded any RTs longer than 10 seconds, and any trials on which the initial response was incorrect to control for difference in overall accuracy between participants as well as within blocks. The mean of these medians was then calculated for each block, resulting in five response means.

Figure A2 shows that participants' responses got faster from the first random block through the sequence blocks 2 and 3, then the responses got slower on the random block 4 but got faster again when the sequence was presented in block 5.

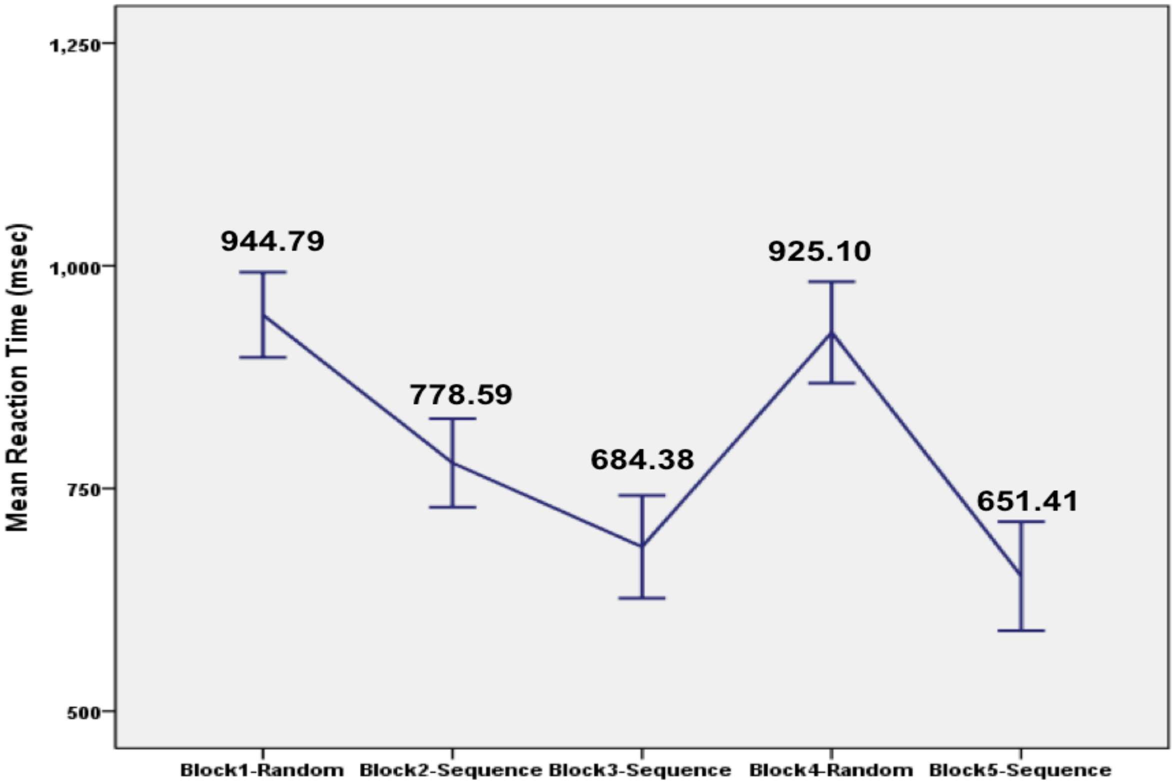

Figure A2. Performance of the TD group on the SRT task. Data points indicate the mean reaction time per block of 40 trials. Error bars represent standard error of the mean. Sequence learning is indicated by significantly faster responses on block 5 (sequence) than block 4 (random).

To investigate whether the TD group learned the sequence after they first encountered pattern in block 2, the response means were compared using repeated sample *t*-tests between the random block 1 and the sequence block 2. Responses were significantly faster on block 2 (M = 778.59, SE = 24.66), than block 1 (M = 944.79, SE = 23.72) $t(44) = 10.46$, $p < .001$, r =.84, showing that sequence learning in the TD group was evident as early as the sequence was presented on block 2.

Moreover, responses on the sequence blocks 2, 3, and 5 were compared to determine whether the TD group continued to get faster in their responses with more exposure to the sequence. First, responses were compared using repeated sample *t*-tests between block 2 and block 3. Responses were significantly faster on block 3 ($M = 684.38$, $SE = 28.61$) than block 2 ($M = 778.59$, $SE = 24.66$), $t(44) = 4.88$, $p < .001$, $r = .59$, suggesting that performance was improving with exposure to the sequence. Here the significant faster responses on the consecutive sequence blocks might be affected by motor training as well. Second, responses in block 3 and 5 were compared. Repeated sample *t*-tests showed no significant difference in responses between block 3 ($M = 684.38$, $SE = 28.61$) and block 5 ($M = 651.41$, $SE = 30.34$), $t(44) = 1.59$, $p = .12$, $r = .23$, suggesting that the participants mastered learning the simple 4-item sequence in block 3 and additional exposure to the sequence did not have significant effect on their learning.

Finally, repeated sample *t*-tests were conducted to examine sequence learning at the end of the experiment in the random block 4 and the sequence block 5. Results demonstrated that responses were significantly faster in the sequence block 5 ($M = 651.41$, $SE = 30.34$) than in the random block 4 ($M = 952.10$, $SE = 28.28$), $t(44) = 12.87$, $p < .001$, $r = .88$, confirming that the TD group learned the sequence.

Explicit knowledge of the sequence

After completing the SRT task, participants were asked to show the way the dog moved from one box to another on the serial response box, providing a measure of explicit knowledge of the sequence. Participants were divided into two groups: those who showed explicit knowledge of the sequence and were able to recreate the sequence they had learned ($n = 32$) and those who did not ($n = 13$). The key comparison of interest in the following analyses was to assess potential differences in the *sequence learning score* ([Block 4 - Block 5] ÷ [Block 4 + Block 5]) between participants who indicated explicit knowledge of the sequence and those who did not.

Mann-Whitney *U*-tests were conducted with *sequence learning score* as dependent variable and explicit knowledge of the sequence as independent variable. Results showed no significant difference in *sequence learning scores* of the group that showed explicit knowledge of the sequence (Mdn = .21) and the group that did not (Mdn = .14), U = 152, z = 1.4, p = .16, r = .21. These results suggest that explicit knowledge of the sequence did not play a role in the performance of the full sample of the TD group on the SRT task. Figure A3 illustrates the performance on the SRT task in participants who had explicit knowledge and participants who did not. Both groups showed similar learning pattern, however, the group who did not show explicit knowledge tended to have slower responses in all of the blocks.

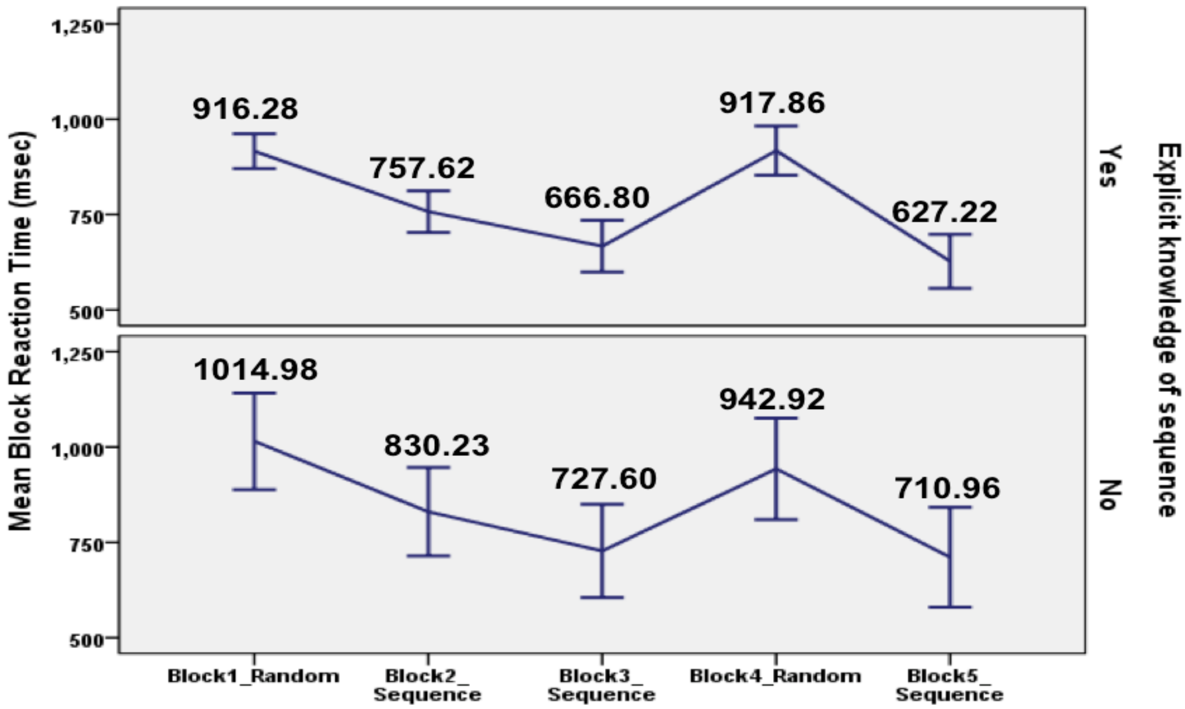

Figure A3. Performance on the SRT task of TD participants who had explicit knowledge of the sequence (Yes) and participants who did not (No). Data points indicate the mean reaction time per block of 40 trials. Error bars represent standard error of the mean. Sequence learning is indicated by significantly faster responses on block 5 (sequence) than block 4 (random).

In addition, as demonstrated in figure A4, the *sequence learning score* of participants with or without explicit knowledge of the sequence indicated that most of the participants learned the sequence regardless of developing explicit knowledge of the sequence.

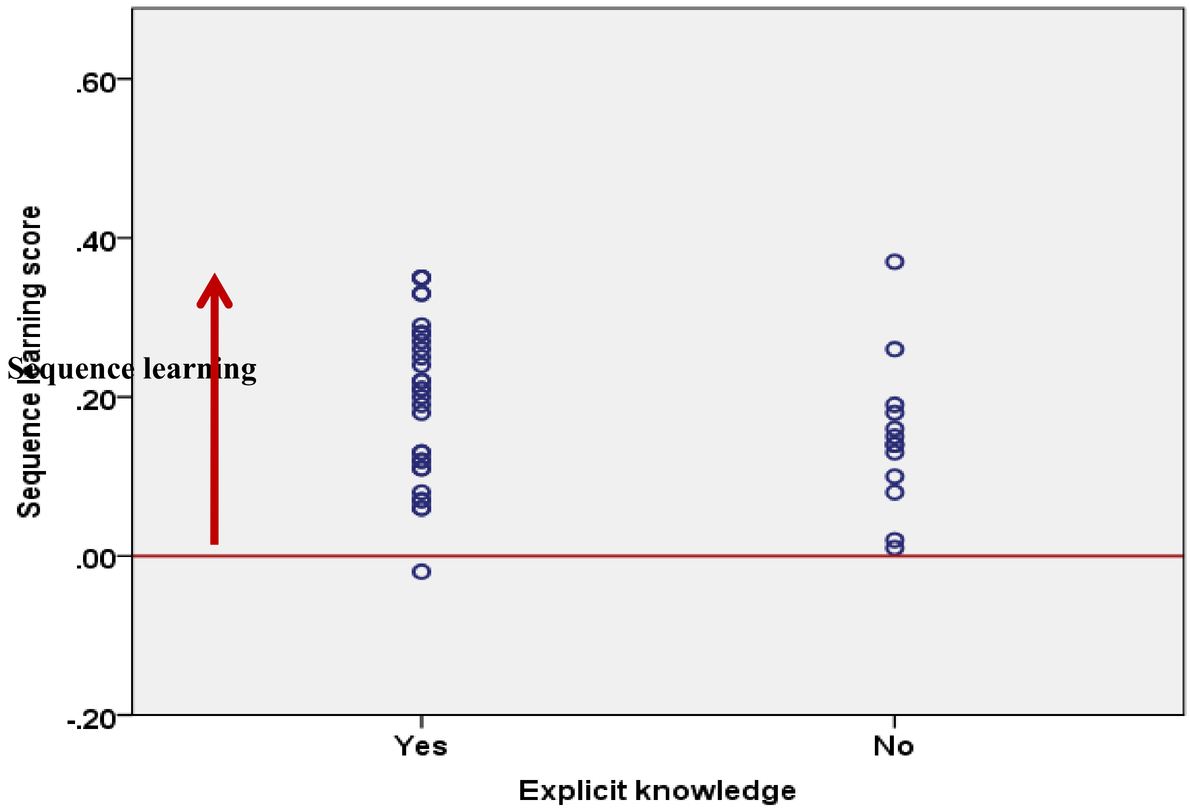

Figure A4. Sequence learning scores of TD participants who showed explicit knowledge of the sequence (Yes) and those who did not (No). Sequence learning scores above 0, indicated by the red line, demonstrate implicit learning of the sequence.

To understand what drives some participants to have explicit knowledge of the sequence but not others in this TD sample two analyses were conducted. First, the characteristics of participants with or without explicit knowledge of the sequence were compared. Second, responses on sequence blocks 3 and 5 were compared between groups to clarify whether the group with explicit knowledge learned the sequence earlier (i.e., in block 3) than the group who did not have explicit knowledge and accordingly the former group developed explicit knowledge by the end of the SRT task. The difference in acquiring explicit knowledge of the sequence could not be explained by differences in participant characteristics or difference in the stage at which participants learned the sequence. Specifically, as shown in table A2, groups with and without explicit knowledge of the sequence were similar in their nonverbal IQ, age, and ability to recall sentences. In addition, the difference in responses on block 3 and 5 was not significant in participants who showed explicit knowledge of the sequence, $T = 190$, p = .17, $r = .24$ or participants who did not, $T = 33$, $p = .38$, $r = .24$, indicating that both groups learned the sequence during block 3. Accordingly, it is unclear what drives some TD participants to develop explicit knowledge of the simple 4-item sequence but not others in the current sample.

Table A2

Characteristics of TD participants who had explicit knowledge of the sequence and those who did not

	Explicit knowledge of sequence (*n* = 32)		No explicit knowledge of sequence (*n* = 13)		
	M (SD)	*Range*	*M (SD)*	*Range*	**p*-value
Chronological age (Y; M)	7; 5 (0; 11)	6 – 9; 7	7; 6 (1; 3)	6 – 9; 10	.73
[a] Nonverbal IQ	110.56 (8.33)	95 - 125	110 (11.37)	100 - 143	.86
[b] Recalling Sentences	11.43 (2.24)	8 - 16	11.07 (2.69)	8 - 16	.65

Note. [a] Leiter International Performance Scale 3 (Leiter-3; Roid et al., 2013). [b] Recalling Sentences subtest of the Clinical Evaluation of Language Fundamentals, Fourth Edition (Semel et al., 2003) or the French standardized adaptation of this subtest. *An alpha level of .05 was used for all statistical comparisons.

Appendix B

Relationship between Memory Systems and Language Measures in Groups Combined

The relationships between the memory systems and language measures (phonology, receptive language, recalling sentences) were examined for the three groups combined (*N* = 77: TD *n* = 45, ASD *n* = 18, SLI *n* = 14) using nonparametric correlations, Kendall's tau_b.

The *sequence learning score* was used to reflect procedural memory processing. For declarative memory, a composite score was computed by adding the score of intra- and cross-modality tasks of each participant resulting in a possible score range between 0 and 24. Turning to language measures, a composite score was calculated for phonological abilities by adding the *z* score on the phonological awareness measure (number of correct deletions of phonemes or syllables) and the *z* score on the articulation measure (percent of consonants correct) for each participant. *Z* scores for the three groups were calculated based on the mean and standard deviation of the full sample of the TD group in the respective language (English speaking *n* = 25, French speaking *n* = 20). The raw scores on the receptive vocabulary test (PPVT-IV; Dunn & Dunn, 2007) and the Recalling Sentences subtest (CELF-IV; Semel et al., 2003) in their English or French versions were used to demonstrate the variability in scores. Table B1 demonstrates the results of the correlations.

Table B1

Relationships between memory systems and language measures in groups combined

Language measures		Declarative memory (Composite score)	Sequence learning score
Phonology (Composite score)	Correlation Coefficient	.16*	.04
	p value	.04	.58
Receptive vocabulary (Raw score)	Correlation Coefficient	.25**	.19*
	p value	<.01	.02
Recalling sentences (Raw score)	Correlation Coefficient	.33**	.18*
	p value	<.001	.02

Note. ** Correlation is significant at the 0.01 level (2-tailed).
* Correlation is significant at the 0.05 level (2-tailed).