5 The repetition tasks and the role of memory resources in grammar development

5.1 Introduction

In the previous chapters, the comprehension and the production of subject and object relative clauses was investigated and discussed in groups of individuals with normal hearing and hearing impairment. To explain the difficulties that these individuals have with these complex syntactic structures, and especially object relatives, grammatical-based approaches have been adopted. The low performance with object relatives by children with hearing impairment is to be attributed to the movement of the object to a non-canonical position. In particular, movement is especially impaired when the object shares a subset of features (namely the lexical restriction, Friedmann, Belletti, Rizzi, 2009) with the argument it crosses over. A further refinement of this proposal suggested that in normal hearing children,

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the feature set associated to the DPs modulates the comprehension of relative clauses and explains the high percentages of accuracy in the conditions with number mismatch and the low percentages in the match conditions (the two DP have the same number features). A feature number mismatch facilitates the correct interpretation of object relatives in hearing children and adolescents, but not in children with hearing impairment. Conditions with number mismatch were problematic because number agreement fails to be computed, and this causes incorrect theta role assignment.

In addition to syntactic deficits, the difficulties that children with cochlear implants have with grammar and complex syntactic structures have also been attributed to cognitive resources, and specifically to reduced memory abilities (the relevant studies are presented in section 5.6 below). That memory skills may influence language acquisition, also including complex syntax, is well-documented by several studies carried out cross-linguistically. This was found to be true for both typically developing children and children with language disorders and individuals with hearing impairment.

This chapter focuses on memory skills and on the relationship between comprehension of complex syntactic structures (namely relative clauses) and memory resources in children and adolescents with normal hearing, children with cochlear implants, and LIS signers, presenting data collected in Volpato (2010b). The first part of the chapter is devoted to briefly sketch the multicomponent memory system and to present some measures assessing memory skills (word and nonword repetition, sentence recall, digit span). Then, I present data from typically developing populations and populations with hearing impairment (children with cochlear implants and adolescent LIS signers). In the second part of the chapter, I investigate how memory resources may predict or may be associated to outcomes in different linguistic domains, with a focus on the correlation existing between comprehension and memory resources.[35]

5.2 The memory system and the measures assessing memory skills

According to Baddeley's multicomponent memory system (Baddeley, Hitch 1974; Baddeley 1986), working memory is a mental storage where verbal information is temporarily hold and manipulated (Gathercole et al. 2006). It includes the phonological loop, namely a

35 It would be interesting to investigate how the different measures assessing working memory interact with each other. These questions go far beyond the scope of this study and are left for future research.

system devoted to the storage of verbal (phonological) information, the visuospatial sketchpad, which is responsible for the storage of visual and spatial information, and the central executive, which coordinates the operations on the information stored in the phonological loop and the visuospatial sketchpad.

One measure to evaluate storage of verbal/phonological information is nonword repetition. The nonword repetition task assesses rapid phonological processing and measures phonological information stored in phonological short-term memory. The process necessary to repeat non-existing words is complex. A completely novel sound pattern is perceived without the possibility of relying on pragmatic or semantic knowledge and must be held and verbally rehearsed in immediate phonological memory. The last part of the process is to turn the perceived sound pattern into an articulatory output.

Differently from nonword repetition, the digit span task investigates memory resources for word units (digits) that are already stored in the mental lexicon (Baddeley 2003). Digit span tasks are used to measure immediate verbal memory. Forward digit spans consist in repeating digits in the same order as they are presented. Backward digit spans consist in repeating digits in reverse order. The two tasks share a component of verbal short-term memory. Forward digit span, tapping short-term memory, involves significant storage, but only minimal processing. Backward digit span, which taps working memory, also includes an additional component which allows performing operations on linguistic material, and places significant demands on both processing and storage.

Children's phonological capacity increases with age and is measured using a variety of tasks. In addition to nonword repetition and digit recall, recall of unrelated series of words and repetition of words within a sentence (Baddeley 1986; Gathercole et al. 2004; Alloway, Gathercole 2005) are also important tools to assess phonological short-term memory. Individuals with deficits in the phonological short-term memory show difficulties in the recall of both word lists and sentences (Alloway, Gathercole 2005). Sentence repetition assesses the ability to repeat spoken sentences, namely the ability of children to recode and keep phonological representations active in immediate memory for short periods of time. These processes can affect immediate memory because information must be kept active in memory for other complex linguistic activities (spoken word recognition, sentence comprehension, and language production). Short-term memory contributes to sentence recall as well. A study carried out by Alloway and Gathercole (2005) presents data from two groups of 4- and 5-year-old children matched on nonverbal abilities: one group with high phonological memory and the other with low phonological memory, in order to investigate the association between phonological memory measured with a nonword repetition task and short-term memory measured with a sentence repetition task. The children with low phonological memory were also significantly poorer in sentence recall. Archibald and Joanisse (2009) suggested that sentence repetition may be the best example of a core speech-language skill that is strongly related to working memory.

Deficits in phonological short-term memory hinder the adequate storage of verbal material. Phonological short-term memory, as measured by nonword repetition, has been found to be lower in children with developmental language disorders than in typically developing children. In various language (e.g. English, French, and Italian), nonword repetition is a clinical marker of a language deficit (Gathercole, Baddeley 1990; Bishop, North, Donlan 1996; Bortolini et al. 2006; Botting, Conti-Ramsden 2001; Delage, Frauenfelder 2012; Dispaldro, Leonard, Deevy 2013). In addition to poor performance on nonword repetition, children with dyslexia have phonological short-term deficits documented through poor sentence recall (Catts et al. 2005; Mann, Shankweiler, Smith 1984).

As pointed out at the beginning of this section, the issue concerning the assessment of memory skills is much debated. It is not always well-defined what skills the different tasks tap. In the following sections, starting from this background, I present data on typically developing children compared with a group of adolescents using different tasks. This makes it possible to determine whether a difference exists between young children and adolescents, and depending on the task, which memory skills may be more problematic in the younger participants.

5.3 Memory skills: the comparison between typically developing children and adolescents

In Volpato (2010b), memory resources were assessed in typically developing children and adolescents using many repetition tasks (words, nonwords, digits, and sentence recall), in order to investigate whether children's verbal/phonological short-term memory and working memory skills are comparable to the memory skills of adolescent students. Data were collected from the group of 16 typically developing children (age range: 5;3-7;5, mean age 6;5) and a group of 16 typically developing adolescents (age range: 15;1-17;5, mean age 15;5). Further details on the participants are found in section 2.10.

5.3.1 The word repetition task

The word repetition task consisted in the repetition of trials assembled into sequences of increasing length, ranging from 2 to 6 words, and presented at the rate of one word per second. Only singular words were selected for the word-repetition task. They corresponded to disyllabic high frequency words in elementary Italian (Marconi et al. 1993) and were chosen among the most common nouns. Each series was arranged so that adjacent words did not form meaningful units and did not show phonological similarities. Every participant was presented with four sequences for each series and was asked to repeat them immediately after the experimenter had read them. One point was assigned for each word recalled in the correct position. The word span was assessed in the oral modality. Appendix A1 provides the list of words used in the word repetition task.

The Mann-Whitney statistical test was used to compare the number of correct words repeated by each group. Table 34 reports the results in the word repetition task (number and percentage of correct words repeated in the correct position) in two-, three-, four-, five- and six-word sequences for the group of children and for the group of adolescents.

Table 34: No. and SD of correctly repeated words in each word sequence by typically developing children and adolescents

Groups	**Series of words**									
	2		**3**		**4**		**5**		**6**	
	Mean No.	**SD**	**Mean No.**	**SD**	**Mean No.**	**SD**	**Mean No.**	**SD**	**Mean No.**	**SD**
Children	8	0	11.94	0.25	13.88	2.33	12.13	6.02	5.38	4.30
Adolescents	8	0	12	0	16	0	16.69	2.39	12.88	4.49

Adolescents performed at ceiling in the repetition of two-, three-, and four-word series. The number of correctly repeated words was quite high also for five-word series. More problematic was instead the repetition of six-word sequences. Typically developing children performed at ceiling in the repetition of two- and three-word-series. For four-word series, accuracy is quite high as well. More problematic is the repetition of five-word series and six-word series, for which the number of repeated words is indeed very low.

By running a between group analysis, overall, adolescents performed significantly better than children ($p=.001$). Significant differences between the two groups were found in the repetition of series of four words ($p=.002$), five words ($p=.035$), and six words ($p<.001$). The phonological/verbal short-term memory is definitely lower in children when they are required to store long sequences.

5.3.2 The nonword repetition task

The group of children was also assessed using a nonword repetition task. The nonword repetition task is a subtest of the "Batteria della valutazione del linguaggio in bambini dai 4 ai 12 anni" (Battery for the assessment of language in children from 4 to 12 years, Fabbro 1999), adapted to Italian from the French version ("Batterie d'évaluation du langage oral de l'enfant aphasique") developed by De Agostini et al. (1998).

The nonword repetition task consisted in the repetition of 15 non-existing words of different length (one-two-three-four syllables). The task included four monosyllabic nonwords, five disyllabic nonwords, five trisyllabic nonwords, and one four-syllable nonwords.

For this task, normative data are available for typically developing children ranging in age from 4 to 11 years. One point is awarded for each word correctly repeated. The score of 0 is assigned for every error type.

Data were not collected from typically developing adolescents, because norms are not available for the age range considered. Comparison with normative data is only possible for children. In average, the group of children repeated 13.56 nonwords correctly (SD 2.10). Comparing the performance to normative data, two children were two standard deviations below the mean. The others showed a level of performance corresponding to their age peers.

5.3.3 The digit span tasks

The forward and backward digit span tasks were included in the TEMA (Test di Memoria e Apprendimento, *Test of Memory and Learning*) (subtest 7 and subtest 13, respectively), developed by Reynolds and Bigler (1995). They consisted in the immediate serial recall of sequences of digits (1-10) of increasing length. Trials were assembled into sequences ranging from 2 to 10 numbers for the forward digit span and from 2 to 9 for the backward digit span. They were read aloud at the rate of 1 second per digit, and the individual was required to immediately repeat the digits in the same order as they were presented by the experimenter. For backward digit span, individuals were required to recall numbers in reverse order. Testing proceeded until the children incorrectly repeated fewer than 4 digits in two consecutive trials. One point was assigned for each digit recalled in the correct position. The higher the score, the better the performance. Normative data are available for the different ages and makes it possible to transform raw scores into standard scores. Children obtaining a standard score included between 8 and 12 showed mean performance. Those who achieve lower scores perform below mean, and those who achieve higher scores perform above mean. In the forward digit span task, the mean raw score was 37.06 (SD 13.78), and the mean standard score was 10.94 (2.89). In the backward digit span task, the mean raw score was 10.75 (SD 6.79), and the mean standard score was 10 (2.13). Most children showed age-appropriate performance. Only three children showed below mean performance in the forward digit recall, showing some difficulties with phonological short-term memory. Three children showed below mean performance in the backward digit span task, thus showing some difficulties with working memory.

5.3.4 The sentence repetition task

In this task, the participants were required to repeat twenty sentences of different length and syntactic complexity. The experimenter said each sentence aloud, and the children were required to recall the sentence immediately. The difficulty of sentences ranged from simple active structures with SVO order to sentences with more complex syntactic structures, namely relative clauses, passive sentences, coordinated sentences, and clitic left-dislocation sentences. The list of trials is shown in Appendix A2.

Children's responses were audio recorded. Performance on the sentence recall task was scored following Alloway and Gathercole (2005). A way to calculate the accuracy of sentence recall could have been to consider that a sentence had an error if one or more syntactical or lexical errors occurred in the sentence. However, such a method does not consider the variability in syntactic complexity or sentence length. Hence, to attribute a score percentage to each participant, the accuracy of recall was determined considering as correct each word which was recalled in its original position within the sentence.

Following the scoring methods proposed by Alloway and Gathercole (2005), I counted the number of correct words (out of 146 total words) repeated in the correct position. Table 35 shows the accuracy scores obtained in this task by typically developing children and adolescents.

Table 35 Accuracy scores in the sentence repetition task by typically developing children and adolescents

Groups	**Correct words**	
	No.	**SD**
Children	132.69	11.33
Adolescents	145.69	1.25

The group of typically developing adolescents performed at ceiling. Only one participant made some errors. In particular, he failed to correctly repeat one relative clause, and in some cases, he replaced the target lexical words with other words, semantically associated to the target words. Children achieved lower scores than adolescents. Nonetheless, the overall percentage of accuracy is quite high, above 90%. Children experienced some difficulties in the repetition of long and/or complex sentences, namely coordinated structures and relative clauses, and sometimes also in the repetition of left-dislocation sentences. Clitic pronouns were avoided, and simple SVO sentences were produced instead. Common errors included additions, deletions and substitutions of the target words. By running a between group analysis, a significant difference was observed between the two groups ($p<.001$). Adolescents performed significantly better than children. These data show that phonological short-term memory as measured by sentence recall is poorer in young children.

5.4 Memory resources: the comparison between participants with hearing impairment and participants with normal hearing

In the previous sections, data on typically developing children and adolescents were presented. Young children have sometimes lower scores than adolescents. However, in most cases, memory resources are age appropriate.

Phonological short-term memory and working memory skills have also been studied in individuals with hearing impairment and in cochlear implant users. Cross-linguistically, children with either conventional hearing aids or cochlear implants were found to perform lower than normal hearing children in nonword repetition (for English, Briscoe, Bishop, Norbury 2001; Dillon et al. 2004; Burkholder, Pisoni 2005; Dillon, Pisoni 2006; Casserly, Pisoni 2013; Nittrouer et al. 2014; for German, Penke, Wimmer 2018; for Greek, Talli, Tsalighopoulos, Okalidou 2018; for Egyptian, Shazly et al. 2016; for Turkish, Akçakaya et al. 2019; for Swedish, Willstedt-Svensson et al. 2004; Ibertsson et al. 2008) and digit span tasks (for English, Fagan et al. 2007; Conway, Pisoni, Kronenberger 2009; Pisoni et al. 2011; Pisoni, Cleary 2003; for Italian, Arfé, Rossi, Sicoli 2015). Burkholder and Pisoni (2005) found that children with hearing impairment are three times slower than age-matched normal hearing children in the digit span recalling.

The fact that nonword repetition is affected in children with cochlear implants may be due to their impaired speech perception and the consequent degraded phonological representations.

Pisoni et al. (2011) investigated phonological short-term memory measured by nonword repetition and forward digit span, and working memory measured by backward digit span in children with cochlear implants. They tested them in two different moments and found that children with cochlear implants showed delays with respect to normal hearing children at the first administration but after 10 years almost half of the participants fell in the average range. Children with cochlear implants improved in rapid phonological coding and short-term memory skills. Instead, after 10 years, several children showed weaknesses and delays in verbal working memory. The authors suggested that digit span scores may be affected by the way in which speech is perceived. Indeed, speech perception may require considerable attentional resources, in order to accurately recognize digits, thus increasing the cognitive load of the task, hindering the representation and storage of phonological information in short-term memory, and reducing the resources available for working memory.

The opposite trend was found for Greek by Talli, Tsalighopoulos, Okalidou (2018). The authors compared 15 Greek-speaking children with cochlear implants ranging in age from 4;6 to 8;6 and age-matched controls and younger controls matched on length of exposure to the linguistic input through cochlear implants. The participants were assessed in phonological short-term memory measured with a nonword repetition task, and phonological/verbal short-term memory, measured with backward and forward digit span tasks (in addition to vocabulary). The children with cochlear implants performed lower than the age-matched controls in both nonword repetition and digit recall, but when compared to younger normal hearing children, low performance was only observed in phonological short-term memory. Following Houston et al. (2005), the authors have suggested that phonological representations in children with cochlear implants are not as robust as normal hearing children with the same hearing experience, and this would explain the low performance in nonword repetition. The poor performance and the low scores in these memory measures may depend on the quality of received input, which is partial and degraded, and does not favour appropriate phonological representation in short-term memory (Nittrouer, Caldwell-Tarr, Lowenstein 2013; Talli, Tsalighopoulos, Okalidou 2018).

Contrary to much evidence showing that individuals with cochlear implants have difficulties with nonword repetition, a study carried out on very young Italian-speaking cochlear implant users (aged 4;2-6;10) showed the opposite tendency, i.e. children with cochlear implants were not significantly different from typically developing age peers in nonword repetition (Guasti et al. 2014). The lack of significant difference between experimental and control samples in Guasti et al. (2014) as opposed to other studies was attributed to some phonological and prosodic characteristics of Italian, which facilitates encoding, storing, and rehearsal of new words. As for the assessment of digit span, a study carried out by Colombo, Arfé, and Bronte (2012) similarly pointed out that no significant difference was observed between a group of children with cochlear implants (age 7-12) and a group of normal hearing children (age 6-12) matched on grade level.

Using a sentence repetition task presented visually, Moberly, Pisoni, and Harris (2018) have compared memory resources of a group of adults with cochlear implants and normal hearing peers in order to assess speech recognition: the participants heard a sentence and were asked to repeat as much of the sentence as they could. Scores were attributed counting the percentage of total words and the percentage of sentences correctly produced. Accuracy of adult users was not significantly different from that of controls.

As we have seen, the results of the above-mentioned studies do not converge. In addition, for Italian, few published data exist on memory resources of individuals with hearing impairment and cochlear implants users.

The work carried out in Volpato (2010b) aims at contributing to the debate using the different repetition tasks (words, nonwords, digits, and sentence recall) used to investigate verbal/phonological short-term memory and working memory skills in typically developing children and adolescents. Children with cochlear implants and adolescent LIS signers are compared with normal hearing participants. In the following sections, the data of the group of 13 children with cochlear implants (age range: 7;9-10;8, mean age 9;2) are compared to the data of the 13 normal hearing children (age range: 5;7-7;9, mean age 6;7) matched on language skills. In addition, the group of 6 adolescent LIS signers (age range: 15;5-17;6) was compared to a language-matched group of normal hearing young children (N=6, age range: 5;3-7;5), and an age-matched group of normal hearing adolescents (N=6, age range: 15;3-17;5).

5.4.1 The word repetition task

In this task, participants were required to repeat different sequences of two-syllable of unrelated words (Volpato 2010b) immediately after the experimenter had read them. The Mann-Whitney statistical test was used to compare the number of correct words repeated by each group. Table 36 reports the results in the word repetition task (number and percentage of correct words repeated in the correct position) in two-, three-, four-, five- and six-word sequences for the children with cochlear implants (CI) and their language-matched controls (LA):

Table 36 No. and SD of correctly repeated words in each word sequence by children with cochlear implant and language-matched children

	Series of words									
Group	**2**		**3**		**4**		**5**		**6**	
	Mean No.	**SD**	**Mean No.**	**SD**	**Mean No.**	**SD**	**Mean No.**	**SD**	**Mean No.**	**SD**
CI	7.85	0.38	11.69	0.63	11.69	4.57	7.31	4.89	4.23	3.63
LA	8	0	11.92	0.28	14.15	2.82	13.77	4.17	5.23	3.17

Normal hearing children (LA group) obtained higher scores than children with cochlear implants (CI) in the repetition of all sequences. Overall, a significant difference was found between the two groups (U=35.5 p=.012). However, by comparing the performance between the two groups in each word sequence, a significant difference was only found in the repetition of series of four (U=48 p=.048) and five words (U=27 p=.003).

Table 37 reports the mean and SD of correctly repeated words by LIS signers (LIS), language-matched children (LA), and age-matched adolescents (CA).

Table 37 No. and SD of correctly repeated words in each word sequence by LIS signers, language-matched children, and age-matched adolescents

	Series of words									
Group	**2**		**3**		**4**		**5**		**6**	
	Mean No.	**SD**	**Mean No.**	**SD**	**Mean No.**	**SD**	**Mean No.**	**SD**	**Mean No.**	**SD**
LIS	8	0	11.33	1.21	9.50	3.94	9.17	5.74	8.17	3.71
LA	8	0	11.83	0.41	14.33	1.63	11.83	5.56	4	3.22
CA	8	0	12	0	16	0	17	1.55	13.33	5.01

All groups did not show any difficulty in repeating two-word and three-word series. For LIS signers, four-, five-, and six-word series were much more problematic. The language-matched group (LA) showed much difficulty in the repetition of five-word sequences, and especially in the repetition of six-word series. The age-matched controls (CA) only showed difficulties in six-word sequences. Overall, the CA group performed significantly better than both LA and LIS groups (U=.5 p=.005 in both cases). By comparing the performance between pairs of groups in each word sequence, no significant difference was found for the repetition of series of three words. A significant difference between the LIS group and the LA group was found in the repetition of series from four words (p=.012). Significant differences between the LIS group and the CA group, and between the LA group and the CA group were found in the repetition of series of four words (p=.002 and p=.022, respectively), five words (p=.027 and p=.026, respectively), and six words (p=.037 and p=.016, respectively).

5.4.2 The nonword repetition task

In the nonword repetition task, children were asked to repeat 15 nonwords of increasing length.

The following table shows the number of correct nonwords repeated by children with cochlear implants and language-matched controls.

Table 38 Mean No and SD of correctly repeated nonwords by the CI and the LA groups

Group	Mean No.	SD
CI	13.77	1.04
LA	14.54	1.67

Comparing each participants' scores with the norms reported in Fabbro (1999), it was possible to see that 1 hearing child performed two standard deviations below the normative mean, while the others performed at ceiling. In the group of children with cochlear implants, 7 participants performed at ceiling, while 6 of them performed one standard deviation below the normative mean.

In the control group, the number of correctly repeated nonwords is higher than in the experimental group. The highest number of errors in the CI group also resulted in a significantly lower performance of this group as opposed to that of the LA group (Mann-Whitney, U=43 p=.011).

Table 39 compares number of correct nonwords repeated by the group of LIS signers and that of language-matched controls (LA) (for this task no data are available for age-matched controls, since norms were available only for children aged from 4 to 11 years).

Table 39 Mean No and SD of correctly repeated nonwords by the LIS adolescents and their language-matched controls

Group	Mean No.	SD
LIS	14.83	0.41
LA	12.83	2.23

The LIS signers performed nearly at ceiling, only one error was detected in one participant. They performed significantly better than the language-matched hearing children (p=.049).

For hearing children, the mean number of correct nonwords is quite high. Only 1 child was behind the threshold level for his age.

5.4.3 The forward and backward digit span tasks

These tasks are two subtests (Subtest 7 for forward digit span, and Subtest 13 for backward digit span) included in the TEMA (Reynolds, Bigler 1995). These tasks consisted in the immediate serial recall of sequences of digits of increasing length. Children had to repeat the digits in same exact order as presented by the experimenter in the forward digit span task, and in reversed order in the backward digit span task. One point was attributed for each digit correctly repeated in the exact position within the sequence. The following table reports the mean raw and standard scores (and SDs) obtained by the group of children with cochlear implants (CI) and their normal hearing language-matched controls (LA) in each of the two subtests.

Table 40 Mean raw score and mean standard score (and SD) for each group in each digit span task

Group	Forward digit span				Backward digit span			
	Raw Score		Standard Score		Raw Score		Standard Score	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
CI	31	8	8	2	16	6	10	1
LA	34	11	10	3	15	7	11	2

On the basis of the TEMA guidelines, children who obtained standard scores between 8 and 12 show mean performance, children obtaining higher scores are above the mean, and children obtaining lower scores are below the mean. For the forward digit span task, the number of children who performed below the mean was 6 for the CI group, 3 for the LA group; the number of children who showed mean performance was 7 for the CI and LA group. Only 3 children of the

LA group were above the mean for their age. For the backward digit span task, the number of children who performed below the mean was 1 for the CI group, 1 for the LA group. The number of children who showed mean performance was 12 for the CI group, 9 for the LA group. The number of children who performed above the mean was 3 in the LA group. No children in the CI group performed above the mean. Even though the mean score of each subtest is lower in the CI group than in LA group, the Mann-Whitney test reveals no significant difference between the experimental group and the control group in any of the two TEMA subtests (p>.05 for all comparisons).

The analysis was not possible when comparing LIS signers and their control groups because data on forward and backward digit span were not available for the experimental group.

5.4.4 The sentence repetition task

In this task, the participants were required to repeat 20 sentences of different length and syntactic difficulty. Following the scoring methods proposed by Alloway and Gathercole (2005), I counted the number of correct words (out of 146 total words) repeated in the correct position. Table 41 shows the accuracy scores obtained in this task by children with cochlear implants (CI) and language-matched hearing controls (LA).

Table 41 Accuracy scores in the sentence repetition task by CI and LA groups

Group	**Correct words**	
	No.	**SD**
CI	123.31	18.06
LA	134.85	9.70

Both groups experienced some difficulties in the repetition of long and/or complex sentences, namely coordinated structures and relative clauses. Sometimes, left-dislocation sentences containing clitic pronouns also proved to be difficult. Clitic pronouns were avoided, and simple SVO sentences were produced instead. Common errors include additions, deletions and substitutions of the target words. Even though the percentage of accuracy is higher in the LA group than in the CI group, no significant difference was observed between the two groups (p>.05).

Table 42 shows the accuracy scores of LIS signers compared to the language-matched (LA) and the age-matched (CA) hearing children.

Table 42 Accuracy scores in the sentence repetition task by CI and LA groups

Group	Correct words	
	No.	SD
LIS	118.67	18.92
LA	129.33	10.78
CA	146	0

Hearing adolescents performed at ceiling. LIS signers and hearing children instead obtained lower scores. In the group of LIS signers, a high inter-individual variability was found. The LIS and the LA groups experienced some difficulties in the repetition of long and/or complex sentences, namely coordinated structures and relative clauses, and sometimes also in the repetition of left-dislocation sentences. Clitic pronouns were avoided, and simple SVO sentences were produced instead. Common errors included additions, deletions and substitutions of the target words. The between-group analysis highlighted a significant difference between the CA group and both the LIS and the LA groups (p=.002, in both cases).

5.5 The relationship between grammar and memory resources in typically developing individuals

In previous sections, memory resources in typically developing individuals and in groups of individuals with hearing impairment and cochlear implant users have been presented. I now address the important issue concerning the relationship between the scores obtained in different memory tasks (word and nonword repetition, forward and backward digit recall, and sentence recall) and the comprehension of complex syntactic structures.

Over the years, for typically developing children, the scores obtained in memory skills were found to be an important predictor of language development, vocabulary learning in both native language and foreign languages (Montgomery 1995; Baddeley 2003; Gathercole 2006; Repovš, Baddeley 2006), and reading abilities (Baddeley 2003; Cain, Bryant, Oakhill 2004).

In one of the first studies exploring the interaction between language and memory, Montgomery (1995) asked school-age typically developing children (and children with language learning impairment) to complete a nonword repetition task and a sentence comprehension task. Results of a correlation analysis revealed a strong positive association between the two tasks, suggesting that phonological short-term memory capacity is important to children's sentence comprehension. Children rely on phonological short-term memory during sentence comprehension because words and phrases are temporarily stored to understand the sentence (Robertsson, Joanisse 2010).

Phonological short-term memory (as measured with nonword repetition) has been shown to play a role in sentence processing. Phonological short-term memory was found to predict reading skills (Mann, Liberman, 1984). However, Just and Carpenter (1982) pointed out that the process of spoken sentence comprehension also resorts to working memory, because verbal information must also be processed. Increases in syntactic complexity place a burden on listeners' working memory system. It is necessary to parse the syntactic form and understand the sentence through the decoding of its compositional semantics. Deficits or difficulties in phonological short-term memory also have consequences on working memory, making the processing of syntactic information during spoken sentence comprehension difficult.

The role of memory skills in the comprehension of Italian complex grammatical constructions, namely relative clauses, has been investigated by Arosio, Adani and Guasti (2009). They found that backward digit span predicts comprehension of structures involving movement and long-distance dependences in Italian typically developing children. It positively correlated with relative clause comprehension. In 7-year-olds, backward digit span was associated to accuracy in object relative clauses with preverbal subjects. At the age of 9 and 11, the backward digit span correlated with object relatives with postverbal subjects.

Volpato (2010b) also investigated whether a relation exists between relative clause comprehension and the different measures tapping memory skills. As we have seen in section 3.4.1, the relative clause comprehension task was much more articulated than the test by Arosio, Adani and Guasti (2009). It included more sentence conditions obtained by the manipulation of number features in both the relative head and the embedded DP. The relationship between accuracy in this task and scores in the repetition tasks was investigated both overall and between each sentence condition and the memory measures. In addition, more memory measures are used than in Arosio, Adani and Guasti (2009), namely repetition of words, nonwords, sentences, and forward and backward digit spans.

In typically developing children (age range: 5;3-7;5), the comprehension of relative clauses, overall, positively correlated with backward digit recall ($p=.003$), replicating the results by Arosio, Adani and Guasti (2009). More specifically, positive correlations were observed between backward digit span and accuracy scores obtained in the comprehension of different relative clause conditions, as Table 43 shows.

Table 43 Correlations between relative clause comprehension and backward digit recall in typically developing children

Sentence condition	r_s	P
AMB_SG_SG	.570	.006
AMB_PL_PL	.679	.001
SR_SG_PL	.506	.016
OR_SG_SG	.512	.015
OR_PL_PL	.767	<.001
OR_SG_PL	.712	<.001
OR_PL_SG	.782	<.001
ORp_PL_SG	.555	.007
ORp_SG_PL	.627	.002

In (young) typically developing children, the backward digit span task is strongly associated with almost all sentence conditions, in particular with ambiguous structures and all object relative conditions.

The performance of complex operations in relative clause comprehension may place a heavy load on the computational system. In addition to working memory, verbal short-term memory, as measured through the word repetition task, and especially phonological short-term memory, as measured by nonword repetition, are also related to relative clause comprehension in typically developing children. The scores on the word repetition task positively correlated with the sentence type ORp_SG_PL (r_s=.484 p=.022). The scores on nonword repetition positively correlated with all object relatives (both with preverbal and postverbal subjects) and with one ambiguous condition, as shown in Table 44.

Table 44 Correlations between relative clause comprehension and nonword repetition in typically developing children

Sentence condition	r_s	P
AMB_PL_PL	.499	.018
OR_SG_SG	.699	<.001
OR_PL_PL	.701	<.001
OR_SG_PL	.597	.003
OR_PL_SG	.668	.001
ORp_SG_PL	.638	.001
ORp_PL_SG	.590	.004

Significant positive correlations were also found between sentence repetition scores and performance on the comprehension of different sentence conditions, especially those involving movement of the object to the relative head position. The results of the correlation analysis are reported in Table 45.

Table 45 Correlations between relative clause comprehension and sentence recall in typically developing children

Sentence condition	r_s	p
OR_SG_SG	.515	.014
OR_SG_PL	.486	.022
OR_PL_SG	.433	.044
ORp_SG_PL	.497	.019
ORp_PL_SG	.468	.028

From all these analyses, it is evident that memory places a heavy burden on the processing of complex syntactic structures. For typically developing children, low scores in both phonological short-term memory and working memory positively correlated with the comprehension of various sentences conditions, and especially object relatives with both preverbal and postverbal subjects.

The scores obtained in the sentence repetition task were found to positively correlate with comprehension of relative clauses also in typically developing adolescents (age range: 15;1-17;5). For this group, however, the relationship was only found with one ambiguous sentence condition, namely AMB_PL_PL (r_s=.537 p=.032). In some cases, also for typically developing children, memory measures correlated with the comprehension of ambiguous sentences. This relationship shows that ambiguous sentences are also particularly taxing, since several elements must be stored and processed as in the other sentence conditions. In addition, the analysis and the processing of ambiguity may impose a high demand on the computational system.

5.6 The relationship between language and memory resources in individuals with hearing impairment

A great deal of cross-linguistic research has also addressed the issue concerning the relationship between language development and memory skills in children with hearing impairment, also including children with cochlear implants (a.o., Pisoni, Geers 2000; Briscoe et al. 2001; Cleary, Dillon, Pisoni 2002; Dawson et al. 2002; Dillon et al. 2004; Szagun, 2004; Willstedt-Svensson et al. 2004; Volpato, Adani, 2009; Pisoni et al. 2011; Harris et al. 2013; Kronenberger et al. 2014; Nittrouer et al. 2014; Hansson et al. 2017; Penke, Wimmer, 2018; Talli, Tsalighopoulos, Okalidou 2018).

The linguistic behaviour of individuals with hearing impairment, and especially of children with cochlear implants, shows much interindividual variability. As pointed out in chapter 1, some children with cochlear implant show performances comparable to normal hearing children. Other children show difficulties and delays in different linguistic domains (sentence processing, vocabulary, and syntax). The difficulties that sometimes children with cochlear implants encounter with language might be attributed to an impaired memory system (Pisoni et al. 2011). In children with cochlear implants, a positive correlation has been found between phonological short-term memory skills and lexical and grammatical skills (Cleary, Pisoni, Kirk 2002; Willstedt-Svensson et al. 2004; Nittrouer et al. 2014; Hansson et al. 2017; Talli, Tsalighopoulos, Okalidou 2018). Cleary, Pisoni, and Kirk (2002) found that nonword repetition was strongly correlated with spoken word recognition, language comprehension, speech intelligibility, and speech rate. Dillon et al. (2004) investigated the relation between nonword repetition and vocabulary, speech and linguistic abilities in 24 children with cochlear implants and found that performance in the repetition task was significantly correlated with spoken word recognition, language comprehension, and speech production.

These difficulties with language and grammar may be due to difficulties in processing and temporary storage of linguistic information, which, in turn, are related to impaired phonological representations. Indeed, damaged phonological representations may hinder the ability to create lexical and grammatical representations from auditory input (Gahtercole et al. 2004; Casserly, Pisoni 2013; DeCaro et al. 2016; Talli, Tsalighopoulos, Okalidou 2018).

For Swedish, Hansson et al. (2017) tested nonword repetition, grammatical production, and sentence comprehension measured using a standardized test in 13 adolescents with cochlear implants (age: 11;9-19;1) and 16 children with cochlear implants (age: 5;3-8;0). Phonological short-term memory measured by nonword repetition has been found to be problematic in Swedish-speaking children with cochlear implants. The impaired phonological short-term memory skills also had consequences on the development of language and on grammatical accuracy. In both groups, nonword repetition correlated with accuracy in grammatical production, and in the group of younger children with cochlear implants, it also correlated with sentence comprehension. For Greek, Talli, Tsalighopoulos, Okalidou (2018) observed as well that for children with cochlear implants, a positive correlation was found between vocabulary scores and phonological short-term memory measured by nonword repetition. For younger normal hearing controls, vocabulary correlated with all cognitive measures. This is likely due to the fact that young typically developing children have not developed covert verbal rehearsal strategies yet because of their young age, but they will then acquire the capacity to use them. Conversely children with cochlear implants could have problems in exploiting such strategies even at an older age.

Less efficient rehearsal strategies may also account for low verbal short-term memory skills (measured through digit span tasks) in deaf individuals, also including cochlear implant users (Pisoni, Cleary 2003). Pisoni and Geers (2000) analysed the role of working memory in children with cochlear implants and found a correlation between auditory digit span and some linguistic measures (speech intelligibility, speech perception, language comprehension, and reading proficiency), thus proving that working memory may also influence the performance outcomes. Cleary, Pisoni, and Kirk (2002) showed a strong relationship between forward digit span and spoken word recognition in children with cochlear implants. In Pisoni et al. (2011), children with longer digit spans also had better spoken word recognition abilities. The memory system is fundamental for the encoding, storing, maintenance and retrieval of phonological and lexical information and representations of words in order to successfully perform a wide variety of production and comprehension tasks. Digit recall scores showed a relationship with grammar and language outcomes. Indeed, the forward digit span was correlated with speech and language outcomes. This finding has shown that verbal sequential short-term memory is important for developing speech perception and speech language skills. Pisoni et al. (2011) also showed that immediate verbal short-term phonological memory (assessed with a forward digit span task) and immediate verbal working memory (assessed with digit backward), together with verbal rehearsal speed, are important underlying neurocognitive factors that are strongly related to auditory, speech and language experience and that influence several different speech and language outcomes in children with cochlear implants.

Differently from these studies, Talli, Tsalighopoulos, Okalidou (2018), who in addition to nonword repetition, also tested digit span recall, found that scores in the digit span tasks were not associated to outcomes in receptive vocabulary.

In addition to backward digit recall, the repetition of a sentence implies the use of working memory, which interacts with speech perception, and linguistic and sequencing skills. The ability to repeat sentences is strongly related to working memory and may be at risk in children with cochlear implants.

In the studies I have presented so far, the authors mainly used standardized measures to investigate both memory resources and language skills, and the relationship between them. Other studies that focus on the correlation between memory and language skills in individuals with hearing impairment instead adopted non-standardized measures to assess language, and in particular, complex syntax comprehension. In comprehending complex syntactic structures, verbal sequences are stored and manipulated to correctly relate the moved constituent to the position in which it is interpreted, and the role of working memory is fundamental to perform such a task. Individuals with hearing impairment have less resources to access auditory input and consequently, to develop memory skills properly, which in turn may have consequences for the construction of grammar and the acquisition of complex syntactic structures. Tuller and Delage (2014), for French, suggested that the difficulty that children with hearing impairment encounter with complex sentences containing third person accusative clitic pronouns is due to memory resources rather than to a syntactic deficit. Another study in which a relationship was found between memory resources and syntax development is Volpato and Adani (2009). This study has investigated whether digit span scores correlate with relative clause comprehension in Italian-speaking children with cochlear implants (see section 3.6.1). A significant positive correlation was found between comprehension of object relatives with postverbal subjects and forward and backward digit span. These findings show that the computation of agreement between the embedded verb and the postverbal subject places heavy load on working memory and consequently hinders correct theta-role assignment.

However, as for the relationship between memory skills and processing of complex syntactic structures, the different studies do not always converge on results. Lack of correlation between comprehension of complex syntax and memory capacities was found by Penke and Wimmer (2018), in which difficulties in comprehension of *who*-questions by a group of very young German-speaking children (ages 3-4) with hearing aids cannot be attributed to phonological short-term memory as measured by repetition of nonwords. Memory deficits may affect syntactic movement operations in which the moved constituent has to be stored in memory until it can be related to the position in which it is interpreted. However, the *who*-questions tested by Penke and Wimmer (2018) were very short constructions and memory skills were probably sufficient to support their comprehension.

Given these controversial results, the research carried out in Volpato (2010b) was a further attempt to investigate whether difficulties with comprehension of complex syntax are due to limited memory skills, to some (morpho)-syntactic deficit, or both. In this case, the different conditions of the relative clause comprehension task were correlated with the different memory assessment tasks. Differently from Volpato and Adani (2009), and comparably to Penke and Wimmer (2017), no significant relationships were found in children with cochlear implants between scores on the relative clause conditions and nonword repetition, forward and backward digit span, sentence recall. The only significant positive correlation was found between mean percentage of accuracy in relative clause comprehension and word repetition (r_s=.615 p=.025). Overall, it seems therefore that the relative clause structure may overload the computational system.

In adolescents LIS signers as well, a significant positive correlation was found between short-term memory as measured by word repetition and scores in the relative clause ambiguous condition in which both DPs were plural (AMB_PL_PL, r_s=.907 p=.013). The need to process a long-distance dependency containing plural (marked) number features and the sentence ambiguity may place a heavy load on the computational system. It is important to point out that, especially in the case of adolescent LIS signers, only 6 participants are included in the experimental sample. A larger sample would be necessary to obtain more reliable results and to provide a more in-depth analysis of the relationship between complex syntax performance and memory skills.

This analysis shows that the source of the difficulty encountered by children with normal hearing and children with cochlear implants seems to be different. While for the former, especially the group of younger participants, working memory appears to play a significant role in the computation of relative clauses, for the latter, memory is responsible to a less extent of the computation of these complex syntactic structures. For the group of children with cochlear implants, the difficulty is largely due to a morpho-syntactic deficit associated to hearing impairment, which hinder the correct number computation.